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INSTITUTION
OF
ENGINEERS AND SHIPBUILDERS
IN SCOTLAND
(INCORPORATED).

FORTY-FIFTH SESSION—1901-1902.

PRESIDENTIAL ADDRESS.

By Mr WILLIAM FOULIS.

Delivered 29th October, 1901.

GENTLEMEN,

I have to thank you very sincerely for the honour you have conferred upon me in electing me to preside over your deliberations during the ensuing session.

I am fully sensible that this honour is accompanied by considerable responsibility, more especially as I am the immediate successor to one who has filled this chair with so much distinction, and under whose care the Institution has made marked progress, not only in regard to the number of its members, but also in its importance amongst the scientific institutions of this country; an importance which, may with some gratification be assumed, has been increased by the remarkable success which attended the proceedings of the great Engineering Congress recently held under its guidance.

Whilst many circumstances contributed to that success, it was undoubtedly mainly due to the cordial co-operation with our local committee of the members of other engineering societies, both at home and abroad, and to the indefatigable exertions and untiring energy of your past President, Dr Caird, to whom it must be a source of extreme satisfaction that his efforts resulted in bringing together probably the largest number of members of the engineering profession that has ever met in congress, and also that the whole proceedings were so highly satisfactory, whether as regards the importance of the subjects dealt with or the practical usefulness of the discussions.

Looking back on the proceedings of that Congress, the feature which to my mind stands out most prominently is the evidence adduced of the great variety and comprehensiveness of the work which is embraced under the definition of "engineering." The papers read at the various sections dealt with subjects widely differing in their aims, and yet, notwithstanding this apparent divergence, were so closely connected and so overlapped each other that many of the papers might with equal suitability have been read before several sections. Indeed, so close is the connection between the different branches of the engineering profession, that a young man commencing his career as an engineer, with nothing but his own ability to depend upon, can seldom foresee which branch of the profession he may ultimately follow.

Perhaps the most comprehensive definition of engineering is that given in the often quoted words written seventy years ago in the old charter of the Institution of Civil Engineers :—"The art of directing the great sources of power in nature for the use and convenience of man." Whether or not it may be considered that this sufficiently describes the full scope of what is embraced in the engineering profession, there can be no doubt that the proceedings at such a congress as that recently held sufficiently prove, that there is no known natural source of power which the engineer is not striving to adapt to man's use, and that there is no physical law which he can afford to ignore as being of no importance to him in his professional practice.

And this naturally leads to another consideration which has been referred to in almost all presidential addresses in recent years, and was fully dealt with two years ago in the eloquent address read to you by my predecessor in this chair—and which I do not therefore intend to refer to at any length—I mean the acquirements which are necessary for the efficient education of an engineer.

If engineering is correctly defined by the words I have just quoted, then the education of an engineer must include something beyond what can be obtained in a workshop or an office. If he is to be able to any extent to control the natural sources of power, he must know what those forces are, the laws by which they are governed, their co-relation to each other, and how to apply this knowledge to the practical problems with which he has to deal. This is now generally recognised.

I do not share in the opinion often expressed that we in this country are so far behind other nations in our ideas as to the value of scientific education to the man engaged in practical work, the full appreciation of which is of recent growth in all countries.

In this city, for more than fifty years, it has been possible for a young engineer, if he so desired, to obtain a sound scientific education in the principles of his profession. Our University was one of the first, if not the very first, in which a Chair of Engineering was founded. The occupants of that Chair have all been men of high attainments. One of the first professors was an engineer of world-wide reputation—one of the founders of this Institution, and its first President—whose writings and investigations may be said to form the basis of modern engineering science. And at both the University and Andersonian College for a much longer period there has been a great deal of practical scientific teaching of much value to engineers.

Looking back to a period nearer 40 than 30 years ago, I think I am warranted in saying, from personal knowledge, that there was at that time no great enthusiasm for the acquisition of scientific knowledge amongst young engineers. The classes dealing with subjects specially applicable to engineers were sparsely attended. Nor is this to be wondered at, as no encouragement was then given to young men to acquire such knowledge.

The services of the man who had studied what was called theory were not appreciated. A different condition of things exists now. Young men now crowd the technical classes of the University and Technical College, in both of which there are systematic courses of teaching eminently adapted to the education of the young engineer, in whichever branch of the profession his career may be, and many, if not all, employers give every encouragement to the young men serving under them to take full advantage of the facilities offered.

The great disadvantages under which both Colleges have hitherto laboured, in not having sufficient accommodation, nor the means of affording students the opportunity of efficiently carrying on experimental work, without which all scientific instruction is imperfect and incomplete, will, it is hoped, be remedied before long. The Watt laboratory, recently opened at the University, will, when fully equipped, be of great service, not only to the students but to engineers generally, and it is hoped that it may soon be possible to commence the construction of the much needed new buildings for the Technical College, in which at present the accommodation for the efficient teaching of engineering is so very deficient. It is not creditable to the engineers of the city that room for the engineering laboratory in our Technical College can only be found in imperfectly lighted underground cellars.

The importance of such laboratories as aids to scientific teaching cannot be overrated. Not the least benefit which the student derives is that he there learns scientific methods of investigation—the necessity of eliminating all sources of error, and how to read with accuracy scientific instruments. The importance of this in practical work need not be pointed out.

But while fully appreciating the great advantages of technical education, I need scarcely say that no amount of such education can supersede the practical experience which can only be obtained in the workshop or on works in process of construction. An engineer must not only know, but he must also be able to do. He must not only be able to design, but unless he also knows how to construct, his designing will lose much in practical value. And it is to be remembered that education of any kind is only a means to an end, a training of the mental faculties which will assist the possessor to solve with rapidity and certainty the practical problems that daily arise in the course of professional practice. In giving the young engineer technical education we are only supplying him with tools with which he may be able to carry on his work successfully. The use he will make of those tools depends entirely on his own ability and exertions.

Nor does technical education end when practical work begins. Professor Rankine defined sound theory in physical science as consisting simply of facts and the deductions of common sense from them reduced to a systematic form. And to a mind having the faculty of intelligently observing, which it is one of the objects of technical education to develop, every day elicits some new fact, no detail is considered so unimportant as to be unworthy of consideration, each new fact is mentally connected with what is already known, thus building up theory. And so technical education continues throughout the course of professional life.

Following the wise example of former presidents of this and other engineering societies, of dealing in their addresses with subjects more or less closely connected with the special branch of engineering with which they were associated in their daily work, I propose in the following remarks to deal with some general considerations connected with the economical production of gas from coal and its utilization.

It is just one hundred years since coal gas was first publicly applied for the purposes of general illumination. A few years before that time, Murdoch, a millwright in New Cumnock, in Ayrshire, probably observing that the light emitted by a piece of cannel coal placed on a fire—at that time a common method of obtaining light in cottars houses in certain districts—was due to the combustion of the smoke produced from the coal, conceived the idea of collecting that smoke and conveying it in pipes to a position where it could be burned to greater advantage. Murdoch seems to have been a born engineer, who not only observed, but, by the exercise of strong common sense, drew deductions from his observations which he applied to practical purposes. On leaving Ayrshire he was engaged by the firm of Boulton & Watt in erecting their steam engines, and although his name is best known as the inventor of gas lighting, yet there can be no doubt that he was the originator of many improvements in steam engine design. He constructed a steam motor car long before the locomotive engine was thought of. The D slide-valve and the oscillating steam cylinder, were amongst his inventions. But amidst all his other work he continued his experiments on the production of illuminating coal gas. He rose to a position of influence in the firm, and thus it came about that the first public display of illumination by gas was made at the works of Boulton & Watt in Birmingham, in March, 1802, when the front of their building was illuminated on the occasion of the peace rejoicings then being celebrated. Since that time the manufacture of coal gas has continuously increased, notwithstanding rival systems of lighting, until now the quantity of coal carbonized in gas works in this country alone is not less than 14 million tons per annum, and this quantity is yearly increasing.

Dealing with the gas manufacture in Glasgow only—as accurate figures are more accessible and they may be taken as fairly typical of the general increase—in the year ending May, 1881, the gas manufactured was 1966 million cubic feet; in 1891 this had increased to 3501 million ; and in 1901 the quantity manufactured had risen to 6120 million. To meet this large increase additional works are almost continuously being constructed, and of increasing magnitude. Fifteen years ago the largest gas holder in Glasgow had a capacity of one-and-a-half million cubic feet. Since that time several have been erected to contain over five million feet. Two are at present being constructed 280 feet in diameter, 150 feet high from the ground level, or over 200 feet from the foundation of the tank, each capable of containing eight-and-a-half million cubic feet of gas. And this size of gas holder is not now considered excessive.

During the winter months over 3000 tons of coal are carbonized in 24 hours, besides which about 2000 tons of coke have to be dealt with. When it is considered that this quantity of coal has to be carbonized in 3000 retorts charged every three hours, making altogether 24,000 charges per day, it will be evident that there is here considerable scope for the use of mechanical appliances for the manipulation of this quantity of material. And in most modern gas works the whole work of conveying, breaking, and charging the coal into the retorts is done by machinery. This method of carbonizing coal in small quantities necessarily entails a considerable expense, even when mechanical appliances are adopted, and many suggestions have been made from time to time for charging, either by a continuous process or for carbonizing coal in bulk. Considerable interest is therefore taken in the experiments which are at present being carried out on a large scale in the United States and in Canada, which have for their object the utilization of the gases produced from by-product coke ovens of the Otto Hoffman type, in which the coal is carbonized in what are practically closed retorts having a capacity equal to from 6 to 7 tons of coal. I am inclined to believe that it is in this direction that future improvements in gas making will be made. An interesting paper was read at the Engineering Congress fully describing this method of gas manufacture.

The retorts in which the coal is carbonized are now generally heated by fuel gas made from the coke drawn from the retorts. The temperature of the retorts is usually about 2000 degrees Fah., and efficiency in this mode of gas manufacture depends to a large extent on maintaining that temperature equally throughout the oven in which the retorts are set. An oven containing 12 retorts has a cubical capacity of nearly 1000 cubic feet. To ensure equality of temperature it is necessary so to introduce the air and gas that combustion will take place throughout the whole oven, ending only at the exit flues, where the waste gases pass to the regenerator.

The necessity of maintaining a uniform temperature in the retorts will be evident if we consider, that with few exceptions the numerous chemical compounds obtained from the distillation of coal are products of that distillation. And the quantity and character of those products depend to a large extent on the temperature to which the coal is subjected.

A low temperature of distillation results in the production of a large quantity of condensable gases, forming tars, naphthas, etc., while the volume of permanent gases is reduced. If, on the other hand, a higher temperature is employed a different series of hydrocarbons is produced; a smaller quantity of condensable compounds, and a larger volume of permanent gas.

A few years ago cannel coal was largely used in gas manufacture, but the rapid exhaustion of the cannel coal fields and the diminished output has considerably altered the conditions of gas manufacture. Gas made from oil has, to a certain extent, been substituted for that made from cannel coal. And in some works in this country, a process of gas manufacture has been introduced, which is in extensive use in the United States. Gas is produced by blowing steam through incandescent coke or anthracite in a gas producer, and this is afterwards made illuminating by being mixed with oil gas, by a process I need not now stop to describe. This gas is technically known as carburetted water gas. The object of using oil gas is principally for the purpose of enriching the gases made from coking and splint coals. There is now, however, a very general consensus of opinion amongst gas engineers that such enrichment is unnecessary, or, at all events, that the candle is not worth the cost, and in last session of Parliament several companies and corporations obtained permission to reduce the standard of illuminating power. One of the large London companies obtained Parliamentary sanction to reduce the standard quality of the gas supplied to 14 candles.

It may be interesting, in this connection, to consider for a moment the cause of luminous flames radiating light and also heat. This is now generally considered, and I think correctly, to be due to the free carbon which is liberated by the decomposition of the hydrocarbon gases by the heat of the flame. These carbon particles being raised to the temperature of the flame become incandescent, and continue to radiate light and heat until they are consumed by coming into contact with the oxygen of the air. They are the last component of the flame to burn, and if the supply of oxygen is insufficient they pass off in smoke or are deposited as soot. If the air and gas are intimately mixed before combustion, as is the case in the flame of a Bunsen burner, decomposition of the hydrocarbon gases does not take place, and the flame is non-luminous—of less volume and of higher temperature. The amount of light radiated from a flame depends very much on how the gas is burned. To obtain the maximum amount of light the combustion must not be too rapid, so as to give sufficient time for the decomposition of the hydro-carbons to take place to the fullest extent, and at the same time combustion must be complete to prevent the production of smoke; and as each quality of gas contains a greater or less proportion of carbon, each requires to be burned under the conditions best suited to produce the maximum amount of light it is capable of yielding, but this is seldom attended to in general use. When gas is burned in this way only about two per cent. of the heat energy is converted into light. The luminosity of the carbon particles rapidly increases as the temperature rises, and it was with the object of obtaining a higher illuminating result, by raising the flame temperature, that Sir W. Siemens, about 20 years ago, devised his regenerator burner, from which greatly improved results were obtained.

Many attempts have been made from time to time to utilize the higher flame temperature of the Bunsen burner for producing light, but it was not until Dr. Auer von Welsbach devised the burner which is known by his name, that any practical success was obtained.

In this method of producing light the heat of the flame of a Bunsen burner raises to incandescence a woven fabric or mantle, as it is termed, formed of the oxides of certain metals which have a high capacity for radiating light. By this means it is possible to obtain from six to eight times as much light from a given quantity of gas as can be got by burning it in a flat flame burner under the best possible conditions, and the amount of light emitted is no longer dependent on the quality of the gas or on the number of carbon particles that can be separated in the flame, but only on the flame temperature.

This system of lighting was invented in 1886. The mantles were then made of zirconia, thoria, and other metallic oxides, either singly or combined. For a long time the results obtained were very irregular, and no real progress was made until 1893, when it was discovered that while a pure thoria mantle gave very little light, by adding to it a small quantity of ceria, not exceeding 2 per cent., the light radiation was enormously increased without in any way altering the burner or the quantity of gas consumed. If a larger percentage of ceria be added the light emitted begins to diminish.

Many suggestions have been made as to the cause of this unlooked for result, but none of them are completely satisfactory.

The improvements that have since then been effected have been mostly confined to the Bunsen burner and to getting a more complete mixing of the air and gas. The larger the proportion of air that is mixed with the gas—up to that necessary for complete combustion—before it issues from the burner, the higher will be the flame temperature. One method of increasing the proportion of air is by raising the pressure of the gas, and consequently its velocity as it issues from the nozzle. This increases the velocity of the induced current of air, and a larger proportion of air is drawn into the burner. This is the system which has been adopted in the gas lighting of the grounds of the Glasgow Exhibition. The pressure of the gas is increased by means of a small water engine to about eight inches of water pressure or ·28 lbs. per inch, about four times the ordinary street main pressure. Special pipes are of course necessary to convey the gas from the pressure pumps to the lamp. There are also a number of lamps connected to the low pressure mains, in which the increase in pressure is obtained by a simple and ingenious contrivance actuated by the heat of the flame, and acting somewhat on the principle of a hot air engine, but without any of its complications.

By this high pressure system, as it is called, a very great increase in the lighting power of the gas is obtained. Gas which will develop 20 candles for each five cubic feet consumed, or 4 candles per foot when burned under the best conditions in a flat flame, will yield a light equal to 33 candles per cubic foot, or 165 candles per five cubic feet when burned in an incandescent high pressure burner, and still higher results will no doubt yet be obtained.

The introduction of the incandescent system of gas lighting has not progressed in this country as rapidly as it has done abroad, more especially in Continental cities, in some of which about 90 per cent. of all the gas used for lighting is burned in incandescent burners. In most of those cities the gas is what would, in this country, be called a low quality gas, say from 9 to 12 candles, but capable of producing light when burned in an incandescent burner of 9 or 10 times that amount.

When this method of producing light from gas becomes more extended, as it is sure to do in the next few years, it will have an important influence in altering the conditions of gas manufacture. The standard of comparison will then be the temperature which the gas flame is capable of generating, and not what is now called its illuminating power. The result will be the manufacture of a cheaper gas, equally well suited for the production of heat and power and the purposes of illumination.

The principles involved in the economical production of gas from coal and the utilization of that gas have an interest for engineers generally which is yearly becoming more important. All coal must be converted into gas before it can be consumed. The quality of the gases produced and the means adopted for their combustion form the basis of all fuel economy, whether for the production of steam or in generating heat for any purpose ; and many of the questions with which the gas engineer has to deal are just those which arise in dealing with the economical combustion of coal for other purposes. If, for example, a thin layer of bituminous coal is spread evenly over a brightly glowing fire, the first effect of the action of heat on the cold fuel is the production of hydrocarbon gases, and, just as in retort gas manufacture, the character of these gases will depend on the temperature to which the coal is subjected. Generally it may be assumed that the higher the temperature the more suitable will be the gas produced for after combustion. If the coal is laid on in a thick layer, or if the temperature of the fire is too low, hydrocarbon gases of an entirely different character will be produced, containing a large proportion of condensable tar vapours, requiring a larger volume of air for their combustion, difficult to burn under any circumstances without producing smoke; and, as they have a high ignition temperature, combustion is at once arrested on the flame coming into contact with any surface which is not considerably above a red heat, the result being the well-known emission of black smoke, and there is no doubt that those tar vapours escaping into the atmosphere unconsumed have much to do with the disagreeable effects we are familiar with in foggy weather.

In experimenting with gases for the purpose of testing either their illuminating or heat value there is no point which it is of more importance to attend to than that the flame should be free to burn completely, without interference by contact with any surface, more especially if that surface is below the ignition temperature of the gas. Luminous flames are particularly sensitive to this interference. It is impossible to obtain the complete combustion of such flames in a boiler tube or amongst a nest of tubes set close together; and imperfect combustion means diminished fuel efficiency. About fifteen years ago Mr Frederick Siemens, in a number of papers read before the Royal Institution and other scientific societies on "The Best Means of Utilizing the Heat of Luminous Flames," dealt very fully with this subject. He argued that such flames should not be allowed to come into contact with any surface, however highly it may be heated, and that until the combustion was completed the radiant heat of the flame only should be utilized, as is done to a large extent in high-crowned furnaces for steel melting, glass melting, and other purposes.

There are many questions connected with radiant heat which seem to me to deserve careful investigation. The proportion it bears to the total heat of combustion no doubt depends to a great extent on the temperature of the flame, but I have not been able to find reliable information regarding it.

In some experiments made with an ordinary argand burner the radiant heat absorbed by a quantity of water placed in an annular vessel surrounding the flame, and heated by radiation only, was equal to 50 per cent. of that absorbed by an equal quantity of water in a vessel placed immediately over the flame and heated by direct contact with the products of combustion. We know that the effect of radiant heat diminishes rapidly with the distance of the substance to be heated from the source of heat.

For boiler furnaces Mr Siemens proposed to place rings in the boiler flues so as to keep the flame from contact with the plates, heating by radiation only until the combustion was complete, the heat energy in the products of combustion being afterwards absorbed in the boiler tubes by direct contact. Whether this system of boiler heating would prove effective in all cases I much doubt. But it is certain that to obtain complete combustion with bituminous coal a large combustion chamber is essential, and that it is necessary to carefully consider how the radiant heat emitted by the flame can best be utilized.

When coke or anthracite is employed as fuel, the conditions produced are entirely different. The gas produced is principally CO, which burns with a non-luminous flame. The only radiated heat is that thrown out by the glowing fuel. The combustion chamber may then with advantage be much reduced, and, as the gas produced is of more uniform quality, the air supply may be adjusted with greater certainty. To construct a furnace which will with equal efficiency consume flaming coal and anthracite or coke seems to me almost an impossibility.

The difficulty of efficiently dealing in an open fire grate with coal which produces a large volume of hydrocarbon gases arises from the constant variation in the quality of the gases produced, varying from gases containing a large percentage of hydrocarbons, requiring seven or eight times their volume of air for perfect combustion, to that of the condition of a coke fire, the gases produced from which require only their own volume of air for their complete combustion.

The most satisfactory method of consuming coal is undoubtedly that which is more and more coming into general use. I mean the conversion of the coal into gas by its partial combustion in a separate gas producer. The gas thus produced is of fairly uniform quality, and it is therefore possible to regulate the air supply to exactly what is required for complete combustion ; and a further advantage is that the air and gas can then be brought together in such a way as to produce the character of flame best suited to the purpose for which the heat is required. And on this the economical utilization of the heat of combustion largely depends.

There are so many advantages to be derived from systematically converting the coal into gas outside the furnace or combustion chamber that, I have no doubt whatever that before many years of this new century have passed, we will have arrived at a time when a furnace burning raw coal will seldom be seen, and gas made by one or other of the methods now in operation will be the only fuel used.

Numerous suggestions have been made during the last twenty years to manufacture producer or fuel gas at central stations conveniently situated near the sources of coal supply, and to distribute the gas in pipes over wide districts; but these suggestions led to no practical result until in the last session of Parliament Dr. Mond obtained powers to erect works and supply gas over a large tract of country in the midland counties.

In Mond's system of manufacturing gas the object is not only the production of a good fuel gas from a low class coal, but also the recovery in the form of ammonia of a large proportion of the nitrogen contained in the coal. Coal contains about 1·7 per cent. of nitrogen. If the whole of this could be recovered as ammonia, it would be equivalent to 180 lbs. of sulphate of ammonia per ton of coal, a quantity which would be more than sufficient to pay for the price of the coal. Not more than one-seventh of the total nitrogen is recovered as ammonia in retort gas manufacture. About twenty years ago Professor Foster, in a paper read to the Institution of Civil Engineers, stated, as the results of his experiments, that one-half of the remainder was left in the coke, and about the same time Mr Beilby devised a method of recovering, in the form of ammonia, a considerable proportion of the nitrogen contained in the coke produced in shale oil retorts, by blowing steam and air through it while incandescent—a process which has been of great financial benefit to the Scotch shale oil companies. It is this process which Dr. Mond employs; he blows into the producer along with the air a large volume of steam equal to about 2½ tons per ton of coal. The result being that he obtains ammonia equivalent to about 90 lbs. of sulphate per ton of coal used.

The value of this quantity of sulphate at £10 per ton is 8s. Deducting the cost of manufacturing the sulphate there remains a profit of about 4s 6d per ton of coal. As it is proposed to use cheap slack, or dross, a large percentage of the cost of the coal will thus be recovered. In order to recover the ammonia it is necessary to cool the gas to atmospheric temperature. This is also necessary when the gas is made for use in gas engines without the ammonia recovery process, and one important feature of the Mond gas plant is that the heat abstracted from the gas during this cooling process is returned to the producer.

The gas produced, which has a heat value of from one-fourth to one-fifth of that of retort coal gas, it is proposed to distribute throughout the district in pipes. There is no difficulty in thus distributing gas over many miles. Gas is being daily sent to points ten or fifteen miles from the source of production under low pressure and with little loss. The only difference in dealing with producer gas is that four to five times the volume of gas requires to be sent through the pipes to produce the equivalent heat energy, necessitating either larger mains or higher pressures. It is proposed to sell this gas at 2d per 1000 cubic feet when taken in quanity. Whether or not this will be sufficient to meet all the cost of manufacture and distribution has yet to be proved, and the development of the scheme will be watched with much interest.

There is perhaps no subject of more rapidly increasing interest to engineers than that of the utilization of gas for the direct production of power by its combustion in gas engine cylinders.

The direct conversion of heat into power by internal combustion, instead of first transferring the heat to steam, has occupied the attention of many minds during the last 100 years, but it is only within the last 23 years that it can be said to have come into practical use.

It was in 1878 that the Otto gas engine was first publically exhibited at the Paris Exhibition of that year. Since that time the progress in this means of power production has been far beyond what could have been anticipated. In 1899 Mr B. Donkin estimated that there were then 50,000 Otto gas engines at work, and this number must now be largely exceeded. From information I have been able to gather, the number of gas engines manufactured in this country alone cannot be less than between 6000 and 7000 per annum. But it is not only in the number of engines sold that progress has been made, there has also been a great development in their efficiency. Twenty years ago very few gas engines used less than 30 cubic feet of town gas per B.H.P., the thermal efficiency obtained being about 12 per cent. By improvements since effected the consumption has been gradually reduced to 13 cubic feet per I.H.P., and 15 cubic feet per B.H.P., and the thermal efficiency increased to 25 per cent.; and in tests made on recently constructed engines, consumptions as low as 13·4 cubic feet per B.H.P.

are said to have been obtained, the heat efficiency being 29 per cent.

When using producer gas, the consumption of coal has been reduced to 1 lb. per I.H.P.

The capacity of the engines has also greatly increased, and several makers in this country are now manufacturing engines capable of developing 500 H.P. and upwards. Engines of 1000 H.P. and upwards are at work in other countries, and I understand that engines of from 2000 to 3000 H.P. are being designed, if their construction has not already been begun.

The immediate demand for these large power gas engines is for the purpose of utilizing the gases from blast furnaces, at present being practically wasted. The first application of blast furnace gases for the production of power in gas engines was a 30-H.P. engine erected at Wishaw Iron Works in 1894. At that time engines of much larger size were still in what might be called the experimental stage, but it is evident that the large volume of gas produced in a blast furnace can only be dealt with successfully in engines of large size.

The economy to be obtained by the use of gas engines for this purpose has up till now been more fully appreciated on the Continent than in this country, but there can be no doubt that the utilization in gas engines of the waste gases from blast furnaces, coking ovens, etc., opens up a wide field for the economical production of power. It has been estimated that the surplus gas from a blast furnace—that is, after deducting what is required for the hot blast stove, and providing by means of gas engines the power required for the blowing engine pumps, hoists, etc.—would be sufficient to develop 20 H.P. for every ton of iron produced per day. The President of the Iron and Steel Institute, in his address to that Society in May last, estimated that the surplus gases from blast furnaces at present practically being wasted would, if consumed in gas engines, develop 1900 H.P. per 100 tons of iron made per day, and he proceeded to say, "If to be on the safe side, we take the reduced estimate of 1000 H.P. as the surplus, we get a wonderful result when taken over such a district as Cleveland. The make per day approximates 8000 tons, at 1000 H.P. per 100 tons, we have a surplus of 80,000 H.P., equal to the consumption of over half a million tons of coal per year.” Applying these figures to the whole iron production of this country we get 240,000 H.P. as the total which may be obtained from this source.

Another source of power production which may be utilized is the surplus gas from recovery coke ovens. In a paper read at the Engineering Congress, to which I have already referred, the amount of this surplus gas is stated to be 4000 cubic feet per ton of coal, the gas having a heating value of over 600 B.T.U.

According to figures given by Mr Beilby two years ago, in his address to the Society of Chemical Industry, the total amount of coal converted into coke in this country is 15,000,000 tons. Only about 1¼ million tons is at present made in recovery ovens. The surplus from this would be sufficient to produce 35,000 H.P., but if the whole coke were made in recovery ovens, which it might be with economy, the surplus gas at present being wasted would be sufficient to develop 370,000 horse power.

There is therefore from these two sources a quantity of gas at present being wasted capable of developing, if used in gas engines, 600,000 H.P. applied continuously throughout the year. In Germany and other Continental countries considerable progress has already been made in utilizing these waste gases. In this country not much progress has been made in this direction, but the subject is well worthy of the attention of our engineers.

One difficulty of utilizing these waste gases to their full extent is that the production of gas is constant, while the power required is likely to be intermittent; therefore, some means of storing gas or energy in some form might be necessary. Electrical storage batteries are not yet sufficiently developed to be of much practical use for this purpose. With gases from by-product recovery coke ovens there would be no more difficulty in storing the gas than there is in storing the gas made in retorts, as both have about the same heat value. With blast furnace gases, the difficulty arises from the large amount of gas that has to be dealt with. Ten thousand H.P. requires about 1,300,000 cubic feet of blast furnace gas per hour. It might probably be sufficient to provide storage for six hours consumption, or 7,800,000 cubic feet. A gas holder to contain this quantity of gas would not be of excessive dimensions, and could be erected for a capital expenditure of about £8 per horse power. Whether this expenditure would be profitable would probably depend on local conditions, but I have no doubt some means would be devised to overcome this difficulty. The immediate question which engineers have to consider is the development of the gas engine, to enable it to deal with this large volume of gas.

The majority of gas engines at present at work use town gas, and with considerable economy for engines of moderate size. Assuming that a B.H.P. may be obtained from the consumption of 15 cubic feet of gas—with gas at the price of 2s 2d per 1000 cubic feet, which may be taken as the rate at which gas is sold in Glasgow when coal is at normal price—the cost per B.H.P. hour would be ·39 pence, equivalent to £4·4 per annum, the engine working 54 hours per week for 50 weeks; and it is to be remembered that there are no stand-by losses, no firemen's wages, nor cost of removal of ashes, and that the power may be subdivided and the engines placed in proximity to where it is required.

The area supplied from Glasgow Gas Works is about 15 miles long by 8 miles broad, or say 120 square miles, and over practically the whole of that area, power may be had at the above rate. Here is a system of power distribution which will compare favourably with other systems that have been proposed.

Within this area there are now at work engines using town gas of an aggregate capacity of about 9000 H.P., and the number is rapidly increasing and of increasing dimensions.

It may be of interest to note that 15 cubic feet of gas is produced from 3½ lbs. of coal of average quality, and in addition to the gas produced there remains for sale from 8 to 9 cwt. of coke per ton of coal used, besides tar, ammonia, etc. The whole of the tar produced may be used as fuel, but its true value lies in the number of chemical compounds that may be derived from it, and only a portion of the pitch obtained from it by distillation is used as fuel—mixed with coal in the form of briquettes. It would be difficult to obtain an accurate estimate of how much is used in this way, but I think we may safely estimate that, using town gas, a brake horse power may be obtained from a nett fuel expenditure of not more than 1¾ lbs. of coal per hour, leaving out of consideration the money value of the ammonia and the chemical compounds derived from the tar.

From 70 to 80 cubic feet of producer gas are required per horse power per hour, and this amount is obtained from 1 lb. of coal. With Mond producer gas it is stated that 60 cubic feet are sufficient to develop one I.H.P. per hour, and that this quantity of gas is produced from each 1.03 lbs. of cheap slack put into the producer. It should be remembered that the gas engines hitherto erected have been in nearly all cases in substitution for steam engines of moderate power. If compared with such engines, these figures show that a very substantial economy in coal consumption is obtained from the employment of gas engines.

The consideration of most interest to engineers in connection with the gas engine is the possibilities it possesses for further improvement. As at present constructed about 30 per cent. of the heat generated in the cylinder is lost in the water jacket, and about 40 per cent. is carried off in the exhaust gases. Some means of keeping the cylinders cool will always be necessary, and therefore it is perhaps too much to expect that any very great saving will be effected in the first item, but a considerable proportion, if not the whole, of the heat at present lost in the exhaust may, and I have no doubt will, before long, be prevented or recovered in useful work.

The disadvantages of the Otto cycle, when applied to large gas engines, are the heavy strains thrown on the working parts by the high initial pressure as compared with the mean working pressure in the cylinder, and also that only every fourth stroke of the piston is a working stroke. I am very strongly of opinion that, for large engines, a type of engine in which the expansion due to heat takes place at constant pressure instead of constant volume will come to be adopted. Some years ago I made a long series of experiments with an engine working on this principle which I designed. This engine developed about 5 H.P. The results obtained were very encouraging, but unfortunately my other duties prevented me devoting to it the time necessary to ensure complete success.

An engine working on this principle has a working stroke every revolution. The ratio of the initial pressure to the mean working pressure is less than in the Otto engine. I found that the complete combustion of the gas could be more easily ensured and was more under control; and a further important advantage of this type of engine is that it would then be possible to utilize the heat of the exhaust gases in a regenerator, in a similar manner to the regeneration employed in a hot air engine.

The gas engine has made great advances during the last twenty years. I am convinced that still greater improvements will be made during the next twenty years, and, while we may not agree with Sir F. Bramwell who, twenty years ago, prophesied that in fifty years steam engines would only be found in museums, and that heat would be converted into power in gas engines only, there can be no doubt that for stationary land engines, the gas engine will come more and more into use, supplanting steam engines and resulting in a great economy of fuel and a purer atmosphere.

From the report that has been placed in your hands, you will see that the Institution has made satisfactory progress during the past year. There has been a considerable increase in the number of members, and in other ways the position is satisfactory. Much yet remains to be done before our Institution is all that we wish it to be; and while your Council will continue to devote their best energies to its advancement and well-being, I would like to impress upon you that success can only be attained through [illegible] preparing [illegible] members. [illegible] as I has done in the past.

VOTE OF THANKS.

Mr ARCHIBALD DENNY said that as senior Vice-President it was his [illegible] and pleasure to propose a vote of thanks to Mr Foulis for his address. It was a great pleasure to have heard an address which was [illegible] with regard to gas and all that concerned gas. The address would be discussed with regard to everything [illegible] had been done in [illegible] with gas, and a forecast of what would be done. He had often heard of men more [illegible] than Mr Foulis who proposed to get power from coal without even turning it into gas. Some proposed to do that with a species of galvanic battery. Whether that would be successful or not he did not know, but that the use of gas would go on increasing in efficiency there was not the slightest doubt. One of the parts of the address which had interested him most was the [illegible] where the President dealt with the question of technical education, and it was most refreshing to find that he at least had no fear of the future of this country, and no doubt all present would agree with him. It was quite true that they had been twitted with not taking full advantage of their privileges, and that foreign countries had apparently gone further ahead in technical education; but they had heard what Mr Foulis had said, that at any rate as far as Glasgow was concerned the students had all the necessary opportunities if they would take advantage of them. There was this to be said about the foreign system of technical education, that it to a great extent produced what Mr Foulis deprecated, paper engineers. A man came forward with a great pile of certificates asserting that he had passed in this, that, and the other thing, but when put to work it was found that he sadly lacked practical experience. He (Mr Denny) had no fear, if ad-

Mr Archibald Denny.

vantage were taken of the opportunities for technical education at present offered, that they would fail to hold a first place in the world's manufacturing industry. While they could no longer expect to be the manufacturers for the world, they could at any rate expect to get a full and fair share of what was going. That might be a little apart, but he thought he was giving the essence of what Mr Foulis referred to in the early part of his address. He felt certain from what they had heard that evening that they were all looking forward to a most interesting session under a most able President, and in conclusion he had to ask them to give Mr Foulis a very hearty vote of thanks for his extremely able and eloquent address.

The vote of thanks was carried by acclamation.

The PRESIDENT thanked the meeting for the vote so cordially passed, and said the number of presidential addresses that had been delivered in Glasgow during the last few months had been so great that he thought it would have been a relief to them if the session had been opened without any address. Among so many presidential addresses, to write one containing anything new was almost impossible. If the address he had written had met with their approval he was very pleased. Mr Denny referred to what he had said about technical education. He did not at all wish to depreciate the value of such education, but rather to point out that its practical value depended on individual application to practical purposes of the knowledge acquired.

THE DESIGN AND CONSTRUCTION OF FLY-WHEELS FOR SLOW SPEED ENGINES FOR ELECTRIC LIGHTING AND TRACTION PURPOSES.

By Mr A. Marshall Downie, B.Sc. (Member).

(SEE PLATES I. AND II.)

Read 29th October, 1901.

In all mechanisms such as the steam engine, where reciprocating motion is transformed into rotary motion, the effort producing that rotation is bound to vary in amount, no matter how constant the force producing the reciprocatory motion; and a corresponding acceleration, positive or negative, occurs simultaneously with the change of effort. Further, in all systems where energy is utilized the demand is necessarily subject to fluctuations. In order that the system may be as efficient as possible it is important that the supply should as nearly as possible coincide with, or bear a direct ratio to, the demand. In the design of apparatus for the transformation of mechanical into electrical energy, the question of uniformity of speed in the prime mover is a vital one, and the fulfilment of the conditions above mentioned is subject to the proviso that the velocity of rotation must be kept as nearly as possible constant, or at least must only vary within certain defined limits. In order to realize these conditions fly-wheels and governors are employed, each having a special function to fulfil.

In the following remarks the design and application of fly-wheels to large slow speed engines for electric lighting and traction will be briefly discussed.

In engines for driving electric generators, either for lighting or power, the need for speed regulation is perhaps greater than for any other class of work, and the fluctuations in the external load are greater and more sudden than in any other service, with one or two exceptions. The duty of the fly-wheel is to control the tendency to change of speed due to inequality in amount of internal effort in the engine, and the function of the governor is to limit the variation which arises from change in the amount of the external load. The scope of this paper is confined to the part undertaken by the fly-wheel.

An ordinary reciprocating engine performs one complete cycle of operations, so far as we are presently concerned, in two strokes of the piston, or one complete revolution of the crank pin. During that time the effort or pressure on the piston changes from a maximum at admission to a minimum at release, and again on the return stroke from a maximum at admission on the opposite side of the piston to a minimum at release on the same side. At the same time, the component of that effort, resolved tangentially to the crank-pin circle, varies in a somewhat similar manner; but this "crank-pin effort," as it is called, is modified by the finite length of the connecting rod and the inertia of the reciprocating and rotating parts of the engine. The effect of the finite length of the connecting rod is to produce the maximum effort on the crank pin, at a position on the crank-pin circle nearer the inner dead centre than would be the case were the connecting rod of infinite length; and the change of effort is more rapid and less symmetrical throughout the revolution. The influence of the inertia of the reciprocating parts is important in all large engines where the moving parts have great mass and their actual velocity is considerable, although the number of revolutions in a given time may be small. The effect of inertia may be considered as a force acting in opposition to the steam pressure at the inner dead centre and in conjunction with it at the outer dead centre. This aspect of the subject may be much more clearly explained by the help of actual examples. Figs. 1, 2, and 3 show actual crank-effort diagrams prepared from large compound and triple-expansion engines of the type under consideration, and it will be profitable to examine them briefly.

Fig. 1 shows a complete crank-effort diagram for a compound vertical condensing engine designed to develop 1650 I.H.P., the cylinders being 28 inches and 58 inches in diameter respectively by 48 inches stroke, with a steam pressure of 150 lbs. per square inch, and a speed of 83 revolutions per minute. The cranks are at right angles and the connecting rod is five cranks in length. The steam is superheated and the clearance space is small, so that the curve of expansion will not fall greatly below that obtained in an ideal indicator diagram. The indicator diagrams have been drawn for each cylinder in their relative positions, and the exhaust line of the high pressure cylinder and the admission line of the low pressure cylinder computed in the usual manner, having regard to the receiver volume.

The mass of the reciprocating parts supposed to be concentrated at the radius of the crank-pin circle, and moving with a velocity corresponding to the normal speed of 83 revolutions per minute, produces forces of 35,000 lbs. at the inner dead centre and 24,000 lbs. at the outer dead centre for the high pressure cylinder, and 40,000 and 28,000 lbs. respectively for the low pressure cylinder, which have been reduced to pressures per square inch of piston area and plotted to the same scale as the indicator diagrams are drawn. The nett pressures at various points throughout both strokes—which correspond to a complete revolution—allowing for influence of inertia, have been resolved tangentially and normally at the corresponding points of the crank-pin circle, and the actual value of the tangential effort at each point set out from the crank-pin circle as zero line. The combined effort due to both cylinders in their relative position has been determined and for convenience plotted on a straight line equal in length to the circumference of the crank-pin circle as base. It is evident that the area included in the figure ABCD giving as it does the integral of the product (effort × distance), will be the measure of the total work done by the engine in one complete revolution. Further, we can choose a straight line of mean effort which, if drawn parallel to the base AD and bounded by the vertical lines

AE and DF, will include an area equal to that of the figure above mentioned, and this will be equal, or bear a constant ratio, to the external load, supposed to be uniform.

This line of actual effort is seen to cut the line of mean effort in 8 points—1, 2, 3, 4, 5, 6, 7, 8. Between any consecutive two of these points the effort on the crank pin reaches a maximum or a minimum value, and the area included between the actual effort line and the mean effort line from one point to the next is called a fluctuation of energy. The largest of these areas, be it positive or negative, is called the *fluctuation of energy*, and the ratio of this quantity to the total work done in one revolution is called the *coefficient of fluctuation of energy*, and is denoted in what follows by the letter *k*.

If we consider the effect this fluctuation of effort has on the speed of the engine it will be seen, on referring to Fig. 1, that at the beginning of the revolution the effort is less than the mean, but is increasing. Until the effort reaches the mean, energy is abstracted from the engine at a greater rate than it receives it, and the velocity of the moving parts will decrease. As soon as the effort exceeds the mean, energy is imparted to the moving parts at a greater rate than it is extracted therefrom, and their velocity will thus increase until the effort again reaches the mean, when the velocity will have reached a maximum value. During the time which elapses until the actual effort curve again cuts the mean line, the velocity again diminishes to a minimum at that point, and so on throughout the revolution. Each fluctuation of energy will have its corresponding change of speed in the engine, and the range of speed variation will depend on the mass in the moving parts and their capacity for storing energy. By far the largest mass in the moving system is that of the fly-wheel, and the problem to be solved in fly-wheel design is the determination of the dimensions and mass of a fly-wheel, such that it shall be able to store or give out an amount of energy equal to that represented by the area of the largest fluctuation of energy while changing in speed from one fixed limit to another, the limits being fixed before-hand by consideration of the class of work which the engine is designed to perform.

Before proceeding further with the subject we will turn to Figs. 2 and 3, which give crank-effort diagrams, obtained in the same way as Fig. 1, for a compound engine with two cranks at 180° and a triple-expansion engine with three cranks at 120°, both of the same power and designed for the same purpose as the one aforementioned. It is only necessary to point out that the coefficient of fluctuation of energy in Fig. 2 is much larger than in Fig. 1 and much smaller in Fig 3 than either, as will readily be seen by comparing the relative areas.

The question of the weight of the fly-wheel to fulfil certain conditions can be simply expressed as a mathematical formula involving the use of certain constants whose values will be given later.

If E be the total energy stored in a fly-wheel of weight W (supposed to be concentrated at the radius of gyration) when moving with a mean peripheral velocity of V_0 feet per second,

ΔE the fluctuation of fly-wheel energy or energy stored in the fly-wheel when changing from the minimum velocity V_1 through V_0 to the maximum V_2,

w the work done by the engine in one revolution, and

q the coefficient of speed variation allowable between the maximum and minimum limits:

Then

$$q = \frac{V_2 - V_1}{V_0}. \qquad (1)$$

$$E = \frac{W V_0^2}{2g}. \qquad (2)$$

$$\Delta E = \frac{W}{2g}\left(V_2^2 - V_1^2\right),$$

$$= \frac{W}{2g}\left(V_2 + V_1\right)\left(V_2 - V_1\right).$$

$$\text{or} = \frac{W}{g}.\ V_0\left(V_2 - V_1\right),$$

$$=2\,\mathrm{E}.q. \qquad (3)$$

but $\frac{\Delta \mathrm{E}}{w}=k.$

$$\therefore\ k=\frac{2\mathrm{E}\cdot q}{w}.$$

$$2\mathrm{E}=\frac{k\,w}{q}.$$

$$\frac{\mathrm{W}\,\mathrm{V}_0^2}{g}=\frac{k\,w}{q}.$$

$$\text{and } \frac{\mathrm{W}}{g}=\frac{kw}{q\cdot \mathrm{V}_0^2}\,. \qquad (4)$$

From which it will be seen that the mass of the fly-wheel is directly proportional to the coefficient of fluctuation of energy and the horse power, and inversely proportional to the coefficient of variation of velocity and the square of the speed. It would thus be economical of material to run the fly-wheel with a high peripheral velocity, but as the intensity of the stress in the material due to centrifugal force is independent of the cross-sectional area of the rim, and varies as the square of its linear velocity, the maximum safe speed of a fly-wheel is limited by the strength of the material composing it. In the majority of cases the material is cast iron, and it is found that the safe tensile working stress is reached with a maximum peripheral velocity of about 100 feet per second, which would correspond to about from 80 to 90 feet per second on the mean circumference, the maximum stress due to centrifugal force then being about one thousand pounds per square inch.

The value of the coefficient q depends on the service to which the engine is put, and sometimes on the practice of the makers of the plant. For ordinary lighting loads with continuous current plants, the coefficient q generally varies from $\frac{1}{100}$ to $\frac{1}{200}$. For alternators in parallel on lighting loads, q varies from $\frac{1}{200}$ to $\frac{1}{300}$, and for traction work the value is anything from $\frac{1}{200}$ to $\frac{1}{500}$, or even more. For example, Messrs Sulzer Frères say $\frac{1}{200}$ for lighting and $\frac{1}{350}$ for traction. Continental makers in general do not ask for such great regularity as American and British makers, as may be seen from a comparison given in Table I. The fly-wheels in American traction engines give values of from $\frac{1}{450}$ to $\frac{1}{550}$, and the writer knows of a recent case in which a British firm of electrical engineers required a regularity of $\frac{1}{500}$ for alternators on a lighting load.

The quantity or ratio q is sometimes expressed differently in connection with electrical work as a certain number of "electrical degrees" of variation per impulse. This method is very largely adopted in America, and, the writer believes, was first used by the General Electric Co. of New York, but the two methods of expression, although different in form, are identical in substance as the following explanation will show.

In a multipolar generator having p pairs of poles, the number of degrees described by each pair of poles in one cycle is 360, so that the total number of electrical degrees described is $p \times 360$ per revolution. In a compound engine, such as we have under consideration, the number of impulses per revolution is four, so that the number of degrees described in one impulse is $\frac{p \times 360}{4}$.

If ϕ is put for the permissible total variation expressed in degrees we have a ratio $S = \frac{\phi}{90p}$, which should correspond with "q" as given above.

A common value for ϕ is 6°, *i.e.* a 3° increase or lag from the mean, and this in a 60-pole generator would give a value of $S = \frac{6}{90 \times 30}$ or $\frac{1}{450}$, a result which agrees closely with q as adopted in good American practice.

The cofficient of fluctuation of energy is perhaps the most important factor in fly-wheel design, and the most difficult to determine, and it is mainly for this purpose that crank-effort diagrams must be constructed.

ENGINES.

DESCRIPTION OF ENGINE.	e K.	Corresponding Value of q.	REMARKS.
Vertical 3-cylinder compound, Messrs E. P. Allis & Co. Cylinders 42" and $\frac{2}{60''}$ × 60" str 75 revolutions per minute.		$\frac{1}{600}$	As made for Glasgow Corporation Tramway Power Station.
orizontal 4-cylinder tandem tri sion, by the Nurnberg Enginee yls. 27½", 43½", and $\frac{2}{45\frac{1}{2}''}$ × 63" s 72 revolutions per minute.		$\frac{1}{250}$	As exhibited at Paris, 1900, on lighting load.
rtical side by side compoun Nurnberg Engineering Co. linders 30½", 49" and 71" × 43½" s 84 revolutions per minute.		$\frac{1}{500}$	As exhibited at Paris, one-half on lighting and one-half on power.
ertical 4-cylinder tandem trip pansion, by Borsig, Berlin. linders 30", 46" and $\frac{2}{52''}$ × 48" s 90 revolutions. Cranks at 18		$\frac{1}{380}$	As exhibited at Paris, 1900, on lighting load.
rtical cross compound, by S Français de Construction Mécan Cylinders 32" and 68" × 48" str 75 revolutions per minute.		$\frac{1}{600}$	As exhibited at Paris, 1900, on lighting load, but intended ultimately for traction work.
ertical side by side compoun Société Alsacienne de Construc Mécanique. Cylinders 33½" and 53½" × 48" st 75 revolutions per minute.		$\frac{1}{280}$	As exhibited at Paris, 1900, on lighting load.
ertical side by side compoun Messrs D. Stewart & Co., Lt Cylinders 28" and 58" × 48" str 84 revolutions per minute.		$\frac{1}{370}$	As being made for Dublin Corporation Electric Lighting Station.
Vertical cross-compound, by Messrs D. Stewart & Co. Cylinders 22" and 44" × 42" str 90 revolutions per minute.		$\frac{1}{650}$	As made for Glasgow Corporation Tramway Power Station.

Tables II. and III. give numerical results for fluctuation of energy and fluctuation of effort, deduced from the diagrams in Figs. 1, 2, and 3, and from the sources which are mentioned in the last column.

Passing to the question of the actual design and construction of the fly-wheel, it will be well to consider the nature and distribution of the stresses in its various parts when in motion under working conditions.

TABLE II.

FLUCTUATION OF ENERGY.

Values of K supposing				Length of Connecting Rod.	Remarks.
One Crank.	Two Cranks at Right Angles.	Two Cranks at 180°	Three Cranks at 120°		
·1052	·01055		·00325	Infinite	Uniform pressure on piston. Inertia neglected
·1245	·0314		·0084	Six Cranks.	
·112	·06	·16	·025	Five Cranks.	Actual diagram Inertia included.
·1358	·0418		·0115	Four Cranks.	Uniform pressure.
	·108			Not given.	H.M.S. Nelson. Cotterill p. 229.

Fly-wheels, as generally made, consist of rim, arms and boss, and these are either all cast in one or made of separate pieces and jointed together according to the size of the wheel, and the service to which it is to be put.

The stress in the rim is made up of a tensile stress normal to the radial cross-section, due to centrifugal force, and a compressive stress at the inner side of the rim with a tensile stress at the outer side, due to the bending moment produced by the pressure of centrifugal force on the part of the rim between any two consecutive arms, being in fact analogous to the stress produced at the mid-section of a beam fixed at each end and loaded uniformly. On the whole, the nett stress is a tensile one, increasing in intensity from the inner edge of the rim outwards.

TABLE III.

FLUCTUATION OF CRANK EFFORT.

Ratio to Mean } for	One Crank.	Two Cranks at Right Angles.	Two Cranks at 180°	Three Cranks at 120° T.E.	Length of Connecting Rod.	REMARKS.
Maximum.	1·57	1·112		1·047	Infinite.	Uniform pressure on piston.
Minimum.	0	·785		·907		Inertia neglected
Maximum.	1·62	1·32		1·077	Four Cranks.	Uniform pressure on piston.
Minimum.	0	·785		·794		Inertia neglected
Maximum.	2·09	1·415	1·62	1·179	Five Cranks.	Actual Diagram.
Minimum.	0	·594	0	·738		Inertia included.
Maximum.		1·52			Not given.	H.M.S. Nelson.
Minimum.		·6				Cotterill p. 229.

As has been remarked before, the "hoop" tension, due to centrifugal force, is independent of the cross-section of the rim, and depends only on the specific gravity of the material composing it and its linear velocity. The determination of the stress in this case is analogous to the similar calculation of the stress on a longitudinal joint in a boiler, if for the steam pressure a force-pressure $= \frac{w v^2}{g r}$ is substituted, where w is the weight of the unit length of the rim of unit thickness.

In cast iron, weighing 450 lbs. to the cubic foot, the stress per square inch due to centrifugal tension, in lbs., is approximately equal to $\frac{v^2}{10}$, where v is the velocity of the rim in feet per second. As regards the stresses set up by bending, the portion of the rim extending from one arm to the next may be considered as a beam fixed at both ends, and loaded uniformly with $W = \frac{w v^2}{g r}$ lbs. per foot of length, where w is the weight of rim per foot. Under these conditions, there will be a point of contrary flexure at one-quarter of the span from each arm, where the bending moment = O, and the maximum bending moment will be at the centre, and will be equal to $\frac{W l^2}{12}$, if the fixing at the arms be perfectly rigid. But the fixing can hardly be considered as quite rigid owing to the arm being a more or less flexible column, and its attachment to the rim being at the under side only, so that it may be considered as something between a rigid fixing and a simple support. In the latter case the maximum bending moment would be $\frac{W l^2}{8}$, therefore the actual denominator may be taken as something between 8 and 12.

This expression would hold good for a fly-wheel with a jointless rim. In large and heavy fly-wheels, however, such as those under consideration, joints are necessary for convenience of casting, handling, and erecting. If the joint be made midway between the arms, and it be considered as lacking in rigidity compared with the solid rim, each portion of the rim, as an extreme case, may be considered as a cantilever fixed at each arm, and the maximum bending moment will then be at its junction with the arm, and will have a value $\frac{W l^2}{8}$. If the joint be at the arm, then, with the same assumptions as before, the segment of the rim will be under the same conditions as a beam supported at both ends, the maximum bending moment being at the centre and equal to $\frac{W l^2}{8}$ as before.

The joint is generally placed midway between the arms, but it would certainly be advantageous in designing a fly-wheel, as in designing a built girder, to put the joint at the point of contrary flexure, where the bending moment is zero, *i.e.*, at a 'point about one-quarter of the span from one end. This should present no difficulty from the point of view of construction, machining, and erection. No doubt if it be assumed, as before, that the rim at the joint is lacking in rigidity, the placing of the joint as last mentioned would have the effect of increasing the maximum stress due to bending, to an amount $= 9\frac{W l^2}{32}$, but it would remove the point at which such stress occurs to a position where the rim is quite solid and, therefore, more able to resist the stress; in any case the joint would have a certain amount of rigidity, and thus prevent the stress reaching the value indicated.

The stresses in the arms are principally tensile, and due to the centrifugal force of their own mass and the proportion of the centrifugal force in the rim transmittted to them. There is also the shearing stress at their junction with the hub, arising from the transmission of the force producing positive or negative acceleration between shaft and rim, and a bending moment due to the same cause.

If F be the centrifugal force tending to separate one-half of the rim from the other, and n the number of arms, it can be shown that the portion of this force borne by each arm, if the rim joints are so made that the whole stress comes upon the arms, will be $\frac{\pi}{n}.F$, and this necessitates a cross section in each arm of from one-half to three-quarters of that in the rim to resist this force alone. Such a contingency, however, should never arise in practice, as the rim should be rigid enough to take most of the stress due to its own centrifugal force. The combined cross-sectional area of the arms in well-designed wheels of the type under consideration, is generally from two to three times the cross section of the rim. The strength of the arms as beams fixed at the inner end and loaded at the outer end with the force required to produce an acceleration, positive or negative, in the mass of one segment, while changing the velocity through the limits specified in the time elapsing between two consecutive points of coincidence of the actual and mean crank-effort lines (*e.g.* in Fig. 1 one-eighth of one revolution or ·09 second) should also be considered, and this together with the resistance to shearing by the same load should not tax the material above one-eighth of its ultimate strength.

The fixing of the arms to the hub is usually by means of bolts or cotters, and their strength in double shear should be equal to that of the arm in shear or tension, whichever is greater.

Several forms of rim joints are in general use for fly-wheels, and among the principal may be mentioned the following:—

(1) Flanged and bolted.
(2) Dowel-plate and cotters.
(3) Arrow-headed bolts.
(4) Links and lugs.

These different forms of joints are illustrated in Fig. 4, and the following points regarding their construction are worthy of note:—

(1) In the flanged and bolted joints, the bolts should be as near the rim as possible, consistently with getting a deep flange. The bolts should be carefully fitted at each end and cleared in the centre, so that the stress on them should be tensile rather than shearing. They should all be initially stressed by screwing up if possible to the same amount.

(2) The accurate machining and fitting of the dowel-plate and cotter joint is most important. It should of course be so designed that the strength of the cast iron, cotters, and portion of the dowel-plate, in shear, is equal to the strength of the portion of the dowel-plate in tension. The accuracy with which the initial stress in this form of joint can be adjusted is an important feature in its favour.

(3) The arrow-headed bolt joint is a shrunk joint, and is open to the objection that the initial stress on the bolts due to shrinking-in is a more or less unknown quantity, and the ultimate strength therefore indeterminate. The points to be attended to in its construction are, accurate machining between the checks on bolts and rim, and provision for clearance at the centre, for the same reason as noted in (1).

(4) The "link and lug" joint is also a shrunk one and subject to the same objection as (3) on that score. If made with the lug projecting, as shown on the illustration, it has the advantage that the section of the rim is not diminished at the joint. The increase of weight, however, which such a form necessitates, is a good reason for removing the position of the joint nearer one arm.

Much light has been thrown on the relative strengths of solid rims and various forms of joints by some interesting experiments by Prof. C. H. Benjamin, related in the Proceedings of the American Institution of Mechanical Engineers, Nov. 29th, 1898. In these experiments small fly-wheels of from 15 inches to 24 inches diameter, some of which had solid rims and others jointed, as in (1) and (4), were tested to destruction. The solid-rimmed wheels almost invariably gave way midway between the arms, at a speed slightly below that at which the calculated centrifugal tension would be equal to the ultimate tensile strength of the material as proved in a testing machine.

For example, the cast iron used had an ultimate tensile strength of 19,000 lbs. per sq. inch, corresponding to a speed of 450 feet per second, and the solid wheel failed at 428 feet per second. The wheel with flanged and bolted joints (1) failed when the tensile stress was only about one-fourth of that of the solid rim, although the joint was evidently well proportioned as the failure in one case arose from the flange breaking, and in the other from fracture of the bolts, both occurring at about the same limit. The link joint (4) had a strength slightly over two-thirds of that of the solid, and was thus greatly superior to the flanged joint. The non-reduction of cross section should also give this joint superiority over the dowel-plate and arrow-head bolt joints, as in both these cases the cross-section is reduced by about one-fourth. The reason why the link joint is not so strong as the solid rim, is probably owing to the weight of the lugs and links adding to the bending moment, due to centrifugal force at the point where the rim is weakest to resist this, and of course the initial stress due to shrinking adds another element of weakness. It would be interesting to know what additional strength would be obtained by making such a joint nearer one arm, as it would naturally reduce the maximum stress at the mid-section of the rim. It is worthy of note, however, that the stress produced by the bending moment at the rim cannot be great, as one of the above experiments consisted in testing to destruction several fly-wheels with alternate arms missed out, and they were able to reach almost to the same speed limits as those with all the arms left in.

In some recent cases, principally in America, and notably in the engines for the Metropolitan Street Railway Co. of New York, fly-wheels with riveted steel plate rims have been successfully used, and run at much higher speeds than would be safe with cast iron.

From the above facts some general conclusions may be drawn :—

(1) A good average value for the energy necessary to be stored in fly-wheels for electric lighting purposes is 2·9

foot-tons per electric horse-power, and in traction plant 4 foot-tons.

(2) Cast iron fly-wheels should, where practicable, have solid rims, but when jointed, the best form is the "link and lug" type where such can be adopted without inconvenience, and the next best is the dowel-plate and cotter. Flanged and bolted joints should be avoided, and the best place for a joint is near one arm.

(3) Solid-rimmed cast iron fly-wheels may be run at a peripheral velocity of 100 feet per second, with the certain knowledge that the "factor of safety" is not under 12, and link-jointed wheels may also be run at that speed, and have a factor of safety of 8. A lower factor of safety should not be used, and flange-jointed wheels should not be run above 70 to 75 feet per second. Built steel wheels may be run up to 130 feet per second.

(4) Arms should be joined to rims with large fillets, and their fixing to the hub should be carefully fitted.

(5) The best material of its kind should be used in construction, and homogeneity should be ensured as far as practicable by having test bars cast and proved from each segment.

In conclusion, I have to express my thanks to Messrs Thomas Wishart and Earnest Connell, for assistance in the preparation of lantern slides and diagrams to illustrate the paper, and to Messrs Sulzer Frères, and other firms mentioned, for giving the information necessary to calculate the constants given in the tables.

Discussion.

The discussion on this paper took place on 26th November, 1901.

Professor ANDREW JAMIESON (Member) said that he was not aware of any paper having been previously brought before a British Engineering Institution on this precise subject and manner of treating it. The subject had, however, received much greater attention in America, due to two causes. The Americans were fond of using immense cast iron fly-wheels, and they had experienced many disastrous accidents from the bursting of such wheels.* These accidents had occasioned considerable alarm, and induced American engineers to investigate the causes and remedies. Nevertheless, accidents from defective or overstressed fly-wheels still occurred in this country and elsewhere, and the comparatively recent importation of large steam-dynamos from America and the Continent for electric lighting and tramway traction, together with the greater and greater demand for uniformity of rotational velocity in these machines, rendered a thorough explanation of this whole subject of the greatest importance. Mr Downie had gathered together the latest data regarding the fly-wheels of the present large, popular, slow-speed types of American and Continental steam-dynamos, and arranged the same in the form of three handy tables. His preliminary statements were clear and to the point. But, in addition to the remark on page 25—that "The duty of the fly-wheel is to control the tendency to change of speed due to inequality in amount of internal effort in the engine"—he might have remarked that, the fly-wheel also automatically compensated or smoothed over any rapid changes of external load. And, should the external load continue to change (+ or −), in the same sense, for an appreciable time, the fly-wheel would permit the governor to gradually come into action. Of course, the fly-wheel did nothing to make the mean effort of the engine equal to the mean resistance. In electric tramway traction, the sudden changes of external load due to starting and stopping of cars, or short circuits of the trolley wires, etc., would be beyond the immediate control of any governor attached to reciprocating, slow-speed, compound engines, if unassisted by the inertia of a fly-wheel. Moreover, he did not give any definite reasons for the special demand of exceedingly uniform circular motion, in the case of engines driving alterna-

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* See *The Practical Engineer*, September 3rd, 1897, p. 285, *re* "Bursting of a fly-wheel at the Tacoma Railway Company's Power House."

Prof. A. Jamieson.

tors which generated high pressure currents at low frequency. He believed, that the chief cause for this demand, arose from the necessity of transforming low-frequency alternate currents (of, say, 6500 volts in the case of the Glasgow Tramways) into lower pressure continuous currents of 500 to 550 volts at sub-stations, by means of static and rotary transformers. These sub-stations, had to be conveniently situated with respect to the economical supply of the continuous currents to the more immediately surrounding tramway routes, and were often miles away from the central power-station where the alternate currents were generated. Now, if any great difference existed in the angular velocity of the alternator (as driven direct by the steam engine at the central power-house), the synchronous alternating current motors at the sub-stations, would be subjected to corresponding alterations of frequency, and might "buck" or "get out of step," and thus cause damage, not only to themselves, but, by reaction, to their main alternating current dynamo. If such a circumstance did occur, then the tramcars depending upon these motors would be stopped until other motors, or perhaps main alternator, or both, were substituted by fresh ones or a complete set. Besides which, there was always the desirability of being able to run two or more sets of the prime steam-dynamos in parallel; and there again, the demand for very uniform and synchronous angular velocity was imperative. How far one might depart from absolutely uniform rotary motion with safety, had not yet, he believed, been made perfectly clear. Of course, each case would differ somewhat from another, due to the natural tendency which a properly designed alternate current motor had of keeping step with its parent or feeding alternator, and *vice versa*. However, he could not see the necessity for such a fine "coefficient of speed variation" in the case of Messrs D. Stewart & Co.'s engines, where $q = \frac{1}{250}$. (See Table I.) These engines had only to drive continuous current dynamos, to generate 500 to 600 volts, for the lesser night, or for closely surrounding traffic, and for the local auxiliary electrically driven pumps, coal conveyors, and automatic stokers, etc.

Surely from $\frac{1}{300}$ to $\frac{1}{350}$ would have been a sufficient "coefficient of speed variation" in this case. It would certainly have lessened the internal load of those engines and increased their output and mechanical efficiency. Now for a few minor details. Neither at line 3 on page 26, nor under Fig. 1, was there any numerical value or mention of the vacuum. In line 7 from the foot of page 27, Mr Downie used the words "and their capacity for storing energy." Would not the words, and *their capability of storing energy*, be better? On page 27, line 13, and in the formula on page 29, the small italic letter *k* was used for the "coefficient of fluctuation of energy," whereas in Tables I. and II. the large letter K was employed. On pages 28 and 29 the small italic letter *w* represented "the work done by the engine in one revolution;" whereas on page 33, line 4, etc., the same small italic letter *w* represented "the weight of the unit length of the rim of unit thickness." With regard to the working out of the formulæ on pages 28 and 29, the final result was quite correct, yet the various steps might not be clear to every one. Although the meaning and value of *g* was apparent to those who had studied questions on acceleration, yet Mr Downie might have said that it referred to gravity and was equal to 32 feet per second per second. Perhaps the following method of stating and working out the result would be found easier to follow. From the author's definitions and the first principles of mechanics, and using the same letters as in the paper, it might be assumed in this particular case with sufficient accuracy, that the mean peripheral velocity $V_0 = \frac{1}{2}(V_1 + V_2)$. Hence:—

$$(1)\ q = \frac{V_2 - V_1}{V_0}. \quad (2)\ k = \frac{\Delta E}{w}. \quad (3)\ E = \frac{W V_0^2}{2g};\ \text{or, } 2E = \frac{W}{g} V_0^2$$

From preliminary data at p. 28—

$$\Delta E = \frac{W}{2g}(V_2^2 - V_1^2) = \frac{W}{2g}(V_2 + V_1)(V_2 - V_1).$$

Substituting value of V_0 from above, then—

$$\Delta E = \frac{W}{g} V_0 (V_2 - V_1).$$

Prof. A. Jamieson.

Multiplying numerator and denominator by V_0,

$$\Delta_E = \frac{W}{g} V_0^2 \left(\frac{V_2 - V_1}{V_0}\right).$$

Substituting from (3) the value of $2E$, and from (1) the value of q,

$$\left.\begin{array}{l} \Delta_E = 2Eq \\ \text{But from (2) } \Delta'_E = kw \end{array}\right\} \text{Hence, } 2Eq = kw,$$

$$\left.\begin{array}{ll} & \text{Or, } 2E = \frac{kw}{q} \\ \text{But from (3) - - - -} & 2E = \frac{W}{g} V_0^2 \end{array}\right\} \therefore \frac{W}{g} V_0^2 = \frac{kw}{q}.$$

Consequently - - - - $\frac{W}{g} = \frac{kw}{qV_0^2}$. (as found at p. 29).

Mr Downie had referred to steel fly-wheels, and pointed out very clearly the advantage of thereby being able to run them at higher speeds; since the energy stored was proportional to the square of the velocity, as shown by the above equation (3) ... $E = \frac{W V_0^2}{2g}$. Mr Downie had, however, omitted to mention the fly-wheel devised by Prof. Sharp, wherein steel wires of great tensile strength were wound round the periphery in a similar manner to the pianoforte steel wires in Lord Kelvin's sounding machines. With a well made steel fly-wheel of this description, it would be quite safe to run the same at three times the velocity of an ordinary cast iron one; and hence, for the same weight concentrated at the same radius of gyration, it would store nine times the energy. With fast speed engines coupled to such a wheel, and dynamos of comparatively small diameter, the total bulk, weight, and price of the plant would be very much less than was the case with those huge slow speed American engines. The very large, heavy fly-wheel, crank-shaft, and other moving parts of the latter type, must of necessity reduce the output and mechanical efficiency as compared with the former, for the same indicated horse power. He hoped to live to see the day when steam turbines of the "Parson" type would be in use, working steadily at 5000 H.P. or more, with absolutely perfect angular velocity, and with the steam admission so beautifully governed and guided that they could automatically adjust themselves to the variations of external load, without the use of small or any fly-wheels. He asked how Mr Downie managed to practically test the truth of the calculated "coefficient of speed variation" in the case of the engines by Messrs D. Stewart & Co., where the value of q was given as $\frac{1}{850}$. There were a few other points that he would have liked to have drawn attention to, such as the author's method of ascertaining the crank-effort curves, since it varied from that published in his (Prof. Jamieson's) book on Steam Engines. But, seeing that others were to follow, he would conclude by congratulating Mr Downie on his paper.

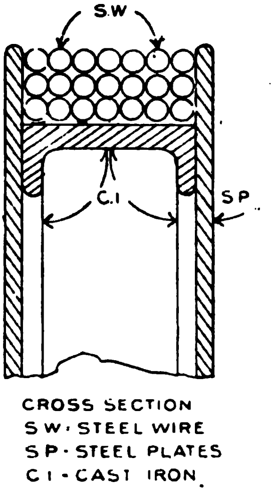

Fig. 5

Prof. A. Barr, D.Sc. (Member of Council) thought it was not always realised how dangerous fly-wheels were. The bursting of a

Prof. A. Barr, D.Sc.

fly-wheel was not very uncommon, but they did not hear of all the cases that occurred. He had had a case of the breaking of a fly-wheel within his own experience. It was on an experimental engine. The makers of the fly-wheel on which a friction brake was used had, contrary to his wishes, and entirely on their own responsibility, made the fly-wheel with a solid boss. One evening, during a run, a report like a gun-shot was heard, and observers noticed that the fly-wheel was running out of truth ; the rim of the fly-wheel was just warm—about as warm as one's hand. The engine was stopped, and they found three of the arms out, and six broken. One was open about $\frac{3}{32}$nds of an inch. There must, therefore, have been an enormous initial stress in the arms. There were two fly-wheels on the engine, and he told the makers that they must replace both. They said they would replace the broken wheel with a new one having a split boss, and cut the boss of the remaining wheel. He warned them what would happen, but they put the wheel in a slotting machine, and before the machine got half-way through one side of the boss, the stresses in the wheel completed the job in a manner rather astonishing to the slotter. That case illustrated a point of the greatest importance. On page 38 Mr Downie said—" Solid-rimmed cast iron fly-wheels may be run at a peripheral velocity of 100 feet per second, with the certain knowledge that the 'factor of safety' is not under 12" ; and he referred to casting test specimens. He (Prof. Barr) questioned the truth of the remark quoted, and he thought they could not trust that a test specimen cast from the same melting as the fly-wheel indicated at all exactly the strength of the material of the fly-wheel, much less the strength of the fly-wheel as a whole. Great variations were found in the strength of test specimens according to the particular manner in which they were cast. The particular way in which a specimen was cast was never the same as when a large casting was made. Although it was his business to deal with the testing of material, he always tried to impress upon engineers how little the results of tests of cast specimens could be trusted as showing the strength the main casting would have. There were a great many points in the paper which he would like to remark upon. Perhaps, as one of his old students, Mr Downie would pardon him if he drew attention to one or two points in which he thought he was in error. On page 33, Mr Downie said—"Under these conditions, there will be a point of contrary flexure at one-quarter of the span from each arm, where the bending moment = O, and the maximum bending moment will be at the centre, and will be equal to $\frac{W\,l^2}{12}$, if the fixing at the arms be perfectly rigid." He (Prof. Barr) thought that that was not quite right. Assuming an absolutely uniform stiffness, the point of contrary flexure came out at 0·211 of the span from the arm. The maximum bending moment was at the arm, not at the centre of the span. The bending moment at the centre was only one-half that amount. Mr Downie said—"But the fixing can hardly be considered as quite rigid owing to the arm being a more or less flexible column." He thought Mr Downie had overlooked the fact that there was a segment on each side of the arm, so that at the arm there was only an outward force, and no tendency to bend the arm, which acted as a tie, and might be jointed to the rim. He was glad that Mr Downie had brought up the question of making the joints at points of contrary flexure. It was a matter that engineers habitually neglected. They usually put the joints midway between the arms. On page 34 Mr Downie said—"No doubt if it be assumed, as before, that the rim at the joint is lacking in rigidity, the placing of the joint as last mentioned would have the effect of increasing the maximum stress due to bending, to an amount $= 9\,\frac{W\,l^2}{32}$, but it would remove the point at which such stress occurs to a position where the rim is quite solid and, therefore, more able to resist the stress; in any case the joint would have a certain amount of rigidity, and thus prevent the stress reaching the value indicated." He could not follow him on that point. By making a joint at the point of contrary flexure the stresses in the rim, considered as a beam, were not altered.

Prof. A. Barr, D.Sc.

A perfectly flexible joint at the point of contrary flexure would produce no effect upon the strength. He would like to point out the difficulty of making any exact calculation regarding the strength of an actual fly-wheel. It would not do to take the calculated centrifugal tension and add to it the stress obtained by considering the rim as a beam. If the fly-wheel rim were perfectly inextensible, and the arms extensible, there would be no beam action at all. The stress would be entirely centrifugal tension. If, on the other hand, the arms were inextensible and the rim extensible, it would be practically all beam action. The question was exceedingly complicated, since both the rim and the arms were more or less extensible. But, even although account could be taken in the calculations of the extensibility of the rim and arms, one could not trust the calculations to give the actual strength of a cast fly-wheel, on account of the effects of unequal shrinkage, non-homogeneity of the metal, and other disturbing causes. Prof. Jamieson had referred to a fly-wheel which he attributed to Prof. Sharp, but, so far as he (Prof. Barr) knew, that type of fly-wheel was not originally designed by Prof. Sharp. Prof. Jamieson had given what was practically a sketch of the large fly-wheel at the Mannesmann Tube Works. He understood that some 70 tons of steel wire was wound on the wheel, with a tension of about 50 lbs. The fly-wheel was 20 feet in diameter, and ran at 240 revolutions per minute. That gave a peripheral speed of about 250 feet per second, as against, say, 100 feet per second, which was usually taken as the safe maximum for ordinary cast iron wheels. A question had been asked as to how the variations of angular velocity could be determined. At the Glasgow Gas Exhibition in 1881, he had been engaged on the testing of the engines, and he designed an apparatus for that purpose, which was made, but was not put into use. An apparatus on the same general principle had been brought out by Messrs Manlove, Alliott & Co., in the form of a drum carrying a sheet of smoked paper upon which a fine style attached to a tuning-fork recorded vibrations. The drum revolved with the crank-shaft of the engine, and vibrations of the tuning-fork were recorded upon it for each revolution, and the distance that each one occupied could be measured. It would be very difficult to indicate $\frac{1}{500}$th part of the angular velocity, but, so far as he knew, that was the most accurate device for ascertaining the variations of angular velocity, as, for example, in the case of a gas engine. In speaking of the gas engine, he thought that Mr Downie had founded his calculations on page 28, on the assumption that the mean velocity was equal to half the sum of the extreme velocities. That was, of course, not necessarily the case, and in a gas engine it would be considerably away from the fact, because the speed went up suddenly when an explosion took place, and went down gradually.

Mr E. Hall-Brown (Member) said any remarks that he had to offer would be confined to the first part of the paper—that relating to the determination of the fly-wheel required to fulfil certain conditions. Those conditions related to the degree of uniformity required during one complete cycle of the engine. The use of slow speed engines for various electric generating plants seemed to have caused a demand for great regularity in the speed of rotation. Mr Downie stated that the maximum variation allowed was from $\frac{1}{100}$ to $\frac{1}{500}$, according to the service rendered and the ideas of the electrical engineer who made out the specification. These figures were useful figures when understood in a certain sense, but he joined with Prof. Jamieson in saying that he would like to know very much how an engine was tested for such extreme regularity. He was sure that it would be most interesting to the meeting if the writer of the paper, or some other gentleman who was acquainted with the testing of slow speed engines for electric traction, would describe the method of testing for a variation of $\frac{1}{400}$ or $\frac{1}{500}$ in the speed of rotation. Such regularity could of course be attained, but he was doubtful if it was required, and he thought that a fly-wheel determined upon the lines laid down in the paper could not be depended upon to give the regularity for which it was designed. The paper seemed to him to be based upon the definition of the duties of the fly-wheel and governor given on page 25. He did not think the whole duty of the fly-wheel was

Mr E. Hall-Brown.

stated there. He could imagine, for instance, a fluctuation, say an increase, in the external load occurring after the point of cut-off in the high pressure cylinder, and so out of the control of the governor until the next stroke. It seemed to him that such a fluctuation in the external load would have to be taken into account in designing the fly-wheel, unless they were to understand that great regularity in angular velocity was only required with a constant load. This he had just learned was actually the case. A constant external load was therefore assumed in the paper, and from diagrams of turning moments derived from actual or theoretical indicator cards the size of fly-wheel was determined. If they bore in mind the whole of the conditions assumed in making these calculations, the results given in the paper were valuable and gave a correct basis for comparing the fly-wheels used for certain duties. He must, however, again repeat that he would not depend upon a fly-wheel designed upon these lines for a given coefficient of fluctuation maintaining that regularity. As the value of the figures given depended upon the whole of the conditions being known, as well as the methods by which the figures were determined, he might be excused from referring to the method upon which the diagrams were constructed. Referring to figures 1, 2, and 3 it would be seen that, although the indicator diagrams were approximately the same length they were not placed over one another, or in other words the "heel" of the one diagram was not vertically over the "toe" of the other. He was at a loss to know why they should have been placed as they were. Indeed in the form in which they were shown they had no direct bearing upon the construction of the curve of turning moments, and were somewhat misleading as regarded the actual pressure exerted upon the piston at any part of the stroke. The unbalanced steam pressure upon the piston at any point of the out stroke, would be correctly shown by drawing the steam line of the card taken from the back end of the cylinder and the exhaust line from the card taken simultaneously from the front end of the cylinder, and *vice versa*, Fig. 6, It would be seen that the pressure upon the piston was not represented directly by the indicator cards, the pressure being positive at the beginning of the stroke and negative at the end.

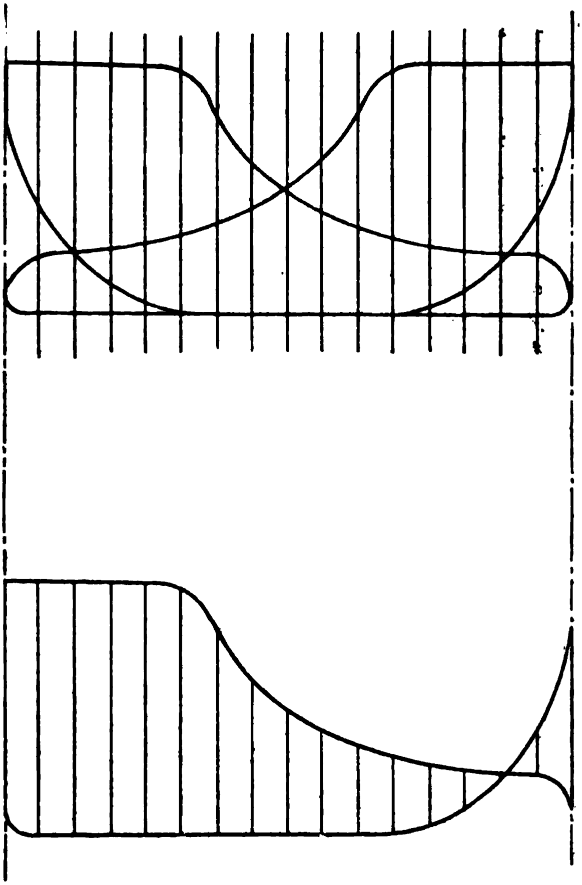

Fig. 6.

That pressure was of course modified by the inertia of the reciprocating masses. He called attention to the point, because it was not shown in any way in the diagrams, although probably taken into account. There seemed to have been a slip in the paper on page 26

Mr E. Hall-Brown.

where the writer was made to say that the mass of the reciprocating parts was supposed to have been concentrated at the radius of the crank-pin circle. It was evident that part at least of the mass of the reciprocating parts was supposed to have been concentrated at the crosshead, otherwise there would have been no acceleration required at the ends of the stroke. Would Mr Marshall Downie in his reply state what proportion of the reciprocating masses he had supposed concentrated at the crosshead and what at the crank pin? He hoped his remarks would not be taken as made in a captious spirit, but only with the intention of eliciting such information as would add to the undoubted value of Mr Downie's paper.

Mr H. A. Mavor (Member) said there were one or two points that Mr Downie had not touched upon in his paper. These points were in connection with periodic vibrations of the fly-wheel which had, during the last few months, been exciting some interest in certain parts of the engineering world. Some years ago he noticed, in one of Mr Longridge's very useful reports, an account of the breakage of a large fly-wheel due to synchronism of period of the fly-wheel and the engine. If the period of the fly-wheel coincided with the period of the engine the result was to increase the amplitude of vibration of the fly-wheel. The same thing, he understood, had occurred in high and low speed engines. In the case of a slow speed engine with two fly-wheels, as might occur in an electrical generator, the two large rotating bodies nearly approaching synchronism in their period would set up a great torsional strain. He would like very much to hear from Mr Downie if he had made any calculation as to the relative power absorbed by fly-wheels of the different constructions spoken of that evening, and where a large percentage was saved by putting steel sheeting over the spokes.

The President stated that it would take too long to read the correspondence which had been received in connection with this subject, but it would be published in the "Transactions," and Mr Downie would have an opportunity of replying to it. He was sure that he was only expressing the wish of the members when he

The President.

said that they should give Mr Downie a hearty vote of thanks for his very excellent paper. It must have cost a great deal of trouble and care to write such a paper, and it would no doubt form a very important part of their transactions this session.

The vote of thanks was carried by acclamation.

Correspondence.

Mr C. A. Matthey (Member) hoped he would not be considered hypercritical if he pointed out that the figures given by Mr Downie for the inertia forces on the near and far centres were not quite correct. With a connecting rod five cranks long, the force on the near centre was one-fifth greater, and that on the far centre one-fifth less, than if the rod were of infinite length, and therefore those forces must be in the ratio of 2 to 3. Now, neither 24,000 and 35,000, nor 28,000 and 40,000, Mr Downie's figures, were in that ratio. On calculating the force for the high pressure engine, for an infinite rod, he found it to be 31,000 lbs., and therefore with a rod of five cranks the forces on the two centres were respectively 24,800 and 37,200 lbs.; those for the low pressure were 26,850 and 40,250 respectively. It might be a printer's error, but it was well to have it corrected; the inertia diagrams in Figs. 1 and 2 scaled correctly, the end ordinates were in the ratio of 2 to 3. He would also remark that although it came to the same thing in the end, it was more correct, more in accordance with the grammar of graphic mechanics, to first enlarge the ordinates of the low pressure cards in the ratio of the piston areas and the low pressure inertia diagram, and then proceed to plot the tangential turning efforts radially on the crank circle. Then equal lengths represented equal forces. In Mr Downie's radial diagram there were two scales, one for the high and one for the low pressure engine, and then in plotting the combined curve CC, Mr Downie introduced the necessary correction, and added to the high pressure radial measurement, not the low pressure measurement, but a length about 4¼ times greater. He (Mr Matthey) thought the fact ought to be presented to the eye that

Mr C. A. Matthey.

the CC measurements, intercepted between the curve and the base circle, were the sums of the corresponding H.P.C. and L.P.C. measurements. In the combined H.P. and L.P. diagrams it was true that this principle of equal lengths representing equal forces was not carried out; but there was a good reason for enlarging the stroke instead of the ordinates, namely, to show the expansion curve; but even here, equal areas represented equal numbers of foot-pounds. Another point to be noticed was, that Mr Downie took the indicator cards as drawn by the indicator, and accepted as the net steam pressure on the piston at any point of the stroke, the length of ordinate intercepted between the steam and exhaust lines. That was only correct in those cases where the exhaust lines for both ends of the cylinder coincided, the proper procedure being to take the steam line of one end and the exhaust line of the other; that gave the net pressure acting on the piston at any moment. The difference might be very considerable where there was a large degree of compression; for instance, take the pair of cards shown in Fig. 7 annexed. If Mr Downie's method were adopted, the card shown in Fig. 8 would be taken as representing the pressures during the left-to-right stroke, and the pressure for a point near the beginning would be a length such as A B, and for one near the end a positive pressure, urging the piston, such as CD; but as a matter of fact the real pressure on the piston at the early point was EF in Fig. 9, and at the later point was a negative pressure, or opposing force GH. The net area of the diagrams in Figs. 8 and 9 was the same, the triangle on the right of Fig. 9 being negative, and subtracted from the area on the left to the point of crossing of the steam and exhaust lines. There was nothing new in this, it had been stated again and again, but it was curious how often it happened that when the observer took account of this truth, he neglected the inertia diagram, and *vice versa.* As to the strength of fly-wheel rims, he thought that instead of adopting a general rule, such as 100 feet per second for all wheels, which gave a different degree of safety according as the rim was cast solid or had a more or less efficient joint, each

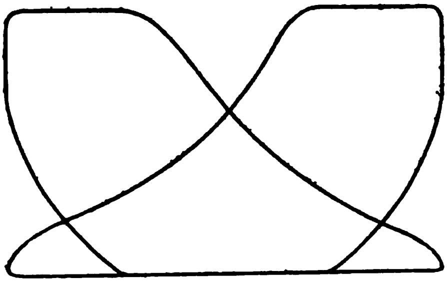

Fig 7.

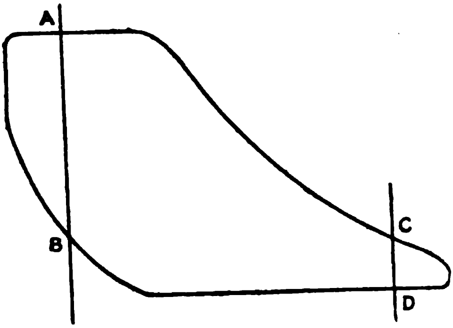

Fig. 8.

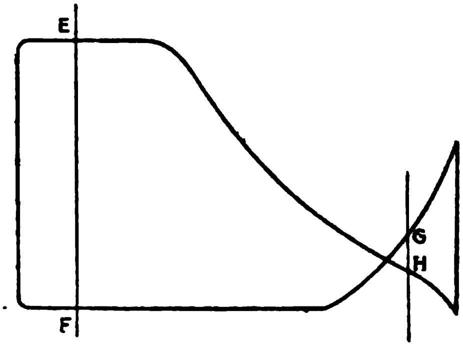

Fig. 9.

Mr C. A. Matthey.

case should be considered on its merits. Was the only reward for going to the inconvenience of casting the wheel in one piece to be the thrill of virtue resulting from the knowledge that it had an unnecessarily large factor of safety? The ultimate tensile strength of 19,000 lbs. given for American iron could not be depended on in Britain, perhaps 16,000 was as much as it was safe to assume; but on that basis, and with a factor of safety of 8, a speed of 140 feet per second might be adopted for rims cast in one piece. The arms might be cast with the rim but without the hub, thus avoiding cooling stresses; the hub being afterwards conscientiously fitted. This would involve entering the arms sideways, and not radially, into pockets in the hub, but it was a construction which had been amply justified in cane mill practice where both flywheels and gear wheels were often so made (he meant as far as the pockets were concerned, not that the rim was in one), and had stood well that extremely severe work. Unfortunately, large wheels could not be transported by rail; they would either foul the train on the other line, or the bridges and tunnels; but the advantage of the solid rim was such as to justify the casting of the rim in the town in which the engine was to work, if practicable. He thought the attachment of the arms to the rim, when separate from solid rims, should be such as to drive the rim round without pulling it in towards the centre; let the rim support itself by its own tensile strength without radial pressures at a number of points; such assistance did probably more harm than good. In the case of built rims, their knowledge of the matter was surely sufficient to calculate the safe stress, just as in the case of boiler or bridge joints. No. 1 in Fig. 4 of the paper was atrocious, and he was glad to see that it had been tested to destruction, and had only stood one-quarter of the breaking stress of the rim. In such cases the application of any such general rule as 100 feet per second might lead to disaster. No. 2 was better, and would be still better if the lug were chipped off and thrown on the scrap heap; unless, indeed, another lug were cast outside the rim so as to bring the pull central, and projections outwards from the rim

Mr C. A. Matthey.

would be considered dangerous to the attendants. In No. 3, the dowels were too near the inside; they should be central to the cross section, or rather farther out than that, so as to come into line with the resultant pull of the cast iron. No. 4 was a very good joint, he thought it was the best known for spur wheels. In fly-wheels the matter was complicated by the introduction of extra weight, but he would like to have Mr Downie's opinion as to whether a joint, approaching in strength to the solid rim, could not be designed without introducing any extra weight by coring out the rim at the ends of the segments between the projections, keeping the total weight, inclusive of the links, the same as for an equal length of solid rim. Mr Downie's estimate for the safe speed of built steel wheels was a very modest one—130 feet per second. What factor of safety did he wish? It seemed to him (Mr Matthey) that even 200 feet per second was a limit that erred on the side of over-cautious timidity; the stress per square inch was less than two tons for the solid rim, and if the joint took away one-third of the strength there was only a maximum of three tons. He would be inclined to place the limit for steel at 300 feet, which gave four tons for the solid rims, and with a joint of 66 per cent. six tons maximum. This stress was allowed in other steel constructions: Why not here? One thing was certain, and that was that the electrician was bent on a higher linear speed of his wires in the magnetic fields; it gave him a vast economy all round, not only in copper but in the whole construction. And in this matter the engineer was his servant, and would have to give him what he wanted if it were at all practicable. The problem, not only of fly-wheels which had only their own centrifugal force to resist, but of those which carried an additional load that contributed nothing to the strength, like the rotor fly-wheels of alternators, must be faced; and he had no doubt that in a few years wrought wheels would be seen running at speeds far beyond any hitherto adopted. Mr Downie deserved the thanks of members for presenting this subject in such an interesting manner, and for the evident pains he had taken in collecting good examples of modern practice.

Mr D. Kemp.

Mr D. Kemp (Member) thought the subject the author had dealt with a very interesting one, especially at the present time when so much difficulty was experienced in governing traction engines. In reading over the paper, one or two points attracted his special attention. In the constants given, no mention was made of what percentage of maximum variation of the revolutions from full load to no load and from no load to full load, which was the usual way the governing of traction work was specified, they allowed for. In a tramway system at a holiday resort, with which he had to deal recently, there were 12 or 14 cars worked with the disadvantage of a single loop line of rails, which caused a great number of stoppages when the cars were passing each other. The management of outside working was not the best, and there were one or two heavy inclines. On this system he frequently found that in ordinary working two-thirds of the total normal load was thrown off and on every now and again, which caused the regulating power to be very severely taxed. He considered that for the same weight of fly-wheel, on specified governing tests, an engine might give good results, and still when running cars would compare very unfavourably with a similar engine on a system where the cars were more numerous, and the regulation of outside working better. Other conditions being the same, systems which had fewer cars required the greater weight of fly-wheel for the same degree of regulation, also those which had loop lines and inclines must be specially considered as requiring heavier fly-wheels. Some specifications called for 2 per cent. up and down, some 2½ per cent., and others more, and to comply with these terms a greater or less fly-wheel was required. No mention was made in the paper of how the weight of the rotors was taken into consideration, and as this was an important factor increasing in proportion to the squares of the diameters, it affected the final result considerably. He would like to know what difference in the constant Mr Downie would allow for continuous current as compared with alternating current machines in consequence of the tendency to surging, which took

Mr D. Kemp.

place in rotary converters, and the necessity of keeping down the percentage variation of speed in one revolution. In the formula given in the paper it was stated that the mass varied as the horse power, but he hoped the author would correct him if he was wrong in saying that this should read, as the work done per revolution, instead of horse power. As a means of comparison with similar engines it would have been an advantage if the formula had been given also in terms of horse power, revolutions, and diameter, by substituting for V^2 its value in terms of diameter and revolutions. It would have been an advantage also if the author had worked out in figures, in detail, the example he had taken up, as it would then be much easier followed.

Mr A. Sproul (Member) considered that in the general conclusions on this paper, it would be better in No. 1 to delete the word "electric" in the phrase "electric horse-power," as one horse power with the engineer, was 33,000 foot-pounds of work, irrespective of the form of energy, and this reduced to foot-tons to bring it into line with the unit employed by Mr Downie, was 14·732 foot-tons per minute. Mr Downie stated that 2·9 to 4 foot-tons of stored energy per horse power in fly-wheels was a good proportion for lighting and traction purposes, this meant $\frac{2{\cdot}9 \times 100}{14{\cdot}732} = 19{\cdot}68$ per cent. of effective work was to be stored for lighting purposes and $\frac{4 \times 100}{14{\cdot}731} = 27{\cdot}15$ per cent. of effective work for traction purposes. What did this mean? By reference to Table I, in the paper, in Example 1, the I.H.P. was 4000, and the effective H.P. 3400, which gave an engine efficiency of 85 per cent.; this, he presumed, included the rotor, which was unfortunate from a steam user's point of view, as the efficiency of the generator was incorporated in the deductions, but if the aforementioned percentages of 19·68 and 27·15 were adopted, it meant that 923 E.H.P. would be required to keep the engine running at 75 revolutions per minute, where the stored energy was 4 foot-tons per E.H.P., while the efficiency of the set was

Mr A. Sproul.

$\frac{3400}{4000} \times 100 = 85$ per cent. In Example 2, the I.H.P. was 2800, and the E.H.P. 2300, which gave an efficiency of 82·14 per cent.; while the stored energy was 23·75 per cent. of the effective work. The governing factors q, in No. 1 $\frac{1}{600}$, and in No. 2 $\frac{1}{250}$ showed that No. 1 was 2·4 times better regulated than No. 2, while the stored energy was only $\frac{1}{7}$ more than in No. 2. In No. 3 the regulation was twice as good as in No. 2, the stored energy being the same. In No. 5, the stored energy was still higher, with a regulation of $\frac{1}{600}$ the same as in No. 1; the efficiency of this engine being 83·33 per cent., or 1·67 per cent. less than in No. 1. Referring to the last one in the table, the stored energy was the same as in No. 5, while the engine efficiency was still less, being 81·25 per cent., but with a more regular turning factor than No. 1 in the ratio of $\frac{1}{650}$ to $\frac{1}{600}$. This all pointed to the fact that other means of regulation than a fly-wheel could be resorted to. Such as better steam distribution, better balancing, and more effective governing. The results would be higher efficiency by having less stored energy, which simply meant a battle between inertia and momentum, kept up at the initial cost of material and a constantly high coal bill; and from practical considerations and frequent investigations of such problems, he would recommend a lower storage of energy than that given by Mr Downie. If he might be allowed to coin a word, when one came to *Parsonise* a power plant, he bade farewell to fly-wheels on steam engines. On the other hand, in the President's classical address, to which he listened with much interest, the President with justice gave the gas engine a great future, and in that type of engine fly-wheels were even of more importance than in steam engines, while the Otto cycle was worked. Mr Downie's paper would give a basis for much greater consideration of the form of accumulator known as a fly-wheel, and he (Mr Sproul) heartily tendered him his best thanks, more particularly for the compilation of Table I, which would have been greatly enhanced if the diameters and other particulars of the fly-wheels and rotors had been given, together with the weight and the disposition of the moving parts of the engines in question.

Mr John Barr.

Mr John Barr (Member) thought that on page 37, second line from top, 450 feet should read 430 feet, as $\frac{450^2}{10} = 20,250$, but $\frac{430^2}{10} = 18,490$, which was rather under the 19,000 lbs. found by Prof. Benjamin. It was really only on high-speed engines that fly-wheels were worked up to anything approaching 100 feet per second. In these engines the "the best value for the money" was given in the shape of fly-wheels, as very properly observed in the paper. As a rule, structural considerations did not permit of fly-wheels being run up to anything like 100 feet per second on ordinary engines. For small fly-wheels a wrought iron or steel band shrunk over the rim would, he thought, be a good and simple manner of strengthening them for high speeds.

Mr William Alexander felt that with regard to general conclusions (1) on page 37 it was not advisable to fix "a good average value" for the energy stored in fly-wheels per E.H.P. for electric lighting and for traction, for the value should depend on the revolutions per minute as well as on the disposition of the cranks of the engines; and these two variables could act conjointly in such a way as to require quite a different fly-wheel energy. It was easily seen that the coefficient of fluctuation of energy for an engine changed with the disposition of the cranks, and, therefore, also the fly-wheel energy per E.H.P. It could be shown as follows that the foot-tons of energy per E.H.P. varied inversely as the revolutions per minute—

From the paper—

$$2\,\mathrm{E} = \frac{k\,w}{q}, \text{ and } {}^{\Delta}\mathrm{E} = w\,k,$$

$$\therefore\ 2\,\mathrm{E} = \frac{{}^{\Delta}\mathrm{E}}{q}.$$

Now, in engines of the same type ${}^{\Delta}\mathrm{E}$ would be nearly directly

Mr William Alexander.

proportional to the horse power divided by the revolutions per minute,

$$\therefore\ 2\text{E} = \frac{a.\,\text{H.P.}}{q\text{N}},$$

$$\therefore\ \frac{\text{E}}{\text{H.P.}} = \frac{a}{2q\text{N}},$$

$$\text{where H.P.} = \text{horse power},$$

$$\text{and } a = \text{a constant}.$$

This equation showed that the energy stored in the fly-wheel per horse power should vary as a constant divided by the number of revolutions per minute. In compound engines the constant, *a*, would not vary much with the usual ratios of expansion and pressures, and would depend mostly on the disposition of the cranks. The rules which appeared to best fit the examples given in Table I. were—

$$\text{For lighting, foot-tons in fly-wheel per E.H.P.} = \frac{240}{\text{N}},$$

$$\text{,, traction ,, ,, ,,} = \frac{320}{\text{N}},$$

where N = revolutions per minute.

The 1st, 2nd, 3rd, 5th and 7th examples were fairly well represented in these rules. Suppose they held good for two-crank engines with cranks at right angles, then Table II. of the paper enabled the following Table to be obtained—

Number and arrangement of cranks.		One crank.	Two cranks at right angles.	Two cranks at 180°.	Three cranks at 180°.
Foot-tons of energy in fly-wheel per E.H.P.	Lighting	$\frac{240}{\text{N}} \times 18{\cdot}6$	$\frac{240}{\text{N}}$	$\frac{240}{\text{N}} \times 2{\cdot}66$	$\frac{240}{\text{N}} \times 0{\cdot}416$
	Traction	$\frac{320}{\text{N}} \times 18{\cdot}6$	$\frac{320}{\text{N}}$	$\frac{320}{\text{N}} \times 2{\cdot}66$	$\frac{320}{\text{N}} \times 0{\cdot}416$

Mr William Alexander.

It would be seen from this Table that in the case of an engine with two cranks at 180 degrees, there must be stored in the fly-wheel 2·6 times the foot-tons of energy per E.H.P. that were required when the two cranks were at right angles, and 6·3 times that required when there were three cranks at 180 degrees. This Table could easily be extended to suit the different kinds of service to which an engine might be put. He did not agree that "the initial stress due to shrinking added another element of weakness," as stated on page 37. The case was analogous to an initially stressed bolt, which was none the less effective in resisting a separating force on the pieces it connected, as long as the elastic limit was not passed. Fig. 10 illustrated a novel type of fly-wheel that might be of interest, and which would be very suitable for work so severe as occurred in electric traction. It was used in a 600 K.W. set for power and light, in the works of Messrs Workman, Clark & Co., Ltd., Belfast, and was designed by Mr Charles E. Allen, a director of that firm. It had a diameter of 12 feet, and it possessed the following advantages—(1) The rim was continuous, and the strength was therefore maintained practically to the full; (2) the number of bolts in the rim being much more numerous than spokes, the stresses that occurred, due to the bending of the rim between the points of support, were correspondingly less; (3) there was little wind resistance; (4) the steel discs connecting the rim with the hub were made very strong to resist the great torques of sudden changes of speed, a very important matter in a fly-wheel for electric traction; (5) it was exceedingly cheap to make. Although it might be necessary in wheels of large size to divide the rim into sections, all the advantages enumerated would hold to the same extent, except the first; but even then the strength of the wheel would be considerably greater, owing to the assistance that the steel discs would give to the joints. In making such a wheel it would be well to take a cut off the rim after the parts were assembled to ensure true running. The wheel mentioned fulfilled its function very well, and gave no trouble. If Mr Downie would add to Table I. the number and

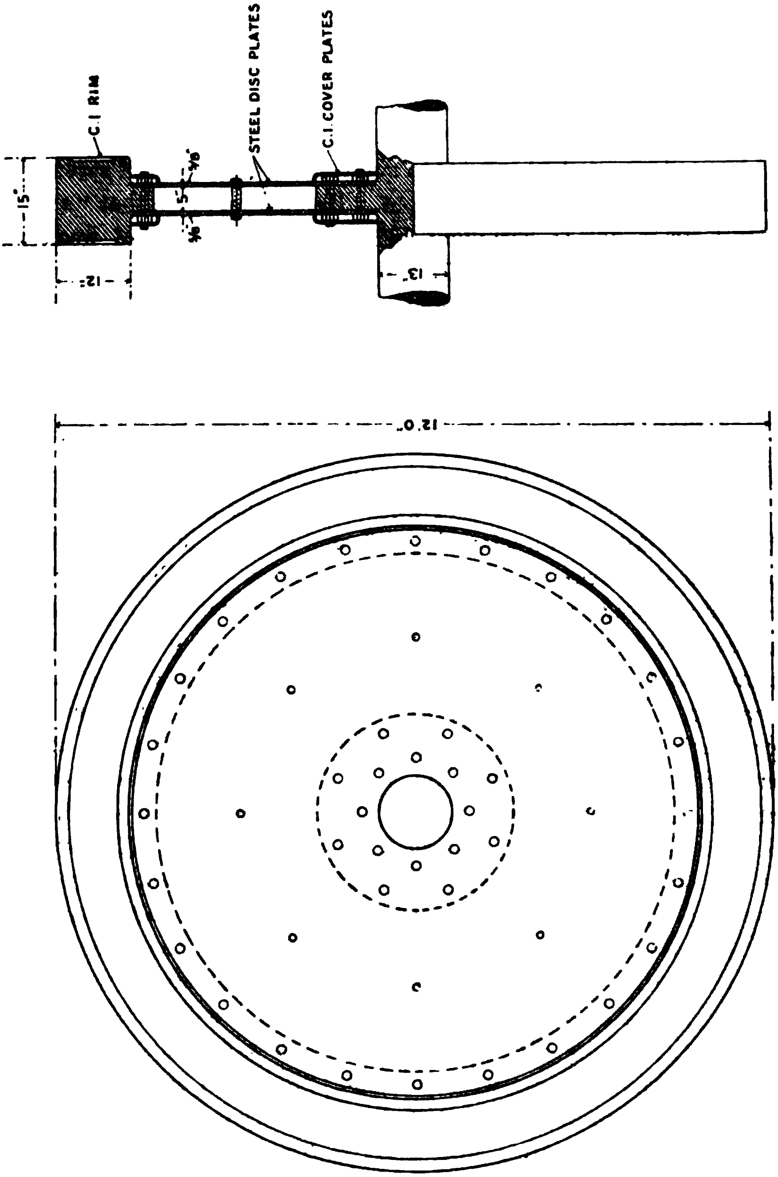

Fig. 10.

Mr William Alexander.

arrangement of cranks for the engines mentioned, it would be rendered more useful. It was difficult to get particular information on the subject of which Mr Downie had treated, and members ought to be glad that he had so unreservedly laid his experience before the Institution.

Professor Robert H. Smith (London) remarked that he had, in a paper published in *The Engineer* of 9th January, 1885, treated this subject in much the same way as was adopted by Mr Downie. In that paper numerical rules were given for the design of fly-wheels which might be found simple and easy of application. It was there pointed out also that the driven resistance might, and often did actually, go through periodic variations, and that these variations had to be taken into account in reckoning the true effect of the fly-wheel. They affected the energy area which Mr Downie called $^{\Delta}{}_{E}$, and which he (Prof. Smith) called ΔE in the above mentioned paper. In some driven machines the variation of resistance ran through a much larger range than that of the driving effort of the engine. When a large number of machines of various kinds were driven by an engine, the curve of resistance, of course, got very much smoothed out. Its periodic variation was of most importance when the engine drove one machine only. To find the largest ΔE area, on which the size of fly-wheel chosen ought to depend, the investigation should stretch over a period which was a common multiple of the periods of cyclic variation in the engine driving efforts and in the resistance. A recognition of the importance of the resistant variation often led to the placing of the fly-wheel on the driven machine instead of on the engine. That was now often done in dynamos, but the best illustration of that mode of using fly-wheels was in those punching and shearing machines which were shaft driven. Mr Downie said that the "duty of the fly-wheel is to control the tendency to change of speed due to inequality in amount of internal effort in the engine, and the function of the governor is to limit the variation which arises from change in the amount of the external load." He thought

Prof. Robert H. Smith.

that was a serious misconception, the more so because he found it rather a common one. The main duty of the fly-wheel was to steady against periodic inequality between driving effort and driven resistance, this inequality being a function of the two combined. It was the periodicity of the variation which defined the separate main fly-wheel function, not the question of the variation being internal or external. For instance, when the engine effort varied by change of initial steam pressure, this was certainly an internal change, and it was to be corrected, not by the fly-wheel, but by the governor. On the other hand, the governor was never called on to check periodic variations unless they were long and slow waves of what might be called diurnal variation. A subsidiary function of the fly-wheel, which Mr Downie and many others overlooked, but which was often extremely important, was to help a not very sensitive governor by giving it time to come into operation on the occurrence of a very sudden large change in resistance. It must be remembered that it was not always advisable to use an extremely sensitive governor, and in such cases a heavy fly-wheel helped a great deal to prevent racing. Thus fly-wheels might be said to perform two useful functions; firstly, to minimise the range of change of speed inevitably produced by periodic inequality between driving and driven efforts; secondly, in the case of large sudden change of resistance to slow down the change from the old to the new speed, and prevent a hunting oscillation of speed consequent upon violent change of condition. It would be well if engineers made less of a fetish of close uniformity of speed, and recognised that uniformity of speed was not always what was desired; that a considerable deviation was, or might be made to be, very often useful; and that a pretty large variation often took place in spite of the efforts to prevent it. Thus, in dynamo driving for lighting, the real object was to obtain uniform voltage at a certain point in the circuit, not uniform speed. It so happened that it was rather difficult to make a dynamo give uniform voltage if the speed were kept strictly constant: Then why not arrange to let the speed vary in such a way as to simplify the electro-magnetic problem in obtaining unchanged voltage with largely changed current? Many other illustrations of this proposition could be given from various domains in mechanical engineering. Would not a locomotive-driver be considered a fool if he endeavoured to keep up full speed on a long up grade, forgetful of the fact that his boiler pressure would run down rapidly if he so used his engines as to succeed in this endeavour? It must be understood that the moderate variation of speed here spoken of as sometimes desirable, was to be taken charge of by the governor and not by the fly-wheel. With reference to it, however, the fly-wheel still performed the useful function of steadying the change over from one to the other speed and freeing it from the evil of oscillation. With reference to the construction of fly-wheels, the author did not mention the use of sheet steel discs in place of arms, which he thought was an important innovation. The strength necessary in the arms had little, if anything, to do with centrifugal force; their sections should be proportioned to the driving moments they exerted in storing up energy in the rim and in redelivering it to the shaft. For at least certain kinds of engine service, a good rule appeared to be to make the fly-wheel arms strong enough to pull up the wheel from full speed to a dead stop in the course of one revolution.

Professor JAMIESON wrote, that Professor Barr was quite correct in his remarks, that the particular kind of fly-wheel referred to by him, was not the invention of Prof. Sharp, but was probably first applied by the Mannesmann Tube Co. at their Landore Steel Works, South Wales.

Mr DOWNIE, in reply, said he was much indebted to those gentlemen who had taken part in the discussion and to those who had contributed correspondence bearing on the subject of the paper. He was sure their contributions were much more valuable than the paper itself, but he was glad he had written it if only to elicit these expressions of opinion. Prof. Jamieson in the discussion, and Prof. Smith in the correspondence, had taken exception to the restricted statement of the func-

Mr Downie.

tion of a fly-wheel which he had given; more with a view of differentiating between the relative functions of fly-wheels and governors. There was certainly another duty undertaken by the fly-wheel — as had been so clearly pointed out by Prof. Smith—in retarding the effect of sudden changes of external load. He had, however, purposely confined himself, as Mr Hall-Brown had pointed out, to the case where the external load was kept constant, as it was on those lines that specifications of speed regulation were mostly drawn up. He had mentioned in the paper that greater regularity was demanded from engines driving alternators in parallel, the reason of course being to ensure that the generators would not get "out of step." He admitted that Prof. Jamieson's method of working out the formula on page 29 was more "elegant" than his; but he doubted if it was necessary in such a paper to enter into elaborate definitions of constants whose conventional symbols were well known to engineers. He agreed with Prof. Jamieson that the value $\frac{1}{850}$ given for q in the last example on Table I. was much greater than was necessary in the particular service to which that engine was put, but the lowering of the mechanical efficiency thereby was, he thought, almost negligible. There were, of course, many types of fly-wheels which he had not described, as it would have taken up too much space to do so in a general paper of this nature. He was much indebted to Prof. Barr for his remarks on the paper, and especially for the reference to the question of beams. He should have stated that the point of contrary flexure was only approximately a quarter of the span from one arm, and the value given by Prof. Barr was the correct one. When he said that the effect of lack of rigidity at the joint when made at the point of contrary flexure would increase the bending moment, he meant such lack of rigidity as would arise from faulty fitting of the joint, and that would undoubtedly have the effect of increasing the bending moment, due to each portion of the rim becoming a separate cantilever. Again, even supposing that the fact of the rim extending on each side of an arm constituted a case of rigid fixing at

Mr Downie.

the arm, there was still a complication introduced by the flexure of the arm in a direction opposite to that of rotation, in the plane of the wheel, and this was the flexibility to which he referred, although it was not perhaps made quite clear in the paper. He agreed with Prof. Barr that a test specimen was not a reliable criterion of the actual strength of a casting, but still he was relying on the experiments of Prof. Benjamin, which showed that an actual wheel did not burst until the stress by calculation was practically the same as that shown by the test specimen. He was perhaps wrong in saying that cast iron wheels when run at the speeds referred to had a "certain" factor of safety of 12; but, again, Prof. Benjamin's experiments showed that practically all the wheels tested to destruction had a certain factor of safety of 18, so that 12 appeared to him a reasonable figure to take. He thanked Mr Hall-Brown for his criticisms, which he assured him were taken entirely in the spirit in which they were made. As Mr Hall-Brown, in common with others, had inquired regarding the methods of measuring the coefficient q, in actual practice, he might say that besides the mechanical method described by Prof. Barr there was also an electrical method which he believed was first used by the General Electrical Co. of America, and described by Mr Meyer, of Rugby, in the *Electrical Review*, of July 5th, 1901. In it a small bipolar generator was driven direct by a bicycle wheel, the tyre of which was pressed against the fly-wheel rim of the engine to be tested. The field of the generator was separately excited from a storage battery, and another storage battery was connected up in the external circuit of the generator, but in opposition to the current generated by the dynamo. The voltage of the second storage battery was exactly equal to that of the generator at normal speed, so that under normal conditions a voltmeter in the circuit would stand at zero. Any variation of speed in the engine would, however, cause a proportionate variation of voltage in the generator, which would be indicated on the voltmeter. For example, in the paper referred to, a case was cited where the nominal voltage was 70 and the maximum

Mr Downie.

per E.H.P. criticised by Mr Alexander was undoubtedly open to the objections which applied to most generalisations, and he should have qualified his statement by saying that he intended it to apply to the type of slow speed engine which was rapidly becoming a standard for sizes from 200 to 2000 kilowatts output; namely, the two cylinder compound with cranks at 90 degrees and a piston speed of from 650 to 750 feet per minute. Under these conditions the "good average value" given would be found quite reliable. The formula deduced by Mr Alexander was, he thought, very useful and capable of wide application. He regretted he had not seen the type of fly-wheel referred to by Mr Alexander, but in that connection he might say, in reply to Mr Mavor, that he believed the mechanical efficiency of one of the large horizontal engines at the Paris Exhibition was said to be improved by from 1·5 to 2 per cent. by lagging the fly-wheel arms. From memory' he should say the dispositions of cranks for the engines in Table I., given in order, were as follows:—(1) 3 cranks at 120 degrees apart; (2) 2 at 90 degrees; (3) 2 at 90 degrees; (4) 2 at 180 degrees; (5) 2 at 90 degrees; (6) 2 at 90 degrees; (7) 2 at 90 degrees; and (8) 2 at 90 degrees. Referring again to Prof. Smith's valuable remarks, he regretted he had not seen the article alluded to, but would take an early opportunity of perusing it. He strongly agreed with Prof. Smith's desire for wider limits of permissible speed variation, and especially in engines for running alternators in parallel, although the "momentary" should be kept as small as possible the "permanent" variation should be allowed to fluctuate within wider limits, and thus a sensitive governor in such cases did more harm than good. The built steel wheels referred to in the paper were made of sheet steel. Mr Kemp referred to governing, but he did not propose to go further into that matter beyond what had been said above. He thought Mr Sproul was under a slight misconception with respect to the meaning of his figures. The energy stored in the fly-wheel was not lost, but could be given out at any time to meet changes of load, except, of course, a small proportion

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due to loss in transmission which would not amount to more than 1 or 2 per cent. The weight and stored energy of a fly-wheel did not, within the limits of ordinary practice, appreciably affect the ratio $\frac{\text{E.H.P.}}{\text{I.H.P.}}$ Mr John Barr took exception to the statement that a velocity of 430 feet per second would produce a centrifugal tension of 19,000 lbs. per square inch, but he might explain that the value for this tension $\left(\frac{v^2}{10}\right)$ as given in the paper was approximate, although near enough for all practical purposes, the exact value being $\frac{v^2}{10 \cdot 3}$. This would give the value for the tension corresponding to 450 feet per second as 19,660 lbs., or the velocity corresponding to a tension of 19,000 lbs. would be 443 feet per second instead of 450 as given in the paper. He thanked the members for their trouble in discussing the paper, and hoped his reply would be found to meet the majority of the points raised.

NOTES ON THE SERIOUS DETERIORATION OF STEEL VESSELS FROM THE EFFECTS OF CORROSION.

By Mr George Johnstone (Member).

Held as read 29th October, 1901.

In the following notes I propose recording my experience in dealing with the serious deterioration of steel vessels from the effects of corrosion. These notes apply more especially to the internal parts of the structure and to vessels employed within the tropics, which, owing to the change of temperature, the moist character of the atmosphere, and the condensation of vapours containing active corrosive agents, suffer much more than those trading in a more temperate climate, and under less trying conditions.

My experience proves beyond a doubt that within the tropics, and under similar conditions, steel corrodes more rapidly and more unevenly than iron.

Oxidation may be said to commence from the moment the finished article leaves the hands of the manufacturer. And the magnitude and intensity of decay is governed by climatic conditions, quality of material, its initial treatment, and the care taken in its preservation, after the vessel passes from the builder to the owner.

The importance of a periodical inspection of the exposed parts of the structure cannot be overestimated. And special care should be taken, on every available opportunity, to attend to the parts that were previously inaccessible.

Having had considerable experience in dealing with the upkeep and repairs of a large fleet of steamers, employed principally within the tropics, I have no hesitation in stating that, in my opinion, a large percentage of the money spent on these repairs was due to defective treatment. It is a well-known fact, that in the early eighties, when steel may be said to have finally replaced iron in ship construction, it practically received the same treatment that iron had previously received; although, owing to its greater strength, a considerable reduction was allowed in the scantlings of vessels built of steel. This reduction in the weight of material meant a corresponding gain in the vessel's dead-weight capabilities and earning power when carrying dead-weight cargoes, but it also meant that under similar conditions the life of the steel vessel would be considerably shorter than that of her predecessor built of iron. This, of course, is owing to the lighter scantlings, and to the finer quality of steel being more intensely affected by corrosion, and also to the fact that the lighter the scantlings, the more rapid the decay.

Although it is not possible to entirely prevent corrosion, yet it has been found that by a careful periodical inspection at short intervals, and by the removal of all rust, and by carefully coating the affected parts with a good anti-corrosive composition (which will be referred to later on), corrosion in many cases has been reduced to a minimum.

I shall firstly deal with local corrosion, although it only affects a small area; still, in my opinion, it is very important, not only because it is not easily detected and will, if neglected, produce serious local weakness, but also because of the fact that a large percentage of the money that has been spent on the repairs to vessels of thirteen years old and upwards has been due to local deterioration.

The most serious local corrosion takes place on the frames, reverse frames, and shell plating, immediately above the cement in waterways, and under the deck in wake of deck stringer plates. As it is not easily detected unless carefully inspected, it is in a great many cases neglected, and oxidation, although slow in its initial stage, increases rapidly with age or with a decrease in the sectional area of the metal, so much so that I have known cases where the flanges of the frame and reverse frames were completely corroded through before the steamer was nine years old.

The rapid deterioration of these parts is due, in a great measure, to the racking strains they are subjected to when the vessel is rolling in a sea-way, causing the paint to fissure and thereby allowing condensed vapour and other liquids containing active corrosive agents to come into direct contact with the unprotected steel.

Corrosion is most intense in alleyways and bunkers abreast of machinery and boilers; owing to the great heat and to the fact that coal is very often bunkered in a very wet condition. This is especially so during the rainy season when large quantities of water pass into the bunkers with the coal, resulting in extensive evaporation and condensation, causing rapid oxidation, not only on the parts already referred to, but, in a less degree, throughout the whole bunker space, and if not carefully looked after, will, in the course of time, seriously affect both the transverse and longitudinal strength of the vessel in her most vital parts.

The mode of treatment I have adopted is to remove all rust, and have the parts thoroughly rubbed down with wire brushes and sandstone, and, when clean and free from all damp and moisture, to have the surfaces well covered with two good coats of anti-corrosive composition. In the bunker alleyways where corrosion is most intense, I have, in many cases, raised the cement around the frames and against the shell plating, and also done the same thing in the between decks and orlops of steamers carrying native passengers and cattle. By adopting this plan, and having the cement well sloped, it not only prevents the water and urine or any other injurious liquid from lodging on the plating and frames above the cement, but it also prevents rust from forming on those parts previously affected. In a few cases the cement was found to contract, leaving an open space around the frames. This space was filled in with some of the composition referred to above. Reverting to local corrosion, the next in importance is the side plating and frames immediately behind the baths and w.c's, and under scuttles and square ports. As you may be aware, it was the practice, until quite recently, to permanently line up the sides of cabins, baths, and w.c's, in passengers', officers', and engineers' quarters. Consequently, these parts not being accessible were neglected, and oxidation went on rapidly until the plates became perforated. To make these parts more accessible, it has been the custom in vessels under my charge, when opportunity offered, to panel the lining in wake of the frame spacing under the ports and remove the same from behind baths and w.c's, and since this has been done, and more attention paid to the topside plating in general, and to the parts referred to in particular, it is the exception, not the rule, to see the topside plating of vessels under fourteen years of age, drawn in in wake of the rivets, and disfigured by a number of outside patches. There are other parts that require special attention. I refer to the shell plating, frames, and reverse frames behind the casing of all bilge, soil, and scupper pipes, etc.; also to the bulkhead plating immediately above the deck ends in the between decks and orlops, and where the decomposed cargo lodges between the ceiling and bulkhead over the bilges and ballast tanks. I would also recommend that more attention should be paid to the space under closed ceiling, extending from below the bilge stringers to the margin plate in ballast tank steamers.

This space received practically the same initial treatment as the inside of the cellular double bottom. Yet it is common knowledge that the bilge water in many cases contains decomposed vegetable matter which acts in a most deleterious manner on the steel, if not properly protected.

To illustrate the importance of not only making these parts more accessible, but also in improving the present mode of protecting the metal, I may mention two cases that came directly under my observation a short time ago. Both steamers were of the cellular double bottom type and about five-and-a-half years old. The closed ceiling was fitted in the usual manner extending from a little below the bilge stringer to the margin plate. For the purposes of examining the condition of the parts not accessible, two strakes of planking were removed on both sides. It was then observed that a thick layer of rust had formed on the shell, and on the margin and bracket plating from the cement upwards, increasing in thickness on the flanged part of the margin plate, and on the reverse angles on the bracket plate. To prevent, if possible, any further deterioration the ceiling was removed and the affected parts thoroughly scaled and rubbed down with wire brushes and sandstone. When the surface of the metal was found to be dry and free from all rust and moisture, it was coated with three good coats of anti-corrosive paint, immediately the third coat was applied it was covered with dry Portland cement, and the carpenters proceeded at once to relay the ceiling; during this process the cement was pressed into the paint.

It may be mentioned that previous to removing the ceiling the wood appeared to be in very fair condition, but after removal the planking on the under side was found to be very spongy and rotten and it had to be removed throughout. Before laying the new ceiling it was well coated with purified coal tar, care being taken to apply a thick coating of paint to the metal where the ceiling rested, to prevent water and moisture from getting between the wood and steel and thereby setting up corrosion.

I would suggest that all wood used for ceiling or sparring battens, and in fact for any purpose that would bring it into contact with the metal, should be carefully coated with a good preservative to prevent decomposition. Pine and all other soft woods absorb moisture to a great extent, and consequently, when in contact with steel, promote corrosion. This applies much more so when it is in a decomposed state, as owing to its spongy nature it becomes a most active corrosive agent.

No antiseptic should be used for preserving the wood that is at all likely to be injurious to the metal.

With reference to the cellular double bottom, the most extensive corrosion takes place in the ballast tank immediately under the boilers, so much so that in many cases deterioration has been of such a serious nature that a number of shipowners have entirely dispensed with the double bottom compartment in the boiler space. The space containing the engines and boilers is undoubtedly the most vital part of the structure, and the inner bottom plate adds greatly to its safety. This being so it is very important that nothing should be done that would in any way impair its efficiency as a water-tight compartment.

It is satisfactory to note that, the knowledge obtained from careful experiments made by engineers and others has resulted in a very considerable reduction in the magnitude and intensity of the corrosion affecting this part of the structure, so much so that steamers of thirteen and fourteen years of age are now being taken in hand to make good these defects.

Raising the boiler is undoubtedly a step in the right direction. Apart from the fact that it will prolong the life of the parts referred to, it will also facilitate repairs to the same. I would suggest going still further, subdividing the double-bottom in the machinery and boiler spaces in such a manner that the section immediately under the boilers could be kept dry and be at all times accessible. I would also suggest that a proper system of ventilation be fitted, and that the plating from the cement upwards be carefully coated with a good anti-corrosive composition that would withstand the heat.

Outside the boiler space internal corrosion is slight as compared with what takes place under the boilers and with ordinary attention should give no trouble.

The inner bottom plating in the holds corrodes rapidly if not properly protected, and my mode of treatment is simply a repetition of what is done in the bilges. I have used Stockholm tar instead of paint in several cases, but the results were not so satisfactory.

In these notes I have only referred to those parts that require special attention, and to others of a less important nature; with these exceptions, there should be no cause for anxiety.

It is very often the case when scaling or painting out the holds that, owing to the want of time or to neglect, nothing is done to ascertain the condition of the frames and plating behind the sparring battens and pipe casing. It is important that these parts should not be neglected.

I have a standing rule that on no account must paint be applied to a bare surface until it is perfectly clean and free from all damp and moisture. Applying paint to a damp surface will simply invite corrosion, as it will not absorb the moisture from the pores and surface, nor yet will it adhere to the metal.

Unsheathed steel weather decks.—On no part of the structure have I found corrosion so extensive or so intense as on the exposed area of the weather decks. I have tried many patent compositions in order if possible to preserve the deck plating from rust, but without success. Some of these were not only said to prevent corrosion, but would also absorb all damp or rust remaining on the steel when it was applied. I believe the only effective means of protecting the deck is to have it efficiently sheathed, until someone invents a composition that will be absolutely water-tight, impervious, elastic, and adhesive, and not affected by heat, salt or fresh water, or air.

The anti-corrosive paint referred to in these notes was made by mixing one part of white zinc to two parts of red lead, and thinning it to the required consistency by applying boiled linseed oil. This mixture was found to be, when carefully applied, a good preservative, retaining its anti-corrosive qualities longer than any of the other pigments used. About six years ago, as a test, the inner bottom plating of a steamer was carefully coated with two coats of this composition. Previous to its application the plating was thoroughly scaled and rubbed down with wire brushes and sandstone. Immediately the second coat was applied it was covered with dry Portland cement, which was pressed into the wet paint during the process of relaying the ceiling. Four years after the ceiling was lifted and the plating examined and found to be in good order.

Of course this does not prove that a better composition is not in use; but I think it does prove that with ordinary pigments, when properly applied, the results are satisfactory.

Referring to the space under closed ceiling, from bilge stringer to margin plate, I would suggest that the parts that are usually cement washed should be coated with a good bitumastic enamel.

In conclusion I may say that the cost of keeping the holds and ballast tanks of a steamer of 5400 tons gross in efficient order, has been found to approximate to 3d per ton per annum on the under deck tonnage. This of course only includes cleaning, scaling, cement washing, and painting.

Attached is a copy of the docking and condition report for steamers under my charge. This form is filled in annually for each vessel and filed for reference.

Discussion.

The discussion on this paper took place on 26th November, 1901

Mr Archibald Denny (Vice-President) said that this paper ha been written perhaps a good deal at his instigation. While he (M Denny) was in Calcutta two years ago Mr Johnstone showe him the effects of corrosion in that climate, where there wa not only great heat, but great dampness in the atmospher and also showed him what steps had been taken to minimis corrosion as much as possible. He then suggested to M Johnstone that the subject would form a valuable paper whic would be certain to bring out a good discussion from the marin superintendents in this country who had been troubled in th same way, although not perhaps to the same extent. What h observed there was, that corrosion with any reasonable care wa principally confined to the water-ballast tank under the boiler At that part corrosion was due to excessive heat combined wit the dampness which arose from the tanks being sometimes us as water-ballast tanks and sometimes empty. In several cas Mr Johnstone showed him that in the course of a few yea the plates on the tank top were practically gone, and co siderable corrosion had taken place in the longitudinals a wing plates. The rest of the inner bottom in the hold, howeve had not been at all affected. Mr Johnstone said matters we

Sanitary and other pipes passing through holds
Sounding pipes, air pipes, and rose boxes
Fresh water tanks
Pumps
Water service and other pipes leading above 1st deck
Paint and cement in ballast tanks, wells, bilges, and fresh water tanks
Paint in all holds and peaks

[illegible]

Remarks :

Equipment
Chronometers
Compasses
Boat compasses
Anchors
Cables
Sounding machine, leads, and lines
Wire hawsers
Hauling lines
Sails, awnings, and tarpaulins
Boats and their equipment

Remarks :

NOTE.—All work done to be carefully detailed.

Mr Archibald Denny.

much improved by keeping the boilers as high as possible from the inner bottom, and providing very large air pipe ventilators. That, he believed, was now the accepted practice, and was recommended by many of the Registration Societies. In addition, some superintendents had taken to fitting big masses of cement under the boilers, combined with old boiler tubes placed athwartships, so that any water might pass through and keep the tanks as cool as possible. He thought that with proper ventilation and these means, the corrosion in that part of the ship would be largely stopped. Some years ago his own firm had endeavoured to prevent corrosion by galvanising the whole of the inner bottom underneath the boilers. That, no doubt, did some good, but Mr Johnstone informed him that it only prevented it for a year or so more, but did not stop it. Another part where corrosion principally took place was just at the bottom of the frames, at the top of the cement which was used for filling the chocks. The moisture trickled down the frames and sides of the ship, and lodged along the line of the frame and along the top of the cement. In several instances the framing was practically cut through, and the plating nearly so. That occurred because, as a rule, it was the practice of shipbuilders to place any salt water pipes or fresh water pipes along the bottom of the frames and to box them in, which prevented examination unless the boxing was removed. The cure that had been adopted, not only there but throughout the cabins, was to have no casing for about 9 inches up from the decks underneath the berths in the cabins, so that the space might be cleaned out. After all, he thought that while, as Mr Johnstone had pointed out in his paper, steel might be—perhaps he should say was—more ready to corrode than iron, it was a question of care. In all the ships that he had inspected in various countries—and they were numerous—he had always noticed that, where ample care was taken corrosion was not a very serious factor, but it meant a certain expenditure of care and money to avoid it.

Mr James Mollison (Member of Council) said that Mr John-

Mr James Mollison.

stone had certainly given a very full description of all the parts of a steel ship likely, under certain conditions, to be affected by corrosion. He had also given the result of his experience and observation as to the best means of preventing corrosion which in many instances had proved so destructive, and often in a very short space of time. To shipowners and marine superintendents the paper should be of great value, and he would be glad to learn that it had been widely circulated among all those who were interested in the condition and preservation of ships.

Mr Henry Hand (Member) observed that this paper had been of considerable interest to him, as for a number of years, in his capacity as a Surveyor to Lloyd's Register, he had been engaged in surveying old vessels, and had had a good deal to do with repairs to steel vessels caused through corrosion. The places mentioned by Mr Johnstone were well known as being particularly liable to corrosion, and involved at times very heavy and expensive repairs, the keeping down of which was a matter of great importance to the shipowner. To keep steel from corroding, its surface should be hermetically sealed from the atmosphere. This could only be done practically by paint, and the question was: Which was the best paint for this purpose? Red lead was very suitable, but it ought to be of good quality mixed with boiled linseed oil. Red lead could easily be tested by mixing a spoonful of the powder in a solution of nitric acid and water, three parts of water to one of acid, then by adding a little sugar and heating the mixture slowly the red lead would dissolve if pure. There were several other good anti-corrosive paints, but it did not matter how good these might be, bad results would follow if they were not properly applied. It was a great mistake to allow vessels to run too long at first with a view to the mill scale being thrown off both externally and internally, as a coating of rust would form on the steel which would require a chipping hammer to remove it; and no matter how good the supervision might be, places difficult to get at were neglected, especially in way of the stringers, and at these places oxidation rapidly developed, pro-

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bably due to the condensation of the vapour in the atmosphere lodging at those parts and not by any working of the vessel. He believed in having vessels scraped and recoated as soon as the paint commenced to peel off, as the oxidation that formed under the loose paint could then be readily removed. Another part which often got neglected was the back of the reverse frames. As this was hidden from sight it was frequently left alone by the painters. No surface should be missed in painting, and close workmanship during building was very essential, as rust would accumulate between any two surfaces. This was sometimes found to occur between the frame and reverse frame, and there was no doubt that vessels with joggled landings in the plating should be carefully looked after, especially at the openings between the joggle of the plate and the frame. He had never noticed any serious corrosion between the bilge stringer and the margin plates, the framing and the plating in way of the closed ceiling was usually found to be in good condition, and he thought the removal of the closed ceiling when required at special surveys, was quite often enough, as anyone could see fairly well up the bilge when the portable ceiling at the margin was removed. The plastering up of the tank margin with thick cement, or carrying the cement too high up the sides of the vessel was not very desirable, as it got loose and allowed corrosion to go on at the back. He had known vessels which had to have their shell plates renewed on account of oxidation going on at the back of loose cement. The tanks of double bottoms in the holds of steel vessels were generally to be found in good condition, and seemed to give no more trouble than in iron vessels. It was usual to coat the tank top with Stockholm tar and the inside with cement wash, which answered quite well. The oxidation that occurred inside was of a loose description, and was easily scraped off; and scraping and cement washing inside once in four years would keep the hold tanks in first-class condition. In the boiler space cement wash was hardly of any practical use, as the vapour which gathered there readily removed it, and the upper part of the

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floors and longitudinals, as well as the top plating, deteriorated very rapidly where the heat was most intense. The use of any good anti-corrosive paint at this part, instead of cement wash, would be a very difficult matter when the ship was out of the builder's hands, and to coat the inside of the tanks with red lead paint was very injurious to workmen, while patent paints gave off gases which stupefied them. The lifetime of a tank under the boilers if coated internally while being built, with a good anti-corrosive paint instead of the ordinary cement wash, would be considerably lengthened. Good results would no doubt follow the use of a thick coating of bitumastic paint. This paint had a tendency to run, but still it would adhere to the metal when affected by heat. If it were absolutely necessary to carry ballast at this part the inside temperature should be kept as low as possible. Mr Lyall, of the Clan Line, reduced the temperature by using two air pipes, six inches in diameter, leading direct from the forced draught fans into the tanks where the heat was most intense; valves were fixed in the pipes about six feet above the tank top, and these were closed when the tanks were full, to prevent the water from getting into the fans, and whenever the tanks were being pumped out the valves were opened and a fresh current of air circulated through them. This continually went on all the time the tanks were empty, and he believed with very good results. If found unnecessary to carry water-ballast at this part it was a great mistake to leave the tank top open, which a number of owners were now doing. The top plating not only made a vessel safer in case of being holed, but it also prevented the accumulation of dirt and rubbish. With an open tank it was impossible to keep it dry, and there would always be bilge water present, consequently the vapours arising from this would deteriorate the floors almost as rapidly as if water-ballast were carried. In vessels with ordinary floors and keelsons under boilers, it was found that the reverse frames and keelson angles deteriorated very rapidly; the cement got worn by the cinder ashes getting into the limbers and cutting through it, thus exposing the steel plating to

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corrosive agencies which sometimes carried destruction to such an extent as to cause the renewal of plates at this part, and he thought this a very important reason why it was of great benefit to a vessel to have the top plating intact. The bunkers required special attention, especially between the hold beam stringer and the upper deck; the lower part, which was more or less full of coal, kept in very fair condition, whereas the upper part received all the vapours and sulphurous fumes arising from the coal. Vessels that were originally coated with bitumastic paint appeared to keep in very good condition and last much longer than those covered with ordinary paint, but every care no doubt was bestowed on the coating when in the builder's hands. Deterioration went on rapidly in way of the coaling hatchways, and no composition or paint would prevent corrosion at this part, as in coaling it got rubbed off and destroyed. The repairs, however, at this part were not of a serious nature, as only saddle-back casing and deck plating were affected. He presumed the alleyways mentioned by Mr Johnstone was the 'tween deck bunker space within the bridge house; this place was often empty, and he saw no reason why more care should not be bestowed upon it. With regard to the deck plating, chequered plates kept in better condition and lasted longer than smooth plates; this was no doubt caused by the paint remaining in the sunken part of the chequer and all the wear coming on the raised part. Composition or paint on the smooth plating wore off very quickly, and deck plating seemed to do as well without paint as with it—in fact the best part of a vessel's deck was where the traffic was greatest, namely, at the entrances to galley and cabins, no rust being allowed to gather at these parts. Wood sheathing should be very carefully laid on decks and well bedded in lead paint or else the wood would become rotton on the under surface. He knew of a case of a complete steel deck wasting entirely below teak sheathing; this was very exceptional, and was probably due to the wood having been laid during wet weather. There were a few other places, not mentioned by Mr Johnstone, where local deterioration

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occurred in vessels. These were below donkey boilers, in galleys, and in way of steam winch pipes, also in built-in ash shoots. Such ash shoots should be carefully examined on the lower surface, as they discharged near the load line, and, of course, would allow water to get into the vessel if they got wasted through. The form of docking and condition report, as used by Mr Johnstone, was a very good one, but some masters were much more interested in the condition of their vessels than others, and kept an account themselves of the date and particulars of each part of the hold when recoated.

The adjourned discussion on this paper took place on 24th December, 1901.

Mr W. T. Courtier-Dutton (Member) thought that they were all agreed as to the importance of Mr Johnstone's paper, and although the subject dealt with was by no means a new one to members of the Institution, the thanks of the meeting were due to Mr Johnstone for still pressing the matter on their attention. When steel first came into use for the construction of vessels, it soon became evident that unless special precautions were taken to preserve its condition there would be much more trouble with it than with iron. Mr Johnstone seemed to have dealt with the different items of scantlings throughout the vessel in a very comprehensive way, pointing out the parts that were more liable to rapid corrosion than others. He did not, however, quite see that Mr Johnstone was giving much more information than they already possessed, but no doubt members would be able to throw further light on the best means of preserving steel from corrosion. His attention, as a registry surveyor, was called to the serious effects of corrosion in steel vessels in the early eighties, being the time which Mr Johnstone referred to as marking the transition from iron to steel. This was in the case of a sailing vessel built in 1882—a very large vessel for that time—310 feet in length. When she had completed her first round voyage she was placed in dry dock, and the whole of the bottom was found to be pitted to such an alarming extent that he was deputed to make a special report on the subject, and to take impressions of the pitting for record and for comparison when the vessel's condition came to be examined at subsequent periods. Unfortunately, shortly after that took place the registry which he then represented—the late Liverpool Registry—was swallowed up by Lloyd's, so that the records and report were lost. The vessel, after examination, was thoroughly cleaned, and scrubbed down with wire brushes, then coated with paint and anti-fouling composition, and being carefully attended to, she subsequently gave no further trouble. He thought that the best remedy against undue corrosion in the hulls of steel vessels was to launch them without any coating whatever and allow them to remain in the Clyde, or whatever water they might be launched into, during the whole period of their fitting out, say from a month to two months. That, he thought, would effectually remove the black oxide which was formed on the plates during the process of rolling. The Admiralty practice was to pickle the plates in a bath of hydrochloric acid, and Mr Hamilton had referred to that matter in his written communication,* and stated that it was the practice of his late firm, Messrs Napier & Sons, to pickle the plates in a somewhat similar manner for use in the construction of vessels for the merchant service. He thought, however, that the suggestion he had made would be more economical, and equally efficacious in throwing off this oxide and putting the vessel in the best possible condition for coating before she went to sea. As to anti-fouling compositions, he supposed that almost every superintendent had his own favourite, and it was difficult to lay down rules on this subject, but he thought that the old mixture of white lead and tallow was pretty hard to beat. Then as to internal corrosion, and with reference more particularly to the parts which were more subject to it, namely, the tank top, floor plates, and intercostals under the boilers, he might say that the Corporation for the Survey and Registry of Shipping, which he had the honour to represent, had a rule which provided that where the lowest part of the boiler was less than 15

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* Page 101.

Mr W. T. Courtier-Dutton.

inches from the top of the tank, the tank top plating must be increased in thickness. That, no doubt, went some way towards preventing the action of the heat and moisture on the tank top. but he thought a still better remedy was to galvanize the plating, Mr Denny, in opening the discussion, referred to that matter and pointed out that while his firm had been accustomed to adopt that method for several years, the experience of some of the superintendents of the lines for which they built vessels, and in which that plan had been tried, was not quite so favourable as might have been expected, and that at the best the process of galvanizing seemed to increase the life of the plating for three or four years longer than if it had not been so treated. He ventured to think that even three or four years addition to the duration of plating which wore so rapidly was a consideration which he was sure shipowners, in spite of the small first cost, would welcome eagerly. He would venture to go further, knowing from experience that the process of galvanizing did not depreciate the quality of the material, and extend the process to other parts of the structure, such as the whole of the tanks throughout the vessel, etc. He agreed with Mr Johnstone in his remarks as to unsheathed weather decks. He thought it was useless to attempt to keep them coated, and the best plan was to leave them alone. Iron was, on the whole, preferable for such decks, but it was a commodity which was now almost impossible to get; except at increased cost and in small quantities. The Institution had been favoured with a considerable addition to the Associate membership in the shape of several prominent shipowners, and he had no doubt that the Institution would welcome any remarks from them as based upon their own special experience on the subject of corrosion. Before sitting down he would like to pay a tribute of admiration to Mr Johnstone on his "Docking and Condition Report." If such a report were filled up faithfully from the actual conditions of the vessels under his charge, and the vessels were kept up to the standard that was implied, he thought the Registry Surveyors at least would very much congratulate him, and their work would be considerably simplified.

Mr **Archibald Denny** asked Mr Courtier-Dutton whether, when he was referring to launching a vessel without paint, he anticipated docking her before she started on her voyage.

Mr **Courtier-Dutton** said he would not go so far as that. Of course, on completion of the fitting out he intended that the vessel should be docked and well scrubbed down before coating her. If the vessel were painted before launching, the scale and the paint with it would most likely be thrown off during the first voyage of the vessel. Corrosion would set in, and the vessel would come back in a very bad state indeed.

Mr **John Reid** (Member) remarked that a large vessel had recently passed through his hands, which, he might say, was one of the worst examples of the effects of corrosion which could possibly be met with. The trade in which she had been engaged was a very good one, with comparatively short voyages, but she had been in the hands of foreigners, who had misused her, with disastrous results. So far as one could see in repairing her, she had been built regardless of expense, and every care had been taken to build her properly. Special precautions had been taken against corrosion, but after only ten years' service the vessel was practically a wreck, and, although he thought that this was a case of absolute negligence, yet it showed an example of parts which were liable to corrode if left to look after themselves. After taking out the boilers, it was discovered that the floors in the boiler space were actually gone, and it was practically a miracle that the boat had arrived in port, as the boilers might have dropped right through the bottom. Under the boilers, where there had been a coating of practically pure Portland cement, the shell and the angle bars, where covered by the cement, were absolutely perfect; and under the engines, where a little lime had been applied, there was no need of any repairs. The majority of the frames and plates were in pretty good order, except for local pitting, and they had received a fair amount of care in dock. The curious thing was that per-

Mr John Reid.

haps the worst place where the corrosion had occurred, excepting the boiler space, was in way of the gangways and under the port holes. There had originally been a catch for water, with a pipe leading the water away, but this had been damaged or destroyed by carelesness, and the water had run down inside along the plating, and the corroded material could be knocked off in pieces of half-an-inch in thickness, the plates being rusted through. Probably that had occurred in five or six years. Under the decks, which were of teak, they found that there was no trouble whatever. The decks had been properly bedded in red lead, and the plates were as good as new, but under the galleys and bathrooms and so forth, where there had been cement, the corrosion was very bad. Taking the ship altogether, the evidence was that a little care would have saved all the trouble, and the vessel might have been perfectly good for other ten years if ordinary precautions had been taken. Having this brought so prominently before him, the conclusion he arrived at in connection with several other vessels was that, with ordinary care, corrosion could be avoided, and that a good deal could be done in connection with the proper use of special sections of material. He thought that the use of bulb frames in the way of bunkers would be of great advantage, and a step in the right direction. He knew that bulb angle frames were very largely adopted in recent vessels, with the best results. There was no doubt that the ordinary reverse bar was a source of trouble. The paint was not applied properly behind the flange, and no one knew exactly what was going on there. Very often coal dust lay behind the bar and set up corrosion, and he had been told that in colliers 30 or 40 tons of coal could not be got at, as it lay under bars, along keelsons, and so forth. He thought that flanging should be used wherever possible, and riveted stiffeners might be dispensed with to guard against corrosion. He also believed that joggling, although some people seemed to object to it, would be a step in the right direction. He thought the use of slip iron had the very worst results—that it was very often badly fitted, and it was very bad stuff. The water

Mr John Reid.

or moisture got in between the various surfaces, and any means that could be adopted to dispense with slip iron would be a help. He would like to instance another case which came under his notice. A small vessel of the Laird Line, when absolutely new, lay, during her first voyage, in Dublin for about a week by pure chance, and when she returned to Glasgow, she was found to be so seriously pitted as to give rise to certain allegations against the material and workmanship, and there was an inquiry on the subject. It was ascertained that the Liffey contained material from chemical works which had acted in an exceedingly serious manner upon the vessel, and the pitting and corrosion were abnormal. In connection with Mr Courtier-Dutton's remarks about putting a vessel into the water without paint, that should be considered. He did not know whether there were chemical properties in the water of the Clyde, but there were a good many foreign constituents, some of which might be detrimental. Perhaps some of the other Members who had launched vessels without paint could say something on that point.

Mr A. Scott Younger, B.Sc. (Member), considered that in dealing with the difficulty of excessive corrosion which took place in the tank tops and floors under boilers, the attempt had been made to solve the problem from the wrong end. The cause of all the trouble was the heat passing out of the boiler and evaporating the moisture which was always present in the tanks, thus creating conditions favourable for oxidising and gradually wasting away the material. The cure for that was to keep the heat in the boiler, where it was generated, and the advantage of doing so would be twofold. In the first place, the heat thus saved would be available for doing useful work in the engine, and its action in promoting corrosion of the structure under the boilers would be prevented. The firm for which he acted as superintendent always specified in new vessels that the boilers were to be two feet clear of the tank top, and, from his own experience of the matter, he did not think that the amount was too great. Mr Courtier-Dutton had indicated that fifteen inches was the figure which the British

Mr A. Scott Younger, B.Sc.

Corporation Registry regarded as reasonable. It seemed to him that fifteen inches was too little, and that it might with advantage be increased to, say, two feet, because, if there were any repairs to be done, it was almost impossible to have them efficiently carried out in the small space between the boiler and the tank top, and the effect of the heat of the boiler on the tank top plating diminished with the height of the boiler. In order to keep the heat in the boilers, it was necessary, of course, to have them efficiently lagged right round, but at present there was really a difficulty in obtaining a thoroughly efficient boiler lagging. He did not know any that gave complete satisfaction, but in some cases asbestos mattresses had been fitted and covered with galvanised iron plates, and they had lasted fairly well. He was quite sure that some better form of lagging would be obtainable in the future, which would give more satisfactory results. His experience of keeping the boiler two feet from the tank top and lagging the bottom had hardly been long enough to enable him to state what length of life was added to the material under the tank top, but from the two or three years that the arrangement had been in operation he was quite safe in saying that a very material advantage had accrued from the adoption of that plan.

Mr Courtier-Dutton claimed the indulgence of the meeting with regard to Mr Younger's statement as to fixing the height of boiler from the tank top. His Committee, after considering the matter very carefully, thought that 15 inches was a very reasonable limit to recommend, and they had found, so far, that there had not been very much difficulty, but he questioned whether it was altogether desirable for a Registry to lay down too hard and fast rules of that kind. In vessels intended for fast sea service the size of the boiler was a very important consideration, and there was not always the depth at command in the vessel to permit of fitting large boilers in position satisfactorily. He might refer to a case in point. A vessel that had received her class from the British Corporation, and in which that difficulty was so prominent that instead of allowing the sheer to be continued in a fair curve

Mr Courtier-Dutton.

it had to be straightened out amidships, so as to increase the depth to get the boiler in. He was afraid that if they were too dogmatic as to the height at which boilers should be placed above the tanks, they would have all the superintendents up in arms against them.

Mr C. C. Lindsay (Member of Council) said he had been interested in the deterioration of steel structures from the effects of corrosion for many years, and his experience was chiefly connected with steel bridges and constructional steel and iron work, but not with steel vessels. He might mention that he was one of the first to draw attention to this subject, in a paper read before this Institution, on "The Corrosion and Preservation of Iron and Steel," in 1881. While he had read Mr Johnstone's paper with pleasure, he found that the real cause of corrosion had not been touched upon, nor had it been referred to in the discussion so far. Up till about 1871, corrosion was believed to be wholly due to moisture, and that rust was simply a hydrated sesquioxide of iron, but Prof. F. C. Calvert, who was an expert, found, after many analyses of rust taken from iron bridges, that it was a compound in which carbonate of iron was a constituent; and he made the important deduction that corrosion would not take place without the essence of carbonic acid in the atmosphere. The deduction was very aptly put, and he would quote Prof. Calvert's own words:—"It was the presence of carbonic acid in the atmosphere and not its oxygen or its aqueous vapour, which determines the oxidisation of iron in common air." No doubt, in a vessel exposed to sea water externally and to sea water and various vapours internally, the considerations were somewhat different. At the same time, corrosive action was the same as in other structures. In the paper referred to, he advocated the introduction of a constituent in the composition of iron and steel for ships and bridges which would retard oxidiation as the best method of meeting the difficulty, and he thought a substantial prize should be offered for the discovery of such a constituent. It was impossible to prevent corrosive action wholly, but if some constituent, introduced in

Mr C. C. Lindsay.

manufacturing the metal, retarded it so that the essential structure of a vessel remained intact for, say, 25 years, the vessel would then be obsolete, and he did not think they should bother themselves about it after that. When cause and effect were known, the cure should follow. Regarding the presence of moisture and carbonic acid in corrosion, in certain parts of Russia, and particularly the country round about St. Petersburg, in some parts of Canada, and the higher Alps, where the air was very dry, an experience of 40 years had shown that sheet iron, and even polished steel, would not rust. And Lord Kelvin showed some years ago that freedom from rust was secured by immersing his deep-sea sounding apparatus in a tank of lime water, the lime excluding carbonic acid, the active principle in corrosion. In many other ways it had been shown that the exclusion of carbonic acid prevented corrosion. In the use of steel and iron as made at present, he advocated the retention of the original rolled surface. It was a black oxide, almost inert, and the best preservative; and its removal, which was advocated by some engineers, was a mistake. He believed that the preservation of the black oxide, and a clean coating of pure oil, followed by a few coats of pure oxide of iron paint, would give the best and most durable results.

Mr Thomas A. Arrol (Member of Council) said that the subject of this paper was not one with which he was closely associated, but he had had considerable experience in connection with rust, and there was not the slightest doubt that steel rusted more quickly than iron, and the iron rust did not apparently take off the body of the material so quickly as the rust of steel. That was pretty well illustrated in the Charing Cross railway bridge in London. There one could see tie bars which varied in size, but some pairs were 8 inches wide, with each bar 2 inches thick and about 15 feet in length, the bars being bolted together by bolts spaced about 5 feet apart. The rust between those tie bars, although they were repeatedly in tension, was quite three-quarters of an inch thick. Recently he had been making experiments with plates about 28 feet long by 24 inches wide. He had special troughs built, and tried different qualities of cement, with the view of ascertaining the best kind of cement for protective purposes and to prevent corrosion. In his opinion, after these experiments, cement was a poor thing to use. He could not see the adhesive properties. He considered that shipbuilders wanted to take more care in applying paint. It was all very well to scrape and clean, but, if they scraped and cleaned, the painter should be there at once, for in half-an-hour the damp surface on the plating in our atmosphere produced a slight oxide over the plate. Some time ago, in discussing this question, a friend told him that he had found it very beneficial to thoroughly scrape the surface as clean as possible, and to send a boy before the painter with a kerosene lamp to heat the whole surface, and then brush it lightly before the painter applied his paint, and that method had been attended with wonderful results. Unless they got rid of the moisture on the iron or steel, they might as well not paint at all. It was not much use putting red lead into paint, for it was not red lead that would preserve the metal; it was the best of boiled oil, or something that would stick to the material. Mr Lindsay had made a remark which he thought was wrong. Mr Lindsay said that the black oxide should not be got rid of. Black oxide would not rust, but it should be got rid of, because, if left on, it would come off at some time. There was no doubt that they were looking for a better steel, and they would get it, and an uncorrodible steel, but they must have patience.

Professor J. H. Biles, LL.D. (Member of Council) observed that he had had a little experience of corrosion, and in common with others his had not been a happy experience. Corrosion was an evil that was ever present, and one had, perhaps to some extent, to look upon it as an almost unavoidable evil. He was sure that the efforts of the steel makers had been devoted as much as possible to produce a steel which had as few corrodible properties as practicable. Everybody who was associated with ship construction knew that while it was possible to produce a structure that was light in itself and thoroughly satisfactory when new,in the course of a year that structure would corrode more or less, and its margin of strength would thereby be considerably reduced. Therefore, they were all most anxious to have a material which would require the least possible margin of weight for corrosion, and that would last, at any rate, until the ship became obsolete, and would not cause the ship to break down from want of strength before its time came to be laid aside through the advance of the shipbuilder's art and the skill of the engineer to produce a newer and better structure. One of the things that impressed him as being important in connection with this subject, was the difficulty of maintaining on the surface of the material, anything that would withstand the contraction and expansion that necessarily went on underneath the boilers, with the changes of temperature that took place there. It was easy to cover the material with a substance that would exclude air, but if the material was subject to changes of temperature and to extreme stresses of compression and tension, it was difficult sometimes for the coating to remain on, and, in his opinion, that caused a great deal of corrosion which took place in ships. Another well-known fact was that some of the ragged edges left in the process of construction in ships, were much more susceptible to corrosion than the smoothed off and carefully covered surfaces. He would like to know from some of the civil engineers, who had experience in the matter, what became of a very interesting process that was proposed some years ago, he thought, by a Russian named Barff?

Mr T. A. Arrol—He was an Englishman.

Professor Biles—Barff proposed to pass superheated steam over the material. He did not know whether anything had been said on that subject in the discussion, but it almost seemed to him that the process had promised exceedingly well, and he did not know whether it had come to the notice of shipbuilders in a practical form, but he was always hoping it would. Mr Lindsay had said that in Canada some steel which had been exposed had never corroded at all on account of the extreme dryness of the atmosphere. He had understood him to advocate the view that it was not dampness of the atmosphere that corroded iron or steel, but the presence of carbonic acid, and there was no amount of dryness in the atmosphere that would exclude the presence of carbonic acid. He did not know why the fact that the steel which did not corrode in the atmosphere should be an argument in favour of the theory that carbonic acid was the cause of corrosion in steel, and not dampness.

Mr THOMAS KENNEDY (Vice-President) remarked that his firm had used the Barff process for fifteen years with perfect success for meters. Some time ago Messrs Braby & Co., Falkirk, asked permission to examine the Bower-Barff furnace in use at his works. After ascertaining particulars they built one, sent a man to his works for ten days to learn the methods of working, and were now using it themselves.

Mr JAMES WEIR (Member of Council) said that he would make a few general remarks on the subject of the corrosion of iron and steel exposed to the action of water. The fact which specially came into prominence during his investigations and experiments on the subject of corrosion was that, water was not the agent which oxidised the iron or steel, but at the same time it was the water that contained the corrosive agents and brought them into contact with the metal. The corrosive agents were atmospheric air and carbonic acid. Both fresh and sea water contained about the same amount of air, but sea water had a very much greater proportion of carbonic acid than fresh water. In sea water the amount of carbonic acid was generally about ten per cent. of the total amount of the dissolved gas, and in fresh water generally there was only a trace. For all practical purposes it might be taken that the corrosive properties of water depended on the amount of carbonic acid held in solution. The solubility of the following gases in water at the temperature of 32 degrees Fah. was:—Oxygen, 4 per cent.; nitrogen, 2 per cent.; carbonic acid, 180 per cent. *Firstly*—At 32 degrees Fah. the maximum amount of gas was dissolved, and as the amount dissolved depended on the temperature, there was no gas dissolved at the boiling point. *Secondly*—The weight of gas dissolved was pro-

Mr James Weir.

portional to the pressure. His investigations proved that when these gases were dissolved in water they were in the true liquid state, and behaved in every way as liquids. *Thirdly*—Gases dissolved in water would and did remain in a liquid state under any condition of temperature and pressure, except in contact with a gas, when they then immediately resumed their state of equilibrium. *Fourthly*—Oxygen and nitrogen had no action on iron when in the gaseous state, or liquid in water. Granting the term "nascent state" to a dissolved gas at the instant when it was passing from the liquid to the gaseous state, then—*Fifthly*—In the nascent state oxygen combined directly with iron, forming hard iron oxide, which adhered to the iron surface and protected it from further action. *Sixthly*—Carbonic acid dissolved in water combined with iron oxide, forming iron carbonate, which was soluble in water. It was a well-known fact that ferrous carbonate was instantly reduced to iron oxide by oxygen dissolved in water, and carbonic acid was liberated. With the above facts in mind, the course of corrosion might be traced as follows:—*Firstly*—When water contained only the constituents of atmospheric air (oxygen and nitrogen), a coating of iron oxide was formed, and if this was allowed to remain, there would be no further action. *Secondly*—When the water contained, in addition, carbonic acid in solution, the oxygen combined with the iron to form iron oxide, which was acted upon by the carbonic acid and changed into ferrous carbonate. This was dissolved in the water, and reduced by the oxygen in it to iron oxide, while the carbonic acid was liberated, and was free to attack more iron oxide, and so on. All that was thus necessary to keep up the corrosion was a supply of oxygen in the water, as the amount of carbonic acid remained constant. Before finally leaving this subject, a few practical examples might be given of forms of corrosion familiar to all marine engineers. Bearing in mind that the nascent state was effected by diminishing the pressure and raising the temperature of the water, *Firstly* put an iron tube in a surface condenser. Corrosion would only take place on the side exposed to the sea water, and a few days would be sufficient to make holes through it. There were present in the sea water carbonic acid and oxygen put into the nascent state by the heat transmitted through the metal to the water. *Secondly*, in the case of iron and steel screw propellers, the pressure increased on the face of the blade and diminished on the back, with the invariable result of corrosion only on the side where the nascent state was brought about by diminished pressure. The peculiar form that corrosion took on a propeller was due to the painting. The paint covered or enclosed little air bubbles between the metal surface and the paint. When the pressure was removed from the paint, the little air bubble expanded, burst its prison wall, and escaped, allowing the sea water to enter with its oxygen pick and carbonic acid shovel to dig out these extraordinary cavities with which they were all so well acquainted. In the ballast tank under the boiler the heat radiated from the boilers heated the metal of the tank, which brought about the nascent state of the gases in the sea water. We had also the same phenomenon at and near the boiler sea connection, if there was the slightest leak through the cock or valves. During all his investigations on this subject he never came across a state of serious corrosion but there was always present in the water air and carbonic acid, and the water was subjected either to changes of temperature or pressure, the effect of either change being the liberation of the gases in solution in the water.

The PRESIDENT said the discussion had shown that this was a subject of very great practical importance, and it seemed also to be a subject on which there was a very considerable difference of opinion. The discussion would probably lead to considerations which might result in some method being devised to lessen the corrosion which was so ruinous to all steel structures, whether bridges or ships. The only experience he had had of protecting large steel structures from corrosion was in connection with gasholders which, as they knew, contained many thousands of feet of surface formed of thin plates, No. 9 and No. 10 B.W.G., and he had been led to the conclusion that the best protection was to coat

The President.

the plates immediately they came from the steel works, without any previous preparation, with a coating of linseed oil applied as hot as possible, and after erection with a foundation coating of pure red lead paint. This had been found so beneficial, that after 20 years he had the paint scraped off and had found the oil coating perfectly sound, and just as good as the day it was put on. This, he thought, tended to support the view of those who expressed the opinion that it was a mistake to remove the scale. It might be that those thin plates, being rolled with more care than the thicker plates, and perhaps being rolled colder, had a smoother surface, but at all events a coating of hot linseed oil applied without removing any of the oxide scale, seemed to be an efficient preservative. Gas-holders were exposed to all conditions of weather, and were alternately wet and dry. Thus protected and periodically painted, they would last for 50 years. If any corrosion set up on the plates it would be a very serious matter because they were so very thin. The discussion had been exceedingly useful, and he thought they would all agree with him that they should ask their secretary to communicate with Mr Johnstone and express the thanks of the Instituion for the trouble he had taken in writing this paper, and probably after he had read the discussion he might have some further remarks to make.

Correspondence.

Mr S. J. P. Thearle (Member) considered that the paper dealt with a subject which was of great importance, not only to shipowners but to all classes of the community. For it discussed the means whereby valuable property might be preserved from early decay, and consequently it sought to conserve that portion of the national wealth which was invested in shipping. He once heard a well-known ship repairer say:—"Why seek to prevent the decay of steel ships? If you were to succeed in so doing, one-half of my business would be gone." But probably he did not expect to be taken seriously. It was, without doubt, a duty of the Institution to concern itself with the means whereby the lifetime of steel ships

Mr S. J. P. Thearle.

might be prolonged. Mr Johstone was correct in saying that the tendency of mild steel, and indeed of any description of refined iron, to waste by oxidation was greater than that of the less pure commercial qualities of iron with which ships were formerly built. He had no doubt also that such wasting proceeded even more rapidly under the atmospheric conditions which prevailed in the tropics than was found to be the case in this country. At the same time it was his experience that, with proper care and attention on the part of those to whose custody ships were entrusted, the rate of wasting might be reduced to an inconsiderable amount. Unfortunately, masters and overlookers were not always afforded time, means, or opportunity, for doing what was necessary in this respect. Steamers were kept so much on the move, cargoes were shipped and unshipped so quickly one upon another, and the stay in port was so brief that rarely did a vessel receive the care and attention necessary for her proper preservation. The idea too often was "a short life and a profitable one," and consequently the officer who sought to keep up the vessel under his command had, in these cases, very little opportunity for doing so. There were, however, many notable exceptions to this general rule, and some of them were to be found in the port of Glasgow. He hesitated to mention any name in particular where there were so many; but there was one gentleman with whom he had discussed this question oftener than with others, and he would like to mention him now. He referred to Mr Lyall of the Clan Line, who had attacked the problem of steel ship preservation with much assiduity and no inconsiderable success. Mr Lyall's experience, and his own, too, went to show that a dry atmosphere was essential to the minimising of steel corrosion. Wherever damp lodged there would be wasting, and if the temperature was high the rate of wasting was much accelerated. Hence, steel surfaces should be kept dry. To do this, first keep them well coated with a paint or other composition which would keep out moisture, and when it could not be ensured that the composition was always in good condition, the air should be kept as dry as possible. This was particularly true of double

Mr S. J. P. Thearle.

bottoms under boilers, which should be abundantly ventilated by way of the funnel uptake. Linings and casings should be reduced to a minimum, and the steel materials kept exposed so that they could be cleaned and painted as often as might be found necessary. This was particularly important in bath-rooms, lavatories, and w.c.'s. As regarded paints, the fluid should be linseed oil in preference to naphtha, and only paint possessing a good body should be applied. The solid material in the paint—whether red lead, iron oxide, zinc oxide, or whatever else—would matter little if the oil were good. For bunkers he preferred thick bituminous enamels; for sheathed decks and ballast tank tops, Stockholm tar with Portland cement; but for unsheathed steel weather decks, he knew of no trustworthy paint or composition—the man who invented one would make a fortune out of it, and deserved what he would get. Again, he would say that the shipowner who grudged time, opportunity, and paint, must be prepared to find his ships shortlived, and if he repaired them he would find that it would have been cheaper had he given them proper attention as they needed it. He had no doubt that Mr Johnstone's paper, excellent as it was in itself, would also serve to elicit valuable expressions of opinion and results of experiments from others

Mr Henry M. Napier (Member) agreed with Mr Johnstone that the life of a steel ship depended on her being from time to time thoroughly scraped and rubbed with wire brushes and sand-stone both inside and out, and painted with a suitable non-corrosive composition. Corrosion was most rapid in way of the boilers; and the tank top, floors, reverse bars, and coal bunkers in close proximity suffered most. This was probably caused by the crust of old paint, or cement wash, or scale being thrown off by the expansion of the metal due to changes of temperature. He did not agree with Mr Johnstone that "the rapid deterioration of those parts is due in a great measure to the racking strains they are subjected to when the vessel is rolling in a sea way, causing the paint to fissure, and thereby allowing condensed vapour and other liquids containing active

Mr Henry M. Napier.

corrosive agents to come in direct contact with the unprotected steel." If such strains existed, there would be far more serious consequences than the mere throwing off of the paint. Much might be said on the subject, and Mr Johnstone's condition report was very complete, and if regularly made and properly carried out would add greatly to the life of the vessel; but there the human element came in, and odd corners were too apt to be omitted in the cleaning process and allowed to go from bad to worse.

Mr James Hamilton (Member) remarked that in addition to the reason given in the paper to account for rapid corrosion, he thought a great deal of mischief was caused in bunkers by salt water, either from the hose pipe when washing decks daily, or from seas coming on board and getting down the coal scuttles on deck. These scuttles had grating lids for ventilation in good weather, and even when the solid lid was in place it was not tight. To provide against water finding admission he had made the coal scuttles square or oblong, with the lids solid and bevelled at the back end; and with the bottom of each lid longer than the top. These were dropped into place and caulked with oakum by the ship's carpenter before each voyage began. Escape manholes were made at the top of the bunker into the boiler space and ventilators fitted to make the ventilation independent of the coal scuttles Following the Admiralty practice, which was very efficient—so many comparatively thinly plated vessels having been kept in good order—he had often pickled all the bottom plating, tank top floors, boiler seats, and such angles and bars that were not furnaced, in weak acid, and afterwards cleaned the parts in fresh water baths to take the blue mill scale off. This was not a very costly process, and it got rid of the galvanic action that was supposed to take place between the blue mill scale and the steel, and which accounted for so much of the corrosion.

Mr Robert Wright (Member) observed that Mr Johnstone had stated "that the lighter the scantlings the more rapid the decay." If by that statement was meant that a thin steel plate would oxidise more rapidly than a thick one, under similar

Mr Robert Wright.

conditions, he thought Mr Johnstone was wrong. The reason that thin steel deteriorated quicker, as a rule, than thick steel was largely due to the fact that it was more flexible, and therefore exfoliated the surface oxide or paint more readily. For painting steel surfaces Mr Johnstone advocated a composition made of one part white zinc to two parts red lead, mixed together with boiled linseed oil. That was no doubt a very good paint for tank tops or surfaces not subjected to much abrasion or work, but otherwise he had found from experience that it was not so suitable, as it flaked off too easily. The only paint, in his opinion, that would adhere satisfactorily to steel ships was one mixed with spirits. A good black spirit varnish, for instance, properly applied could not be beaten, and he thought most experienced marine superintendents would concur in this. Of course, everything depended on the initial treatment of a steel ship, and his experience went to show that if the first coat of paint was deferred until the objectionable mill scale could be properly removed, and a good composition then applied under favourable atmospheric conditions, there was no more danger of serious deterioration in a steel vessel than in one built of iron. Regarding the treatment of the double bottom under the boilers, he had been informed by Mr Wisnom, the superintendent of the Head Line of steamers, of Belfast, that he had found, from a number of years experience, the most beneficial results from using zinc plates, fitted in studs, with a metallic contact to the floor, say one plate on each half floor.

Mr JOHN M'KENZIE (Member) agreed entirely with Mr Johnstone when he said, "that on no account must paint be applied to a bare surface until it is perfectly clean and free from all damp and mosture. Applying paint to a damp surface will simply invite corrosion, as it will not absorb the moisture from the pores and surface, nor will it adhere to the metal." He would, however, submit that it was much easier to keep vessels up in the East, where the weather was warm and dry for a considerable part of the year, than it was in this country, owing to the long damp winters and the great difficulty in getting the surfaces of steel or

Mr John M'Kenzie.

iron plates dry before applying paint. He would not attempt to follow Mr Johnstone over the whole of his paper, but would confine his remarks to the upkeep of ballast tanks under boilers. He had tried may schemes for the preservation of the floors and tank tops, and one of the best that had come under his notice was a good coating of white zinc and tallow applied hot, after the surfaces had been thoroughly well cleaned, but that or any other coating would only be effective after all the mill scale had been thrown off. A great matter in dealing with the tanks under boilers was to keep the temperature of them as low as possible. With this end in view, he had for some years kept the boilers not less than 2 feet clear of the tank tops, and had their bottoms carefully covered with asbestos blankets. In addition to this he had adopted a plan of laying a portable deck of 2½-inch or 3-inch ordinary pine about

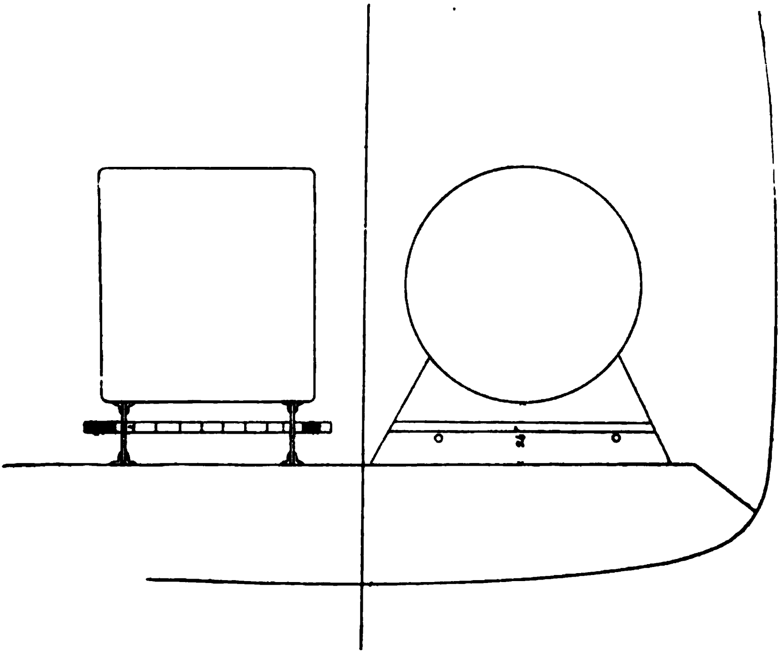

Fig. 1.

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mid-way between the boiler bottoms and the tank tops, Fig. 1. This was found to be most effective in reducing the temperature on the tank top, as it left a clear air space between the tank top and the deck. He noticed in reading the discussion on the paper at the last meeting, that reference was made to a system of ventilating the tanks by Mr Lyall of the Clan Line. He had adopted a similar, and he thought simpler plan, devised by Mr Landreth, of Newcastle-on-Tyne, which consisted of putting in two inlet pipes, each about 2½ inches in diameter, at the wings of the after or engine room end of the tank. These inlet pipes were carried up to a little above the main deck level, and had a swan neck to prevent anything falling into them. The outlet pipes were taken from the forward end of the tank, one large pipe from each side of the centre keelson led up into the main funnel, thereby creating a draught or current of air right through the tank. This plan had been adopted by many owners on the east coast with very good results, and he understood that Mr Landreth had carried out the same idea most successfully in ventilating donkey boilers when at sea and the boilers not in use. Another plan he had used with very good results for the internal coating of tanks under boilers, was to empty a barrel or two of oil into the ballast tank before filling it with water; the oil being of a lighter specific gravity than the water, floated on the surface, and as the tank filled it went into every corner. This he had found to act very well, as when the water was pumped out it always left a film of oil on the surfaces of the tank top and floors. There was one objection, however, to this, which was, that it prevented the use of the tank for carrying fresh water in the event of the steamer carrying cattle. Some owners and builders were cutting off the part of the ballast tank immediately under the boilers and leaving the tank top open. This plan he did not believe in, as it broke the continuity of strength, and was a source of danger to the vessel should the bottom become holed, besides being a receptacle for all kinds of dirt. Rather than do this he had adopted the system for some time of having the entire inner bottom of the tank under engines and boilers of iron,

Mr John M'Kenzie.

and slightly over Lloyd's scantlings, at the same time keeping the boilers not less than 2 feet clear of the tank top, with the result that after eight years work the tanks under the boilers were found to be in perfectly good order. Of course, the tank top all over was covered with a good coating of cement to protect it from corrosion due to the accumulation of dirt and ashes, which was entirely unpreventable in the stokehold of any steamer.

Mr JOHNSTONE, in reply, desired to thank the members of the Institution who had taken part in the discussion on his paper. The paper was written during a passage from India to England, without any reference to notes, which accounted to a certain extent for the incompleteness in detail. Mr Hand in his remarks stated that he had never noticed any serious corrosion between the bilge stringer and margin plate. This certainly did not agree with his (Mr Johnstone's) experience. As a matter of fact, he had known a case, and by no means an isolated one, where the parts referred to had deteriorated to such a serious extent from the effects of corrosion as to necessitate extensive repairs to the margin plate, and the renewal of a number of bracket plates and reverse frames; while within the cellular double bottom there was practically no corrosion. The importance of not only making the bilges more accessible, but also improving the present mode of treatment, could not be overestimated, owing to the fact that not only did they receive the moisture from the holds, and the drainage from cargo such as sugar, vegetable oils, and rice, etc , but in many cases drainage from the between-deck compartments occupied by native passengers or cattle. This combination had a most intense corrosive effect even in a temperate climate, and much more so when exposed to tropical heat. Referring to the between-deck alleyway, Mr Hand was not quite right in his assumption that this space was often empty; in fact, it was seldom so, as it was a part of the passenger or cargo space, and was only used as a temporary coal bunker on long voyages. He quite agreed with him regarding the deck plating under donkey boiler

Mr Johnstone.

and cooking range; these parts corroded rapidly if not sufficiently insulated. With reference to Mr Napier's remarks, he did not appear to have correctly located the parts referred to in the paper as being subject to racking strains when the vessel was rolling in a sea way. Had he done so he would have modified his statement, as it was a fact, whether he recognised it as such or not, that these strains did exist, and the results were only serious when the parts referred to were neglected. Mr Wright took exception to his statement that the lighter the scantling the more rapid the decay. He referred only to the steel used in ship construction, and the cause was due, as Mr Wright said, to the fact that the thin steel, being more flexible, exfoliated more rapidly than the thicker material.

DREDGING AND MODERN DREDGE PLANT.

By Mr William Brown (Member of Council).

(SEE PLATES III., IV., V., VI., VII., VIII. AND IX.)

Read 26th November, 1901.

The subject of "Dredging and Modern Dredge Plant," is one which must ever be of the greatest moment to most civil engineers and contractors, and to all river conservators, harbour, and dock authorities. It has also, I venture to suggest, in these days, a very special significance and interest to engineers and shipbuilders.

Experience has shown the shipping community that the cost, *i.e.*, working expenses, of transport per ton mile is cheaper in the larger than in the smaller vessel. The resultant factor of that experience is shown in that steamers of from 7,000 to 10,000 tons, accounted leviathans a few years ago, are being dwarfed and relegated to the second class by such craft as the "Medic," "Lucania," "Cymric," Oceanic," and "Celtic," with their tonnage ranging from 11,850 to 20,000 tons gross. The draught of the last named vessel is 33 feet. It seems reasonable, therefore, from the economy in working referred to, to anticipate that shipowners will continue to indent for the larger steamers, until they reach a limit of dimensions, which is assuredly not yet; or until they reach a limit of draught in their trading ports, and it is with the means for the prevention of this limit of draught that this paper is more immediately concerned.

It should, however, in all fairness, be said that our Harbour Boards and River Conservancies, with one or two possible exceptions, are fully alive to their responsibilities. The Mersey Docks Board have already resolved upon a minimum depth of 30 feet irrespective of tide in all docks and entrance channels, the

Tyne Improvement Commissioners are moving in the same direction, and other responsible bodies may be safely left to follow suit. The "findings" of the Royal Commission appointed to investigate the conditions prevailing in the Thames and the port of London, will be awaited with interest.

In America and on the Continent authorities are providing for modern ships also. By dredging in what is known as the East Channel, the United States Government are operating to greatly increase the depths at New York. When this work is completed it will give a straight channel 2,000 feet in width, with a depth of 40 feet at low water. Hamburg, the largest port in Germany, has repeatedly been enlarged; and as the Elbe did not afford sufficient depth of water for the enormous modern vessels, Hamburg made Cuxhaven into an outer port for ships of any draught. The increasing accumulation of sand in the Weser below Bremen forced that city to arrange an outer port in Bremerhaven, at the mouth of the Geste; the first works were completed in 1830, a second improvement followed in 1851, and a third Kaser Haven in 1867. Later on, the Lower Weser was improved and made deeper at an outlay of about £1,650,000, and then new harbour works were carried out at Bremen itself costing about £1,500,000. Other three important ports, namely, Rotterdam, Amsterdam, and Antwerp, are not lax in their efforts to keep abreast of the changed conditions regarding draught of water for the largest of ocean steamers, each endeavouring to outvie the other in the facilities offered.

It will thus be seen that the resources of harbour engineers at home and abroad have hitherto been equal to the demands and requirements of the shipping community. Nevertheless, it is becoming increasingly apparent that harbour and dock authorities must carry on their dredging operations with increased vigour, and thus open up the way for further advance in dimensions of craft, not only in length and breadth but also in depth.

The importance of the following is, I think, sufficient to justify the reference to the war in South Africa; and amongst other things to show that this subject of "Dredging and Modern Dredge Plant" has also an interest which is not restricted to any industry or profession, and that the subject, within its own limits, is of national importance.

Speaking at Durban, Natal, in reply to an address from the Corporation, Lord Roberts, after referring in glowing terms to the future of Durban said:—

> "Their descendants would realize how much they owed to those who had so intelligently conducted the affairs of the port and the splendid aid they had given to the soldiers of the Queen during the great war, 1899-1900.
>
> His information, he continued, showed that the number of troops passing through Durban from September, 1899, till 30th October, 1900, comprised 2,400 officers, 68,374 men, 26,789 horses, and 117 guns. In addition, the port had sent to the troops 206,239 tons of supplies, 32,000 tons of forage, and had embarked the large number of 31,935 wounded and invalided officers and men."

That Durban was able to receive oversea and deal so expeditiously with such a large body of men and munitions of war was owing almost, if not entirely, to the extensive dredging operations carried on there in recent years. In support of that statement the author may be permitted to quote from a letter of the late Right Hon. Harry Escombe, addressed to his constituents and dated 1st February, 1898:—

> "The 'Octopus,'" says Mr Escombe, "was set to work in January, 1896, and has only had help from the 'Walrus' for a few days in 1897.
>
> The following table of depths for four years, two before and two after the date that work began tells its own tale:—

1894...	11	feet	11	inches.
1895...	12	,,	1	,,
1896...	15	,,	11	,,
1897...	17	,,	3	,,

> An average depth, he continues, of more than 20 feet (at low water of spring tides) has been maintained for three months since October last.
>
> This steady improvement in depth extending over a period of two years, appears to show that the 'Octopus' is equal to the work expected of her, and that she can quickly undo the ill effects of bad weather. The 'Walrus' is in reserve."

Both vessels named by Mr Escombe are sand-pump hopper dredgers, and were constructed to the order of the Natal Government to work on the very exposed bar at Durban.

After the "Octopus" had made the voyage to, and had been refitted at Natal, it was found, on the first occasion upon which she was put to work on the bar, that there was not sufficient water to float her, and to allow her to fill her own hopper and convey the dredgings to sea as it was intended she should do. In these circumstances it was decided that the vessel should cut her own way through the bar into deep water. The suction pipe was let down and the pumps set to work discharging the spoil overboard into the sea, and in ten-and-a-half hours the dredger had increased the depth from 6 to 16 feet. The widening of the groove made by the dredger was assisted by natural agencies. Having cut her way through the obstruction, she then began to fill her own hopper, finally discharging the spoil at sea. Again in October, 1896, when as a consequence of incessant bad weather the South Channel was completely blocked up, the dredger was set to open up that channel, so far as the heavy seas would permit. On the 15th of the month she attacked the shoal which was only 5 feet below low water, and two days later she opened up the channel to a depth of 15 feet 6 inches, a depth at high water sufficient to admit vessels drawing 20 feet. A still better instance can be given of the efficiency of this dredger to open up the channel in a short space of time. On October 20th, the "Octopus" was driven off by very heavy weather, and on the 28th and 29th the storm cone was up. On the 30th, the "Octopus" got to work on the shoal on the South Channel, which was not more than 6 feet below water in the shoalest part, and on the following day there was a depth of 16 feet at low water.

The chief difficulty in connection with dredging on the Natal bar is, that being beyond the breakwater the bar is practically in the open sea and subject to heavy weather. Obviously then, if the dredgers were to meet successfully such conditions it was necessary that they should be provided with such arrangements as would permit of their being employed with the minimum amount of danger to their appliances. And in suction-pump dredgers, arrangements for meeting such conditions can only be made on or in the attachment of the suction pipe.

The suction pipe of the "Octopus" is fitted in the fore part of the ship to enable her to cut her own way through banks and shoals. The pipe is in two parts, joined together by a flexible amoured leather pipe spanned by a universal joint. The upper end of the suction pipe is carried on a trunnion-bearing at the deck; and the nozzle end is controlled by hydraulic hoist gear, designed to maintain the two lengths of pipe relative to each other in the same line of axis when working at any depth. The hoist gear consists of a hydraulic cylinder with a hollow ram. In this ram is fitted a small ram which travels with the larger one, but has also a movement independent of it. The larger ram controls the upper length of the pipe, that is, the part above the flexible joint; the smaller ram controls the part below the joint. When the length of pipe below the joint deviates from its axis with the upper length, the smaller of the rams acting on the larger one causes the whole to be raised or lowered, thus allowing the lower end to clear the obstruction which caused the deviation.

This arrangement permits of entire flexibility of the suction pipe in any direction, when it is fitted in a comparatively narrow well, and permits also of the pipe plunging about through a 25-feet radius without disturbing the nozzle on the ground.

It can also, and with equal truth, be ascribed to dredging operations consistently carried on, that the British Government were able to land another large contingent of the South African Field Force at East London.

When referring to East London, I do not forget the partially successful efforts made there, prior to the adoption of dredging, for the improvement of the depths in the Buffalo River and its entrance, by contraction of the latter, by the erection of a huge breakwater and training walls and other harbour works The breakwater was completed in 1884, but sand formations still continued in the river and at the river entrance, shoaling on some occasions to 3 feet.

On the recommendation of the late Sir John Coode, the sand-pump dredger "Lucy" was procured. This vessel was fitted with one suction pipe at the side with an ordinary leather connection at the upper end; and she did fairly good work from the date of her arrival in 1887, until she was unfortunately stranded in 1895. The "Lucy" was of 500 tons hopper capacity.

In 1891, the "Sir Gordon" sand-pump dredger of 600 tons hopper capacity was put to work. She is provided with an arrangement at the upper end of the suction pipe, consisting of a bend pipe constructed of pleated rope, designed by Mr George Tippet, resident engineer of the Harbour Board. The "Sir Gordon" has accomplished very good work on the bar.

In the month of July (winter) in the years 1893 to 1897, the depths on the harbour entrance were as follows:—

1893	... ...	9 feet	2	inches.
1894	... ...	10 „	8	„
1895	... ...	14 „	3	„
1896	... ...	10 „	0	„
1897	.. ...	14 „	6	„

Recognising from these depths the need of a larger vessel, the Harbour Board ordered a specially designed sand-pump dredger of 1,000 tons hopper capacity.

In order to reduce the possibility of damage to the suction pipes to a minimum, when working on the stormy and greatly exposed bar at East London, the builders' patent arrangement of swivel bends and hydraulic cushioning gear was applied. The advantages of this arrangement have been amply proved by the complete immunity of the suction pipes from damage since the dredger was put to work in 1897.

Each suction pipe, one on either side of the vessel, is connected at its upper end to swivel bends, designed to give free movement vertically, horizontally, and laterally, and also to admit of the pipes being brought inboard by hydraulic appliances, thus leaving the vessel's side free of all obstructions. Another special feature of this design is that the pipes may lay either forward or aft when at work, as best suits the requirements of the situation.

The automatic hydraulic cushioning gear is so arranged that the required degree of resistance is variable according to the conditions of work. Specially designed cranes are fitted fore and aft for manipulating the nozzle ends of the suction pipes, up to a radius of 15 feet 8 inches from the vessel's side, and for housing them on deck without manual assistance.

The primary object of the Harbour Board in securing a dredger which could work in the exceptionally exposed situation of East London, was to obtain a minimum depth of 18 feet at low water all the year round, which object has, I believe, been attained with a considerable margin, as is witnessed by the large number of transports which lately crossed the bar and discharged their living freights, and also by the fact that the Harbour Board lately secured from the builders of the "Kate" a bucket-ladder dredger for the improvement of the depth in the river, which was less than that prevailing on the bar and at the entrance to the port.

Regarding the performances of the "Kate" let me say that on 17th October, 1897, or three months after her arrival, the guarantee engineer reported to the builders that there was a depth of 21 feet at low water on the bar, and that the dredger had been able to remain at work on a swell of from 7 to 8 feet until recalled by the port captain.

The centrifugal sand pumps of the "Kate" are of the parallel fan type, constructed of steel plates and angles, and all the interior surfaces are protected by hard steel renewable liners. This type has been found in practice to give very good results, owing to the open construction of the fan, when dealing with heavy materials and when discharging ashore at long distances. The taper fan type of pump, somewhat similar to the ordinary water pump, as fitted in the "Octopus" and "Walrus," is used for sand pumping and for discharging at a low head or on a short distance with fine sand. This form of fan requires much less power for driving.

The following particulars, taken from two 18¼-inch sand pumps, will be of interest, and show at once the difference in the power required and of the peripheral speed of the two types.

	Parallel Arm.	Taper Arm.
Impeller, ...	5 feet 6 inches.	4 feet 6 inches.
Suction and discharge,	18¼ ,,	18¼ ,,
H.P. Cylinder,... ...	15 ,,	11 ,,
L.P. Cylinder,... ...	30 ,,	22 ,,
Stroke, ...	21 ,,	21 ,,
Revolutions per minute,	140	200
I.H.P.,...	153.3	112.5
Peripheral speed per second,	40 feet.	47 feet.

These pumps were fitted on two vessels of similar design and worked under identical conditions as to lift, delivery, and arrangement, and the dredging results per hour were about the same.

When loading into the hoppers the best results were obtained from centrifugal suction-pumps when working in clean heavy sand. With light or fine sand, or sand mixed with mud, the great quantity escaping overboard with the overflow from the hopper has made suction-pump dredging on this class of material prohibitive for economical reasons.

At Liverpool the loss of fine sand and mud escaping with the overflow of water averages about 20 per cent. of the total quantity raised by the pumps. This material going thus overboard represents not only a great loss in working expenses and a diminution of the actual output of the dredger employed, but also creates a serious obstacle to the efficient employment of the suction pumps by overlaying the neighbourhood of the dredging operations with fine sand and mud. To overcome this difficulty Mr A. G. Lyster, engineer-in-chief of the Mersey Docks and Harbour Board, has designed and patented the following arrangement. The description is Mr Lyster's own.

"The hopper of one of the smaller pump dredgers has been covered in with light iron plates, with the exception of a strip down the centre of the hopper 4 feet in width. Here a trunk 5 feet in height and 4 feet in width by the whole length of the hopper is formed of vertical plates of iron, carried up above the covering of the hopper. The upper edges of this trunk are fitted with adjustable coamings to ensure an even overflow from the hopper independently of the trim of the vessel. At the same time the discharge pipes in the hopper are laid as close to its outer sides as possible, and the openings in them are so formed as to ensure the sand and water being delivered with a minimum of commotion. The effect of this arrangement is that all the water passing from the hopper overboard has to traverse a considerable distance in passing from the discharge orifice in the pipe to the upper edge of the trunk over which it flows.

The sectional area of the trunk is such that the rate of vertical motion through it is reduced to a minimum.

The head of water which the trunk affords, and the fact that in the course of its discharge it has to rise vertically, have the effect of producing a steady and almost imperceptible flow of water, which is thus unable to take with it any sand or silt.

The experiments with this apparatus at the Liverpool landing-stage show that, as compared with the other pump dredger, which is not so fitted, the discharge water from the special hopper is clear in appearance and gives practically hardly any percentage of silt, whilst the dredger is able on an average to load herself in 20 per cent. to 25 per cent. less time than the sister vessel that is not so fitted."

Reference has already been made to the improvement effected in two South African ports by the employment of sand-suction dredgers; and of home ports it may be said that Liverpool furnishes the most notable example of improvement wrought in recent years—say during the past decade—by the employment of this type of dredging machine.

The depth on the Mersey bar at the shallowest part in 1890 was 11 feet, and it was only on flood tide that vessels of any great draught could make the port, the range of tide being so much as 31 feet on spring tides.

It will thus be seen that to obtain the minimum depth of 30 feet, irrespective of tide, the depth on the bar had to be increased by 19 feet. In August of last year there was a channel across the bar 1500 feet in width with a depth of 27 feet at low water of spring tides at the shallowest part, the average depth being 28 feet.

As an experiment, and before entering upon any extensive undertaking of suction-pump dredging, the Mersey Board decided to fit sand-pumping apparatus to their hopper barges Nos. 5 and 7, which barges had been constructed in 1877.

The contract conditions for both vessels stipulated that they should be capable of loading the 500-ton hoppers in one hour. In each case this was accomplished, and it was found that under favourable conditions they could load themselves in from 20 to 25 minutes. The best percentage of sand raised by these dredgers was 45.

The suction pipe of each dredger is trailed aft on one side of the vessel, and has a dredging depth of about 36 feet. In No. 5 the suction pipe was taken through the side of the vessel and was suspended alongside when idle. In No. 7 the suction pipe was let over the side of the vessel, and by travelling on a segment path was brought entirely inboard when not at work. Large iron shackles were on occasions taken up by the pumps without apparently doing them any harm.

It was the success attending the operations of these experimental dredgers which encouraged the Mersey Board to face, in a wholesale manner, the improvement of the bar depths by the employment of suction-pump dredgers of greater size and pumping capacity.

In 1893 the 3000-ton twin-screw pump dredger "Brancker" was put to work, and she was joined by a sister ship, the "G. B. Crow," in 1895. In 1893 the minimum depth along the line of dredging was 18 feet at the centre, and 16 feet at the sides of the cut, which was 1000 feet in width. These depths were obtained before the "Brancker" was put to work, and represent the improvement wrought by the two experimental dredgers.

The total quantity of sand removed from the Mersey bar and channels since sand pumping was begun in 1890, to 24th November, 1900, was 58,930,940 tons. The following table shows the quantities raised by all four dredgers, and also the quantities taken from the various sections upon which pumping operations have been carried out.

For fuller information of the work accomplished at Liverpool by sand-suction dredgers and of the machines employed, the author would refer those interested in the subject to Mr Lyster's able papers, "Dredging Operations on the Mersey Bar," read at the British Association Meeting in 1895, and "Sand-Pump Dredgers," read at the Engineering Conference (Section II—Harbours, Docks and Canals), on 8th June, 1899.

The dredger "Antleon," designed and constructed for the New South Wales Government in 1898, was specially designed to deal with the many sand bars on the New South Wales sea-board, where the breakers and shallowness of the water had hitherto prevented the employment of sand-pump dredgers for their removal. Her dimensions are—165 feet by 35 feet by 8½ feet, and the draught of water, with 250 tons of sand in hopper, is 5 feet. She is fitted with two independent sets of triple-expansion engines,

TOTAL QUANTITY OF SAND REMOVED FROM THE FOLLOWING PLACES BY SAND-PUMP DREDGERS FROM COMMENCEMENT IN SEPTEMBER, 1890, TO 24TH NOVEMBER, 1900.

	Queen's Channel bar.	Q. 4 B. and Q. 6 B.	Shoals in the Crosby Channel.	River opposite dock entrances.	River opposite Prince's and George's landing stages.	Total.
No. 5 Sand-Pump	1,964,950	960	230,240	359,330	2,514,380	5,069,860
No. 7 Sand-Pump	1,940,540	960	109,360	278,750	2,841,590	5,171,200
"Brancker" ...	11,546,050	11,524,050	4,062,080	36,650	526,450	27,695,280
"G. B. Crow" ...	10,387,600	6,671,200	3,585,500	10,550	339,750	20,994,600
Total	25,839,140	18,197,170	7,987,180	685,280	6,222,170	58,930,940

supplied with steam from two Babcock & Wilcox water-tube boilers, with a working pressure of 200 lbs. per square inch, reduced to 150 lbs. at the engines. Two sand suction pumps, driven by separate engines, are provided and connected to suction pipes, one on either side of the dredger, trailed aft.

To facilitate quick turning the fore-foot is well cut away, and her twin-screws enable her to spin round almost in her own length.

When dredging, neither anchors nor chains are used. The dredger steams very slowly over the bar, then turning round and recrossing the bar, takes her load, ready for dumping in deep water, by trailing her suction pipes on the bottom, while she is thus manœuvred. The "Antleon" loads her hopper, containing 250 tons of sand, in 18 minutes, and makes the round trip of loading and discharging in one hour.

The Under Secretary for Public Works, New South Wales, in his statement on the report of his Department, for the year ending 30th January, 1899, said that Mr Darley, Engineer-in-chief, had the following in his report:—

> " . . The important results obtained by working the new self-loading bar sand-pump dredger "Antleon" . . . . demand more than a passing notice. Hitherto no attempt to deepen, by dredging, sea-bars having only 5 feet of water on them has, as far as I am aware, been made either in Europe or America, all the bars dealt with having sufficient depth to float a dredge drawing 8 feet. To overcome the difficulty I took advantage of the latest improvements in boilers, engines, pumps, and steel shipbuilding, and had the twin-screw dredge "Antleon" constructed to load herself with 250 tons of sand on a rough bar, when steaming slowly over it, and to draw, when so loaded, only 5 feet of water, her speed being 9¼ knots. No pump-dredge of this size, with such a draught, has ever been

> built before, and it is gratifying to report that the experiment has been entirely successful, no less than 2000 tons of sand having been pumped and discharged in 8 hours from the crown of a shallow and tortuous sea-bar where there had been only 5 feet of water previously."

To tell the story of the evolution of ladder dredgers would be to repeat an oft-told tale of how the Clyde has been converted from an insignificant stream into one of the most important commercial arteries of the Empire. It is only my intention, however, simply to give a few descriptions of the most modern ladder dredgers, which embody in this design such improvements and arrangements as experience taught, and to give where possible the results of their work over more or less extended periods.

During the years 1893 to 1898, the 400-ton bucket-ladder hopper dredger "Waterloo" dredged from the Southampton docks and approaches, in round figures, 2,000,000 tons at the average cost of 3·4 pence per ton dredged and deposited. For the first and second years the cost per ton was 2·5 pence and 2·91 pence respectively. During that period there were no repairs to speak of. The distance to the site of deposit varies from 21 to 23 miles.

One of the Southampton dock officials stated recently at the trials of another dredger that, it was owing greatly to the dredging operations of the "Waterloo" that his company were able to dispatch large transports with the regularity of railway trains, irrespective of the state of the tide.

The total number of transports leaving and entering Southampton, from 6th October, 1899, until 9th December, 1900, was 271, representing a gross tonnage of 1,671,975 tons, the nett tonnage being 1,047,850, carrying 163,600 officers and men, 11,851 horses, 93 guns, and about 35,000 tons of stores. I am indebted to Mr John Dixon, Docks and Marine Superintendent of the London & South Western Railway Company, for the above figures.

In dealing with dredging appliances the author proposes to confine himself to the following types :—

(1) Bow- and stern- well bucket hopper dredgers, receiving the materials raised by the buckets into one or more hopper compartments arranged on board. The majority of these dredgers are also arranged to load hopper barges moored alongside.

(2) Stationary bucket-ladder dredgers, discharging the spoil into barges moored alongside; or into a receiver on board and afterwards discharged on shore by means of centrifugal pumps and floating pipes for land reclamation.

(3) Suction-pump hopper dredgers.

As representative vessels of these types, the following 11 vessels have been selected, each having more or less distinctive features of its own—

		Hopper Capacity in Tons.
Stern-well hopper dredger,	" La Puissante."	2200
Do.	" Percy Sanderson."	1250
Do.	" St. Enoch."	600
Bow-well hopper dredger,	" William Price."	1250
Do.	" Mermaid."	1000
Stationary or barge-loading dredger,	" Michail Lissovsky."	
Do.	" Lyster."	
Do.	" Andrei Stempinsky."	
Hopper barge (Liverpool),	" No. 15."	1200
Sand-pump hopper dredger,	" Walrus."	1250
Do.	" Kate."	1000

As none of the stationary dredgers mentioned above are provided with apparatus for land reclamation, I may be permitted to give here some particulars of two vessels so fitted and constructed for the improvement of Port Arthur and Talienwan.

These dredgers are provided with two sets of compound surface-condensing engines, driving twin screws, and steam is supplied by two cylindrical multitubular boilers at 120 lbs. working pressure. Either set of engines can be used when dredging by means of the buckets. The port set of engines is connected to the sand suction pump, and the starboard set to the discharging pump. The bucket-ladder and chain of buckets, and the sand suction pipe are controlled by special steam hoisting appliances. Steam winches are placed at the bow and stern for manœuvring purposes.

The material raised by the buckets is discharged directly from the upper tumbler into a reservoir containing a bar screen to disintegrate the debris, and to prevent large stones or wreckage from entering the pipes. (The sand suction pump also discharges into the reservoir, or direct overboard, as desired). An independent centrifugal pump delivers a large volume of water through a series of jets, pulverizing and breaking up the material which can then be dealt with by the discharge pump. Water is also introduced by an inlet from the sea to the bottom of the reservoir and opposite the inlet to the discharging pump. The discharge pipes are led over the deck and connected to the floating pipe line by means of a special swivel connection. The floating pipe line consists of 93 lengths of steel pipe connected together by flexible leather couplings, and carried by steel floaters, the total length being 2100 feet.

The volume of water required when discharging at long distances by means of floating pipes varies according to the quality of material, and in some cases a ratio of 10 to 1 of water to spoil has been found necessary.

In Russia, plant of this class has been very extensively used for a number of years, and all kinds of spoil dealt with, discharging up to distances of over a mile, the pipes and floaters being made entirely of wood.

When discharging at long distances it has been found necessary to prevent stones getting into the discharge pipes, and for this purpose gratings are fitted in the shoots of the dredgers. Another modification required when discharging at long distances—say, of one mile—is that an independent water pump is required to supply additional water to carry off the heavy material. This pump is placed in position to discharge into the centre of the line of piping, and has proved eminently satisfactory.

It would be observed from the technical names given to the ladder dredgers that this type is divided into two classes, namely, "Bow-well" and "Stern-well." In the latter the ladder is taken through an opening or well at the stern instead of at the bow, and a raised deck connects both sides of the vessel at the well end.

The employment of traversing ladders enabled dredgers so fitted to cut in advance and make their own way through banks and shoals. That arrangement, however, is now greatly displaced by the later one of raised bow and forecastle, which permits of the upper end of the bucket-ladder being made in a fixed position, and also permits of the dredger cutting in front. With the traversing gear arrangement the lower end of the ladder can be housed on deck, and examination of the lower tumbler more easily effected; and the speed when taking the load to the site of deposit is also greater than with the raised forecastle, unless for a hopper dredger, and even then with a long distance to go to the discharging ground the difference in speed is not great.

The first steam hopper barge in this country (one of four ordered by the Trustees of the Clyde Navigation) was constructed in 1861. All four barges are understood to be still at work. The first "hopper" dredger was built to the order of the Canadian Government in 1872.

Where the material to be dredged is of a variable nature, that is, hard and soft, the bucket dredger has been found in experience to best meet the essentials of efficiency, expedition and economy. For dredging soft ground the buckets should be made of large capacity, and they have been constructed up to 37 cubic feet capacity. For hard ground the buckets should be of much smaller capacity, and for very hard ground ripping claws alternating with every 3 or 4 buckets should be fitted. In a number of dredgers two sets of buckets have been supplied to deal with hard and soft ground as required. Where large quantities of clean sand and gravel have to be dealt with the sand-pump suction dredger has been found *par excellence* the machine to be employed.

"LA PUISSANTE."

Fig. 1.—The stern-well hopper dredger "La Puissante," constructed for the Suez Canal Co., is the largest of her class afloat, and is of the following dimensions:—

Length on deck line,	275 feet.
Breadth moulded,	47 ,,
Depth moulded,	19 ,,
Hopper capacity,	2200 tons.
Draught loaded,	16 feet 5 inches.

Her maximum dredging depth is 40 feet, while the minimum dredging depth is only limited by her draught; or, in other words, the dredger can cut her own way.

The hull, of steel, is divided into 13 water-tight compartments, and there are 8 transverse bulkheads, each carried up to the main deck. The hopper space is one large compartment arranged forward of the ladder-well and engine and boiler spaces.

(The hopper space in the dredger "Percy Sanderson" is arranged in a similar position, but in most of the other stern-well dredgers the hopper spaces are placed one on either side of the ladder well and abaft the engine and boiler spaces, with a consequent long length of shafting in tunnels carried through the hopper compartments.)

The hopper doors are formed with steel channels, plated top and bottom, and filled in solid with greenheart. The hopper winches, actuated by either steam or hand power, are fitted with frictional appliances to prevent damage should the doors by any chance get fouled. The tackle for lowering and closing the hopper doors is carried over large pulleys fixed in wrought iron brackets, having regulating screws, the whole being carried on cross and fore-and-aft girders. The lifting gear of the hopper doors is under the control of one man stationed on deck.

Propelling power is provided by two sets of independent triple-expansion engines, having cylinders of 17 inches, 27 inches, and 43 inches diameter respectively by 27 inches stroke; steam being supplied at a working pressure of 160 lbs. per square inch, from two mild steel multitubular boilers, each 14 feet 6 inches in diameter by 11 feet long. Both boilers have three furnaces, each 3 feet 8 inches in diameter. Either set of engines is available for driving the buckets independently.

A unique feature in the arrangement of machinery in a vessel of this class is that the boilers are placed in a common stokehold, arranged aft of the engine space and adjacent thereto, both engines and boilers being abaft the hopper space.

A large horizontal duplex pump, for ballast tank and bilge purposes and also for supplying water to assist the dredged material along the shoots, is provided.

The bucket-ladder, including bucket-chain, weighs 120 tons, and is fitted with buffer springs at the upper end to lessen the shock when working in a sea-way. The buckets, each of 31 cubic feet capacity, are formed with cast steel backs, with mild steel bodies, and lip or cutting plates of harder quality. The ladder is suspended from the shears by a 10-sheave wire rope purchase. Powerful hoisting gear, fitted with frictional brake apparatus, for raising and lowering the ladder at two speeds, one at 7 feet and the other at 13 feet per minute, is driven by large independent steam engines.

For manœuvring the dredger when at work a combined winch and windlass is fitted at the bow and a specially powerful winch is provided aft. Each winch is arranged for two speeds, one for dredging and the other for taking in slack chain.

Two wide shoots, having hinged doors at intervals for the even distribution of the dredged spoil in the hopper, are provided, and there are overside shoots, wrought by steam power, for loading barges on either side when required.

To improve the steering qualities, and to place the vessel more thoroughly under command when light, a trimming tank is fitted and there are two independent ballast tanks built into the structure of the vessel, one on each side of the hopper space. The bunker capacity is 80 tons of coal, and there are independent tanks for petroleum fuel. There is accommodation forward for the officers, and at each side aft for the crew, consisting of native and European quarters. All the compartments have lofty ceilings, and were specially designed for a hot climate. A complete installation of electric light is provided above and below deck.

The following trial results will convey some idea of the "La Puissante's" capabilities:—

The contract dredging capacity per hour was 1,150 tons; but the mean result over an extended series of dredging trials was 1,600 tons per hour, with the engines indicating 380 I.H.P., and the buckets running at from 18 to 20 per minute. Theoretically, the maximum lifting capacity of the buckets per hour is 1,800 tons; on one occasion, however, during these trials they raised over 2,000 tons. During the time this load was being made, the dredger had got into a very suitable bed of clay, which more than filled the buckets with the result indicated. This load was not included when computing the average given above. On the measured mile a speed of 9¾ knots was obtained, with 1,620 I.H.P. The coal consumption on a six hours run was 1·66 lbs. per I.H.P. per hour.

On the dredger being put to work at Port Said some difficulty was experienced in getting the hopper doors to retain the soft slimy mud raised by the buckets. The difficulty was, however, got over by fitting leather slips along the doors and by tightening the hopper chains. The material raised by the buckets, from the Port Said Roads, is brought up in large pieces, but immediately they come into contact with the water in the hopper they dissolve into a consistence which is really not much thicker than pea soup. When this initial difficulty of retaining the spoil in the hopper had been got over, the vessel loaded her own hopper in a thoroughly satisfactory manner and has since been doing splendid work.

"PERCY SANDERSON."

Fig. 2.—The 1,250-ton stern-well, combined bucket and suction-pump, hopper dredger "Percy Sanderson," constructed for the European Commission of the Danube, and measuring 227 feet in length, 40 feet in breadth, and 17 feet 2 inches in depth moulded, is the next in point of size, and hopper capacity, to the "La Puissante."

Water-ballast tanks are provided in the side compartments of the hopper and also in the fore peak. The hopper doors are formed of steel plates $\frac{7}{20}$ of an inch thick, stiffened round the outside edges by angle steels, the inside being lined with 4-inch American elm. The doors can be raised or lowered by either steam or hand power, and brakes with quick-acting screw gear are fitted to each winch.

The propelling machinery consists of two sets of triple-expansion surface-condensing engines, driving twin screws; each set having inverted cylinders of the following diameters: H.P., 15½ inches; I.P., 24½ inches; L.P., 39 inches, with a stroke of 24 inches. Besides the usual engine-room donkey pumps, a special large pump of "Duplex" type is provided to assist in clearing the dredgings from the shoots. There are two steel boilers on board, each fitted with three patent ribbed furnaces, and measuring 13 feet in diameter and 10 feet long. The working pressure is 160 lbs. per square inch, and each boiler is capable of supplying steam to all the dredging machinery.

Bow and stern steam mooring crabs are fitted for regulating the cut of the dredger while working. These are worked by two sets of independent engines, and have each three chain barrels arranged to work separately or conjointly so that the head, stern, or thwartship chains can be taken in separately or together. The lockers for the mooring chains are so arranged that the chains are led to and from them without manual assistance.

The dredging gear has a variable speed of from 14 to 18 buckets per minute, and the buckets can dredge to a depth of 35 feet below water level. The bucket-ladder, 90 feet long, is formed of parallel plate girders strongly bound together by cross ties of box section, and by intermediate tie plates. The upper end of the ladder is suspended independently from the tumbler shaft, and the lower end is hung from the sheers by wire rope working through sheave blocks. The hoist barrel is driven by an auxiliary engine capable of raising and lowering the ladder seven feet per minute. Whenever necessary the ladder can be raised on deck for overhaul.

The upper and lower tumblers, four- and five-sided respectively, have extra large flanges. The buckets, thirty in number, and each of 24 cubic feet capacity, are made of mild steel, with double link backs of cast steel. The intermediate links are of forged steel. Shoots are fitted under the upper tumbler for conveying the dredged spoil into the vessel's own hopper or into barges on either side.

In addition to the chain of dredging buckets, a powerful centrifugal pump is fitted on board. It is driven by a pair of triple-expansion engines of 300 I.H.P., and is capable of raising at least 700 tons of clean sharp sand per hour. The pump casing is built of steel, and is fitted with a steel fan, keyed on a steel shaft, working on a deep gun-metal bearing. The outboard suction pipe, 22 inches in diameter and 70 feet long, is constructed of steel plates, and is capable of dredging to 35 feet depth of water.

Mr Charles Kuhl, Resident Engineer of the European Commission of the Danube has favoured me with the following particulars of the work done by the "Percy Sanderson," together with the cost per ton since she was put to work in 1894:—

Dredged by "Percy Sanderson" in Sulina Entrance Channel.

1894—October	to December,	...	168,280	tons.
1895—January	to October,	...	562,870	,,
1896—March	to December,	...	421,300	,,
1897—January	to October,	...	443,300	,,
1898—April	to November,	...	502,700	,,
1899—June	to November,	...	664,400	,,
		Total	2,762,850	tons.

Average cost per ton, 1894 *to* 1899, *Dredging and Discharging at an average distance of* 3 *Nautical Miles.*

Dredging ...	Coal and Stores,	0·53d	1·33d.
	Crew and Wages,	0·80d	
Repairs of dredger	Coal and Stores,	0·66d	1·41d.
	Wages, ...	0·75d	

Total pence per ton, 2·74.

No allowance has been made in the above figures for interest on capital, depreciation, or insurance.

The I.H.P. at the trials of the "Percy Sanderson," when the buckets were run at 16 per minute, was 140, and a speed of 10 knots was easily obtained with 1140 I.H.P., when loaded with 1250 tons of dredgings in the hopper.

"St. Enoch."

Fig. 3 shows the elevation and deck plan of the stern-well dredger "St. Enoch." Two dredgers of this type have already been described, and it will probably be sufficient in this case to merely state the leading features.

The bucket-ladder is of sufficient length to dredge to 46 feet below the water-line when the dredger is in the light condition. The buckets, each of 15 cubic feet capacity, were specially designed for raising and discharging very adhesive clay. Two separate hopper compartments are arranged one on each side of the ladder well, for the reception of the dredged material. With the exceptions stated it may be said that this is the arrangement generally adopted on this type of dredger. Between the hoppers and ladder well, tunnels are constructed for carrying the propeller shafting. The total capacity of both hoppers is 600 tons. A feature in the construction of these hopper compartments is that the sides are vertical instead of sloping, thus allowing the dredged clay, of a very sticky nature, to be easily and quickly discharged.

There are two sets of engines placed forward of the hoppers, each of the compound surface condensing type, having cylinders of 20 inches and 39 inches diameter respectively by 24 inches stroke, driving twin screws—steam being supplied from two steel boilers at a working pressure of 120 lbs. per square inch.

It is against Admiralty practice to divulge particulars of the improvements wrought at the various Royal dockyards by dredging operations. The author is therefore unable to give any particulars of the work done by the "St. Enoch"; but the following particulars of one year's work by a similar vessel may not be without interest.

No. of days dredging	265
Average No. of hours per day	10¼
Total quantity dredged and conveyed to sea (nearly the whole of this being very hard clay)	386,410 tons
Average time to load in soft material	1½ hours
Do., do., hard material	3 „
Average cost per week for wages, coals, and stores	£47 2 0
Do., do., repairs ...	57 8 0
Cost per ton of material dredged and conveyed to sea	1·85 pence
Cost per ton of material dredged and conveyed to sea, including 5% on capital ...	2·56 „
I.H.P. when dredging	From 50 to 80
Do. when on trip loaded	836·31

"WILLIAM PRICE."

Fig. 4.—The bow-well hopper dredger, "William Price," is of the following dimensions:—Length, 236 feet; breadth, 42·6 feet; and depth, 16 feet. Dredging depth when the hopper is empty, from 0 down to 43 feet. She is fitted with two sets of triple-expansion engines capable of developing collectively 1,840 I.H.P.; and two return tubular boilers having a working pressure of 160 lbs. per square inch. Either set of engines can be used for dredging, and change gear is provided for altering the speed of the buckets ac-

cording to the nature of the bottom upon which the dredger is to operate.

In the published administration report of the Karachi Port Trust for 1898-1899, Mr Jackson, Engineer to the Port Trust, makes the following remarks regarding the "William Price:"—

> "This dredger was completed and launched on the 22nd April, 1898, tried at Greenock for dredging and speed on the measured mile on the 28th of the same month, and found to be satisfactory and up to the specification. The contract speed was 10 knots per hour when fully loaded with 1250 tons of dredged material, and the average of a number of runs taken was slightly over this. The vessel left the Clyde on the 27th May, in working condition, with all the machinery and ladder in place, and half the buckets on, and was 39 days in steaming out to Karachi, arriving on the 5th July during heavy monsoon weather without having sustained the slightest damage of any kind, or having met with any hitch on the journey out. She is provided with two sets of buckets, one set for sand and free soil having a capacity of 22 cubic feet, and the other for dealing with very hard indurated clay and stone, and having a capacity of about 12 cubic feet. The latter has justified anticipations in the work that has so far been done this year, and it is anticipated that the bell diving and blasting operations which have hitherto been necessary in breaking the hard ground before dredging will now be dispensed with. The vessel worked for the first three months under guarantee of her machinery and working parts by the builders, when she was finally taken over in working order on the 31st December, 1898."

The I.H.P. developed on the speed trials was 1840; on dredging trials 180 I.H.P. when running the smaller buckets at 13 per

STATEMENT SHOWING RESULTS OF WORKING OF THE ADEN PORT TRUST HOPPER DREDGER "MERMAID," FROM 1ST APRIL, 1893, TO 31ST MARCH, 1900.

Years.	Dredging.	Depositing.	Picking up moorings.	Shifting anchors forward.	Coaling.	Repairs to machinery and consequent stoppages.	Total.	Days working.	Tons dredged.	Cost Rs.	Rate per ton at 1/4 exchange.
	Hrs. Mts.	Hrs. Mts.	Hrs. Mts.	Hrs. Mts.	Hrs. Mts.	Hrs. Mts.	Hrs. Mts.				Pence.
1893-4	1070 09	601 01	200 10	290 15	— —	725 50	2887 25	256	555,000	80,286	2·31
1894-5	776 40	415 40	94 30	163 15	5 55	883 35	2339 35	247	356,000	82,783	3·72
1895-6	957 45	455 28	162 12	239 40	2 40	735 45	2553 30	264	444,000	101,615	3·66
1896-7	904 30	513 —	159 10	259 45	8 50	1112 20	2957 35	302	404,000	72,964	2·89
1897-8	829 05	416 35	147 10	245 25	1 05	758 20	2397 40	243	358,000	82,706	3·69
1898-9	980 25	488 45	221 00	296 50	3 40	573 30	2564 10	265	453,000	103,265	3·65
1899-1900	1121 35	568 25	234 27	281 25	9 10	703 43	2918 45	300	501,000	75,457	2·41
Total	6640 09	3458 54	1218 39	1776 35	31 20	5493 03	18,618 40	1877	3,071,000	599,076	22·33
Average	949 —	494 —	174 —	254 —	4 —	785 —	2660 —	268	439,000	85,582	3·19

Overtime for about one hour per day is wrought on those occasions when there is any chance of completing a load before stopping for the day, instead of leaving an unfinished load.

Note.—The rates entered above include all charges such as wages, stores, coals, repairs, renewals, insurance, two dockings at Bombay in 9 years, *but* do not include supervision charges and depreciation of plant and interest on the same.

minute; and 230 I.H.P. when running the large buckets at 18 per minute.

"MERMAID."

Fig. 5.—The bow-well twin-screw hopper dredger "Mermaid," of 1000 tons hopper capacity, measures 191 feet in length, 38 feet 6 inches in breadth, and 15 feet 9 inches in depth, moulded, and has a maximum dredging depth of 35 feet. The hopper compartment is arranged forward of the propelling engines, and mooring winches are provided fore and aft. Speed on trials 9¾ knots.

The author is indebted to Mr W. S. Child, Port Engineer, Aden, for the foregoing statement of the work accomplished by the "Mermaid" for seven years ending 31st March, 1900.

"MICHAIL LISSOVSKY."

Fig. 6.—The bow-well, barge-loading dredger, "Michail Lissovsky," while not differing greatly in general arrangement of machinery, etc., from the dredgers of the same type, has the distinctive feature of having the largest bucket lifting capacity of any dredger afloat. The buckets are exceptionally large, having each a capacity of fully 36 cubic feet, or 1¾ tons, and the length of the bucket-ladder enables them to dredge to a depth of 36 feet below water level. With the engines indicating 250 I.H.P. on the dredging trials, 2000 tons were raised in one hour.

The propelling power is supplied by one pair of compound surface-condensing engines and two mild steel boilers for 120 lbs. working pressure. Each boiler is capable of supplying steam to either the propelling or dredging machinery when under full working conditions, and thus the vessel has always a boiler in reserve.

The bucket-ladder, exclusive of dredgings, weighs over 100 tons, and is controlled by a powerful set of independent engines.

"LYSTER."

Fig. 7.—The Mersey Docks and Harbour Board's barge-loading dredger "Lyster," built of steel, is of the centre-ladder type. Her principle dimensions are:—Length on deck line, 196 feet;

breath, 35 feet 6 inches; and depth, 13 feet. She is exceptionally well fitted with appliances for handling the moorings and machinery; and has a powerful windlass and compound winches for manœuvring and other purposes. The propelling machinery consists of two sets of triple-expansion engines, driving twin screws, and either set is capable of driving the dredging machinery. The auxiliary machinery consists of feed-heater, filter, dynamo engine, and independent centrifugal pumps for circulating purposes. Steam is supplied from two steel boilers at a pressure of 180 lbs.

The dredging is done by 39 steel buckets, each of 20 cubic feet capacity, and of great strength. Each bucket, with pins, weighs two tons, and each connecting link 5 cwts. The buckets are capable of dredging sandstone rock. On a hard clay bottom they are run at a speed of 15 buckets per minute, while on harder material ten buckets per minute is maintained.

The guaranteed dredging capacity of the "Lyster," on very hard ground, was 400 tons per hour, but that amount has been greatly exceeded, and she has done a lot of hard dredging in lifting rock previously blasted. The speed on the trial trip was 10¼ knots.

The dredgings are conveyed into barges in such a manner that two hoppers can be loaded together. The shoots have independent engines for hoisting and lowering. The ladder can be lowered to dredge to a depth of 45 feet below water, and can be raised so as to dredge a channel for the dredger itself.

"Andrei Stempinsky."

Fig. 8. — The bow-well barge-loading dredger "Andrei Stempinsky," constructed for the Russian Imperial Ministry of Ways and Communications, is of the following dimensions:— Length, 152 feet; breadth, 32 feet 6 inches; and depth, 12 feet. The vessel is designed to cut her own flotation and down to a depth of 32 feet below water level. The main gearing for driving the buckets is of a powerful description for dredging hard ground, and is driven by surface-condensing

engines fitted with two changes of speed for dredging hard and soft ground.

Steam hoist gear for ladder, mooring crabs at bow and stern, and all other usual fittings for vessels of this type are fitted on board.

During continuous dredging operations for two periods of eight months each, working double shifts, a sister vessel to the abovenamed, "Victor Augustinovitch," raised 180,000 Russian cubic fathoms at a cost of 76½ copecs per cubic fathom, or, say 3,086,100 tons at 1·14 pence per ton. Altogether this dredger wrought for 6495 hours. For fully a quarter of that time she was employed working on clay; the remainder of the time was occupied in raising clay and mud.

Another similar dredger, "Fedor Enrold," raised in 2791 hours 1,484,300 tons of sand and silt with sand.

Hopper Barges Nos. 14 and 15.

Fig. 9.—These vessels, constructed for the Mersey Docks and Harbour Board, measure 205 feet in length, 35 feet in breadth, and 16 feet in depth, and have a hopper capacity to carry 1200 tons of dredgings. They are propelled by twin screws driven by two sets of triple-expansion engines supplied with steam from two return tubular boilers having a working pressure of 160 lbs. per square inch. The hopper doors are worked by steam power from independent engines placed at the fore and after ends of the hopper. A steam windlass is fitted forward and a steam captsan aft.

On the measured mile a speed of 10½ knots was obtained, when loaded, with the engines indicating 1300 H.P.

"Octopus" and "Walrus."

Fig. 10.—The sand-pump dredgers "Octopus" and "Walrus," constructed for the Natal Government for work at the port of Durban, are fitted with two 33-inch centrifugal sand pumps capable of raising 3000 tons of sand per hour from a depth of 40 feet. They are driven separately by two sets of independent triple-expansion engines, which enable them, in conjunction with the arrangement

of the suction pipe, to be wrought separately or together as required. The large main suction pipe of 44 inches internal diameter, fitted in a central well at the fore part of the ship, is controlled by hydraulic gear, and is attached to the hull by the swivelling gear and flexible joint on the suction pipe already described. The hopper doors are also controlled by hydraulic gear.

The propelling machinery consists of two sets of triple-expansion engines, driving twin screws to give a speed of 9½ knots. Steam is supplied by two steel boilers constructed for a working pressure of 160 lbs. per square inch.

At the bow a powerful steam winch is fitted for working the anchors and chains, besides which there are independent steam capstans forward and aft to work the mooring chains.

Special attention was paid to the ventilation of the cabins, and separate accommodation is provided for the native portion of the crew.

On one occasion a piece of bar iron weighing 87 lbs. was sucked up by the "Walrus" pump, and pieces weighing upwards of 56 lbs. have been frequently brought up by both dredgers.

The author is indebted to Mr C. J. Crofts, engineer of the Natal Harbour Department, for the following returns for the years 1898 and 1899, showing the work of each dredger at Natal and the cost per ton. It may be interesting at this point to say that, the Natal Government are so alive to the question of providing facilities to meet the rapidly increasing shipping trade at the port of Durban that they have now at work, or under course of construction, eleven dredging vessels alone, exclusive of hopper barges.

"KATE."

Fig. 11.—The twin-screw sand-pump hopper dredger "Kate" was constructed for the East London Harbour Board and has a hopper capacity for 1000 tons of dredgings. Her dimensions are:—200 feet in length, 39 feet in breadth, and 14 feet 6 inches in depth, and she is fitted with two sets of triple-expansion

Return Showing Work Done by the Dredgers at Port Natal During the Year ending 31st December, 1898.

DREDGERS.	DREDGING SECTIONS (See Plan No. 1.)						TOTALS.	Cost per ton in pence.	NOTES.
	Outside breakwat'r	Section A	Section B	Section C	Section D	Section E			
"Walrus" suction sea-going dredger, 1200 tons hopper capacity, ...	236,000	46,400	19,200	60,600	323,300	490,900	1,176,400	1·785	The "Walrus" did very little work on the bar until July when her new windlass was fitted.
"Octopus" do.	388,600	104,800	...	1,100	56,100	562,100	1,112,700	2·140	
"Beaver" 18" suction sea-going dredger of 500 tons hopper capacity, ...	...	...	...	...	...	426,150	426,150	2·772	
"Otter" sea-going bucket-dredger, 500 tons hopper capacity and capable of dredging about 500 tons per hour, ..	...	...	118,380	16,890	18,550	1,795	155,615	6·387	The "Otter" was at East London until April 9th, and started work here on 15th April. Nearly the whole of the material dredged was soft rock, boulders, or shingle, which accounts for the high cost per ton; 153,900 tons of the spoil raised by this dredger was carried over the bar by the hopper barges at a cost of 3·1 pence per ton.
"Platypus" stationary bucket-dredger capable of raising about 250 tons per hour, ...	...	...	...	14,000	3,750	174,830	192,580	2·458	Of this output 160,510 tons was carried over the bar and deposited by the hopper barges at a cost of 3·1 pence per ton. The remainder (32,080 tons) was supplied as ballast to vessels in harbour.
"Water Rat" and...	...	...	...	...	...	48,100	48,100	...	It would be very misleading to give the cost per ton of the spoil raised by the "Water Rat" and "Sandpiper," as these two vessels have been engaged almost entirely in connection with the foundation trench of the quay wall which frequently requires hours of work with little or no spoil actually raised.
"Sandpiper" 12"-suction stationary dredgers, ...	...	...	...	...	...	28,926	28,926	...	
Totals, ...	624,600	151,200	137,580	92,590	401,700	1,732,801	3,140,471		

RETURN SHOWING WORK DONE BY THE DREDGERS AT PORT NATAL DURING THE YEAR ENDING 31ST DECEMBER, 1899.

DREDGERS.	DREDGING SECTIONS (See Plan No. 1.)						TOTALS.	Cost per ton in pence.	NOTES.
	Outside breakwat'r	Section A	Section B	Section C	Section D	Section E			
"Walrus,"	115,500	36,300	102,300	13,200	67,100	768,900	1,103,300	1·984	
"Octopus,"	140,300	61,600	80,500	62,700	136,700	594,000	1,075 800	1·913	
"Beaver,"	...	...	...	...	23,850	352,075	375,925	2·714	
"Otter,"	...	...	95,730	600	10,620	26,130	133 080	11·642	Laid up for repairs from 20th Oct. to end of year. Principally employed in dredging rock, lifting boulders, etc., hence the high price per ton.
"Platypus," ...	...	..	...	..	...	185,660	185,660	2·85	
"Water Rat," ...	...	...	...	...	...	41,275	41,275	...	The remarks made in 1898 are again repeated.
"Sandpiper," ...	...	..	...	...	..	9,000	9,000	.	
Totals, ...	255,800	97,900	278,530	76,500	238,270	1,977,040	2,924 040		

In the letter accompanying these returns, Mr Crofts says:—"That for many years the bottom of the Bluff Channel was supposed to be solid rock with a depth only of about 11 feet at low water. This has been deepened to about 21 feet below low water by the dredger "Otter."

engines, each set having cylinders of 14½ inches, 23 inches, and 36 inches diameter respectively, by 24 inches stroke, steam being supplied from two mild steel boilers.

The hopper doors, actuated by hydraulic power, are raised simultaneously, and, so far as I am aware, they have sustained no damage since the dredger began work, even when let go, as they frequently are, to discharge the debris in boisterous weather.

Reference has already been made in detail to the sand suction pumps of this dredger, and also to the special arrangements made in connection with the attachment of the suction pipes to the hull. It only remains to be added that there are two 27-inch centrifugal sand-dredging pumps on board, each driven from one of the propelling engines and connected to suction pipes of 27 inches internal diameter.

Working with one pump the dredger takes her load in from 30 to 40 minutes.

During the pumping trials the I.H.P. of the port and starboard engines was 550 and 600 respectively.

I am indebted to Mr George Tippett, engineer of East London Harbour Board, for the following particulars of the "Kate's" work during 1899:—

Dredger "Kate," Year 1899.

Loads deposited at sea	654
Total cubic yards „	364,001
Average quantity per day	1826 cubic yards
Total number of hours under steam ...	1657 hrs. 18 mins.
Total time occupied in pumping	890 „ 50 „
Days working...	198
„ „ suspended	167
Total cost (excluding interest and depreciation)	£12,404 16 8
Cubic yards dredged on the bar in the open sea, seaward of the works and deposited two miles off shore	312,701
Cost of above	6·9d per cubic yd.

Cubic yards dredged inside works and deposited as above	51,300
Cost of above	15·1d per cubic yd.
Average quantity dredged per hour when working on the bar	518·5 cubic yards
Average quantity dredged per hour when working inside	218 cubic yards
Coal consumption per ton dredged	5·7 lbs.

> "You will notice," says Mr Tippett, "that a much larger quantity per hour is dredged when working outside than is the case when working inside, which is to be accounted for by the fact that there is now but little sand to be found inside the works, whereas outside there are extensive banks which it is possible to undermine with the suction pipe, causing the sand to flow freely to the pump. The cost per cubic yard (6·9 pence) is perhaps high, but it must be remembered that the vessel is lying up a great part of the year waiting for favourable weather."

In closing, I have to tender the gentlemen named my cordial thanks for their kind assistance in furnishing me with particulars of the work done under their direction.

Discussion.

The discussion on this paper took place on 24th December, 1901.

Mr JAMES MOLLISON (Member of Council) desired to thank Mr Brown for giving, in his valuable paper, such a full description of the many different kinds of dredgers which had been built and equipped by his firm, together with particulars of the great work done by them in deepening and improving so many harbours in various parts of the world, and more especially those of our own colonies—Australia, New Zealand, and South Africa. While every credit was due to the builders of those splendid machines, which were fitted with many ingenious contrivances whereby they could be worked and handled in all conditions of sea and weather, much might also be said to the credit of the port and harbour authorities for their enterprise in grappling with and overcoming the difficult problems attending the deepening of their harbours. He was sure they must all be struck with that part of the paper relating to the Mersey Bar, which for generations was such a drawback to the great port of Liverpool, and in which during the last ten years a channel had been cut 1500 feet wide, with a depth at low water of 27 feet. While that had been a great boon to Liverpool, it had also been a distinct gain to the whole commerce of this country. Mr Brown's paper having been accompanied by so many fine drawings and illustrations of these dredgers, he would not enter into the details connected with dredger construction, or of the many novel appliances with which dredgers were fitted; but it might not be out of place to remark that they should not forget the steelmakers, who had assisted engineers to achieve much better results than they otherwise could have accomplished, by supplying them with steel castings for wheels and all sorts of gear. Many years ago he had had something to do with the building of dredgers himself, and he could assure them that, in looking through these fine modern dredgers, it had often occurred to him how much it would have relieved his mind had he been able to have command, even to a small extent, of the modern steel castings for wheels.

Mr John Reid (Member) said there was one point which struck him in connection with this paper, and that was the amount of information which Mr Brown had put into their hands by its means. The extent to which Mr Brown had given away the special work of his firm was remarkable, and he thought it augured very well for the success of the Institution if the Members had such a liberal spirit to give so much information. Dredging work was so much of a special class of work that to many members it was a sealed book, and he thought they could open it now by using Mr Brown's paper as a key. He had often wondered, in thinking over the subject of the dredging of the Clyde, whether the dredged spoil could not be utilized by being placed on the

Mr John Reid.

banks instead of being carried out to sea. It must be valuable stuff, and there was plenty of scope for it about Port-Glasgow, where there was a wide area of bank, and the sweep of the tide over it silted up the channel, and caused lots of trouble in that way. He had often thought that a retaining wall might be built, having this spoil pumped over it. It was certainly not a new idea, but perhaps it came in in connection with this paper, and might be acted upon. In Holland, steps were always taken to save the spoil, and in the New York Shipbuilding Company's building yard at Camden, near Philadelphia, he had seen a shipyard made out of the mud dredged from the river in the deepening of the channel, and not one cubic foot of matter was wasted. One would have said that it was impossible to use in this way such stuff as was obtained in deepening the channel, but building berths had been constructed capable of sustaining vessels of almost any size.

Mr R. T. NAPIER (Member) said that over 25 years ago the late Mr Charles Randolph brought forward a proposal for removing banks in the River Clyde by means of centrifugal pumps. He (Mr Napier) remembered assisting a senior in making calculations as to the probable efficiency of such an arrangement, and the conclusion arrived at was, that the efficiency would be low. Since then, as the examples put forward by Mr Brown abundantly showed, centrifugal pumps had been made a success in dredging operations. He suggested that the value of the paper would be much increased if some data were given on this matter of efficiency, such as, the ratio of the useful work, as represented by the weight of solid matter lifted, to the non-useful work, as represented by the water handled.

The PRESIDENT stated that with regard to depositing dredgings on the banks of the Clyde, he was afraid that the neighbouring proprietors would probably raise serious objections. He quite agreed with Mr Reid that Mr Brown had given them a very great deal of information upon the special subject on which his firm was engaged, and he had not only given them a paper, but he had also supplied them with an exceedingly useful set of diagrams and

The President.

drawings of his dredgers, and while there had been very little discussion upon it, he supposed that the paper in itself was so full that there was very little difference of opinion. He was sure, therefore, that they would heartily agree to give Mr Brown a very cordial vote of thanks for the paper that he had contributed.

The vote of the thanks was carried by acclamation.

Mr **Brown**, in reply to Mr Napier, wrote that, in his opinion, it was very satisfactory in sand suction dredging to have a proportion of one part of sand to three of water of the total volume raised by the pumps. Of course, that ratio had been exceeded but only in very exceptional circumstances.

Correspondence.

Mr L. F. **Vernon-Harcourt** (London) considered that Mr William Brown's paper, giving the dimensions, particulars, novelties, and working results of some of the most recent dredgers and dredging appliances constructed by the firm of Messrs William Simons & Co., would be very valuable to engineers concerned, like himself, with harbour and river works. Mr Brown had commenced his paper precisely as he himself had done in a paper presented last year at the Paris International Navigation Congress on "The Most Recent Works at Some of the Principal British Seaports and Harbours," namely, by drawing attention to the increasing size of the largest seagoing vessels, and the consequent necessity of providing an adequate depth in the approach channels and entrances to ports. This circumstance rendered the provision of dredgers capable of dredging in a greater depth of water, and with a greater capacity for work, indispensable in the present day. He had had an opportunity last year of becoming better acquainted with the progress achieved by Messrs Simons & Co. in recent years, by having to examine the models, and go through the particulars furnished by that firm, at the Paris Exhibition, in his official position as the British Member of the International Jury for Civil Engineering. It also

Mr L. F. Vernon-Harcourt.

unexpectedly fell to his lot, in the absence of any representative or agent of the firm, when the Jury inspected their exhibits, to explain, to the best of his ability, the special features of the fine set of models of dredging plant exhibited by Messrs Simons & Co., to his fellow foreign jurors. The most notable advance in recent years had probably been made in suction dredgers, used either with a simple jointed suction pipe in pure sand, as on the Mersey bar, or with the addition of cutters round the nozzle in silt or clay, or with water-jets for stirring up the sand and increasing the volume drawn up, as resorted to on the Lower Mississippi. This system had undoubtedly great advantages in loose material and exposed situations; and M. M. Coiseau & Cousin, the contractors for the Bruges ship-canal, had contrived, by fixing a sort of wide roller near the nozzle of the suction pipe, and thus keeping *the* widened-out orifice at a constant depth of 5 feet below the surface of the fine silt deposited in the entrance channel, to draw up a stream of almost pure silt, with very little water, which readily deposited in the hopper of the dredger. Bucket-ladder dredgers, however, were decidedly the most suitable machines for the systematic deepening of rivers, where large quantities of material had to be removed along a continuous length, and more especially where stiff clay or boulders had to be raised. When, in 1890, he advised the Newport Harbour Commissioners to have a strong bucket-ladder hopper dredger specially built for the deepening of the River Usk—as besides sand, silt, and debris from ironworks brought down by the River Ebbw, a tributary of the Usk flowing in below Newport, there was a large shoal composed of boulders, gravel, and clay, in the middle of the river—the Commissioners entrusted the construction of the dredger to Messrs Fleming & Ferguson, and the dredger readily removed the hard shoal with its large boulders. Moreover, in reporting to the Sligo Harbour Commissioners in 1895, he recommended, amongst other improvements in the navigable channel of the River Garvogue forming the approach channel to Sligo, the removal of a portion of the Blennick shoal (which by its protrusion caused a very tortuous bend in the channel near its outlet) by a very strong bucket-ladder hopper dredger under the direction of the Commissioners. A dredger was subsequently built for the Sligo Harbour Commissioners, in accordance with his advice, from the designs of Mr Henry West of Liverpool; and he had an opportunity last spring of inspecting, in company with its designer, the work which the dredger was carrying out at the Blennick shoal which was composed of large boulders, in some instances almost as big as the buckets of the dredger, together with rough gravel and sand. The shoal, in fact, consisted of as rough and difficult material as could well be conceived; but the dredger, with the aid of occasional claws in place of buckets, was performing her work remarkably well; though naturally the steel lips of the buckets were subjected to considerable wear and tear. Under such conditions, the bucket-ladder dredger was the only type of dredging machine that could be relied upon to remove a large quantity of material in a regular continuous manner; and it was in this class of dredger that Messrs Simons had achieved the most notable improvements; though their exhibits at the Paris Exhibition of 1900 and the present paper, demonstrated that they had also been successful in the construction of sand-pump dredgers.

Mr W. H. Hunter (Manchester) having, like most engineers engaged in the formation and maintenance of harbours and docks and in the regulation of navigable rivers, had practical experience of the excellence of design and workmanship in dredging craft constructed by Mr Brown's firm, heartily welcomed the paper on "Dredging and Modern Dredge Plant," by so competent an authority as Mr Brown, and especially welcomed the *resumé* of particulars of so many dredgers of such various types actually built in and launched from the London Works, Renfrew. For construction work in which hard clays, marls, and rocks of various classes, required to be removed under water, nothing better than the bucket dredger was at present available, as it did not appear to be likely that the expectations of those who advocated the raising of such materials by means of the eroding

Mr W. H. Hunter.

action of cutters combined with suction, would be realised. Of the bucket class of steam-driven dredgers, Mr Brown's list contained types which might be considered fairly representative. Cases arose from time to time in which several dredgers were required to work in a limited area, for construction purposes, in which cases it was probable that increased economy and efficiency, together with decrease in size and weight of vessel, would be arrived at by driving the machinery by means of electric motors supplied with current from a single central station. In his opinion, however, the maintenance dredger of the future would be of the suction type. Much of the material deposited in docks, rivers, and canals, was sludge, rather than pure silt (much less sand), which contained a certain proportion of organic matter, as well as a large proportion of water held in suspension by capillary attraction. The sludge was, therefore, of low specific gravity, as it lay *in situ*, while the residue of solid matter which it contained was so finely divided that, when mixed with several times its volume of water, it required so long a time for precipitation in a hopper that the use of the ordinary type of suction dredger was altogether out of the question, except under very exceptional circumstances which permitted of the material being directly discharged on shore. None of the suction dredgers contained in Mr Brown's *resumé* were in the least suited for dealing with this class of material. They were suitable and, as Mr Brown had shown, very effective for dealing with pure sand. The following table might be of interest as showing the contrast between the two classes of material. The samples were in both cases taken from the bed of the estuary of the Mersey between Bromborough Pool and Eastham Locks, which formed the entrance to the Manchester Ship Canal. The sludge met with in the higher parts of the Ship Canal was of still lower specific gravity, as it was composed of still finer material, and contained a larger quantity of water held in suspension. The problem of raising sludge by suction, of its being deposited in a hopper and conveyed to sea, was being tackled by certain of the Continental dredger building firms. One firm

	Sand.	Sludge.
Average weight of one cubic foot, *in situ*, ...	124 lbs.	86 lbs.
Specific gravity (wet),	1·98	1·37
Proportion of water contained in 1 cubic foot,...	24 lbs., 19°/₀	45½ lbs., 53°/₀
Proportion of solid matter, ...	100 lbs., 81%	40½ lbs., 47%
Specific gravity of residue of solid matter,	2·58	2·34

claimed to have arrived at a solution of the difficulty, though he was obliged to confess that he had some scepticism as to the perfect success of the methods proposed to be adopted, and it would be gratifying to find that expert builders in this country were also devoting themselves to the consideration of the question. Having regard to the low specific gravity of the material, the problem to be solved was, the raising of the sludge in a condition as nearly as possible similar to that in which it lay in its place of deposit, *i.e.*, with the minimum quantity of water beyond that held in suspension, added to the material. To this end he would venture to suggest that it was essential—

(1). That the suction pipe should be trailed behind the vessel instead of being thrust before it.

(2). That positive action should be fitted to the suction pipe by means of which the nozzle could be thrust beneath the surface of the silt.

Mr W. H. Hunter.

(3). That the nozzle should be of such form as would permit of the adjustment of the quantity of water flowing into it from above.

He would only add that these conclusions had been arrived at by means of a process of experimental research.

Mr Brown, in reply, stated that Mr Vernon Harcourt had made reference to a contrivance employed by the contractors of the Bruges Canal for keeping the nozzle of the suction pipe at a fixed depth below the surface of the silt in the channel. The suction pipe gear of the "Octopus" and "Walrus"—already described—was designed to keep the suction nozzle always in contact with the materials, and the suction pipe nozzles of these dredgers were generally embedded in from 3 to 4 feet of sand when dredging. With regard to the three essentials enumerated by Mr Hunter for the profitable and satisfactory employment of suction pump dredgers dealing with sludge, he might mention that all three points were embodied in the design of the pump dredger "Antleon," to which dredger reference was made in the paper. (1) The "Antleon's" suction pipes were trailed aft. (2 and 3) The nozzles of the "Antleon" were weighted with valves in the upper portion of the nozzle for regulating the supply of water, the valves being controlled from deck. They could be thrust below the surface of the silt and the supply of water adjusted from above. It would be noted that this arrangement served the same purpose as the arrangements on the "Octopus" and "Walrus" and that referred to by Mr Vernon Harcourt.

GAS AND OTHER INTERNAL COMBUSTION ENGINES.

By Mr DUGALD CLERK.

(SEE PLATES X., XI., AND XII.)

Read 21st January, 1902.

A gas engine is a heat engine in which the working fluid is atmospheric air and the fuel is an inflammable gas or vapour. It differs from a hot air or a steam engine in one important point, namely, the heat to supply the motive power is given directly to the working fluid by combustion within the motor cylinder. The gas engine, in fact, resembles a gun more closely than a steam engine. In both the gun and the gas engine cylinder the motive power is produced by heat, and the heat is applied directly within the cylinder, to produce the driving pressure. A gaseous explosion, however, differs somewhat fundamentally from the explosion produced in a gun by chemical action. In a gunpowder or cordite explosion a chemical change is effected, whereby a solid or semi-solid substance evolves large volumes of gases; that is, the solid substance, after chemical decomposition, produces gases which, when cooled, are hundreds of times the volume of the original solid powder. In addition to this evolution of gas, great heat is produced by the chemical action, and so very high pressures are obtained. The substances as producing pressures within a gun are quite unsuitable for obtaining controllable motive power, and, although attempts have been made to actuate engines by gunpowder and gun-cotton, yet all such attempts have been failures. A gaseous explosion is a much more controllable phenomenon than a powder explosion. In gaseous explosions the action is much simpler. There is no change of state during the reaction from solid to gas; on the contrary, in all ordinary gaseous explosions the volume of the gases formed by combustion, reduced to standard temperature and pressure, is less than their original volume before combustion. In the gaseous explosion the increase of pressure is due wholly to the increase of temperature of the gases entering into the chemical action.

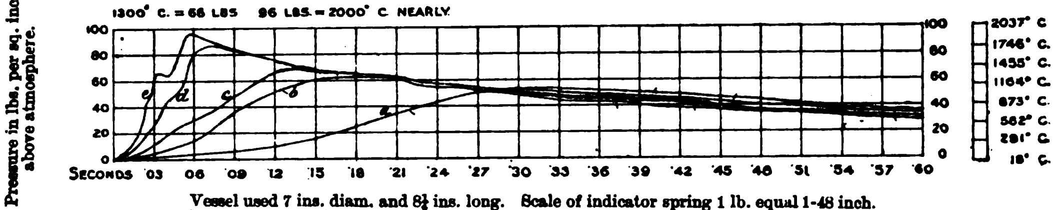
Before proceeding with the description of the mechanical features of the gas engine, it will be desirable to consider briefly the nature of a gaseous explosion. If air at temperature 0° Cent. and atmospheric pressure be confined within a closed space, say a closed vessel, and then heated, for every increase in temperature of 1° Cent. the pressure will increase by $\frac{1}{273}$; that is, when the temperature is raised to 273° Cent., the pressure within the vessel will have increased 2 atmospheres. At a temperature of 546° Cent., the pressure will be 3 atmospheres; and the pressure will continue rising with the temperature, so that at a temperature of 2184° Cent. the pressure of our confined air will have risen to 8 atmospheres. This will occur in whatever way the air be heated. The air might be heated by heating the enclosing vessel; or by heating by means of, say, electric currents passing through platinum wires; or by heating the air so enclosed by combustion. This is practically what happens when gas is mixed with air and the mixture then ignited within a closed vessel.

If a mixture of 1 cubic foot of London coal gas be made with, say, 5½ cubic feet of air, there is just enough oxygen in the air to combine with the carbon and hydrogen of the coal gas without leaving either excess of oxygen or excess of the inflammable gas. Such a mixture, when enclosed in a vessel, and ignited, will produce a temperature of close upon 2000° Cent., and the pressure will rise to something like 7½ atmospheres, that is, slightly over 100 lbs. on the square inch above atmosphere. This pressure is the highest which can be obtained from a mixture of gas and air at atmospheric pressure. This I have proved by a series of experiments, published in 1886.

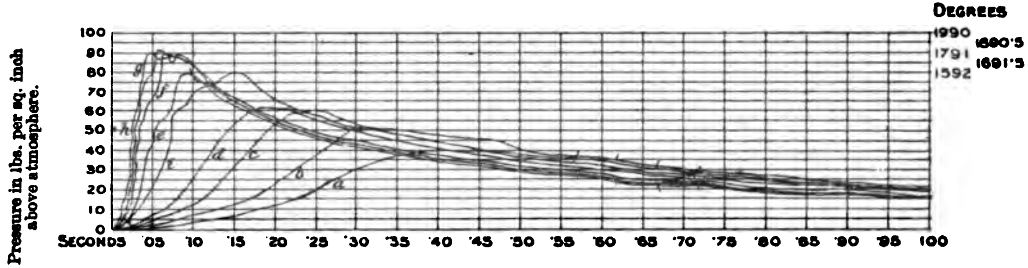
Fig. 1 shows the apparatus used by me. It consists of a closed cylindrical vessel, with the cylindrical surface and the internal cover surfaces turned to represent the interior of an engine cylinder. The covers are strongly bolted, so as to withstand high pressure. Upon the upper cover is placed a Richards' indicator, in which the reciprocating drum has been replaced by a revolving one. The rate of revolution is adjusted by a small fan, the weight and gear wheels giving the necessary power. The cylinder is filled with explosive mixture to be tested, the drum is set revolving, and the pencil of the indicator pressed gently against it, and the electric spark is passed between the points placed at the bottom of the space. The drum is enamelled, and the pencil is a blacklead one. The pressure of the explosion acts upon the indicator piston, and the line is traced upon the drum, which shows the rise and fall of pressure. The rising line traces the progress of the explosion, the falling line the progress of the loss of pressure by cooling. The rate of the revolution of the drum being known, the interval of time elapsing between the periods of the explosion or cooling curve is also known.

Fig. 2 shows explosion curves from mixtures of Glasgow gas and air and Oldham gas and air. On these diagrams I have also marked the maximum temperatures. From these it appears that the maximum pressure obtained with a mixture of Glasgow gas and air, ignited at atmospheric pressure, is some 96 lbs. per square inch above atmosphere; and the maximum pressure obtained with Oldham gas is some 90 lbs. per square inch above atmosphere. From these curves it is possible to calculate many of the properties of gaseous explosive mixtures used in gas engines, and these experiments prove that a gaseous explosion is a strictly controllable phenomenon, quite unlike the explosions of gunpowder or gun-cotton.

In making such a mixture, and introducing it into an engine cylinder, the engineer can feel confident that under no circumstances will the pressures produced within the engine exceed about 100 lbs. on the square inch. The earlier engines were constructed on the low pressure or non-compression principle;



Vessel used 7 ins. diam. and 8½ ins. long. Scale of indicator spring 1 lb. equal 1·48 inch. Mixtures used, Glasgow coal-gas and air. Experiments *a*, 1 vol. gas to 13 vols air; *b*, 1 to 11; *c*, 1 to 9; *d*, 1 to 7; *e*, 1 to 5.
Temperature of gases before ignition, 18 degrees C.; pressure atmospheric.



Vessel used 7 ins. diam. and 8½ ins. long. Scale of indicator spring 1 lb. equal 1·32 inch. Mixtures used, Oldham coal-gas and air. Experiment *a*, 1 vol. gas to 14 vols. air, temp. (of explosion and measuring vessels) 18 degrees C.; *b*, 1 to 13, 16·2 degrees: *c*, 1 to 12, 16 degrees; *d*, 1 to 11, 16·1 degrees; *e*, 1 to 9, 16·7 degrees; *f*, 1 to 7, 16·7 degrees; *g*, 1 to 6, 16 degrees; *h*, 1 to 5, 19 degrees; *i*, 1 to 4, 19 degrees.
Centigrade temperatures, assuming no loss of volume, owing to combination of mixtures. Atmospheric pressure, 14·7 lbs., and mean temperature before ignition, 17 degrees C.

Fig. 2.—Explosion of gaseous mixtures. Experiments in a closed vessel.

that is, the engine was arranged to draw in to the cylinder a mixture of gas and air—air from the atmosphere, and gas from a gas pipe; the communication with the outer atmosphere was cut off at a certain part of the forward stroke; the mixture was fired by the electric spark; and then the piston was driven forward for the rest of the stroke, under the pressure so produced. This type of engine formed for many years the only working engine attempted to be brought into use. It was speedily found, however, that in such an engine the power obtained was very low for the size of the cylinder, and the gas consumption was very high. Such engines consumed about 90 cubic feet of London coal gas per hour.

Fig. 3 shows sectional drawings of the little Bischoff gas engine—the last non-compression engine which remained upon the market. It clearly illustrates the main features of the non-compression engine, so I will describe it alone as illustrating that type. The piston in the first part of its stroke takes in a mixture of gas and air—air from the atmosphere, and gas from a pipe marked 2. The piston overruns an aperture in the side of the cylinder marked 5, and a flame burning in a chamber outside is sucked through the aperture by way of a little flap valve, and so ignites the mixture. An explosion follows, and the piston is pushed forward. The return stroke discharges the exhaust gases by way of the passage 8. In this engine it will be seen an impulse is given for every revolution; but the impulse was only given at half the stroke of the engine.

It occurred very early to quite a number of inventors that if a mixture of gas and air be compressed before explosion, then higher pressures would be obtained, less heat would be lost to the sides of the cylinder, and greater economies would be found. This compression idea occurred to one English inventor as far back as 1838; but it remained for a distinguished Frenchman, Monsieur Beau de Rochas, to propose with perfect clearness a practicable cycle of operations enabling the compression idea to be carried out. This he did in a pamphlet published in Paris in 1862. He there stated that to obtain economy with an explosion engine, four conditions are requisite:—

(1.) The greatest possible cylinder volume with the least possible cooling surface;
(2.) The greatest possible rapidity of explosion;
(3.) The greatest possible expansion; and
(4.) The greatest possible pressure at the beginning of the expansion.

The sole arrangement capable of satisfying these conditions, he stated, would be found in an engine operating as follows:—

(1.) Suction during an entire outstroke of the piston;
(2.) Compression during the following instroke;
(3.) Ignition at the dead point, and expansion during the third stroke; and
(4.) Forcing out the burned gases from the cylinder on the fourth and last return stroke.

M. Beau de Rochas did not himself produce a workable engine. To the late Dr. Nicolaus August Otto belongs the merit of producing the first successful compression gas engine. The commercial history of the gas engine, indeed, may be said to date from the year 1876, when Dr. Otto patented the form of gas engine now so well-known as the Otto engine. Nearly all the gas engines at present on the market follow what is known as the Otto cycle. At first the engines built were of small size. In 1878 a 6 H.P. Otto gas engine was considered quite a large one; but gradually, as the difficulties of construction were overcome, the power slowly increased, until now the largest single cylinder gas engine in the world develops 1000 H.P. if operated by town gas, and 600 H.P. when operated by blast furnace gas.

The Otto cycle engine has thus been wonderfully successful. In this country some 50,000 Otto cycle engines have been made and sold, and on the Continent some 35,000 engines. The average power may be taken as about 10 horse; so that not less than half a million H.P. is now at work in gas engines in Britain, and not less than 300,000 H.P. on the Continent. Including American engines, and the large gas engines recently built, we may safely consider that at the present moment the gas power of the world is at least a million H.P. This estimate includes oil engines as well as gas engines, and is, in my view, somewhat short of the true power.

The stationary gas engine is used extensively in almost every industry. An interesting enquiry was made recently in Germany, when it was found that, of 2300 gas engines distributed throughout thirty-six German towns, 65·6 per cent. of the engines were engaged in the following work:—Printing, pumping water, textile manufacture, electric lighting, driving machine shops, joiners' works, cabinetmakers' works, butchers' shops, locksmiths' works, coffee-roasters, cutlery factories, and lifts or elevators. Of the 65·6 per cent., the printing industry used the greater number; pumping water came next. The remaining 34·4 per cent. of the engines were scattered throughout no less than 140 industries. Practically all these engines are operated on the Otto cycle.

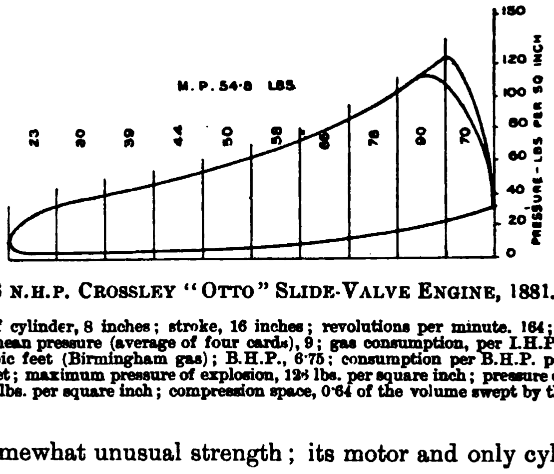
Oil engines are simply gas engines in which inflammable vapour is produced from oil, mixed with air, and compressed. They differ from gas engines in having the additional parts necessary to vapourize the oil. The Otto cycle is used almost exclusively in these engines also. The Otto cycle is therefore one of great practical importance, and I will now describe to you, first, an early form of the Otto engine, as made by Messrs Crossley, of Manchester.

Fig. 4 shows a sectional plan of a slide-valve Otto engine.

Fig. 5 is an indicator diagram, taken from such an engine by me.

In this gas engine, the very first to combine the compression principle with a simple and thoroughly efficient working cycle, the difficulties of compression are overcome in a strikingly original manner. To the engineer accustomed to the steam engine, the main idea seems a bold and, indeed, a retrograde step. The early gas engines were moulded more upon the steam engine model, and were, to some extent, double acting. This Otto compression engine is only half single acting. The steam engine, in its advance, passed from single to double acting, and then to four, and even more, impulses per revolution. The gas engine, in its progress, has in this respect moved backwards, beginning with double action, and then going back. The practical gain of the arrangement, however, has completely justified the apparent retrogression. In external appearance, it will be seen, the engine closely resembles a modern high pressure steam engine, the working parts of which

Fig. 5.



6 N.H.P. CROSSLEY "OTTO" SLIDE-VALVE ENGINE, 1881.

Diameter of cylinder, 8 inches; stroke, 16 inches; revolutions per minute. 164; I.H.P., at 57 lbs. mean pressure (average of four cards), 9; gas consumption, per I.H.P. per hour, 25·5 cubic feet (Birmingham gas); B.H.P., 6·75; consumption per B.H.P. per hour, 34 cubic feet; maximum pressure of explosion, 128 lbs. per square inch; pressure of compression, 31 lbs. per square inch; compression space, 0·64 of the volume swept by the piston.

are of somewhat unusual strength; its motor and only cylinder is horizontal and open-ended; in it works a long trunk piston, the front end of which serves as a guide, and does not enter the cylinder proper; the connecting rod communicates between the guide and the crank shaft, and the side thrust is thus kept off the piston and cylinder proper, which become hot. This arrangement, however, is not quite the one shown in the sectional plan. In this sectional plan, the cylinder and guide are in one. The crank shaft is heavy, and the fly-wheel a large one, considerable energy being required to take the piston through the negative part of the cycle. The cylinder is considerably longer than the piston stroke, so that the piston, when full in, leaves a considerable space, into which it does not enter. Outside the cylinder, and running across the end of the combustion space, there works a large slide-valve; it is held against the cylinder face by a cover plate and strong spiral springs. It is driven to and fro by a small crank on the end of a shaft parallel to the cylinder axis. This shaft is rotated at half the rate of the crank shaft, and is driven from the crank shaft by bevel gearing.

An exhaust valve leading into the space by a port is also actuated at suitable times from the valve shaft, and this shaft also operates the governing and oiling gear.

The single cylinder serves alternately the purposes of motor and pump; during the first forward stroke of the piston, the slide valve is in such a position that gas and air stream into the cylinder from the beginning to the end of the stroke; the charge mixes as it enters with whatever gases the space may contain; the return stroke of the piston then compresses the mixture into the space, and when the piston is full in, the pressure has increased to an amount determined by the relative capacity of the space. Meantime, the slide valve has moved to another position, first closing the admission gas and air ports to permit of the compression, then bringing on a cavity in the valve, which is filled with flame when the compression is complete. The compressed charge therefore ignites, and the pressure rises so rapidly that the maximum is attained before the piston has moved appreciably on its forward stroke (second stroke). The piston is thus under the highest pressure at the beginning of its stroke, and the whole stroke is available for expansion.

This is the motive stroke. At the end of it the exhaust valve opens, and the return stroke is occupied in driving out the burned gas, except that portion remaining in the space which cannot be entered by the piston. These operations form a complete cycle of four single strokes, and at the end the piston is again in position to begin the cycle over again.

To perform the Otto engine cycle of four single strokes requires two complete revolutions, as follows:—

First outstroke,	...	Charging cylinder with gas and air.
First instroke,	...	Compressing the charge into the space.
Second outstroke,	...	Explosion impelling piston.
Second instroke,	...	Discharging burned gases into the atmosphere.

The regulation of the speed of the engine is accomplished by a centrifugal governor, which is arranged to close a gas supply valve whenever the speed increases. An explosion is thereby missed, and the engine goes through its cycle as usual, but as there is no gas mixed with the air, there is no explosion when the flame enters; the compressed air merely expands and gives back to the piston the energy taken during compression.

This cycle of operations is clearly seen from the indicator diagram, Fig. 5. The engine tested was one having a cylinder diameter of 8 inches, with a stroke of 16 inches, and running at 164 revolutions per minute. The power indicated was 9-horse, and the brake power obtained was 6¾-horse. The pressure of compression, it should be noted, was only 31 lbs. per square inch.

This type of engine was built by Messrs Crossley for many years; but year by year certain modifications were introduced, and the pressure of compression very much increased. At the date on which that engine was built, 31 lbs. per square inch above atmosphere was a standard compression. Now, engines of the Otto type use compression of from 90 lbs. to 120 lbs. per square inch above atmosphere. An engine using high compressions requires to be modified in certain ways, and Fig. 7 gives details of a Crossley Otto engine, of later date, using a higher compression.

Comparing the details of this engine with those of the earlier engine I have just described, it will be seen that, although the fundamental principle and operations remain the same, yet considerable points of mechanical development are found. In the earlier engine, for example, the crosshead guide and the engine cylinder were two distinct parts, requiring to be bolted together in accurate alignment, in order to allow the piston, with its crosshead slide, to work freely without jambing. In the latter engine a longer trunk piston is used, which serves the double purpose of piston and crosshead guide; the separate crosshead slide is, in fact, dispensed with, and consequently the cylinder serves as its own slide guide, requiring no adjustment of separate parts. The cylinder, that is to say, serves both as cylinder and slide guide, and the whole cylinder is bolted to the bed against a powerful faced flange. The bevel wheels of the earlier design are also dispensed with, and replaced by skew or worm wheels, which, besides taking up much less space, provide a much quieter drive for the two-to-one shaft. The unsightly distortion of the bed necessary to admit the bevel wheels in the early design is quite avoided, as is clearly shown in the plan. There are many smaller points, also, of constructive difference, which the experience of years has shown to be desirable, but the great points of departure are to be found in—

(1) The suppression of the flame slide valve method of ignition, and introduction of the incandescent tube igniter;

(2) The diminution of the relative volume of the compression space, and thereby the increase of compression; and

(3) Improved proportioning of the valves and ports, in order to minimise the throttling of the charge during the inlet period, and the back pressure of the exhaust gases during discharge.

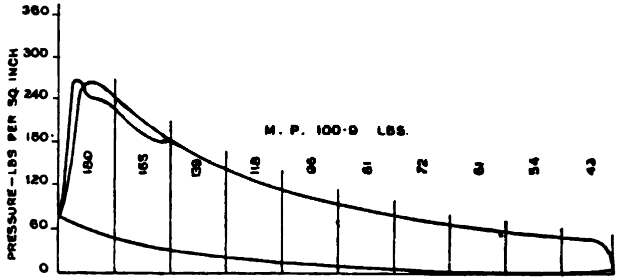
In this particular engine shown, the compression is not raised to so high a point as in the very latest engines; it has only attained some 50 lbs. per square inch; but in the later engines a pressure of 90 lbs. per square inch is common before ignition.

Fig. 8 is an indicator diagram taken by me from a recent engine, showing very remarkable results in power and economy.

Among other makers of gas engines producing excellent results, I may mention the National Company, The Stockport, and the Barker Otto gas engine.

These engines are very similar in their general arrangements, indeed the Otto cycle engine has now become a fairly standard type, and in a well-made Otto engine the maximum present economy should always be found.

Fig. 8.



4 N.H.P. CROSSLEY "OTTO" SCAVENGING ENGINE.

Diameter of cylinder, 7 inches; stroke, 15 inches; revolutions per minute, 200; I.H.P., 14 at 100 lbs. per square inch mean pressure (average of three cards); gas consumption, per I.H.P. per hour, 14·8 cubic feet (Openshaw gas, 20 candle-power); B.H.P., 11·97; gas consumption per B.H.P. per hour, 17 cubic feet; maximum pressure of explosion, 275 lbs. per square inch; pressure of compression, 87·5 lbs. per square inch; compression space, 34 per cent. of volume swept by piston.

The result of these changes in the construction of the engine has been to increase the economy. This improvement in economy is clearly shown by the Table, Fig. 9. In this Table the economy is given in the shape of heat efficiency. It will be seen that the efficiency rises from ·16 in 1882 to ·25 in 1894. Recent tests of very large engines have shown an efficiency of about 30 per cent.

I have now briefly described the Otto cycle, as shown by the Crossley, Stockport, and Barker engines; and, before proceeding to describe some of the larger engines and their applications in this country, in America, and on the Continent, it will be desirable to consider briefly the principles which have been followed with regard to the ignition of the charge. I have mentioned the means of ignition in the previous description, but I have not gone into that feature with any minuteness.

In the early engines, in pre-Otto times—the Lenoir engine, for example—ignition was accomplished by means of an electric spark. In the Otto engine at first flame igniters were used, and these deserve to be understood. The earliest flame igniter was the invention of an Englishman named Barnett. The valve consists of a conical stop-cock having a hollow plug The shell contains two ports—one which opens to the atmosphere, and one which communicates with the cylinder. The plug of the cock has only one port, and it is arranged so that it may open to the atmosphere or to the cylinder; but cover enough is left to prevent it opening to both at the same time. A gas jet burns at the bottom of the shell in the hollow of the plug. The ports are wide and long enough to allow free circulation of air. The flame must not be too large, or it will fill the whole interior of the plug with gas, and prevent air getting in. When burning, if the plug be rapidly turned round, so as to close to the atmosphere and open to the cylinder, the flame still remains burning, and the explosive mixture from the cylinder enters (as the air did from the atmosphere), comes into contact with the flame, and ignites the mixture. The explosion follows, and extinguishes the flame; but when the

ABSOLUTE INDICATED EFFICENCY OF CROSSLEY "OTTO" ENGINES OF SIMILAR SIZE SINCE 1882.

	Efficiency.	Pressure of Compression above Atmosphere.
		Lbs. per sq. in.
1. 1882-88 - -	0·16	38·0
2. 1888-94 - -	0·19	66·6
3. 1894 - - -	0·25	87·5

Fig. 9.

plug is again rotated the external flame relights it, and it is ready for another ignition. This valve of Barnett's proposed in 1838, acted on the same principle as the Otto flame ignition.

The problem to be solved in igniting the gases within the cylinder of a compression engine is much more difficult than that to be faced in a non-compression engine. It is an easier matter to transfer a flame burning at atmospheric pressure than it is to transfer the flame to a pressure of several atmospheres. Otto's arrangement is as follows:—A small quantity of coal gas is introduced into the upper part of a cavity in the ignition slide, and, being lighter than air, it remains separate from the air, and has little tendency beneath it, except by the slow process of gaseous diffusion.

It thus lights at the surface of contact with the air, and it burns there with a blue flickering flame. The movement of the ignition slide cuts off communication with the outer atmosphere, and very shortly thereafter opens on the admission port of the engine; but before doing this it opens to a small hole communicating with the engine cylinder. This hole communicates with the gas passage in the upper part of the slide, so that the gases under pressure enter and force the gas downwards. The pressure thus rises in the port more slowly than it would do if the main port opened at once. When the main port opens to the cylinder port, the pressure within it is therefore nearly equal to that of the cylinder, and the flame still burns at the point or surface of junction between the gas and air, and so ignites the mixture. If the pressure was not raised in the igniting port by pressing the gases downwards, and thereby avoiding a rush past the flame portion, the rush would often extinguish the flame and an ignition would be missed. The apparent difficulty of transferring the flame from atmosphere to a pressure of 40 lbs. above it is thus simply and beautifully overcome. This flame ignition of Otto's was used in a very large number of engines.

Another type of flame igniter was invented by me. In this case the gases from the explosion cylinder are carried by means of a groove in a slide regulated by a pin through a block grating; that is, a portion of the explosive charge is allowed to pass from the motor cylinder through a regulated passage to a grating placed at the end of a cavity in the slide, and it is there ignited by a Bunsen flame. The grating prevents the passage of the flame backwards, and the mixture burns in the cavity without requiring the presence of the external atmosphere. It will be remembered that the mixture within the cylinder has oxygen present more than sufficient to burn all the gases. This flame is lit by an external flame, and the slide valve carries a pocket filled with the flame towards the explosion port. The passage of the mixture through the regulated opening keeps the combustion within the port alive, and also raises the pressure within the port to nearly that of the cylinder before ignition. This igniter was formerly extensively used in engines of my invention.

All the flame igniters, however, have now practically disappeared. In England the incandescent tube method of ignition is the one which is almost universal. It is also used largely on the Continen and in America; but in America the electric spark method in various forms is much used.

Tube igniters are sometimes used, in which a metal tube, or in some cases a porcelain tube, is raised to incandescence by a Bunsen burner, and the explosive mixture is admitted to the incandescent interior by means of what is called a timing valve. The mixture from the cylinder reaches the incandescent surface, ignites, and the flame strikes back into the cylinder. In one modification, used largely in the Daimler engine, no valve is used, and ignition occurs upon compression of the mixture, because of the forcing of the mixture up the tube to the hot spot.

So far, I have endeavoured to give you some idea of the construction and operation of gas engines of moderate dimensions. I will now describe very briefly the modifications required for oil engines. Oil engines resemble gas engines in that the power is generated by the explosion of a compressed inflammable mixture in an engine operating according to the "Otto" cycle. In the earlier forms of oil engines, and in those used in motor-cars, very light inflammable oils of the gasoline or petrol kind are consumed. Here the problem of vapourizing the oil is comparatively simple. It is only necessary to draw air over a surface saturated with one of these light oils, or throw a jet of light oil into an air current, to produce a mixture of inflammable vapour and air which, when taken into the cylinder, readily supplies the place of coal gas, and gives explosions under compression closely resembling those obtained with coal gas.

Of oil engines of this kind, the most important is, of course, the petrol motor, so largely used on motor-vehicles.

Fig. 10 shows in section a modern Daimler motor, which I will now describe.

The engine has two cylinders which open into a casing. This casing is entirely closed, and it contains the cranks and connecting rods. A small fly-wheel is carried by the crank shaft, and it serves the double purpose of a fly-wheel and a clutch. A single port serves both for inlet of the charge and discharge of the exhaust. The charge inlet valve is automatic in its action. It opens by the suction of the piston, and closes by a spring action. The exhaust valve is operated from a two-to-one gear; and in this engine the governing is operated from the exhaust valve. The light oil or petrol, as it is now commonly called, is supplied to the float chamber of a vapourizer by means of a valve. So long as the level is high this valve is closed; when the level falls the valve opens, and fills up the oil vessel, until the float closes the valve again. When the piston makes its charging stroke, air passes from the atmosphere by a passage through the inlet valve, which it opens automatically. The pressure falls within this passage, and a spurt of petrol is thereby forced in by atmospheric pressure through the jet shown; it strikes against a breaking up surface, and mixes with the air passing into the cylinder. It vapourizes so readily that a mixture of inflammable vapour and air is fully formed when the air reaches

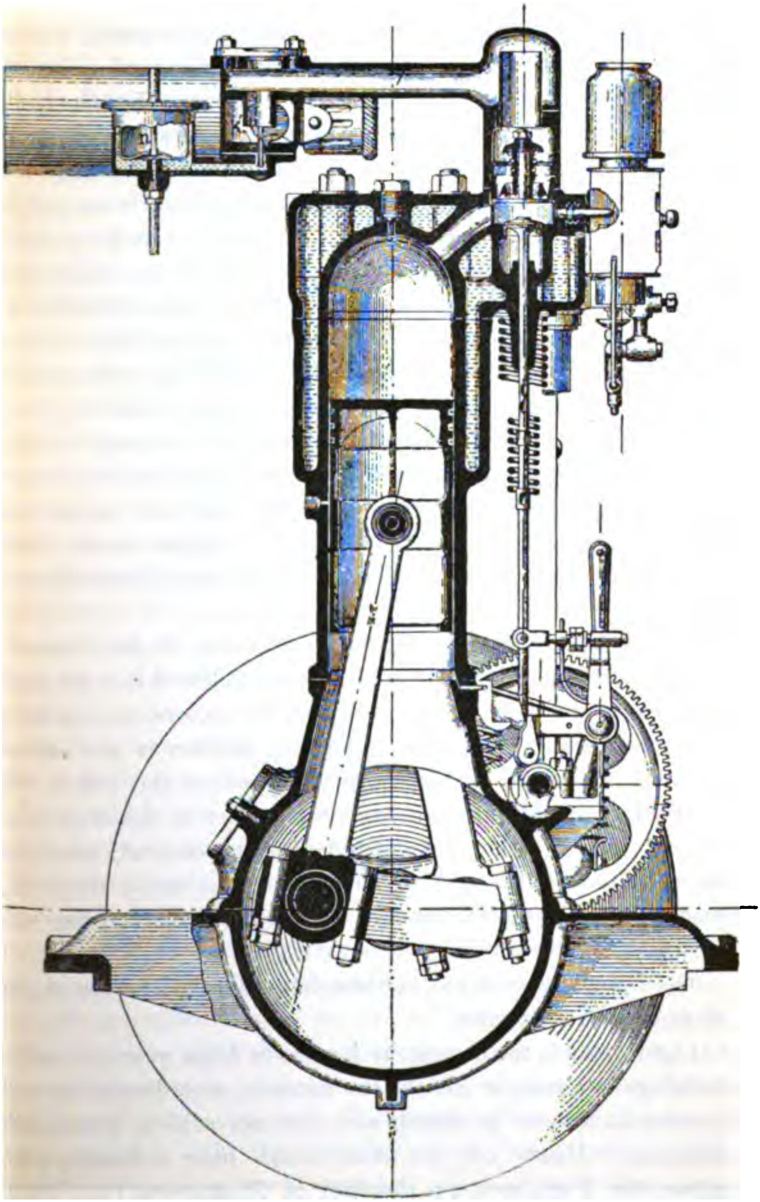


Fig. 10.

the cylinder. When the charge is complete the piston returns, compresses the charge into the combustion space, and up into the incandescent igniter tube, which is always open. Here the igniter fires the charge, and the piston proceeds on its explosion stroke. On the return stroke again, the exhaust is discharged to atmosphere. This open incandescent tube is found to act well for small engines, and it can be readily adjusted so as not to ignite the charge until compression is complete, because the inflammable mixture cannot come into contact with the hot part of the tube till it is forced up by compression. The governing of this engine is accomplished by cutting out explosions; but the governor operates by preventing the exhaust valve from opening, so that no charge is discharged from the cylinder, and therefore no charge is drawn in. The governor pulls aside a knife edge shown in the drawing; the exhaust valve thereby remains upon its seat; and no explosion can be obtained until the knife edge engages again, when permitted to do so by the governor, when the speed has sufficiently fallen.

The Daimler engine is practically the first of the motor-car engines; and most of these engines have followed it in the main features. The tube ignition, however, for motor-cars, has fallen somewhat into disrepute, and electric ignition is now almost universally applied on motor-cars, even where the tube is still retained. Electric ignition has proved safer in the event of an upset. Several rather nasty accidents have occured, where the flame for heating the igniting tube has set the whole car on fire, when the car has been upset. This is not liable to occur with electric ignition.

The Daimler engine, too, has been largely applied for the purpose of small launch engines.

Light petrol is too dangerous for use in large quantities within buildings in towns, or even in the country, accordingly, heavy oil engines have been produced, and they are sold in considerable numbers. Heavy oils are those which have a flashing point above the Parliamentary standard of 73 degrees Fah. Such engines may be divided into three distinct classes:—

(1.) Engines in which the oil is subjected to a spraying operation before vapourization;
(2.) Engines in which the oil is injected into the cylinder, and vapourized within the cylinder; and
(3.) Engines in which the oil is vapourized in a device external to the cylinder, and introduced into the cylinder, in a state of vapour.

Of these three types of engine, as time presses, I can only refer you to one engine of each type. The oil-spraying type of engine is best shown by Messrs Priestman's engine, which was the first oil engine capable of using heavy safe oils.

In this engine, oil is forced by means of air pressure from a reservoir through a pipe to a spraying nozzle, and air passes from an air pump by way of an annular channel into a sprayer. It there meets oil issuing from a jet, the air impinges on the oil, breaks it up into spray, and the air charged with oil spray flows into the vapourizer. This vapourizer is heated up in the first place on starting the engine by means of a lamp. The engine operates on the cycle, and it draws a mixture of air and vapourized oil from the vapourizer at every second stroke, compresses the charge, and ignites by the electric spark. This is the first engine which was used in this country for operating with heavy oils.

The second type of engine, where oil is injected into the cylinder, is best shown by the Hornsby engine.

The main idea of this engine is simple in the extreme. Vapourizing is conducted in the interior of the combustion chamber, which chamber is so arranged that the heat of each explosion maintains it at a temperature sufficiently high to enable the oil to be vapourized by mere injection upon the hot surfaces. The heat of these surfaces is also sufficient to cause ignition of vapour and air when compression is completed. Here the vapourizer also serves as the combustion chamber. It consists of a cast iron vessel communicating with the cylinder by a bottle neck. This chamber is heated up to a very dull red heat by a blast lamp before starting the engine, and oil is then injected by means of a nozzle. The oil vapourizes, but it does not ignite until a sufficient supply of air has been compressed through the bottle neck from the engine cylinder. The ignition takes place just upon complete compression, and a forward impulse is given. This Hornsby engine is perhaps the oil engine at present most extensively in use. The pressures got throughout the stroke are somewhat low, but the engine is one which works well under the rough conditions met with in practice. It takes a great deal to put it out of order. It has been largely introduced into use, and is now made and sold in sizes from about 2-horse to 100-brake horse power. This engine has many good points, and is perhaps the simplest and most easily operated heavy oil engine yet produced.

In the Crossley oil engine a separate vapourizer is arranged which communicates with the cylinder by a vapour valve. Oil is pumped into the channels; a lamp heats up the incandescent tube and also the channels; the waste heat passes up the funnel, and heats a small supply of air which passes within a jacket entering by holes; the valve is opened just as the gas valve is opened in a gas engine, and the mixture is formed within the cylinder in the same way as gas and air are mixed in the gas engine. This engine also works well and gives good economy.

There are many other excellent oil engines now upon the market including those made by Messrs Tangyes, Limited; The Campbell Gas Engine Co.; your local firm Messrs Pollock, Whyte & Waddell; Messrs Field & Platt; Messrs Robey & Co.; and others. All I can do, however, in the course of this short paper, is to give a general idea of the principles of operation. This I have done in the three examples I have described to you.

The oil engine is at present in the development stage. Large alterations are continually being made, and in a few years great extension may be looked for in the application of oil engines to industrial purposes.

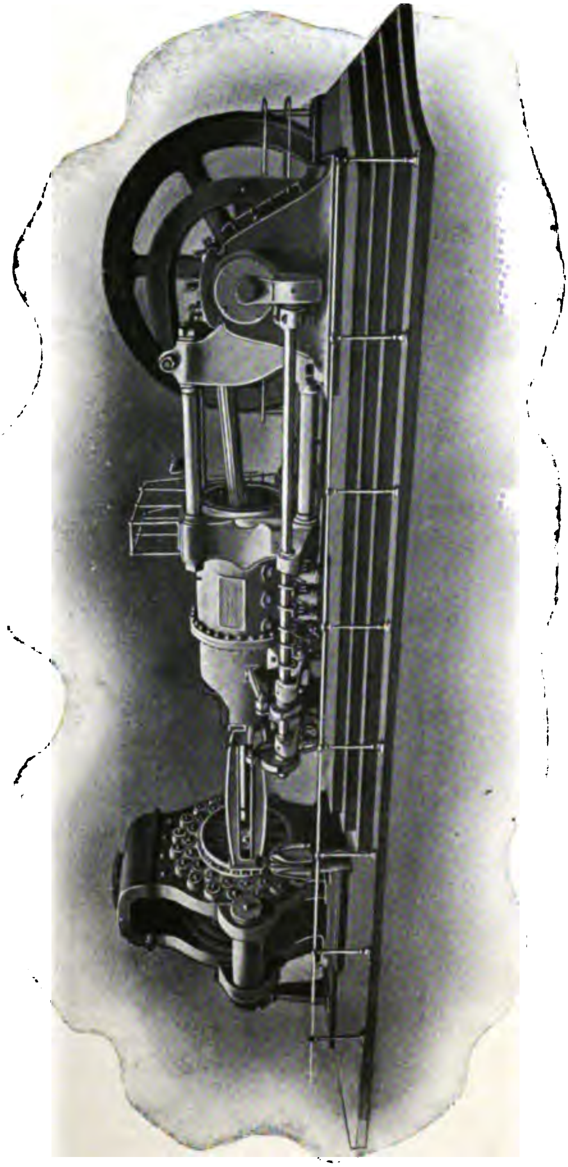


Fig. 11.

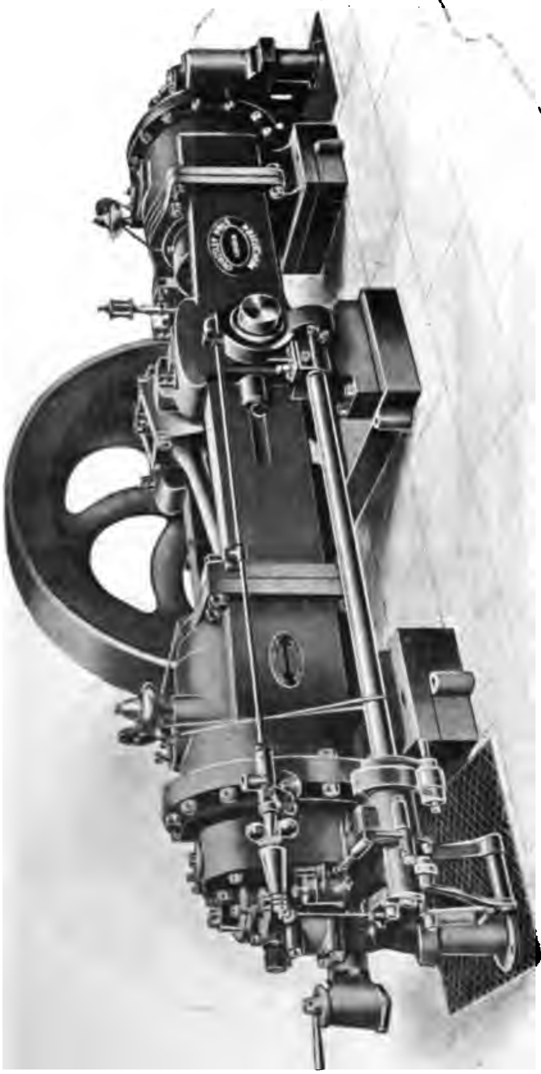


Fig. 14.

Before leaving this part of my subject, I wish to refer briefly to one great source of power which is now being developed on the Continent and in this country. I refer to power obtained by the use of blast furnace gas, and by the use of gas producers, such as Mond's and Dowson's. The largest engines which have yet been made are those which utilize blast furnace gas. It has been calculated, for example, that if all the gas from the blast furnaces of the United States of America could be utilized in gas engines, about two million H.P. could be continuously produced. On the Continent, quite a number of large gas engines are now operated by blast furnace gas.

Fig. 11 shows a large engine which is running at the works of Messrs Cockerill, at Seraing, in Belgium. I inspected this engine recently, and was much interested in the smoothness and regularity of its operations. This is perhaps, at present, the largest single cylinder gas engine in the world. Some idea of its magnitude will be gathered by looking at the figure of the man standing upright in the illustration. I may mention that the diameter of the piston is 51·2 inches, and the stroke 55·13 inches. The diameter of the piston rod is 9·61 inches; the diameter of the crank shaft, 18·11 inches. The height of the engine above the ground is 13·1 feet; the length, 36·1 feet; the width, 19·7 feet; and the compression is 135 lbs. per square inch. The total weight of the engine and fly-wheel, without blower, is 124·9 tons. This engine, running at 90 revolutions per minute, gives 600 brake H.P. with blast furnace gas, and it converts 28 per cent. of all the heat given to it into indicated work in the cylinder.

Fig. 12 shows another design by Messrs Cockerill, of an engine of 1200 H.P. It consists practically of the same engine as shown in the previous figure; but two explosion cylinders are operated tandem fashion.

In the largest and most powerful gas engine central station at present in the world, nine engines give altogether, with blast furnace gas, 5400 horse. Six of the engines are operating blowing cylinders for the blast furnaces, and three are used for producing electric light. They are at work at Differdengen, in Luxembourg.

Several other large gas engines are also at work on the Continent, and on my last visit, I found many thousands of H.P. of these large engines in course of construction for blast furnace work.

Several large gas engines are also at work in this country.

Fig. 30 shows a large Premier gas engine of 600 brake H.P., which is now at work in Messrs Brunner, Mond & Co.'s Works, Winnington, in Cheshire, driving a dynamo for electrolytic work. This engine was working very smoothly and well, when inspected by me early in the present year.

Another large gas engine, of Messrs Crossley's construction, is illustrated by Fig. 14. This engine is of 400 brake H.P., and it also is working at Messrs Brunner, Mond & Co.'s establishment.

Messrs Crossley Bros., of Manchester, have finished and delivered one large gas engine to Sir Alfred Hickman's Works, near Wolverhampton, for operating with blast furnace gas. This engine will, I am informed, give 700 brake H.P.

I have now attempted to give you an idea of what is at present being done in gas and oil engines; and I would conclude by saying that great future developments may be expected, both in gas and oil engines. So far as economy of heat is concerned, both have considerably surpassed the best steam engines; but much remains to be done before they equal the steam engine in frequency of impulses, lightness of machinery, and absolute steadiness of governing; in power of control, for instance, where reversal is required. As yet, the application of gas and oil to any but fixed engines, has been very limited; but ultimately, I have no doubt, gas and oil engines will be used with great advantage for propelling ships, and for driving locomotives.

Before gas engines can be applied, however, to ships or locomotives, it is necessary to depart somewhat largely from the lines of development hitherto followed. For many years I have advocated the use of high compression in gas engines, and also the construction of gas engines more closely resembling the steam engine than the present Otto cycle engines. So far the Otto cycle engine has triumphed, and it has attained an overwhelming lead in the market. Notwithstanding this, I still retain my belief of twenty-five years ago, that the path of progress in this line must lie through the impulse-every-revolution engine, and, later on, engines giving two impulses per revolution for a single crank just like the steam engine. Many distinguished inventors have agreed with me in considering it necessary to aim at not only an impulse every revolution in gas engines, but also to aim at regulating the combustion impulse in the same manner as steam is regulated in a steam cylinder. Many inventors in Britain have devoted years of their lives to this work, and prominently among them I may mention the name of your distinguished President, Mr Foulis. Mr Foulis began to give attention to gas engine problems at almost as early a date as myself. Mr Foulis' first application for a patent in connection with gas engines I find was made in 1878; my own first application was at the beginning of 1877. As considerable pioneer work was done in Glasgow in those early days of the gas engine, perhaps you will allow me a few minutes to describe some of my own early Glasgow work, and its present development; and I hope that Mr Foulis will describe to us, in the course of the discussion, the results of some of his experiments with combustion engines.

I began work upon the development of the gas engine at the works of Messrs L. Sterne & Co., Glasgow, in the beginning of 1877. The first engine produced by me which was run in public was built and tested in 1878, and it was shown at the Kilburn Exhibition of the Royal Agricultural Society, London, in 1879. This engine is shown at Fig. 15. In this engine a pump was mounted alongside of a motor cylinder, and the pistons were driven from a crank shaft carrying two cranks. The pump took in a charge of gas and air, compressed it into a reservoir at the back of the cylinder, and this reservoir fed the motor cylinder through a slide which served the double purpose of admission and ignition. The ignition was effected by means of an incandescent platinum cage. The cage was first heated by means of a mixture flame, and then it was exposed, by means of a slide valve, to the gases within the cylinder, in such a manner that these gases were exposed; and the heat of the explosion kept the incandescent cage hot. This engine worked with fair efficiency for the time, and it was the first explosion compression gas engine built in the world which gave an impulse for every revolution. This engine did not reach the market.

My next engine was patented in 1881. It is shown at Fig. 16. This engine was sold in large numbers, and many of the engines then built are still at work. Here also an explosion impulse at every revolution is obtained. But the charging pump shown at the side of the main cylinder does not compress the charge; it merely forces it into the working cylinder while the motor piston is crossing the out-centre; and it discharges the gases of combustion through ports overrun by the piston. The side cylinder thus acts as a displacer only; and, to enable its piston to displace the gases in the cylinder, the displacer crank was set at about a right angle in advance of the motor crank. This engine gave a high efficiency for its time, and developed 24 indicated horse power. This type of engine has been made in England, America, and on the Continent, to the extent of some four thousand engines, partly during the currency of my patent, and partly since it expired. In America especially the impulse-every-revolution engine continues in favour; and in Germany the makers of the large gas engines appear to be returning practically to the old Clerk cycle. Messrs Koerting, for example, have built a double-acting gas engine of 350 H.P. which operates in exact accordance with the Clerk cycle; but, as it is intended for use with weak blast furnace gas, separate air and gas pumps are used, and these discharge the gases from the cylinder, and replace the burned gases by live charge in exactly the manner of the Clerk engine. Both engine cylinder and pump cylinder are double-acting, so that the operations which in the Clerk engine were performed on one end of the cylinder only, are in the Koerting engine performed in both ends of the cylinder.

Another large Continental gas engine of 500 H.P. is the invention of Mr Oechelhauser, and several large gas engines of the type have been fitted up by him at Hoerde, in Westphalia, for supplying air to blast furnaces. The action of this engine resembles the Clerk engine, which I have described, but the air pump is driven in time with the motor piston, and it compresses air and gas into an intermediate reservoir, raising the pressure to a few pounds, just sufficient to discharge the cylinder contents, and replace them with fresh mixture. In this engine the main cylinder contains two pistons, which operate in opposite directions, actuated by three cranks, two outside connecting rods, and one direct connecting rod. The charge is admitted by way of ports and covered by one piston, while the exhaust is discharged by ports, and covered by the other piston. This engine has an advantage in using blast furnace gases containing some little dust. It has no valves in the engine part which can be put out of action by cutting.

Many of the smaller launch engines also operate on the impulse-every-revolution cycle. The old Clerk cycle consequently remains in considerable use; but, in my opinion, further developments are necessary before gas engines can be applied, say, to marine purposes. To do this it would be necessary to produce an engine actuated not by explosion, but by constant pressure flame, something in the manner of the old Brayton flame engine. Brayton made many attempts, but he never succeeded in reaching the market. Many other inventors have also attempted constant pressure engines, among them, as I have said, being your esteemed President, Mr Foulis. I understand his engine was operated in Glasgow many years ago.

In my view, further progress will be on the lines of the combustion engine, and many English inventors have worked on these lines. In 1887, I had an experimental combustion engine of my design running in Birmingham, giving about 7 H.P., at 150 revolutions, with great smoothness; and since that time I have continued experimenting in that line. Other inventors have also experimented in the combustion engine line, including Herr Diesel; and there is good hope for believing that in time a constant pressure gas engine will be produced which can be as easily handled for marine purposes as a steam engine. At present, of course, there is no possibility of reversing or cutting off power impulse in the way done in steam engines. Apart, however, from the engine, further work requires to be done in connection with gas producers before marine gas engines become commercially feasible. Both in Germany and this country several inventors are at work upon gas producers intended to use ordinary steam coal, which would produce gas on board ship, without gas-holders, and supply the gas direct to marine or other engines. One great point is to get rid of the present gas-holder. Several inventors have made this attempt. Perhaps the first engine of this kind to be run in public was that of Mr Benier; but recently I inspected at the little suburb of Heusy, near Verviers, a gas plant supplying two 80-horse Otto cycle engines, in which no gas-holder was employed.

In my view the gas engine affords to the engineer and inventor an enormous field of work, likely to result in a very considerable revolution, certainly in land engine work as well as marine work. A gas engine with an efficient gas producer would easily give 1 I.H.P. on half-a-pound of coal per hour, as against 1¼ to 1½ lbs. for the best steam engine now in use; that is, power for marine propulsion could be obtained at less than half the present cost.

Many engineers are now at work on the subject, and when the problem is further solved, it will aid much in meeting the fuel difficulty, which must face this country at a comparatively early date. My view is that the nineteenth century was the century of the steam engine; and that the twentieth century will be the century of the gas engine. Steam will ultimately be displaced almost entirely by gas engines.

Discussion.

The **President** said Mr Clerk had given them very fully the history of the gas engine from an early date, and had also given a very clear description of the gas engine as it existed at the present day. Perhaps he might be allowed to say something about the experiments that he himself had made several years ago with the engine which Mr Clerk referred to, which was called a constant pressure engine. The difference between an explosive engine and a constant pressure engine had been fully described to them. In the one case a quantity of gas and air was drawn into the cylinder, compressed, and then fired. The combustion raised the pressure almost instantaneously to a very high degree, the expansion taking place during practically the whole stroke. In the other case, the mixture of air and gas was compressed in a pump, and then ignited as it entered the cylinder. The ignition expanded the air and gas, the pressure being maintained constant in the working cylinder during a certain portion of the stroke, and then the expansion took place. The great drawback, to his mind, of the Otto engine and the Otto cycle in engines of large powers—and they must look to engines being made in a very short time capable of producing thousands of horse power—was that the sudden blow of the explosion produced an enormous strain on all the parts of the engine. The consequence was that the crank shafts of some of the large engines were about half the diameter of the cylinder. For a 3-feet cylinder, the crank shaft was 18 inches in diameter. If that was the case with an engine of 400 or 500 horse power, which was about the largest now in existence, it would easily be seen that with much larger powers the parts of the engine would become quite unwieldy, and therefore he thought that there could be no doubt at all that a different style of engine must be adopted for large powers, and the style best suited for engines of large size was that in which the expansion due to heat took place at a constant pressure. While making his experiments, his great difficulty in working with such an engine was to get it to work in any other way than as an explosive engine. A mixture

The President.

in which the proportions of air and gas were in anything like the theoretical quantity required for complete combustion was exceedingly difficult to ignite. He had tried a number of experiments in reference to this, and they were exceedingly interesting, but, unfortunately, the record of results had been mislaid. For example, he had filled a gas-holder of about 10 cubic feet capacity with air and gas in proportions to form a highly explosive mixture, and allowed the mixture to issue from a pipe about half-an-inch in diameter. The pressure was about three inches, he thought, and therefore the velocity was not excessive, but when a light was applied to the orifice from which the air and gas was escaping, it was blown out. By no possibility from an orifice of that kind could he succeed in getting the air and gas to ignite. Those experiments were carried out because of the difficulty experienced for a long time in getting the engine to work as he wished it, and the gas to ignite as it entered the cylinder. He thought such experiments were very well worth repeating. There could be no doubt that an engine working on this principle, as Mr Clerk had explained to them, would be as much under control as a steam engine. Its speed could be regulated, and there would be no difficulty whatever with a three-cylinder engine in reversing it by a very simple system. He believed that in a very few years such an engine would be available. He thought that they owed a very hearty vote of thanks to Mr Clerk for his kindness in coming from London to read this paper. Mr Clerk had now been working on this subject, and closely studying it, for over 27 years, and he did not know of anyone in this country who had a more thorough knowledge of the gas engine in all its details, and he proposed that they should give him a very hearty vote of thanks. He would be very glad indeed to hear any remarks which any of the members had to make, and he was sure that Mr Clerk would be very glad to answer any questions.

The vote of thanks was carried by acclamation.

Prof. W. H. Watkinson (Member) wished to tender his hearty thanks to Mr Clerk for his most interesting paper. Mr

Prof. W. H. Watkinson.

Clerk had dealt with the historical part of the subject in a most able way. He, however, rather regretted that Mr Clerk had not referred to the Otto and Langen engine. The results of the tests of that type of engine showed the economical advantages of a great ratio of expansion in the consumption of gas, which was reduced to about 25 cubic feet per I.H.P. as against 90 cubic feet in the Lenoir engine. Both engines were non-compression engines. These facts were very valuable, because they indicated the direction in which improvement in compression engines might be made. As Mr Clerk had referred specially to Watson's tube igniter, it might be of some interest to mention that he had had some experience with the tube igniter in its earliest days. In April or May of 1881, while he was working at gas engines with Messrs Clayton, of Bradford, Mr Watson of Leeds, to whom Mr Clerk had referred, came there with his tube igniter, and while there they made an experiment with even a simpler piece of apparatus. The bowl of an ordinary long stemmed clay pipe was attached to the cylinder of one of the gas engines, and carefully packed round with shred asbestos; it was then fastened in position with a gland and the mouthpiece closed. On applying a Bunsen flame to the stem of the pipe the engine worked very satisfactorily for about ten minutes, at the end of which time the bowl of the pipe burst. He thought that was the first occasion on which a tube igniter was actually applied to an engine. He believed that Sir William Siemens was the first to propose this type of igniter, but, so far as he knew, he never actually applied it to an engine.

Mr Peter Burt (Visitor) supposed that the main point of the discussion would be the future of the gas engine. They were not so much interested in what had taken place in the past except in so far as it was a guide to the future. He would not like to discuss the theoretical developments very seriously. There might be prospects for the constant pressure engine that they did not realise at the present moment; at least, the inventors or experimenters had not demonstrated that they were able to do better

Mr Peter Burt.

than with the internal combustion engine, and the progress that the latter had made was so great that they ought to feel satisfied that they were going in a direction that was appreciated at least. Raising the efficiency of an engine from 15 or 16 per cent. to 30 per cent. was certainly a marvellous work in such a short time, and that was what the gas engine maker had done according to the figures Mr Clerk had put before them. It was perhaps a little disappointing and disheartening to see thrown on the screen pictures of large gas engines, and then to find that they belonged to either German or Belgian firms, and that it was not British firms who were associated with these great developments. One would have felt a little more pleased in the home of engineering to see that they were keeping abreast of the times. He thought that he, himself, might claim to have made the first engine in the world to work with blast furnace gas, and that engine was working to-day at Wishaw—at least, it was working according to the last accounts—but why the ironmasters of Scotland did not take advantage of the developments then made possible, he did not know. Apparently they had not yet realised the advantage of this. Mr Galbraith, the manager of the Wishaw Iron Works, had read a paper in which he demonstrated that it was possible with the engine to produce an electrical horse power for every 1¼ lbs. of fuel put into the furnace to make iron, and he thought that ought to have been an attraction in the way of economy. The amount of power which was going to waste just now was realised in some of the points that Mr Clerk had made in his paper, when he referred to the enormous power that might be produced in America from blast furnace gas. Here, there was the possibility of a great development. In regard to what was said about the high initial pressure in the internal combustion engine, that to a large extent appeared to be minimised by the use of producer or blast furnace gases. They did not with these deal with such enormous temperatures and high initial pressures; at least, the combustion was not so rapid as with town gas. With the poorer gases the working of the engine appeared to approximate more to the steam engine, but

Mr Peter Burt.

there were a great many directions in which it might be improved. Mr Clerk, in his book, had dealt with one, and he thought he might have amplified it. The possibility of compounding the gas engine was worth considering. While at the present moment, dealing with such high pressures, it might look as if it was not worth troubling with an exhaust of 40 or 50 lbs., still, as far as he saw, the exhaust was much higher than that, because the exhaust valve was open before the end of the stroke. From the diagram it appeared to be about 50 lbs., but he expected that it would be nearer 60 lbs. if the exhaust valve was not opened till the end of the stroke.

Mr Clerk—It was often 60 lbs.

Mr Burt—They could understand that a considerable amount of power was going to waste if they were working a large engine.

Mr Clerk—It had been calculated that it was exactly 10 per cent.

Mr Burt—He did not know whether in the 10 per cent. due allowance was made for radiation.

Mr Clerk—Yes, cf course ; they could get 10 per cent.

Mr Burt—An increased efficiency of 10 per cent. would be a great advantage. Then as to the question of scavenging. The paper read in Glasgow lately claimed that this system had special advantages, which added to the efficiency of the engine. He did not know that they had yet come to the solution of the power problem when they saw the large castings in the 700-horse power engine. The ironfounder was perhaps the one most interested in the job, and he was afraid that ships were not built to take such large weight of engines into them to drive them across the Atlantic. It was, however, a hopeful sign to him when he looked at the engine made by Mr Daimler, in one of the Cycle Exhibitions in London. He had examined some of the small engines and they were marvellously light for their power, and he failed to see why it was that the gas engine maker could not strike the happy medium between the two. Weight for weight, as high an efficiency should be given in a gas as in a steam engine at the

Mr Peter Burt.

present moment. If an electric-lighting station steam engine, say a Willan's, was compared with a tandem gas engine, it would be seen that the same conditions obtained in both as to regularity of impulse. Some of these gas engines had a mean pressure of over 100 lbs., and that was a very high mean pressure even for a steam engine. If, in the gas engine, they tried to approximate the conditions of the Willan's engine he thought they would be able to build it as cheaply, and as efficient for its weight, as a steam engine of this class, and in the event of compounding being successful there was the possibility of greater developments. The question of producer gas was one he would not go into. It was almost impossible to take all the subjects in connection with the gas engine and discuss them in detail. In his opinion the gas engine had reached a point when to have lectures on particular features of detail were required. He thought Mr Clerk had earned the thanks of the Institution by the able manner in which he had brought the general question before it.

Prof. A. **Barr**, D.Sc. (Member of Council) said Mr Clerk had referred to the question of the combustion *versus* the explosive engine as being one of the necessities of the future. Necessity was said to be the mother of invention, but he might say that he had attacked this problem to a small extent, and he thought the proverb would be more likely to be true in his case if reversed. There were very great difficulties as far as he had studied the subject in producing a workable engine on anything like a slow combustion system. In connection with what Mr Foulis had proposed, he would be very pleased indeed if he could carry out the experiments in the engineering laboratory, but one was more or less responsible there for the lives of those around him, and he felt that he would not like to be responsible for the carrying out of such experiments, indoors at least. He knew more or less what the President had done, but he did not know it in detail. He had always been surprised that Mr Foulis had not proceeded further with an invention of such promise. With regard to what Mr Burt had said, he was afraid that he could not at all agree with him. First of all, Mr Burt had said that engineers should be contented with the present engine, because it seemed to have met a want. It did meet a want, but he thought that while all engineers would agree that the Otto cycle engine was the best gas engine for general use that had yet been produced, and that it worked extraordinarily well for many purposes, it was exceedingly crude in its mechanical principle, and he thought that engines working on some other cycle would yet be successfully produced. Mr Burt had also suggested that compounding would be one of the directions in which progress would be made. He did not know whether he was anything of a prophet, but he would say he did not expect that that would be the direction in which the most hopeful progress would be made. So far as he could see, there would be great difficulties in making important progress in the direction of compounding. He thought what must be looked for was an engine with an explosion every revolution in one cylinder. He had himself attempted the problem, but he had been very far from being successful in the direction in which he had worked. Whether he would be more successful if he should find time to take the matter up again he could not say, but he thought that they would yet have a gas engine that would give an explosion every stroke in one cylinder, and would be governed by varying the energy of the explosions instead of by missing explosions, and which would be reversible. He thought these were the directions in which progress would be made as regarded the uniformity of the turning moment, and that increased economy would be got by greater compression and further expansion, and the use of higher temperatures. He remembered that when Sir William Siemens, lecturing in Glasgow many years ago, described his new gas producer, into which he could put cold coals and cold water and cold air, and get out cold gas with little loss by radiation, Lord Kelvin said that the steam engine had been practically a creation of the 19th century, and that it would be the machine of the 19th century, but in the 20th century it would be relegated to the museums. Prophecies of that kind, he was afraid, were rather

Prof. A. Barr.

apt to be long in fulfilment. The President would remember the Exhibition of Gas and Electric Lighting Appliances held in Glasgow in 1881. At that time he (Prof. Barr) was engaged testing one of the earliest Otto engines that had been exhibited in this country, when a well-known electrical engineer said to him that before "next year" they would see every house in Glasgow lighted by the incandescent electric light. That prophecy was one that had not been quite realised, and, while enormous progress had been made in gas engines, he was sure that in the course of fifty years there would be a great displacement of steam engines by internal combustion engines, though he thought the steam engine had still many years of usefulness before it.

Mr W. A. Chamen (Member of Council) said he was one of those people who did not pretend to be an inventor or investigator, and possibly he had not been so, because, as Dr. Barr had so truly put it, he might have felt that *invention* was the mother of *necessity*. He had used gas engines a good deal, although not in Glasgow, and had about as much trouble with them as most people, but in spite of all the trouble, he had for a long time felt that the gas engine was the engine of the future. One thing that struck him very much in listening to the discussion was that all the gentlemen who knew most about these things, and to whom everyone looked for information, were asking somebody else to do the job. He did not think that he could help the gas engine people much except by saying that, if they would bring out a gas engine of 2000 or 3000 horse power that would give an even turning-moment fit to drive a dynamo, electrical engineers would find plenty of outlet for their production.

Mr Robert Williamson remarked that he had at present a gas engine driving his workshop, in which two explosions were obtained per revolution. Prof. Barr referred to one of the methods of increasing the efficiency of gas engines by getting at least one explosion in one revolution, but, as already stated, he had got two. Then Mr Burt had referred to striking the happy medium between the weight of a Daimler motor and those very

Mr Robert Williamson.

large engines that Mr Clerk had shown on the screen. His engine had only got a 5-inch crank shaft, and it gave out 100 brake horse power working with producer gas. The total weight of the engine was not more than one of the fly-wheels of some of the engines shown, and the floor space occupied was about 8 feet by 4 feet. It was of the inverted cylinder type, with four cylinders. There were two tandem pistons working on each crank. A chamber between each of the two pairs of cylinders was utilized as a pump, to pump a scavenging charge of air through each cylinder alternately, and he thought he was getting a little bit on the lines of what Mr Burt and Prof. Barr had been suggesting. The engine, he might state, was the invention of Prof. Rowden, a gentleman who was well known to the members of the Institution. He (Mr Williamson) had listened with great pleasure to Mr Clerk's paper on the history of the gas engine, because he was very much interested in all concerning it, and personally he thanked him very much.

Prof. Barr thought that the last speaker had probably misunderstood Mr Burt and himself. As many explosions could be got as was wished for, but what they referred to was one explosion in every cylinder without a pump.

Prof. Andrew Jamieson (Member) said Mr Clerk had drawn a clear, concise distinction between gaseous and powder explosions, by explaining the fundamental nature of each. His different explosion curves were interesting and instructive. Those curves elucidated how very important and correct the four original conditions, laid down by Monsieur Beau de Rochas in 1862, had been. They also proved how successfully the Otto cycle engine first embodied and then gradually complied more and more thoroughly with these primary conditions. Although the Otto cycle was by no means an ideal one—since there was only one power producing stroke out of every four in succession—and consequently its mechanical efficiency became less and less as it was called upon to produce smaller and smaller efforts, yet, the machine, as a whole, had been so well designed and constructed that, whenever the time of the patent

Prof. Andrew Jamieson.

expired most of the other patentees or their consignees immediately dropped their patentable modifications, and took to the Otto cycle as a better means of satisfying their customers. This spontaneous imitation was the best form of flattery, but it had undoubtedly tended of late to keep the design of gas engines in a somewhat narrow groove. Until someone made a decided departure from this groove further efficiency could not be very great. For, the mere working details of valves, ports, mixtures, and ignitions, had been so perfected, and the changes had been so frequently rung upon them, that the heat efficiency had risen from 16 per cent. in 1882 to 25 per cent. 1894, and quite recently it had jumped up, in very large engines, to nearly 30 per cent. Crank shafts and other parts which had to withstand the sudden severe impulses of the explosions, and the necessity for a great moment of inertia in the fly-wheels, to produce even an approximate uniformity in the speed of rotation, led him (Prof. Jamieson) to ask: Could no one "Parsonise" the gas engine? Our President's worthy persevering efforts of more than a dozen years ago, to effect economical extended combustion within the cylinder of his gas engine, with the view of reducing sudden changes of pressure, and of getting a more ideal indicator diagram, like that of a good steam engine, were frustrated by his excessive zeal for, and attention to, his Corporation duties. This question of an extended combustion within the working cylinder, was a difficult one of attainment with certainty and uniformity, when using rich heat producing gas; but there was undoubtedly here, an opportunity for the inventor with the less powerful and heretofore much wasted blast furnace gases. The past efforts at trying to get their most useful working friends to live upon less and less quanties of internal fuel, and at the same time to do satisfactory labour, had failed, and spasmodic efforts at recuperation had often produced premature extinction due to overheating. Whereas, larger quantities of milder feeding, with less specific potentiality, had effected more satisfactory and uniform results. Might they not, therefore, apply this lesson to the gas engine of the present and the future, and thus feed it uniformly up to one-third, or even one-half stroke, from each end during every alternate stroke, with the milder gas, just referred to, and thus obtain the beau-ideal efficiency suggested by Mr Clerk in his excellent paper.

Mr F. J. Rowan (Member) asked Mr Clerk if he would say why he had mentioned 700 horse power as the largest gas engine in the world. He had understood for some time that engines of 1000 horse power were at work.

Mr Clerk—The engines that he had shown gave with producer or blast furnace gas 600 horse power, and 1000 horse power with town gas. These were the engines which had been called 1000 horse power engines.

Mr Rowan—Did Mr Clerk mean that those engines that were working with blast furnace gas were not giving 1000 horse power? He referred to the engines installed at the Hoerde works in Westphalia.

Mr Clerk—They were giving 600 horse power. He was not talking of the Hoerde works, but of the Seraing works.

Mr Rowan—There was a 600 horse power Simplex engine first installed at Hoerde and then Oechelhauser engines of 1000 horse power. The makers of the Oechelhauser engine had informed him that engines of 1500 horse power were at work, and engines of 2000 horse power were being made.

Mr Clerk—They were made with multiple cylinders, and he was talking of single cylinder engines.

Mr Rowan—The Oechelhauser was a single cylinder engine, with a double piston. Then as to the fuel combustion; when Mr Clerk spoke of one-half lb. of coal per I.H.P. per hour: Was that an estimate of what could be done or what had been done?

Mr Clerk—It had never been done. The best that had been done was three-fourths of a lb.

Mr Rowan—The best he knew of was the result given by Mr Humphreys with producer gas, namely, ·95 lb.

Mr Clerk—He thought they would find better than that.

Mr Rowan—Mr Humphreys had given some figures of another

Mr Rowan.

trial which he thought would work out at about ·75 lb., but, according to the complete report in his last paper, it did not work out at that. He (Mr Rowan) thought one-half lb. per I.H.P. per hour would be reached. Did Mr Clerk refer to producer gas or illuminating gas?

Mr CLERK—Producer gas.

Mr CLERK, in reply, said that Prof. Watkinson had asked about the Otto-Langen engine. He had not said anything about it because it belonged to the non-compression type, and although it gave a certain economy, the economy never approached the figure they had now, and it was got at an enormous expense. The Otto-Langen engine had a cylinder of about 9 inches diameter with a stroke of some 4 feet, and it gave 3 brake horse power. It was not the kind of engine to construct of large dimensions, and many of them would remember that it had been called the "Shooter" engine; it had a piston in the cylinder and with a rack running on to a pinion, when the explosion came it could be heard three buildings off. It was really a gun. It shot the piston against the atmosphere, and the piston compressed the air in front and made a vacuum behind by the velocity of the piston. He had fully described the old engine with others in his book, but he had thought it better to keep his paper to more modern lines if possible. Such an engine as that was hopeless as giving any help towards the future. He fitted one of Mr Watson's tube igniters in one of his engines in Messrs Sterne's works, and it worked exceedingly well. Mr Burt, as a practical man, had said that the constant pressure engine had not been proved yet, and he quite agreed with him. It had been a favourite of many inventors, and he knew six, every one of whom had built an engine and each had worked well. The first was the old Brayton engine, and he had had one at the Crown Ironworks, where a good many engines of that kind were made. The next he knew of that type was an engine made by Mr Foulis, and that engine worked all right, although there were certain

Mr Clerk.

difficulties which seemed to him not insuperable. Messrs Crow of Middlesbrough built another, and he himself had built one closely resembling the latest Diesel engine in 1887, in which air was compressed up to the full pressure. The flame was injected into the cylinder, and the available pressure was about 30 lbs. per square inch. All these engines were working, and they had been carefully getting knowledge of what a flame did in the cylinder. When he started to work on these engines twenty-five years ago the most ridiculous notions were prevalent. It was said that compression had nothing to do with the economy of the gas engine, and it was only within recent years that high compressions gave a good result. It seemed to him a great pity that the enormous success of the Otto cycle should have led so many people away from experimenting on a promising line. A great deal had been said about the motor-car engine, which would give a horse power on 20 lbs., and no doubt 10 horse power could be got with about 200 lbs. weight of engine; but these engines were running up to 1500 or even 2000 revolutions per minute. It was all very well for a motor-car which might be on the scrap heap six months hence, but he thought Mr Burt would not sell many engines which ran at 2000 revolutions, as people wanted engines that would last more than ten years. Many of his own old engines were running, and had been for nearly twenty years. An engine had to be built that would meet different wants. There was considerable reaction as to speed in very light engines, and more reasonable speeds were now being considered. He knew that engines were made to drive a boat with gasoline, and as much as 100 horse power, he believed, had been put on yachts in America, but these engines did not give a true solution of the problem. They were very clever temporary solutions, but a better solution would be obtained by and by. What he was trying to impress upon them was not to let the success of one line prevent engineers from looking at others which might turn out better, and which fundamentally might have better principles more resembling the steam engine. He thought that

Mr Clerk.

Prof. Barr, to a certain extent, agreed with him (Mr Clerk) that the slow combustion engine was the engine of the future. He did not quite agree with Prof. Barr as to compounding, but rather with Mr Burt on that point. Mr Burt made a very good attempt in an engine that he produced that had some of the features of compounding, although not all. He thought engineers were doing better now, and after a time the compounding would come, not in the way of saving exhaust pressure because there was only about 10 per cent. to be saved altogether, but in saving weight of engines. The weight of an engine depended upon the ratio of the average pressure and the maximum pressure. With a maximum of 300 lbs. to the square inch, the 300 lbs. determined the weight of the engine, while the mean pressure, say 100 lbs., determined the power, and if they designed another engine of 50 lbs. mean pressure for 500 lbs. maximum they would have a much heavier engine for equal power. The cranks in existing gas engines were not too heavy for the strain that might possibly come on them. These large engines would ultimately be arranged so that they had several cylinders with expansion from one to another equally divided. This would save weight in a gas engine as it did in steam engines. It was difficult to compound with the explosion engine, but it could easily be done with a flame engine. There was a great deal to be done outside the Otto cycle. He rather agreed with Mr Chamen that *invention* was often the mother of *necessity*. Many unfortunate inventors found that it was very much a matter of necessity. They worked very hard and sometimes made but little. In that sense Mr Chamen was quite right, and if they looked at the history of the gas engine they would find that both Beau de Rochas and Lenoir would have ended their days in poverty but for a timely Government grant. He was much interested in Prof. Rowden's engine, and he wished that he had some additional details. He was also very much pleased that Prof. Rowden had made some advance in the direction of a light engine.

Correspondence.

Mr C. A. Matthey (Member) thought the paper would have the effect of stimulating those inventors who were working at the gas engine, and more particularly the oil engine, to further efforts, and that perhaps before long some advance made on the lines indicated by Mr Clerk would be seen. One statement had interested and surprised him very much; it was that the loss from incomplete expansion was only 10 per cent; that was if an engine was constructed with short charging and compressing strokes, and long power and rejection strokes (as had been done in the Atkinson engine, but without its constructive disabilities), so that the expansion was carried down to atmospheric pressure, or nearly so, the gain in power would be only 10 per cent. A perusal of Mr Clerk's earlier book on the subject, and later of his larger treatise, led him to accept any statement of the author with a great deal of confidence; but he would like to mention that not long ago an engine of this kind was brought out in America, in which it was claimed that the economy so effected was from 20 to 25 per cent. He should like to have Mr Clerk's opinion as to whether this was merely the optimism of an inventor, or whether it was possibly true. Would he kindly give the argument for the 10 per cent. estimate? The engine in question did not actually give short and long strokes; any mechanism which did that, though undoubtedly ingenious, would inevitably have serious practical objections; but the inventor, Mr C. E. Sargent, got what was virtually the same action with the ordinary crank and connecting rod, by an exceedingly simple and happy expedient. He shut off the admission of air and gas at half stroke or thereabouts; then the admission line fell till the end of the stroke was reached, power being expended, of course, in overcoming the external atmospheric pressure. On the return, or compression stroke, however, all this power had been given back by the time the original point of cut-off was reached, and thereafter the pressure rose above that of the atmosphere, just as if the admission and compression strokes had been only half that of the piston. Then the ratio of expansion

Mr C. A. Matthey.

was greater than that of compression, and by properly proportioning the engine, the full expansive power of the gases could be obtained. The engine was described in a paper read before the American Society of Mechanical Engineers, N.Y., in December, 1900. He thought Mr Clerk's opinion on it would interest others beside himself. The rough diagram appended, Fig. 17, showed the action of the engine.

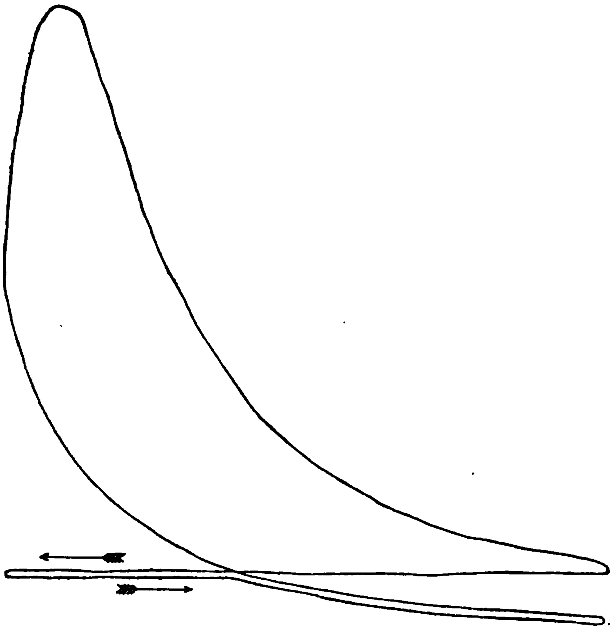


Fig. 17.

Mr Clerk, in reply, said with regard to his statement as to complete expansion, it was quite true that completion of expansion was looked upon as very important in earlier days, and it was, in those days, relatively important. When his earlier calculations were made, the average pressure common in gas engine cylinders but little exceeded 60 lbs. per square inch. At such pressures the proportional increase to be gained by continual expansion was

Mr Clerk.

considerable. It had to be remembered now, however, that by increased compression, average pressures had been obtained of considerably over 100 lbs. per square inch. If the gain to be obtained by expanding fully were calculated from a diagram, such as that given by Mr Humphrey for the "Premier" engine in his recent paper at the Institution of Mechanical Engineers, then only 10 per cent. would be added to the total effect. The fact was, modern changes, including high compressions, had diminished the saving possible by increased expansion. The method indicated by Mr Matthey as invented by Mr C. E. Sargent was a very old one, and many engines had been operated by expansion produced in that way. The first engine within his knowledge to be so operated was one shown in Glasgow about 1887. It was invented by Mr M'Ghee, and it produced a diagram exactly similar to that shown by Mr Matthey. The charge was cut off at about half forward stroke, exactly as Mr Matthey showed upon his diagram. Modern practice showed that it was better to compress highly and get expansion in that way than to continue the expansion beyond atmospheric lines. The diagram sent by Mr Matthey would not be an economical one. It did not pay to carry expansion too far. Mr Matthey would find this subject of complete and incomplete expansion dealt with fair fullness in his (Mr Clerk's) book upon the Gas and Oil Engine. He quite agreed that it was desirable to produce a compound gas engine, but compounding must be carried out more on steam engine lines, namely, to produce good results the power must be divided equally, or fairly equally, between the different cylinders. The main advantage of compounding would not be increased economy in gas engines, but diminished weight of engine and moving parts.

RUDDERS.

By Mr J. Foster King (Member).

(SEE PLATES XIII., XIV. AND XV.)

Read 18th February, 1902.

In attempting to bring before the members of this Institution a few considerations relative to rudders and the steering of vessels, it has seemed desirable to limit the scope of the remarks to the types of rudder commonly in use in normal vessels of the merchant service, to the exclusion of rare designs.

It might be expected that the gradual evolution of the tramp steamer, and the accumulated experience of hundreds of vessels of varying types, would have produced a generally similar and presumably "best" form of rudder for each type, but on the contrary, the most striking feature of this subject is the diversity of opinion which is expressed in the forms of rudder to be found in vessels of the same type and the small effect of difference in type of vessel upon individual design of rudder.

Fig. 1 shows how this variation in modern practice appears in rudders of different vessels, while Fig. 2 shows how this difference of opinion is expressed in two sister vessels which were built in different yards, the steering qualities apparently being equally satisfactory to the owners in each case.

In order, if possible, to ascertain the effect of rudder form upon steering, Mr Archibald Denny very kindly allowed some experiments to be made for me in his firm's experimental tank at Dumbarton, the results of which are now submitted. In making these experiments, the models were towed at a constant speed corresponding to 13·8 knots in the actual ship, and the rudders were set in each case at an angle of 10 degrees from the middle line.

A rudder of ordinary full form, Fig. 3a, was found to have exactly the same turning force as a rectangular rudder, Fig. 3b, of the same depth and area. The rectangular shape, however, possesses the practical advantage of showing a reduction in the twisting moment and corresponding area of stock, on account of the centre of gravity of the rudder plane being nearer to the centre of the stock.

A series of experiments with different breadths of rectangular ruddders, Fig. 3, and triangular rudders, Figs. 4 and 5, having the bases and the apices respectively at the water line, showed that with each type of rudder the turning force varied directly as the area or breadth abaft a point, the position of which changed with different models. This point, which may be called the efficiency point, was actually forward of the leading edge of each of the rudder blades when placed on a model of ·6 coefficient of fineness. The explanation of this apparently impossible result is probably to be found in the thickness of the experimental rudder blades being such that the leading edge has a certain steering value which cannot well be determined or eliminated. In the experiment with full models, the efficient surface of each rudder began at a point situated approximately one-fifth of the breadth of an ordinary rudder behind the leading edge of the blade. This falling back of the efficiency point is doubtless caused by that increase of eddy-making and instability of wake which follows upon increased fullness of form and breadth of vessel. It is in accord also with that experience of abnormally broad and full vessels, where, even with rudders of very large areas, it has been found to be extremely difficult, and sometimes impossible, to steer them. A reliable quantitative figure cannot well be put upon experimental results where the modifying influence of the propeller and its aperture are unknown, but, as the greatest distance recorded corresponds roughly with the position of the centre of the rudder stock abaft the stern post, where the pintles are fitted forward of the stock, it should be sufficient for the designer who is dealing with normal vessels up to, say, ·78 coefficient, to calculate the effective rudder area from that point or from the back of the stock when it is of circular section. This is the method adopted in calculating the areas used in the comparisons made hereafter.

An analysis of the results shows that triangular rudders with the broad part at the water line fitted to models of both full and fine forms, have about 20 per cent. greater steering efficiency per foot of area than the rectangular rudders, while those having the broad part at the bottom of the stock show from 4 to 12 per cent. less efficiency in the fuller models, which may be said to represent a nett loss of 22 to 30 per cent.; as the theoretical gain due to the altered position of the centre of gravity in relation to the centre of the stock, should be about 18 per cent. Apparently, however, the value of this type of rudder improves as the after body of the vessel is made finer, until on a model of ·6 coefficient, the efficiencies of the different breadths of rudder became fully as high as those of the triangles having the bases at the water line Experiments made with rectangular rudders bisected at mid draught showed equality of forces in the fuller models, and about 3 per cent. higher value for the lower half in the very fine vessel, but the same value should not be attached to such experiments as to those upon the rudders of normal depth, because of the greater relative disturbing effect of small differences. The experiments generally show an advantage to be gained in ordinary vessels by increasing the breadth of rudder at the load line, results which are probably due to the increase in wave-making resistance from the rudder blade towards the surface of the water and the diagonal movement of the stream lines in an upward direction. They seem to be entirely opposed to those given by Sir William White in his well-known Manual of Naval Architecture, and to the popular opinion that the lower part should be the broad part of the rudder because it acts in "solid water."

The effect of fineness of form of vessel upon the efficiency of the rudder is very considerable, in fact, an examination of the tank results points to the conclusion that the steering value of each foot of effective area in a vessel of ·8 coefficient is only about two-thirds of that in a vessel of ·6 coefficient of displacement. This conclusion obtains practical support from the fact that the evolution of the modern sailing vessel out of the old time clipper, has carried with it an increase in efficient rudder area in proportion to increase in fullness of form which would represent about 25 per cent. within the above range of coefficients.

In order to learn something of the effect upon steering of the present day spectacle bossing in twin-screw vessels, experiments were made upon a moderately full model which showed that the rectangular rudder had fully 15 per cent. greater efficiency with the bossing than without it, while the triangular series, Figs. 4 and 5, showed relatively greater respective loss and gain than in the corresponding single-screw vessel. One model, of course, cannot be accepted as settling results for all models, but it is at least interesting to learn that the spectacle boss in one normal instance showed such an increase in the effect of the stream lines above the bossing.

In view of the fact that all the experiments showed that the highest efficiency per foot of area was to be found in the triangular rudders having the broad part at the water line, it might be concluded that the best form of rudder for a merchant vessel would be one very wide at the load line and narrow at the bottom; but apart from the fact that a rudder of this form would require a specially large stock and powerful working gear on account of the great breadth which would be necessary in order to secure sufficient area, it is probable that the action of the propeller accelerates the movement of water past all parts of the blade, and we know that such a rudder would be absolutely useless with the vessel in ballast trim. The importance of this latter question is shown by Mr Lorentzen, owner of the barque "John Ena," in a communication which appeared in the American press and in *Fair Play*, where he describes this vessel as being equipped with a regular British rudder, having a blade on the upper part and nothing below. The ship referred to stands up without ballast and draws 12 feet in ballast trim with 1100 tons on board. Mr Lorentzen describes an attempt to shift the "John Ena" with clean swept holds and in smooth water, which showed that even with the assistance of a powerful tug the vessel could not be steered. Subsequently the lower part of the rudder was increased in area, with the result that the vessel steered well in all conditions, and the owner, who formerly was unwilling to send her on ocean trips in ballast, had now perfect confidence in doing so. Mr Lorentzen finished by saying that "the want of a blade on the lower part of the rudder is why your ships are lost."

These experiments and considerations suggest that a rectangular rudder is the most satisfactory form to adopt, as presenting a larger surface at the load line in all conditions of trim, and requiring a smaller stock and working gear, in proportion to efficient area, than any other shape.

There does not appear to be any sufficient reason beyond fondness for sweet curves, for the common practice of extending the rudder blade high above the load line. The extra area can have little or no steering value, while it exposes additional surface to shocks from seas and adds unnecessary weight.

With regard to the proportion which the rudder area should bear to size of vessel, it is fairly evident that a small rudder which can be rapidly set to a large angle without undue loss of speed, will steer as well as, and perhaps better than a broad rudder, provided it has sufficient area to steer properly; a proposition which would seem to be proved by the case of the sister vessels whose rudders are shown in Fig. 2. It is also apparent that the smallest *efficient* rudder is the most economical, because weight, size of stock, steering gear, etc., are reduced in proportion to reduction in area and consequent working stress. In order to ascertain, if possible, from practice, what is the smallest efficient area in proportion to size of vessel, I have made an analysis of the effective areas of the rudders fitted in a very large number of merchant vessels within recent years, which shows that with the modern full or approximately square-shaped blade, this minimum for steamers of all sizes, speeds, and most forms, is apparently one square foot of effective rudder blade to each 100 square feet of immersed middle line plane, *i.e.*, the area given by multiplying length of vessel by draught of water. This figure gives about one-half of the area based on Admiralty practice, which is mentioned in text-books, and the analysis shows that there is no tendency in practice to increase but rather to decrease, the proportion of rudder area with increasing length of vessel. It will be remembered that Sir William White suggests a variation in terms of the square of the length.

From such data as I have obtained the idea suggests itself that the action of the screw propeller eliminates to a large extent the influence of fineness of form of hull upon the steering efficiency of the rudder, as it is even more common to find a very large rudder on a fine vessel than on a full one, and small rudders give as bad steering results in the one case as the other. Experience, as embodied in practice, would seem to show that only in steamers which are very broad and full in the after body, is it necessary to provide rudder areas of more than one per cent. of the immersed middle line plane, which to some extent is in harmony with the tank experiments, while the minimum for modern sailing vessels and for coasting or other steamers, which require to manœuvre under their own steam at slow speeds in narrow waters, is about 1·4 square feet per 100 square feet of middle line plane. The change in form in sailing vessels within the past half century is apparently responsible for an increase from 1·1 to the present 1·4 ratio.

So far as I am aware the only form of balanced rudder which may be considered as coming within the limits of this paper is that known as the "Doxford" rudder, shown in Fig 11. The effective area of this rudder is usually 1·4 of the immersed middle line plane, and I am informed by Mr C. Doxford that in experimenting with 340 feet steamers the half-circle was turned in a little over three minutes, the time being the same with both port and starboard helm, a result which is apparently due to the rudder acting on both sides of the centre line and so having effective surface always exposed to the most active propeller streams. The advantages of a type of rudder which provides an effective area so great as to avoid the necessity for fitting auxiliary rudders for canal work, and at the same time, from its design, reduces so greatly the work upon stock and steering gear, are so real that it is a little strange that the appearance of a simple form of construction has not led to its more general adoption.

In connection with the practical construction of rudders, perhaps too little consideration has been paid to the actual movement which occurs in stock and blade due to torsion, even in conjunction with a safe working stress. Fig. 6 shows diagrammatically the application of an investigation of this nature to a modern single plate rudder. Each rudder arm has to support its proportion of the total pressure due to the segment of plate connected to it and transmits the corresponding stress to the stock. The diagram of stresses shown on one side of the stock gives the effect of each element, based on the assumption that the whole blade, under working conditions, causes a stress of 9000 lbs. per square inch in the stock above the load line. The practical lesson from this diagram is found in the excess of stress on the stock at the two upper arms, and points to the advisability of extending the full diameter of stock to the topmost arm below the load line. The part of the plate above the water is ignored in this calculation, as it usually is in that which decides the diameter of the stock. The curve on the other side of the post shows the number of degrees of twist upon the rudder stock corresponding to the stresses, and the diagram at the bottom shows the actual number of inches deflection in the after edge of the plate corresponding to the curve of degrees. It will be seen that parts of the blade travel through no less than 5½ inches on each side of the centre under the effect of the assumed working stress, and that in addition to the work of securing the plate the rivets at the outer ends of the arms have in practice to withstand the alternating strains caused by actual movement along the edge of the rudder plate.

It is probable that this actual movement of the rudder blade accounted for the occasional fracture of the bow frame in the old double plate rudder, as well as the failure of rudder stocks through fatigue of the metal where the margin of safety was unduly small; a not improbable condition when one remembers the variety of rudder forms and the fact that not so long ago, the diameter of the stock was settled by the size of the ship, apart from all considerations of speed of vessel or area of rudder.

In Figs. 7 to 11 inclusive, an attempt is made to trace the development of the ordinary rudder, as distinct from those of special design which (from considerations of cost or complication) have not come into general use.

Fig. 7 shows the earliest and for many years, the most common type of modern forged rudder. The rudder stock, bow frame, arms and pintles, are forged in one piece; the frame is covered with two thin plates, often after having been filled in with wood, so that the finished article provides the closest practicable resemblance to its wooden ancestor. The whole weight of the rudder is usually borne by the bottom pintle. As the pintles are forged solid to the frame it is practically impossible to have them all truly centred with the stock, and it is usually necessary to dress each pintle by hand before the rudder can be shipped in place. Some of the objectionable features of a design which for many years held practically undisturbed sway, are to be found in the rapid wear on the pintles and gudgeons caused by want of truth, difficulty in repairing pintles when worn, and rapid corrosion of the thin plates because of the initial difficulty of obtaining sound caulking. The rivets were necessarily out of all proportion to the plating both in diameter and pitch, but apart from this defect the alternating deflections of the bow or following edge of the blade would probably have had the effect of starting any caulking.

Fig. 8 shows that higher development of the double-plate rudder where the forging of the lower stock is straight, so placed as to clear the sternpost gudgeons, and which has corresponding gudgeons forged on the foreside, into which separate pintles are fitted. The improvement in design is evident, as it removes the risk of failure of the stock from bad welding or local strains which attended the earlier "gap" form. The fitted pintles possesses the great advantage of being dead true in centre and of easy renewal, but they generally extended through the gudgeon, as shown in Detail A, except in the case of the bottom pintle, which carried the whole of the rudder weight. The arrangement at Detail B shows the advance to a form where each pintle is intended to take part of the rudder weight by means of a hard steel washer fitted into the bottom of the gudgeon to receive the conical point of the pintle. Sometimes adjusting screws are fitted under the washers, but their value is doubtful as they tend to increase the risk of uneven wear. This arrangement gives very good results in practice, and is still adopted by many builders. A number of rudders have been fitted with convex points to the pintles which work on convex washers of hard steel, but this is not found to be satisfactory because of the unequal and rapid wearing of the bearing surfaces.

Fig. 9 shows the evolution of the single plate rudder out of the previous design, the arrangement of the forging being the same, except that the arms are forged on alternate sides of the stock so as to permit of a heavy single plate being shipped between them and into a recess or slot in the stock. The single plate was an important step in advance and like all new departures it made but slow headway at first, but now in one design or another, it has almost entirely superseded the double plate form. In the single plate design, the forged bow piece is removed, the blade is no longer a little water-tank always leaky and liable to corrosion, and all the surfaces are accessible for painting. The objections to the earlier designs, such as shown in Fig. 9, lay in the difficulty of forging the arms to the main piece, and the liability to fracture at the fillet of the arms on account of the abrupt change of section, a defect sometimes accentuated by unsound welding. In some earlier instances insufficient allowance was made in the size of the arms for the work to be done in supporting the pressure upon the surface of the plate. This type of design is still adopted in cases where cast steel replaces the iron forging, and the whole rudder is not cast solid. The pintle illustrated in Detail A is amongst the best and certainly the most expensive forms of this type of bearing. A brass sleeve is shrunk on to the fitted steel pintle, and works in a lignum-vitæ bush and bottom bearing fitted into the sternpost gudgeon. To give the best results the lignum-vitæ bush should be turned out of the solid, so as to reduce the risk of dislodgment, and the bearing under the pintle is better to have the grain "end up." Given perfect fitting and workmanship, this type of bearing is extremely durable and easy of repair; but if the shrinking of the brass bushes is not perfect, the speedy destruction of the pintle through corrosion naturally follows. Detail B shows a type of pintle and gudgeon, which appears to be about the best design for this sort of bearing. There is no brass sleeve on the steel pintle but it works in a white metal bush, and the weight of the rudder is taken by white metal bearing rings pinned on top of the gudgeons, so that the rate of wear can always be seen. This arrangement is simple, durable, easily repaired, and gives larger wearing surfaces than the other designs. Steel bushes are sometimes fitted, but steel working in steel is not an ideal arrangement with water as the only lubricant.

All fitted pintles should have a slight taper in the gudgeon of, say, 1 in 12, rather than be made parallel and screwed against a shoulder on the pintle, as the taper ensures a more solid fit when driven home in the gudgeon. The nut on top should always be fitted with a locking pin, if not with a locking nut in addition.

Fig. 10 shows what may be called the rudder of the present day, where the stock is of circular section down to the heel of the rudder and the arms are separate forgings shrunk on and keyed to the stock. The stock is usually tapered towards the bottom, this being theoretically correct as well as permitting each arm to slip easily to its place. In the best practice a turned parallel part of slightly larger diameter is left on the stock in way of each arm so as to ensure a perfect fit, and the arm-collar is gradually tapered into the arm proper in order to minimise, as far as possible, the change of section. A slot is usually cut in the stock into which the plate is fitted, but in many cases this is not done and there does not appear to be any very sound reason why it should be. Owing to the necessity for allowing the plate to slip into place as easily as possible, the slot is cut wide enough for the arm keyways and from one-tenth to one-eighth of an inch wider than the thickness of the plate, and the forging is usually caulked down upon the plate. Corrosion often occurs on each side of the slot which takes a V-shape form, and frequently becomes so bad as to require to be protected by cover plates. As it is practically certain that the leading edge of the rudder plate is of no steering value, because it lies in the eddies formed by the passage of the water round the stock, it would probably be better to shear the plate so as to leave an inch or so of clearance between stock and plate. All the surfaces could then be properly painted, the efficiency of the stock would not be impaired by cutting away part of its most valuable section, and the evil effects of corrosion would be avoided. It is necessary under the present system of placing the rudder arms alternately on different sides of the plate, to leave sufficent clearance to allow of the plate being shipped into position, with the result that the rivets have an initial strain put upon them through having to deflect the heavy rudder plate out of the straight line between each pair of arms. Might it not be better to have all the arms on one side and in one plane, and to rely upon a larger number of rivets in the arms?

The rudder arms are usually forged with a gudgeon on the fore side of the stock to take fitted pintles, but in this figure a different style of bearing is illustrated as being theoretically more appropriate to the design of stock. It is unnecessary, with a rudder stock of large diameter throughout its length, to fit closely pitched bearings, because, under its working load, the stock is sufficiently strong to resist deflection with bearings more than twice as far apart as in the pintle system. The "Collar" type of bearing provides large wearing surfaces, and a relatively small number of bearings to fit and keep in repair, while experience has proved its durability. In this case the bearings are shown as riveted to the sternpost and bolted together at the outer surface; brass sleeves are shrunk on to the stock in way of the same and they work in lignum-vitæ bushes. As it is found that the brass sleeves and the rivets in the sternport are apt to work slack, a more satisfactory arrangement is that in which the brass sleeve is replaced by a local increase in the diameter of the stock of, say, ¼ inch; one-half of the bearing is forged on to the sternpost and the other half is a bolted cover, while the bush is made of white metal instead of lignum-vitæ. The increase in diameter provides for the fact that the stock wears faster than the white metal, the bolted cover is portable, and experience has shown that the white metal wears as well as, or better than, lignum-vitæ and is not so liable to dislodgement. With this arrangement the rudder can be unshipped afloat if the bearings are made longer and only one middle bearing is fitted at or above the light load line. The weight of the rudder in this instance is carried by a collar on the stock, working in a cast iron bearing on the deck having white metal bearing surfaces. Where the rudder is hung from an upper collar a considerable "knocking" often occurs when the bearings work slack due to side play, but experience has shown that this objection is removed by paying attention to the size and arrangement of the heel bearing, and fitting an additional white metal bearing-ring under the bottom arm.

Fig. 11 illustrates what for convenience I have called the "Doxford" rudder, because it was first introduced by Messrs Doxford of Sunderland, although I understand the idea originated with Mr Pilcher of Liverpool. This is a single plate balanced rudder of simple design, the arms extend before as well as abaft the rudder stock, and each blade of the rudder is fitted as in the ordinary single plate rudder. The after post of the propeller frame is dispensed with, and as this is the chief objection urged against the design, it may be as well to consider it first. The rudder stock is made of such diameter that it is capable of withstanding all the stresses and shocks to which it is subjected, even with the bearings further apart than shown on the diagram, therefore the after post is not required as an aid to resist deflection, so that the chief remaining use of the post is to act as a stanchion in case of grounding. Apart from the fact that ships are not usually intended to take the ground, the shoe-piece is made so very strong in the Doxford design that it does not appear to be possible for an upward blow which would have the effect of bending it, not to bend the outer post of the common arrangement with its relatively light shoe-piece, and so jamb the bearings more effectually perhaps than with the wide-spaced bearings. A side blow might jamb both arrangements, but the chances would be in favour of the stronger shoe-piece, because the outer post adds but little to lateral strength. Even if the shoe-piece were broken, the rudder would not necessarily be rendered useless, because of the size of stock provided and the large bearing surface which would still remain. With regard to the propeller frame itself, it should be pointed out that the strength of the part below the boss can be made considerably in excess of present ordinary practice to the advantage of the ship, without adding to the total weight of the forging as compared with the ordinary frame. This type of propeller frame has been fitted in something like 35 vessels, ranging in size from 200 to 440 feet, and the record, so far, is unblemished by damage or defect. The "Doxford" rudder appears to be peculiarly adapted for use in twin-screw vessels, although I am not aware of it having been applied hitherto.

It will be observed that the upper bearing is similar to that described in the latter part of the explanation of Fig. 6, having a bolted cap, white metal bush, and a white metal bearing-ring under a collar on the stock. The bottom bearing is also fitted with a white metal bush and bearing-ring under the lowest rudder arm, but the end of the stock is turned with a slightly conical point, bearing on a hard steel washer in the bottom gudgeon, for the purpose of providing a large wearing surface without increasing the lift required when unshipping the rudder. The collar bolted on to the stock below the upper bearing is intended to prevent the rudder from lifting when at sea, an object attained with ordinary pintles by fitting one having a "head" under the gudgeon. In rudders of this design, it is sometimes necessary to make the lower stock somewhat larger than is required for the turning forces, in order to secure an ample margin for side deflection, but the diameter does not usually exceed that required for an unbalanced rudder of the smaller area usually fitted. The extension of the rudder plate above the coupling is a concession to prejudice, and is not always fitted.

Experience with single-plate rudders of all designs has shown that the most common trouble is the need for frequent renewal of the rivets at the outer ends of the rudder arms, as might be expected from the investigation into the effects of torsion previously illustrated. The trouble in question has been successfully overcome by maintaining the whole breadth of the rudder arm right to the outer end, and putting in two complete rows of rivets not more than 5 diameters pitch at that part.

Rudder stock couplings were first introduced to assist manufacture, and were afterwards found to be useful as simplifying the unshipping of rudders. The simplest and most effective coupling is probably that shown on Fig. 11 and adopted in the "Doxford" rudder, where the two posts are fitted and bolted together in exactly the same way as a shaft coupling. This form can only be used where the upper and lower stocks are in the same line, and may be objected to because the rudder cannot be unshipped without disturbing the steering gear, unless all the bearings are made with bolted covers.

Figs. 12 to 14 inclusive show most of the other forms of rudder coupling in common use. Fig. 12 shows the plain circular coupling as applied to the case where the upper and lower posts are on different centres. With the arrangement shown, the coupling flanges do not clear so as to permit of unshipping the rudder without disturbing the steering gear, but in the more recent couplings of this type the designers have succeeded in arranging the position of the flanges so as to clear each other when set at opposite angles.

The horizontal flat palm, Fig. 13, is arranged so as to allow the flanges to clear when uncoupled. The objection to this design is the distance from the centre of the upper stock to the centre of the nearest bolts, which permits a certain spring in the coupling and probably is the occasional cause of the coupling bolts working slack.

The patent coupling, Fig. 14, brought out by Mr Kincaid has been adopted with a large measure of success. Mechanically the design is better than the horizontal coupling where the posts are on different centres, as there is very little strain upon the bolts, but there is the relatively unimportant objection that if the coupling faces are perfectly fitted and tightly screwed up, it is difficult to disengage them when required. Exception is sometimes taken to the thwartship surface exposed to the water when fully laden.

The patent coupling, Fig. 15, was designed by Mr Wedgwood, of Dennystown Forge, and its use is rapidly on the increase. It possesses the advantage in the eyes of those who are inclined to place what they consider good appearance on a higher plane than that of mere utility, of carrying the curved form of the rudder up to the straight stock. Mechanically however, this may be an advantage, because it gives a gradual alteration in line of stress. The coupling in its essential principle is a bolted scarph, the check at the point of each scarph is square to the forging surfaces and not to the side of the stock, so that with a solid fit, there would be a considerable reduction in the strain upon the bolts. As the bolts are made sufficient for their work without the check, the practical advantage of the latter is a little doubtful, for besides being difficult to fit properly in the first instance, it increases the difficulty of disengaging the coupling. The Wedgwood design has the advantage that when the checks are raised clear, the two faces can be turned away from each other. As the locking plates require to be renewed each time a slight extra turn is put upon a nut, a box nut is now adopted instead, which has a locking pin $\frac{7}{8}$ of an inch in diameter screwed down through the cap of the nut into the centre of the bolt.

It will be observed that some of these couplings are shown with feathers and grooves but modern practice appears to tend in the direction of fitting large bolts and dispensing with the feather. The feather is usually made a close fit in the groove, pinned in place in the lower coupling and the upper coupling dropped down on top of it, a job which falls so far short of the standard of efficiency supplied by a driven key bearing hard throughout its whole length, that the feather should be regarded merely as an additional safeguard, the bolts being in any case made sufficient for the whole work upon the coupling. The fact that coupling bolts are often made with a head as well as a slight taper, is one of those things in daily practice which it is difficult to understand, if the bolt fits tight in the taper the head will probably not bear, and if the head is hard home on the flange it is unlikely that the bolt is a tight fit in the hole. A parallel bolt which is a driving fit would seem to be a better job. The nuts should always be efficiently locked, and if the bolts are fitted point downwards it is possible to turn the rudder even if the nuts should work off.

Before concluding a paper which, after all, merely opens up some parts of the subject for discussion and does not deal at all with such important matters as quadrants and steering machinery generally, I wish to take this opportunity for thanking Mr Archibald Denny and his scientific staff, as well as my own colleagues, for the assistance they have given me in its preparation.

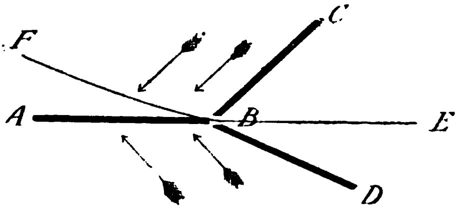
Discussion.

Mr James Hamilton (Member) thought there was room for very considerable controversial discussion in connection with the last part of the paper, that which dealt with couplings. He would like, however, to deal with the earlier part of the paper, which had reference to model experiments, and which seemed to him the most interesting part. As Mr Parker had been good enough to send him a proof, he had had the opportunity of perusing the paper for half an hour, and he thought he could agree with some of the conclusions which Mr King had come to,

Mr James Hamilton.

although not for the reasons that he had given. Taking, for instance, the reasons why a moderately fine or moderately full ship should be easily steered and easily handled, he thought that was quite easily understood if the angle that the water line made with the centre line of the vessel was considered. Mr Hamilton then illustrated, by a sketch on the blackboard, the reason why a moderately full vessel should be much more easily steered than one with fine lines or full lines. If A B represented the rudder amidships in, say, a twin-screw steamer, and C B D the form of the hull at half the draught of water, there would be balanced forces on each side of the rudder as indicated by the arrows, Fig. 16, which represented the water closing in round the stern. If the rudder were moved over to the line F B the force on one side would be reduced, and the pressure on the other side increased, thereby getting a double effect which did not obtain when the angle of the ship's run practically made no angle with the rudder when amidships and there was no force to reduce on the one side. In the case of a ship with full lines where an acute angle was formed by the rudder and run of the ship, it was his idea that she carried the same water forward with her, which water practically became part of the ship, and the water closing in around the stern simply glided past it, so that a greater rudder was required. In the case of a fine vessel, again, where the water lines at the upper part of the ship were practically as fine as those at the bottom, and made no angle with the

Fig. 16.



rudder, there was not the same double effect that was to be found in a moderately full form of vessel. What he had indicated also explained what Mr King brought out in his experiments, that by increasing the width of the rudder at the water line where the water lines formed the most acute angle with the rudder, the turning power was improved and the under portion was cut away which had not this double effect upon it. Thereby, per square foot of rudder, one gained enormously by increasing the top part. The only thing he could not understand about Mr King's statement was that in very fine vessels he began to gain again by the other form of rudder, or the triangular rudder with the broadest part at the bottom. He did not see the philosophy of that, and it rather led one to say that an angle of 10°—of course he (Mr Hamilton) had been speaking without reference to the author's experiments which were all made with rudders at an angle of 10°—was a very small angle compared with different angles of the water line that were being dealt with. The angle which the water line made with the centre line, in a full ship, was perhaps 40°, so that they had 10° + 40° in one case, and in another case of a fine ship they had 10° + 10°, or something like that, so that there was a very great difference· He failed to see the philosophy of it, and thought it was not very safe to generalise from experiments made at such a very small angle as 10°. Possibly, had the experiments been made at an angle of 30°, the results might have been slightly different. There were plenty of points in the paper open to considerable difference of opinion, and he hoped the discussion would be profitable.

Mr A. SCOTT YOUNGER, B.Sc. (Member) considered that one of the most distinctive features of this subject, to which Mr King had called attention, was the immense diversity that existed in practice in connection with the shape and area of rudders as fitted in different steamers. It would seem as if this fact indicated an absence of any sound theory on which to base design, and for that very reason he thought the Institution would welcome any discussion upon the subject, more especially as in this case it was enriched

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by the results of some experiments. He thought it was to be regretted, however, that Mr King had not given more particulars as to how these experiments were carried out, and the means taken to obtain the measurements as shown in the different results, more especially as his conclusions appeared to be, to a certain extent, in conflict with the opinion expressed by Sir William White, and also with the results of some experiments reported by him. In this connection it would have been of great interest had Mr King told exactly how the influence of the wake and the influence of the propeller were taken into account. The influence of the wake produced its greatest effect on the surface of the water where the lines of the ship were fullest, and would tend to produce an effect exactly the opposite to what Mr King had found to be the case, owing to the reduced velocity of the water past the rudder. It seemed to him as if this wake influence might be found sufficient to explain why Mr King's results had differed so widely from those he had referred to as being reported by Sir William White. The experiments must have been very extensive to enable Mr King to draw the conclusions he had, and it certainly would have conduced to clearness had he put them in some graphic form which would appeal to the eye, as well as to the mind, in reading them over. It was a very easy matter to suggest problems for solution in experimental work, and, of course, much more difficult to carry them out; but it seemed to him that a very simple experiment might be made which would lead to a satisfactory explanation regarding the conflict of evidence as to the pressure at the surface of the water and the pressure further down. It might be done, he fancied, by making model experiments with a very shallow rudder, the experiment to be made in the first instance with the rudder at the surface of the water, in the second case with the rudder lowered to mid draught, and again when lowered to the keel; in each case measuring the turning effect that the rudder produced. In that way a very clear appreciation might be got of the different pressures arising from the varying velocity of the wake. The paper contained a very interesting account of the evolution of the modern single-plate rudder now so generally fitted. The only point he wished to refer to in this connection was the absolute necessity for accurate and efficient work in building up those rudders, especially in shrinking on the arms, driving the keys well home, and, of course, riveting the plate to the arms. The coupling between the upper and the lower stock no doubt simplified the process of manufacture, but he did not know that it had much more to recommend it. He thought that perhaps too much was made of being able to disconnect the rudder. It very seldom required to be done, though, no doubt, when such a thing was wanted the advantage was there. He quite agreed with Mr King's opinion that the keys in the rudder coupling should be abolished; in fact, as usually fitted they were practically useless. The experience he had had with built rudders had not been altogether favourable. In one case the coupling bolts first came adrift and were secured at sea, later on the arms began to get slack as also did the riveting, and finally all three together produced such a state of affairs that the rudder had to be unshipped and entirely disconnected. The arms had to be bored out to fit a new stock, and to make a good job a new plate had to be fitted. He thought an experience like that supported what he had already said as to the necessity for accurate and careful work in building up these rudders. Referring to the different forms of coupling, his feeling in the matter was that the horizontal coupling between the upper and the lower stock was likely to give more satisfactory results than the vertical coupling, for the reason that the bolts were all in shear, and that to his mind was the most rational way to have the bolts fitted. In a vertical coupling, such as they saw on either Fig. 14 or 15, the fitted bolts were in tension and the turning of the rudder against pressure tended to open the joint, as it were, so that he should imagine that the vertical coupling would be more likely to give trouble in actual practice than the horizontal one. In Fig. 6 Mr King had given a very interesting diagram explaining

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the probable cause of the frequent trouble arising with the single-plate rudders, namely, the riveting coming adrift in the arms. He thought the diagram was extremely interesting, and one which explained very clearly what undoubtedly must take place when those rudders were put over to large angles. The effect was also partly attributable to the blows of the sea, and another possible cause was the bending of the arms due to the pressure of the water when the rudder was put over. Each of the arms being attached to its own portion of the plate would form a beam resisting the pressure of the water, and the bending moment induced would produce a very considerable shearing stress which would act almost exactly along the line of the rivets. He had no doubt that this cause, as well as that indicated by Mr King, partly explained the very considerable trouble that had been experienced with those rudders.

Mr John Reid (Member) considered that this subject was one which had not received from Societies such as theirs that attention which its importance demanded. As Mr Younger had remarked, there was a most extraordinary diversity of opinion regarding the form of rudders, which only pointed to the lack of an acknowledged standard or basis from which the form of rudder most suitable to any particular design could be arrived at. He remembered, when at Glasgow University, telling a fellow student that he thought the form which he gave to his rudders depended upon which of his pear-shaped curves came uppermost. His fellow student resented the inference, and perhaps he (Mr Reid) should not have made it, because he himself might plead guilty to having sometimes altered the form of a rudder to suit the exigencies of his drawing apparatus. There was no doubt that rudders should nowadays be carefully designed both with regard to their form and structural details. The whole matter resolved itself into a question of what should be the best form, what should be the area, and what should be the best construction, for any particular vessel, and Mr King had treated these points very carefully in the same order. In reference to what Mr Hamilton had said, he

Mr John Reid.

thought experiments made in a tank were somewhat different—that was to say, the conditions were somewhat different—from those in the case of an actual ship, and that therefore the deductions drawn should be very carefully considered. He thoroughly agreed that the point Mr Younger had mentioned about the wake had a very important part to play in the efficiency of rudders. It was a well-known fact that the stream lines which ran along the vessel's sides were entirely altered in their direction by the influence of the wake, and that the water driven by the propeller did not go astern in a series of straight lines, as some people thought, but took a very devious course which no one would be bold enough to trace. It was probable, therefore, that had Mr King been able to introduce the propeller race in his experiments, his remarks might have been modified to some extent. However, Mr King had arrived at results which were certainly a guide in several points in connection with the construction of rudders and the design of their form. He fairly agreed with him that the best form of rudder in almost every case was, as near as possible, the rectangular one. He did not think they could get a better one, taking into consideration the various features which a rudder should possess. Mr Lorentzen's experience and conclusions seemed somewhat peculiar. It was difficult to see on what principle he dubbed the rudder of his vessel a regular British one, unless it was another evidence of the hatred and disgust with which everything British seemed to inspire the foreigner. His explanation of why our ships are lost was distinctly novel, and might be brought before the Board of Trade as a solution to the difficulty of determining the causes for so many unexplained disasters. With regard to the areas of rudders, Mr King had mentioned 1 per cent. of the longitudinal area as being a fair figure. He thought that should be taken as the absolute minimum, and he believed Mr King meant it to be taken in that sense, but for Atlantic liners of large size and full form he thought that 1·5 per cent. of the longitudinal area was a very reasonable figure. He had considered a number of vessels of 400 feet length and upwards,

Mr John Reid.

and had analysed the size of the rudders on lines somewhat similar to those indicated by Mr King, and 1·5 per cent. seemed to be a very good approximation for that kind of rudder. Of course, it was quite impossible to lay down any formula to guide one in estimating the area of rudders for all cases. The steering of vessels in harbour, or while going up and down narrow rivers, necessitated a broad and square rudder, at the foot especially. Mr King had shown a kind of rudder which had been brought forward by Messrs Doxford, and, as Mr King had said, there seemed to be no reason why it should not be adopted, but he was afraid the conservatism of shipbuilders would prevent their departing from the usual form of stern frame with the back leg. That would stand in the way of the adoption of this type of rudder, but he might mention that he had had an opportunity some years ago of studying the construction of vessels on the great American lakes, and there the back leg of the stern frame had been abandoned and a rudder adopted which was a very close copy of the Doxford, and the results, he believed, were perfectly satisfactory. With reference to the structural details, he had followed with particular interest the process of evolution which Mr King had put before them of the modern single-plate rudder from the original double-plated form. He was rather surprised to notice that a rudder very similar to that shown in Fig. 8 had been adopted in a large Transatlantic liner which had just recently been completed; but there was no doubt that if the workmanship was good, the type of rudder shown in Fig. 8 was a very good one, and it did away with a great deal of resistance which would be found in a type similar to Figs. 9 and 10. Fig. 10 showed a rudder which, he believed, was one of the most satisfactory that could be adopted—at least in small vessels. The small number of bearings and pintles, the large surface and the symmetrical way in which the rudder was held, were features which distinguished it from the ordinary type where the stock was cranked out and the pintles were somewhat unsymmetrically held by the gudgeons. He thought it was a type which might be more usually adopted with satisfactory results. With regard to the question of small details, such as pintles, bearings, and so on, he might mention that a common method of bushing the bearings in several yards was to drop the rudder into place and then to run in white metal hot between the pintles and the gudgeons, turning the rudder slightly at the same time to prevent binding, the inside of the gudgeons having been scored by a cold chisel to prevent dislodgment of the white metal. He believed the results had been highly satisfactory. Mr Younger had mentioned that the coupling bolts should always be in sheer and not under tension as in some of the couplings illustrated. There seemed to be no doubt that that was the case, but it was interesting to point out that in Fig. 14 he believed the bolts were not in sheer. It was held, he believed, by the inventor that if the bolts were taken out the flanges of the coupling would not disengage on an attempt being made to turn the rudder from the stock. He did not know whether or not the contention was correct, but he merely mentioned it as of slight interest. A point had been raised by Mr King which he thought was an important one, and that was the questian of the slot, which had almost always been cut in the stock for the reception of the plate. The slot was a mistake; it was not necessary, because if the plate on the outer edge could stand up to its work without support there was no doubt that the plate on the inner edge could do so also. Further, the presence of such a slot running the whole length of the stock was a distinct source of danger, under the rapidly alternating torsional stresses to which rudder stocks were subjected. He had examined one or two rudders which had been destroyed, and although a clean transverse break right across the stock near an arm might have been expected, the stock had parted in a long scarphed fracture about the slot. There was absolutely no necessity that the slot should be there, but he believed it was always insisted upon. Mr King, in his paper, had spoken of ordinary forms of rudders, to the exclusion of the balanced forms, but had brought forward the Doxford balanced pattern as coming within the limits. He thought there was another form which they

Mr John Reid.

ought to have before them, one that might be called the Wortley rudder. This rudder, which was of an extraordinary type, had been fitted on a very great number of large up-to-date cargo vessels. He could scarcely describe it to the members without having a sketch to show them, but it was, roughly speaking, a copy on a large scale of the torpedo-boat destroyer rudders. It was a very revolutionary type, and he thought Mr Wortley ought to be congratulated on the satisfactory result following so great a step in advance. They were indebted to gentlemen like Mr Wortley, who had the courage to adopt so revolutionary a design and to thus promote the spirit of progress. It was very easy to follow the ordinary path which had been trodden before, but it was not very easy to follow the thorny and unfrequented path of novelty and innovation. On the question of balanced rudders, he might mention a rather curious experience which had happened to him quite recently in connection with the trials of a small vessel of abnormal beam. When the rudder, which was a balanced one, was put over to a comparativey large angle, the vessel steered very well, but it was difficult to get the rudder back; the steering gear seemed to get jambed somehow. Latterly, however, it turned out that the rudder was over-balanced, and the defect was remedied by cutting off a portion. He thought this was a somewhat unusual result, but, on consulting a friend, he was informed that it was the case with a very large number of rudders in British Admiralty ships. A great many of their fastest ships were fitted with balanced rudders, which would not return to the central position when released. That was to say, if the rudder in any way got loose from the steering engine, it would fly over against the stops instead of returning to the central position. It had occurred to him that the subject of rudders had not been dealt with very frequently, and if Mr King or any other member would write a paper on balanced rudders, then the subject might be said to have been treated thoroughly.

Mr Nicol MacNicoll (Member) said, in connection with the experiments which Mr King had made, he would like to give his

Mr Nicol MacNicoll.

experience with a full-size steamer, 200 feet long, which he docked about thirty years ago. When going astern she sometimes went to the one side and sometimes to the other, but when going ahead there was no trouble. When she was put into dock, the reason was quite apparent. She had her propeller abaft the rudder, with an elliptic bow on the rudder stock to let the propeller shaft through. This bow had got broken, and the lower part was entirely adrift from the upper part, the consequence being that in going astern she went over to the side on which the lower part of the rudder happened to be, and one could never tell to which side she would go. The point he would like to make clear was that the vessel steered beautifully with the upper part of the rudder, although it was only of the usual breadth, and seemed to be quite independent of the lower part. The rectangular rudders Mr King spoke of would be very ugly, and he did not think they should be introduced. "A thing of beauty is a joy for ever," and, if it was thought right to make the model of a vessel handsome: Why should the rudder not be so also?

The discussion on this paper was resumed on 18th March, 1902.

Mr R. T. Napier (Member) observed that the subject of the rudder would probably be discussed periodically so long as naval architecture was a science. Their fathers had thrashed out the subject nearly forty years ago, and the group of papers on the steering of ships, published in Vol. IV. of the "Trans., I.N.A.," could, with advantage, be read to-day. Among the group was a paper on "Balanced Rudders," a type probably better known then than now, both with respect to its virtues and faults. He did not see why the balanced rudder, shown in Fig. 11, need be honoured with the name of its designer, as it was open to anyone to make such. There was no novelty either in the shape or in the way that the weight was carried; and the arms appeared to be shrunk on the rudder stock in a manner familiar to all. In the case of the balanced rudder of H.M.S. "Hercules," designed in the sixties, special care was taken to prevent any of the weight

[illegible]

being carried in the bottom pintle; the experience that prompted this was figured in the diagram before them. He (Mr Napier) had fitted a few balanced rudders, both double plate and *single* plate, but not to large vessels, and had dispensed with the bottom pintle. He had only one case in his experience of a vessel *steering* badly and, as the coefficient of displacement in her case was ·82, the wake was without doubt accountable. Beyond the well-known condition in the designing of rudders that the breadth must be carried well to the bottom if the vessel had to take the [illegible] the mere shape had very little to do with the steering qualities.

Mr [illegible] (Member) remarked that the paper had raised a very large number of interesting points, and some of them he would like to refer to. At the bottom of the second page Mr *King* referred incidentally to the instability of wake, and he thought that was a very important item indeed. In nine cases out of *ten* where a ship was unsatisfactory from a steering point of view, he believed it was the instability of the wake that was the cause of [illegible]. Some years ago a good deal of discussion took place [illegible] one of His Majesty's ships, the [illegible] a reasonably straight direction [illegible], and after a day's running in [illegible] required three turns of port helm to keep [illegible]. This was unusually bad, and [illegible] were not made public he believed [illegible] entirely due to the instability of [illegible] made to run submarine vessels partly [illegible]. The wake would go to [illegible] in steering was experienced. [illegible] years ago, developed peculi- [illegible]. Similar defects had [illegible] at certain speeds, and [illegible] these defects in all these cases [illegible]. With regard to the experiments [illegible] in carrying them out, any account had been taken of the wave formed at the stern. If the wave crest happened to come at the stern it would not affect the immersed area of the triangular rudder which had its apex at the top, whereas it would make a very material difference to that with its apex at the bottom. Mr King had stated that the results were entirely opposed to those given by Sir William White in his "Manual of Naval Architecture." He did not think that the investigations given in that book threw any light on the subject at all, because it was the same old story of attempting to apply static methods to a problem that was not a static one. He did not think the expressions stated there were of any value; in fact, the author did not place much value on them, as he said "none of these rules can be regarded as entirely satisfactory." The question as to the form of the rudder above the water line did not ordinarily come in, but with the scarph of the Wedgwood form it was necessary to have a considerable area out of the water; otherwise a sufficiently large scarph could not be got, and those who had had to design rudders and scarves (particularly when getting them classified and accepted by the classification societies) knew that there was a big effort required to get up the required area. That was why the profile of the rudder had to be filled out at the top when it would certainly not otherwise be done. He thought that the diagram of the old form of rudder, Fig. 8, was a little unfair to that particular rudder. There, an arm was shown at each pintle, and when that particular form of rudder was fashionable an arm was not required to be put opposite every pintle, only about half that number was adopted, which was quite sufficient for strength. A rudder arm might then have been a little more than twice as heavy as the present arm, but it was fully five times as strong, and one arm was as good in one case as five in the other, so far as transmitting the turning moment from the plate was concerned. The old forging was lighter and cheaper per cwt.; the plating on it was also lighter, but it had the effect of occasionally making slack rivets at the after end. Mr King said that "steel bushes were sometimes fitted, but that was not an ideal arrangement."

Mr James R. Jack.

That was certainly so in clean water, but with vessels that had to work in sandy water he understood that the best results, so far as wear was concerned, were got with a hard steel pin and a hard steel bush, because with a soft pin or a soft bush the sand got embedded in it, and very soon ground away the harder metal. The question of the slot for the blade was rather a vexed one. The slot was required for keying on the arms, as well as a little clearance for getting the keys in, and with the close spacing of the arms there was very little of the stock left without a slot. It was a wrong thing to cut a deeper slot than was absolutely necessary. Mr King had struck a very good idea in suggesting that all the arms should be on one side of the rudder. The difficulty of drawing up a thick plate to the arm was one that every practical shipbuilder must be very painfully familiar with. There was an initial stress on the rivets that was undesirable. In the present type of rudder the arms were far too narrow in the throat. The breadth of the arms must be less than half the breadth of the stock, and so it was very small, whereas if the arm were made the full width of the stock and the blade fitted entirely on the one side a much stronger form would obtain, and it was simpler to make. To his mind the rudder plates were ridiculously too strong. In the original form of rudder the arms were about twice as far apart, and the plates were each about one-third of the present thickness, and there was no difficulty about buckling. If that was too much of a reduction to suggest, he thought, with all the arms on one side of the plate, the blade might be only half the present weight. It was not so much a mere question of weight of the structure as weight on the pintles and bearing surfaces. Another very useful suggestion was to get rid of the outer post in single-screw steamers. The rudder might support it, but the post was a very poor support for the rudder, and it would be better to put that metal into the rudder stock and get rid of the thin useless after post. The question of the rivets at the end of the arms giving trouble only developed with the modern arrangement of rudder, and he thought that it might be partly got over by cutting the arms a bit shorter. If the after end of the blade wanted to waggle about within limits, he did not see why it should be prevented, and if the arms were six inches shorter than the plate he did not think the rudder would be any worse. As to the comparative forms of coupling, every one had a theory of his own, but it seemed to him that a much more satisfactory forging could be made with the vertical coupling than with the coupling at right angles to the stock. With the horizontal coupling the mass of metal was so big that sometimes great difficulty was experienced in getting it into the furnace mouth, and when the bloom became heated it could only receive gentle taps under the hammer, whereas with a flange parallel to the rudder stock it lay close down on the anvil, and good blows could be administered to make thoroughly sound work. With respect to the question of bolts, Mr King thought a parallel bolt would seem to be a better job than a tapered one; he thought there was no question about that. A tapered bolt was not a nice thing to fit, and a parallel bolt was a much safer job. A good thing was to fit the bolts with the heads on the upper side in horizontal scarves. That was a simple point which was often overlooked, but if the nuts did slack back the pin would not fall out. These might seem trifles, but they were of great importance.

Mr **Foster King**, in reply, said that he felt in some measure disappointed that the paper had failed to elicit an expression of opinion from a larger number of marine superintendents and others directly interested in the repairing and making of rudders, and that the Institution had not received the benefit of their experience as it might have done had these gentlemen taken the opportunity of condemning or approving the various practical points which had been referred to in the paper. He could not but feel gratified, however, to find that, so far as the discussion of these questions had gone, although departures from practice were suggested, they seemed to meet with the approval of those gentlemen who had spoken. With regard to Mr James Hamilton's remarks upon the effect of the stream lines on the rudder, it was

Mr Foster King.

possible that Mr Hamilton had not caught his exact meaning, and he expressed regret if any lack of clearness on his part had led to a misunderstanding. Mr Hamilton seemed to think that it was stated in the paper that a full or fine vessel was difficult to steer as compared with a vessel of moderate lines. From an examination of the experimental results and the records of experience, it would be seen that, if any conclusion was arrived at, that conclusion was "the finer the model, the more effective the rudder." Mr Hamilton's idea that increase of effectiveness was due to the difference of the angle of the flow of the stream lines at the load lines as compared with the angle at the base appeared to be hardly sound in theory, because it assumed the stream flow to be horizontal, and experience, as well as experiment, supported the conclusion given, and, *per contra*, that full lines meant greater eddy-making and instability of wake, and less efficiency of rudder. The curious thing about the experiments was the apparent contradiction of results between those from fine-lined vessels and those from broad rudders acting at the lower water lines—that was at the fine lines—of a full vessel. If fineness of line was the whole measure of efficiency, then rudders of the shape shown on Fig. 5 should show, when fitted on full vessels, very much higher efficiency than those shaped as in Fig. 4, because of the lower part of the ship being much finer than the upper, but the experimental results showed, in most instances, the exact opposite. He might explain that originally those experiments were limited to what might be called ordinary boats of from .75 to ·77 coefficient, and the paper had originally been written to embody the results obtained and conclusions derived from those models—results which were absolutely uniform in showing a marked loss of efficiency in rudders with the broad part at the base. Advantage was taken of the postponement of the reading of the paper to make further experiments upon the effect of model upon efficiency of rudder, with the result that, it was found that on a very fine model Fig. 5 type rose to a somewhat higher level than Fig. 4 type; which led one to suppose that the diagonal movement of the stream line was most pronounced in full vessels and gradually dropped towards the horizontal in very fine vessels. Mr Hamilton took exception to the small angle at which the rudders were set, but it should be explained that this was done in order to deal with what one might call ordinary steering conditions. Rudders were not ordinarily turned through angles of 30°, nor could they be so, without considerable diminution of the vessel's speed. It seemed to him, therefore, that the small angle selected was of greater practical value than the large angle suggested. In reply to Mr Younger's request for more light in the form of diagrams, the author sketched roughly on the black board what were the general results of the experiments without going into detail. These experiments, as he thought had been made clear in the paper, could not be regarded to any extent as quantitative except when applied to sailing vessels. With regard to Mr Reid's remarks as to the area of the rudders fitted on vessels in the Atlantic trade, it was a little surprising that he should find a tendency in large vessels to increase the area as compared with those on small vessels, as he (Mr King) had found that the rudders were more often below the minimum of one per cent. in boats of large size than in the smaller vessels. Mr Reid suggested that the subject matter of the paper should have been made to include the Wortley rudder, but as Mr Wortley himself had read a paper dealing very exhaustively with that excellent rudder, and as it must be admitted to be an exceptional and expensive type, it might fairly be considered as outside the scope of the paper. Mr MacNicoll emphasized very strongly, if unintentionally, the efficiency of the upper part of the rudder blade in giving particulars of the full scale experiments with the rudder broken in two. Perhaps Mr Napier had placed the paper in its proper position, but, with all due deference to his criticism, he thought that the type of balanced rudder referred to was not thrashed out forty years ago, nor was it claimed in the paper that there was any novelty in a rudder being balanced, but a balanced rudder so simple in design as that brought out by Messrs Doxford must be regarded as something of a novelty even at the present

Mr Foster King.

time. With regard to the question Mr Jack raised concerning the crest of the following wave, he would say that it had been ignored, and as far as could be judged from watching the experiments in the tank, with most of the models the wave crest was above the rudder top. Mr Jack had suggested that one reason why the objectionable slot in the rudder stock should be retained was the necessity for cutting key-ways for the rudder arms, but it might be pointed out that with the modern rudder the centre ot the stock was in most cases abaft the centre of the pintles, so that it became doubtful if there was so much twisting action in the arm collar as to make the key an absolutely necessary addition to effective shrinking on.

In conclusion, the author desired to thank those gentlemen who had shown their interest in the paper by their remarks and criticism.

The PRESIDENT said before proceeding with the next business he thought they owed Mr Foster King a vote of thanks for the paper which he had brought before them. It evidently was the result of a very large number of experiments and very much thought. The subject seemed to be one on which there was room for very considerable difference of opinion, and they had had an expression of that opinion in the discussion, but he was sure they all felt that they were very much indebted to Mr King for bringing this subject before them, and he had very much pleasure, on behalf of the Institution, in proposing a very hearty vote of thanks to him.

The vote was accorded by acclamation.

Correspondence.

Mr J. BRUHN (Member) said more fads probably existed with regard to rudders than with regard to any other element in a ship except perhaps anchors or propellers. The Institution ought therefore to be thankful to Mr King for providing a few facts whereby such fads could be met and confirmed or condemned. It was, however, a pity that the experiments on the turning effect of rudders did apparently not extend to different speeds and different angles of helm. These elements might affect the results appreciably, and it would not be justifiable to assume that the results deduced

Mr J. Bruhn.

from a given speed and a given angle of helm would be applicable at other speeds and at other angles. If Mr King had any information on this point, it would be of great interest. He did not quite see the object in introducing the point Mr King termed the "efficiency point." The principle of assuming that the turning moments varied as the moments of the rudder area about an axis with a varying position seemed hardly right. It would have been interesting to see the curves from which these efficiency points were obtained. He supposed the curves were simply extended straight back until they reached the base line. In this way one might come to the conclusion that the vessel, if fine, might be steered with a rudder of no breadth, as Mr King said, or even of a negative breadth. This seemed rather irrational. But why bring in at all this receding efficiency point? Why not base all comparisons on the moments of the rudder area about the axis of the stock and make the required corrections where necessary? Did not the irregularity at the beginning of the curves simply indicate, that in fine vessels the fore part of the rudder was the most efficient part, and that in fuller vessels the area of maximum efficiency was further aft? He did not agree with Mr King as to the popular opinion being, that the lower portion of the rudder was the more efficient. He had found that the reverse was the case, and that for once that erratic quantity called popular opinion was right. In the case of the experiments with twin-screw forms of stern: Were the fins horizontal or perpendicular to the form of the hull of the vessel? Might not their guiding of the stream lines account for the increased efficiency of the rudders in those cases? Where Mr King came to calculate the stresses on the rudder, he stated that the part of the rudder area above the water had been omitted, as it was not usually taken into account in the calculation which decided the diameter of the rudder stock. It might be usual to omit this part, though it was not always done, and he did not think it was right to omit it. The assumption that the water line was the limit to the area of pressure might be all right in a student's exercise, but in the case of seagoing vessels

Mr J. Bruhn.

the pressure would often be greatest at the part supposed to be out of the water. Rudder stocks were not usually fractured when going full speed over the measured mile, but when the vessel was at sea and subjected to blows from waves striking the rudder, more in particular that part of the rudder which was above the load water line. The whole of the rudder area ought, therefore, to be included in any reasonably correct estimate of the diameter of the rudder stock. Besides the entire area of the rudder another factor, usually omitted, ought to enter into the proper determination of the scantlings of the rudder, viz., a constant representing the shocks from striking seas. If formulæ were to be used, they ought to be practically correct, more in particular when the correct method was just as simple, if not actually more so, than the wrong one. There were three quantities on which the size of the rudder stock ought to depend, viz.:—

The moment of the entire rudder area about the axis of the stock = M,
The speed of the vessel = S, and
The impact of the seas = P.

In a formula, P might conveniently be taken to represent speed, say an equivalent to the speed of the striking seas. Let C be a constant, then the formula for the diameter D of the rudder stock would be—

$$D = C\sqrt[3]{M\,(P + S)^2}$$

C and P must, of course, be determined by experience. If D were measured in inches, M in $(\text{feet})^3$, and S in knots, then C and P would be about ·13 and 20 respectively for seagoing vessels. The diameters of rudder stocks were usually less in vessels intended for service in smooth waters than in seagoing vessels, other things being equal. The above method admitted of this reduction being made on a proper principle, viz., by reducing the factor P in accordance with results found by experience, say to 10 for vessels intended for channel service, and to 0 for vessels intended for service in absolutely smooth waters. If the factor P were not included in the formula for the diameter of the rudder stock for seagoing vessels, then the resulting diameter would either be too small for the lesser speeds or too large for the greater speeds. The factor P ought to enter into the estimate of all the other parts of the rudder in the same way as the speed of the vessel did. In calculating the stresses on the main piece of the rudder, Mr King had taken a type which he called the present day rudder. That appellation was rather unfortunate, as very few rudders of that kind were now fitted, except in the very smallest of steamers, such as trawlers. It was not a convenient rudder. It could not be unshipped without disturbing the upper part, and without the gudgeons or bands being removed. These bands were also objectionable in themselves, as they necessitated weakening the stern post if fitted below the top of the propeller aperture, and if fitted above they provided a chance for leaky rivets. To this particular type, Mr King's calculations might be applied. But in the usual type there would be no twisting moments proper on the main piece below the top pintle. This pintle prevented a twisting moment being transferred from the stock to the part below; and here it would be a case of bending and shearing between the pintles. Placing all the stiffening arms on one side of the plate would necessitate an increase in their thickness to provide the same strength, otherwise there appeared no reason why this might not be done. In the case of balanced rudders the diameter of the stock ought to be considerably increased between the points of support to make up for the loss of the usual stern post. The usual diameter of the stock would only be sufficient for a very limited span between the supports.

Mr H. Hand (Member) considered that Mr King's paper deserved the attention of the Institution. Mr King had not only dealt with the theoretical part of the question, but also with the practical part, which made it of interest to all concerned in naval construction. He did not think the question of ugliness should be considered in the design of rudders, as all ugliness dis-

Mr H. Hand.

appeared to the person who knew the form adopted was the right one for doing its work. The defects mentioned by Mr King in the old form of rudder shown in Fig. 7, viz., slack rivets and wasting of the plating, occurred through the absence of wood filling between the plates Wood filling prevented the panting movement of the plating, which caused the rivets to become slack, and also the wasting of the plating through fatigue near the frame of the rudder where it was held rigid. He did not think the forged pintles in this style of rudder were a disadvantage, as the lifting of the rudder and the unshipping of steering gear for bushing enabled one to make a thorough examination of the pintles and steering gear, and brought to light any defect which otherwise might have been hidden from view. It was a very rare occurrence that one found a broken forged pintle, but it was not so with fitted ones; and when the broken fitted pintle was replaced, the new one, as a rule, lasted only a very short time. It was usually the pintle near the water line that gave the trouble, and this was probably due to the new pintle having been fitted while the vessel was afloat and not put in a line with the other pintles. Regarding the single plate rudder, the simplicity in forging and not detaining a vessel so long should she require a new rudder, was the only advantages it possessed, as far as he could see, over a well built rudder of the old style. The rudder blade of a single plate rudder was far easier buckled than the plated rudder, and the rivets in the arms required frequent renewal, as all the strain on the blade was brought on those rivets. The slot in the rudder stock was of very little use, as no matter how close the fit of the rudder plate was in the slot of the stock when built, after a few years, corrosion set in at the slot, and there was a perceptible space between the two. Mr King's suggestion to have the arms of the rudder on one side of the plate, and to increase the rivets in the arms was well worth considering, as no doubt better riveting would be obtained, although it was the general opinion that there would be a tendency for the rivet to draw when the strain on the blade was on the same side as the arms, but this defect would probably be found to be more imaginary than real. The horizontal coupling had given every satisfaction, and he saw no reason for so many patents. It was far less costly to unship the steering gear for the lifting of the rudder than to take adrift the coupling bolts; in fact, he had never yet seen the rudder uncoupled, unless for the renewal of part of the forging. Mr King stated that the balanced rudder shown in Fig. 11, had an unblemished record. It was very gratifying to hear this, but he was of opinion that this style of rudder brought an undue strain just above the arch of the stern frame where it was held rigid by the main bearing at the arch. The steering qualities in a rudder should be as perfect as possible, and the rudder built so as to be free from the small defects which had been mentioned in the paper. The main object should be to try and prevent any complete break down of the rudder and steering gear which would render the vessel unseaworthy. Accidents were so often connected with steam steering gear that it was in this direction that Naval Architects should give their attention, and if Mr King had introduced this subject it would have been a valuable addition to his paper.

Mr Bernard C. Laws (Member) remarked that there was apparently plenty of scope for discussion on this subject, when on reading through Mr King's paper one found such diversity of types and details of construction adopted; not only so, but in the first part of the paper Mr King seemed by his experiments to have deduced conclusions which were somewhat at variance with those generally accepted with respect to the action of the rudder and the forces acting on it. The value of the paper would undoubtedly have been enhanced had the author described the means which were adopted in carrying out the experiments. In the absence of these details it would seem that the results obtained could hardly be considered conclusive, for the reason that the models apparently were always constrained to move in a straight line, and consequently the efficiency of the rudder, which was measured by the turning movement of the vessel, could not be properly gauged except by means of a very delicate dynamometer, and then pro-

Mr Bernard C. Laws.

bably only approximately. Mr King, in his experiments, seemed to have taken little or no account of the effect of wake and propeller race on the action of the rudder; two factors which, undoubtedly, in steamships must exercise a very great influence. If all the streams moved with a velocity definite in direction and magnitude, there would be little difficulty in estimating the pressure on and the turning power of a rudder held at any given angle with the line of keel. The case of the sailing vessel presented the least difficulty, but with the screw or paddle steamer the problem required most careful consideration, as the action of the propeller race and wake at once upset ideas based on lines holding good for the former. In Mr King's experiments the models were towed at one speed and the rudders held at one—very small—angle of 10 degrees; had the experiments been carried out for progressive speeds and a progressive angle, the results would have been much more satisfactory. It was quite a common thing to find, when the rudder was allowed to hang free, that it would take up a position of rest out of the line of keel when the vessel was steaming ahead, and it would seem that the effective angle should be measured from this position, and not from the line of keel. The results recorded by Mr King in his comparative experiments on rectangular and triangular rudders appeared to be hardly in accord. He stated that while there was a gain of efficiency over the rectangular rudder, in the case of the triangular with the broad part at the water line, there was less efficiency with full models with the broad part of the triangular rudder at the bottom, and an equality of efficiency of all three types with models of ·6 coefficient and of finer models. In the case of the rectangular rudder bisected at mid draught, Mr King appeared to have obtained a higher efficiency value for the lower half in fine models, and equal efficiency for the two halves with full models. On the whole, this would seem to show that the rudder broad at the heel was the more efficient, and to confirm, rather than otherwise, the experiments already carried out and recorded by Sir William White. The variety of method in construction of rudder frames and couplings given by Mr King, indicated somewhat the difference of opinion held by different builders as to the relative efficiency of the various types. The horizontal coupling, with a feather and groove, was perhaps one of the best when care was taken to secure a good fit. Not only did the feather help to take the strain off the bolts, but the latter were in shear and apparently better able to take the strains put upon them. It was a truism in mechanics that two plane surfaces in contact were only properly so at three points, and so for a similar reason it would seem unnecessary for rudders to have more than three pintles, as there was considerable practical difficulty of fitting them in a line. In rudders of the form shown in Fig. 11 and in balanced rudders generally, this difficulty was obviated, and they seemed to give very good results from the standpoint of efficiency. It was unfortunate that Mr King did not extend his paper, already very interesting into the consideration of balanced rudders, more especially as this type was so widely adopted in war vessels. The author might, however, favour the Institution at a later date with a futher paper on this subject, as a supplement to the one he had already given.

Mr Foster King, in reply said, with reference to Mr Bruhn's suggestion that the experiments should have been extended so as to include different angles and different speeds, there was no doubt of the room for the extension of such work, but the time and labour involved in obtaining the results given in the paper, and the generosity on the part of Messrs Denny which they represented, were so great that further demands could not have been made upon the firm without serious interference with their business. It had, however, been determined both by experiment and theory that the steering effect of the rudder blade varied pretty closely as the sine of the angle and the square of the speed, so that until the more extensive and so desirable series of experiments could be made, it might be safe to assume that the pressures would vary in those ratios. Mr Bruhn's remarks about the efficiency point seemed to show that the intended

Mr Foster King.

meaning had not been made clear. The experiments were made with a series of rudder blades of the three different shapes shown in Figs. 3, 4, and 5, the narrowest rudder in each series having a breadth not much greater than the diameter of the stock. It was found, for instance, that on a certain full model the narrowest rectangular rudder used had no steering effect, and that the pressures upon the rectangular rudders of greater breadth varied directly as their breadth minus the breadth of the narrowest rectangular rudder Obviously, therefore, that particular part of the blade on that particular model was inefficient, and as efficiency varied directly as the breadth abaft the inefficient part, the introduction of the "efficiency point" was thus suggested. This explanation, it was hoped, would make it clear that the turning moments were not assumed about varying positions, but the experiments showed that as models became fuller a large proportion of the fore part of the blade became inefficient, results which, as mentioned in the paper, were supported by experience. The fact that when the rudders were placed upon a very fine model, the results varied as the breadth of the rudder, plus a very small quantity, was explained in the paper as being probably due to the thickness of the leading edge of the blade having an effect upon steering. Mr Bruhn's suggestion that in fine vessels the fore part of the rudder was the most efficient part, and that in full vessels the area of maximum efficiency was further aft, induced an emphasis upon the fact that the experiments seemed to prove conclusively that there was no such more efficient part of the effective surface. The chief object of making the experiments was to ascertain if any part of a rudder blade was more efficient than another, and it was found with every series and on every model that from the moment the efficiency point was reached, for instance, whenever the rudder was of a breadth sufficient to steer at all, the steering value of the blade varied directly as its effective breadth, thus proving, so far as experiments could be held to prove anything, that there was no special virtue in any particular part of the effective blade, other than that due to its geometrical position. In other

Mr Foster King.

words the present practice of estimating the turning moment of a rudder as acting through the centre of gravity of the area of the blade was correct, where the whole blade was effective. In answer to Mr Bruhn's question, it should be said that the arms of the spectacle frame at the after end of the bossing of the twin screw dropped in the ordinary way. The point to be emphasized, however, was not increased efficiency of rudder, but increased efficiency in the rudder with the broad part at the water line and further loss of efficiency in the opposite form, as compared with trials on the same model without the bossing. Mr Bruhn's remarks about the "above water" part of the blade would seem to support strongly the opinion, which was put forward in the paper, that there should be no such part on the blade. His suggestion that the formula for estimating the diameter for rudder stocks should include a constant which would represent shocks from the sea was valuable, if it were practicable to place a quantitative value upon this problem in dynamics. A rudder would be more liable to sustain shocks from the sea when the vessel was flying light than when running full, but there would not be the full twisting moment on the stock from the act of steering, because the speed of the vessel would be reduced in bad weather, and the blade was not fully immersed, so that the proposed variation of the constant for shocks, in terms of the fully immersed area and the square of the full speed of the vessel, would not be quite sound. There did not seem to be sufficient warrant from experience to depart from the ordinary constructive practice of basing sizes upon conditions to which a quantitative value could be given, and providing a sufficient factor of safety to cover the forces which could not be calculated. It should be explained, in reply to Mr Bruhn's criticism of the rudder shown in Fig. 6, that the term "present day rudder" was meant to apply to the type having a circular stock and a single plate, and that the continuous stock was selected for simplicity in indicating the nature of the movement which took place in all rudder blades and stocks. With upper and lower stocks on different centres it was true that the forces and

Mr Foster King.

results would differ from those shown, but there must always be a tendency towards an actual movement of the outer edge of the rudder blade. It was not quite easy to see Mr Bruhn's reason for considering that the placing of the arms on one side of the plate would increase the bending moment upon the arms themselves, as the segment of plate which each had to support remained unaltered, but it was satisfactory to note the support which he and others had given to the somewhat important departure from practice which had been suggested. Mr Bruhn pointed out the necessity for increasing the diameter of the stock where the after post was dispensed with, but in those which had come under the notice of the author this increase had not been of any serious moment. Mr Hand, in his remarks, attributed the defects which developed in double plate rudders to the absence of wood filling, and there was no doubt that wood packing stiffened the plate, but it could not cure the liability of the caulking to spring, a liability which arose from the wide pitch of the rivets and the movement of the rudder blade. Mr Hand, in his remarks, gave the Institution the benefit of a very extensive practical experience, and his references to forged *versus* fitted pintles were the more interesting on that account, as apparently supporting a retrogressive step, but: Were not the defects mentioned as having been found in fitted pintles, due to imperfect workmanship in the first instance? Imperfections which should not exist so far as alignment was concerned. In reply to Mr Laws, it should perhaps have been stated in the paper, instead of allowing it to be understood, that in making such tank experiments as those described, it was only possible to measure the pressure upon the rudder by means of a dynamometer while the model was in process of being towed. The results were comparative of the turning power of the different rudders, as expressed by the differences in the recorded pressures. The turning *effect* upon different models of any particular rudder was an entirely different and extremely difficult problem. The effect of wake was shown to some extent by the phenomenon of the position of the efficiency point, and, as had already been stated, the experiments

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could only have a direct bearing upon sailing vessels, while experience seemed to show that the propeller considerably increased the rudder efficiency although it created a new wake disturbance. On examining the results of the experiments it would be seen that only in the very fine models was the lower part of the rudder slightly better than the upper part, in reality the difference was so small that it might be called practical equality; but in the fuller, that was the ordinary every day models, the rudder with the broad part below showed a loss of efficiency, as compared with those having the broad part at the water line, of from 22 to 30 per cent.

PRODUCER GAS AND ITS USE IN ENGINEERING AND SHIPBUILDING.

By Mr F. J. Rowan (Member).

(SEE PLATES XVI., XVII., XVIII., XIX., XX. AND XXI.)

Read 18th February, 1902.

Producer gas is the generic name for the product of what may be called the comparatively slow resolution of solid fuel by means of heat, in apparatus of a variety of designs. As distinguished from the ordinary system of gas making practised in gas works, where the heat, applied to the exterior of the retorts for the distillation of the coal contained in them, is obtained from coke or other fuel distinct from the charge of coal which is being distilled (although the coke may be the product of coal previously distilled); in the producer system the heat is obtained in the interior of the producer, by the combustion there of the solid portion of the charge of fuel which is being gasified.

It has become so much the fashion to affix the name of the inventor or designer of the form of producer used to the product of that apparatus—and thus to speak of "Siemen's gas," "Dowson gas," "Mond gas," and so on, that ordinary people may be excused for not recognising the fact that the "gas" is virtually the same in all these instances, as the process employed is to all intents identical in all kinds of apparatus employing internal combustion for the production of combustible gas. There are such differences in detail as the employment of coke or anthracite in some cases, of bituminous coal in others, of the use of a smaller or larger amount of steam along with the air required for combustion in the producer (resulting in a greater or less percentage of hydrogen in the gas, and in the preservation of the ammonia formed from the nitrogen of the coal), as well as differences in the form, size, and arrangement of different producers, but none of these affects the principle upon which the production of gas is based, or the main features of the process as a whole. It will thus be seen that an erroneous idea is conveyed by the adoption of distinguishing names, and that, instead of there being so many inventors or "discoverers" of new kinds of gas, there are only inventors of different forms of apparatus, the object of all of which is the preparation of practically the same kind of gas. As to which form of apparatus is the best, there are, of course, different opinions, but practice and experience have demonstrated some well-defined conditions to which a "producer" must conform in order to be a really good one. These we may consider subsequently.

In order to understand the *raison d'être* of the gas producer or the fundamental principle underlying the advantages of employing this method of treating fuel, we have to consider the formation and use of *flame*, and the various chemical reactions which together constitute what is called *combustion*. The production of flame may or may not accompany combustion, for the chemist knows several actions which can be truly termed combustion, in which there is no flame formed. The use of electricity, moreover, furnishes us with an illustration of "incandescence" or glowing, in which there is neither flame nor combustion.

In all industrial heating operations, however, except a very few, the existence of flame is imperative, and, without entering minutely into the physics of the subject, we may accept the definition that ordinary flame is gas or vapour of which the surface is burning with the emission of light. The "burning" is the result of combustion between the gas and an atmosphere, which is usually atmospheric air, in contact with the surface aforesaid. The problem in all these heating operations, to which we have referred, is how to obtain a continuous supply of flame of the requisite quality and of the desired temperature, and this, therefore, leads to the obvious conclusion that for effective heating we must obtain a supply of combustible gas. This has already been pithily said by the President in his address, and it is really what is attempted even with direct coal-firing, although many people do not realize that there is any intermediate condition between that of the solid coal which enters and that of the flame which issues from a fire, any more than they do so in the case of a candle or of an oil lamp. It is a fact, nevertheless, that the first step in the utilization of coal for heating, as in that of a candle or of oil for lighting, is the transformation of the solid or liquid into the gaseous form. In an open domestic fire we can see the gradual resolution of the solid fuel into the gaseous form, and can obtain some evidence of the fact that the burning of coal is a heat-absorbing as well as a heat-yielding operation. It does not matter whether the coal is burned on a grate or in a producer, the fact remains that heat is absorbed in the decomposition of the complex hydrocarbons which constitute the mineral and in the change of physical state from the solid to the gaseous. In the domestic fire the gases thus formed are burned directly on the surface of the fire, but in the producer (which is practically a fire with the upper part enclosed and screened from access of the air required for the combustion of these gases) the gases are led off to yield their sensible and latent heat elsewhere. There is one feature of the heating effect of an open fire which is absent from heating by means of the gas producer, and that is the mass of glowing coke which usually constitutes the under layer of the fire. By some people great stress is laid on the radiating effect of this incandescent mass, but that effect is much over-estimated, because it can only be intermittent, on account of the operation of adding fresh charges of fuel, and it is only in such furnaces as those of boilers that the radiating effect can be utilized for heating anything beyond the fuel, as in other furnaces the fuel occupies a distinct compartment. The radiant effects produced in the body of these other furnaces are due to the flame, and these are much more complete and far-reaching than any that are due to the incandescent coke.

In considering the use of producer gas, it is sometimes urged against it that some of the heat of the fuel must be lost in the process of gasification, and that there will therefore be no economy in employing it. This objection is founded upon an incomplete view of the facts of combustion, as is also the practice of estimating the heat value of a solid fuel by assuming all its carbon to be capable of yielding the full theoretic thermal value of pure carbon burned to carbon dioxide. That is a false assumption, because, in burning solid fuel, part of the heat of combustion is absorbed in transforming the solid into gaseous matter, part in evaporating the moisture originally held in the fuel, and part in dilating and heating the waste gases, so that the theoretical heat of combustion is not the available heat. In burning producer gas, we are wholly freed from two of these sources of loss, and have a much less amount of the third.

Taking the following as a fair specimen of Lanarkshire splint coal, the analysis of which is given by Sir I. Lowthian Bell,* the heat values are as shown:—

	Per Cent.
Water given off at 212° F., - - - - -	11·62
Carbon (fixed 53·41, volatile 12·59), - -	66·00
Hydrogen (available H = 2·96), - - -	4·34
Oxygen, - - - - - - - -	11·09
Nitrogen, - - - - - - - -	0·94
Sulphur, - - - - - - - -	0·59
Ash, - - - - - - - - -	5·42
	100·00

If burned in an open grate, the theoretical heat yield would be:—

	Calories G. C. Units.
Carbon (fixed), - - -	53·41 × 8000 = 427,280
Hydrocarbons (C. volatile 12·59, available H. 2·96), -	15·55 × 12,000 = 186,600
Total, - - - - - -	613,880

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* The Principles of the Manufacture of Iron and Steel. London, 1884, p. 612.

To arrive at the available heat we must deduct the heat required for

		Calories.
Evaporation of water in coal, -	11·62 × 622 =	7,227
Expelling gaseous matters in coal, - -	=	57,920
Total, - - - - -		65,147

Then 613,880 − 65,147 = 548,733 Calories. (1)

If this coal were turned into producer gas, with only air blast, and the gas were burned cold, then the heat value would be:—

		Calories.
Carbon, - -	53·41 = CO 124·62 × 2400 =	299,088
Hydrocarbons (same as above),	15·55 × 12,000 =	186,600
Hydrogen derived from moisture in blast, - - -	0·288 × 28,600 =	8,236
Total heating value, - - - -		493,924 (2)

The difference between these two numbers, viz., 548,733 and 493,924 = 54,800, represents only 9·98 per cent. of the heating value of the coal. Most of this difference would, however, disappear if a steam jet blast were used and the sensible heat of the producer gas were taken into account. It is to be remarked, too, that the figure given above for the volatilisation of the solid matter of the coal is probably too low, as it does not allow for the gasification of the fixed carbon, but only for the hydrocarbons existing in the coal. The heat lost in waste gases is excluded in both cases.

Some years ago it was shown by Mr D. Clerk (in the discussion of a paper on Gas Producers, read by the writer to the Institution of Civil Engineers*) that with pure carbon in a producer and air alone, without steam, a perfect producer would give a mixture of CO and N, in the proportions of 1 volume of CO and 2 volumes of N. The gases would leave at a high temperature, and if cooled before use would yield in burning only 70 per cent. of the

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* Min. Proc. Inst. C. E., Vol. lxxxiv. pp. 2–79.

theoretical value of the original carbon. This apparent loss in gasifying, therefore, should be avoided in either of two ways:—"(1) By retaining the heat in the gas formed; (2) by abstracting heat from the gas formed in such a manner that it might be rendered available in a chemical reaction to give more inflammable gas." This latter can be accomplished by the use of steam. "Mixing steam and, in the proper proportions, air supposed to have given to it by regeneration all the heat of the issuing gases, and supposing no loss by conduction, then, pure carbon would yield a gas of the following composition:—

$$\begin{aligned} CO &= 38{\cdot}7 \\ H &= 16{\cdot}4 \\ N &= 44{\cdot}9 \\ \hline & \quad 100{\cdot}0 \end{aligned}$$

"This gas (Mr Clerk stated) would, on burning, give the same amount of heat as the direct burning of the original carbon; it was the best gas capable of production from air, steam, and carbon, and might be used as a standard of efficiency for producers."

It has been since then pointed out that the higher the proportion of fixed carbon to volatile matters in coal, the greater will be the loss in gasification, so that, whilst anthracite is the most expensive fuel to use, if carbonaceous shales (which are at the opposite point as regards composition) are mixed with ordinary coal in a producer, the gas making process may become theoretically perfect as far as the heat equation is concerned.

The quantity of steam used in the ordinary steam-jet blast (where ammonia is not recovered from the coal) is very small. In a good blower, 1 lb. of steam suffices to force into the producer 20 lbs. of air, and as less air is wanted in the producer than the quantity usually required for complete combustion of the carbon to CO_2, it is probable that about ½ lb. of steam per 1 lb. of coal is the average quantity required in working producers.

GAS PRODUCERS.

Turning now to gas producers, since their introduction by Bischof in 1839, and Ebelmen in 1840, they have been used in a variety of forms, for the history of which I must refer to my papers in "Min. Proc. Inst., C.E.," Vol. LXXXIV., in "Fuel and its Applications;" Vol. I. of "Groves' & Thorp's Chemical Technology;" and in the "Iron and Coal Trades' Review," of January to May, 1901. One form was described by me to this Institution in 1881 (see "Transactions," Vol. XXIV., p. 177), and papers dealing with other individual producers are scattered far and wide. Great advance has been made since the date of the paper referred to, so that what was then considered a good producer is perfectly impossible now. A good producer nowadays must be capable of being cleaned without in any way interfering with the continuous production of gas and without permitting the refuse to carry any heat or combustible matter to waste outside the producer. Hence the days of the open grate producer, like that of Siemens, and of the closed hearth, like that of Wilson, are numbered, as such types are obsolete and are rapidly being, or have been, abandoned for producers with water bottoms. These I purpose dividing into two classes, the distinguishing feature being a most important one, and even vital to efficient and economical working. These classes are—(1) Those producers which send the blast amongst the fuel in a lateral or radial direction, and (2) Those which do so vertically. Of course, the air, or air and steam, must ultimately in all producers ascend, in order to reach the gas outlet, but the primary direction given to it on entering the producer is the important point to which I desire to direct attention —

1. When the blast enters the producer at either the centre or the sides, and is distributed laterally before it can ascend, the centre of the mass of the fuel is not in the direct path of the air, and the most vigorous combustion does not take place there, but is carried towards the walls. The effect of this is to make the walls too hot, favouring loss of heat by radiation, overheating and

softening the brick lining with consequent formation of refractory clinkers, and often (more especially where the blast enters the producer by tuyeres or passages in the side walls) allowing uncombined air to escape upwards along the walls and ignite the combustible gases in the upper portion of the producer. This latter effect may be detected by the percentage of CO_2 in the producer gases. The percentage of unburnt cinder coke or coal in the refuse is another proof of imperfect combustion in such producers. For examples of this class of producers, I refer to the producers of Wilson with water bottom, Dawson, Mond, and others, Figs. 1, 2, 3, and 4. Of these, in the first-named, the blast is blown horizontally towards two opposite sides from the central tuyere or channel placed nearly across the centre of the bottom; in the second, the blast is distributed radially from a circular pipe or tuyere standing vertically at the centre of the bottom, and having a cowl or cone-shaped cover over its end; and in the third, the blast is admitted at the sides from the outside casing or belt. These illustrate varieties in the methods of constructing and working such producers, but there are many modifications.

2. Of the second class referred to above, the only example with which I am acquainted is that of the Duff producer. No other producer has been as yet introduced which combines with a water bottom the means of delivering the air vertically in the very centre of the mass of the fuel, and yet of distributing it evenly throughout the whole mass. This power it owes to its ingenious "grate" or sloping grid which is placed right across the centre of the producer at the bottom, presenting no obstruction to the passage of the air directly upwards through the centre of the fuel and, on account of the angle of the grate, distributing the air over the main surface of the section of the producer, Figs. 5—8. As showing the wide difference between the proportions of the different producers, Mr Duff stated, in the discussion of a paper by Mr Wilson at the West of Scotland Iron and Steel Institute,* that the blowing area in the Duff producer grate

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* Jour. of the West of Scotland Iron and Steel Inst., Vol. viii. p. 168.

was 1720 square inches as against 160 square inches in the tuyere of the Wilson producer of a similar capacity. Such proportions could not fail to exert a marked influence on the completeness of the combustion of the fuel, especially when combined with the excellence of the Duff system of air distribution, and it may be confidently asserted that no one has seen the perfectly burned ash, with a minimum of hard clinker, which issues from the Duff producer, equalled in the working of any other. The quality of the refuse is an unfailing test of efficient working, and one to which attention cannot be too strongly directed.

As to what is the proper basis for the estimation of the efficiency of gas producers, opinions differ. Mr C. F. Jenkin* defined the efficiency as the ratio of the heat contained in the gas as it leaves the producer to that contained in the coal from which the gas was made, but, in order to obtain this ratio, continuous analyses of the gas and observations of its temperature are required, and these are seldom available. Moreover, "the heat contained in the coal" seems to be not so fair a basis of comparison as "the available heat" obtained from the coal.

Mr H. A. Humphrey, in replying to the discussion of his paper, on "Power Gas and Large Gas Engines,"† pointed out that the term "efficiency" might be used to express a variety of different ratios, or that the ratio between the original fuel and the producer gas might be estimated in either of several different ways. None of these seems any clearer than the one proposed by Mr Dugald Clerk, to which I have already referred, which has the convenience of giving a standard with which analyses of producer gases may be readily compared.

Dealing with the table of about fifty analyses of the gases yielded by different producers which was added to my paper on gas producers in 1886,‡ Mr Clerk stated that none of them showed an efficiency of 80 per cent. on his basis, although some closely

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* Min. Proc. Inst. C. E., Vol. cxxiii.

† Proc. Inst. Mech. Engineers, 1901, p. 244.

‡ Min. Proc. Inst. C. E., Vol. lxxxiv.

approached that figure, but that 80 per cent. was a high efficiency. Now, taking the following analysis of gas from Duff producers, we see that on Mr Clerk's basis it shows an efficiency of almost 81 per cent. :—

CO	H	CH_4, etc.	CO_2	N
26·8	13·4	4·4	4·0	51·4

This is not a picked analysis, but is stated to be the average of daily analyses ranging over a period of several weeks. The quality of coal used in the producers is, however, not stated.

FURNACES.

In presence of an abundance of cheap coal, people seldom stop to consider how wasteful a machine a coal-fired furnace is. They argue that it has a comparatively low first cost and a comparatively simple construction, and if penalties for smoke nuisance can be avoided, it will do very well. It is the fact, however, that about $\frac{19}{20}$ths of the theoretical heating power of the coal are wasted in such furnaces when applied to welding, reheating, or forging, and a much greater proportion, or about $\frac{69}{70}$ths where higher heats, such as for steel-melting, are required. Besides going far to prevent this great loss of heat, gas-fired furnaces present another element of saving to the user of them, and that is found in the fact that a much cheaper grade or quality of coal may be used in a gas producer for firing furnaces than could possibly be used in direct coal-firing. In considering the furnaces which are specially useful in engineering and shipbuilding we find there are—(1) Furnaces for steel and iron making; (2) furnaces for metal heating; (3) furnaces for subsidiary heating operations; (4) furnaces for steam-raising and evaporating; (5) brick kilns; (6) furnaces for heating retorts in gas-works and the like.

(1) This section comprises open-hearth and crucible steel-melting furnaces, furnaces for puddling iron, and those used for welding iron, such as for making rolled bars and plates, forgings, and tubes. It is in connection with the high temperatures required in these operations that producer gas has won its greatest triumphs, the reversing

regenerator furnaces, without which they could not be economically obtained, being almost impracticable with solid fuel.

Figs. 9—12 illustrate steel melting furnaces, such as are well known in this district, and Figs. 13 and 14 a welding furnace such as is used for rolling mill work or for forging. At the works of the Lanarkshire Steel Co., steel melting furnaces are worked by gas from a number of Duff producers which have been in operation for five years without costing anything for repairs. At these works there is also a range of producers equipped with a complete elevating and conveying plant for handling the coal which is stored in large hoppers over the producer charging hoppers. Illustrations of this installation appeared in *The Engineer* of 15th November, 1901 (page 507). Figs. 15 and 16 show the general arrangement of Duff producers and steel melting furnaces in a large works in America, and Fig. 17, with Figs. 7 and 8, illustrates a large gas producing unit, viz., a producer gasifying a ton per hour, which is finding favour in some steel works. In the installation shown the coal is dealt with by means of the minimum of labour. In this district Messrs Neilson, Reid & Co. have some examples of comparatively small forge furnaces fired by Duff producers in successful operation. Tube welding by gas furnaces is also in operation in the district. At Barrow-in-Furness Messrs Vickers, Sons & Maxim, Limited, have open-hearth furnaces with air regenerators, for melting bronze, gun metal, etc., a practice which might be followed with advantage.

(2) Reheating furnaces for steel and iron, plate and angle bar furnaces, furnaces for rivet and bolt making, and for weldless chain making, do not require so high a temperature, and consequently may have either modified reversing regenerators or continuous regeneration of the air, or both air and gas. In this connection the "Weardale" form of furnace, with continuous regeneration of air, is doing excellent work. It is of a simple construction, requiring less space than some other types of furnace, and no underground chambers for regenerators. This is

of much importance in situations where drainage is bad, or the ground is waterlogged, as in many shipbuilding yards. Naturally repairs are less than in reversing regenerator furnaces, and there are no reversing valves to give trouble. Another point in the design of this furnace is that it lends itself to combination with steam boilers fired by waste heat from the furnaces—a combination which is specially useful where ground space is restricted. Figs. 18—21 show this furnace adapted for mill work, Figs. 22 and 23 for plate heating, and Figs. 24 and 25 for angle bar heating, such as are used in boilermaking and shipbuilding. In reheating steel slabs for rolling, this furnace has been found to work with from 1¾ to 2¼ cwts. of coal per ton heated, and about 1½ per cent. waste.* Iron piles of about 100 lbs. weight have been heated in this furnace in 40 minutes, with an expenditure of from 3 to 3½ cwts. of coal per ton—the waste of iron being about 10 per cent.

For heating plates, bars, etc., this furnace has been most successful. A furnace 30 feet long by 2 feet wide, at Strathern's Weldless Chain Works, Gartsherrie, heats bars of cruciform section 45 feet long, weighing each 1½ cwts., from cold to white heat in from 4 to 5 minutes. The bars are drawn through the furnace at the rate of from 7 to 8 feet per minute, and any portion of the bar left outside the furnace becomes quite hot enough for the chain pressing machine by the time it arrives at the furnace door.

A "Weardale" furnace in use at the Boiler Works of Messrs Cochrane & Co., Ltd., Annan, for heating large plates for flanging and dishing, has worked steadily for nearly three years almost without repair—the heating of plates of considerable size taking ten minutes, which used to require twenty to thirty with coal furnaces.

The plate furnace at Messrs Cochrane & Co.'s measures inside 11 feet square × 4 feet high at the crown. Its consumption of coal is from 30 to 40 cwts. of nuts per day of 9½ hours, which is little more than half the consumption in economical coal-fired plate furnaces. The repairs required have consisted only in the renewal of a few

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* "Jour. Iron and Steel Inst.," Vol. No. 1, 1897.

bricks in the furnace hearth, damaged by dragging in and out the heavy plates.

Furnaces on this plan have been put down, in the Shipbuilding Works of Messrs Workman, Clark & Co., Belfast, and Messrs Macmillan & Son, Ltd., Dumbarton, for plate heating and angle bar heating, see Figs. 22—25.

An instance of an economical heating furnace with reversing regenerators has been given me by Mr N. K. Turnbull, of Messrs Richard Johnson & Nephew, Manchester. This is a furnace 28 feet long by 12 feet wide, with gas and air ports alternating along the length of the furnace on both sides. It heats 50 tons per shift of 2-inch square billets 26 feet long, with a coal consumption of 3 cwts. per ton, the billets being drawn out of the furnace and rolled into wire.

The testimony of Mr S. W. Johnson, locomotive engineer of the Midland Railway, as to the advantages of heating plates, angles, tyres, etc., by gas, is that, apart from economy of fuel, the indirect advantages of using gas are very marked, as there is less chance of irregular heating or overheating, and the necessity for carrying coal to the furnaces is dispensed with. At Glengarnock, there are gas-fired vertical ingot heating furnaces which Mr Edgar Richards informs me are charged with ingots direct from the casting pit and heated up to the degree at which they can be rolled direct into any steel section, or into 2-inch square billets. These ingots are 17 inches square and weigh each about 34 cwts., and the coal consumed in the producers firing these furnaces is at the rate of half a hundred weight per ton of steel. Two furnaces can heat 40,000 tons of ingots without requiring any other repairs than the renewal of a few arches, and the chequer work of the regenerators has stood three years hard working. Mr Richards adds, "Ingots heated in this type of furnace have a uniform heat on each side which assists considerably in the rolling, for with an ingot heated in a coal-fired furnace there is generally one side cold which often causes a mishap to take place."

(3). Foundry stoves, annealing and case-hardening furnaces fall under this head and in these cases also, although the margin of possible saving in fuel is not great, gas firing has advantages of speed, steadiness of heating, cleanliness, etc., which are a recommendation in themselves.

Figs. 26 and 27 illustrate the usual form and arrangement of foundry stoves, many of which are in successful operation. Messrs Marshall Sons & Co., of Gainsborough, inform me that they get fully one-third more work out of a stove fired by gas than from one with coal firing, as they have their gas stoves charged and dried three times in the 24 hours, instead of twice as formerly. The absence of smoke, more satisfactory and regular drying, with cleanly stoves, are additional advantages. At Barrow, at Messrs Craven Bros., at Bilston, at Kilmarnock, at Springburn, and at Johnstone, and elsewhere, are found examples of gas-fired foundry stoves which work satisfactorily. Annealing and case-hardening furnaces fired by gas are to be found at the works of Messrs H. Wallwork & Co., and Messrs R. Stephenson & Co., and in this district at the Hyde Park Locomotive Works of Messrs Neilson, Reid & Co.

Fig. 28 illustrates a gas-fired annealing oven.

(4). Gas has been applied to firing steam boilers of various designs, more however with a view to economising labour and wear of boilers, to smokelessness and cleanliness, which the system ensures, than to obtaining a saving of fuel. An increased evaporative duty (amounting to from 18 to 25 per cent. in some cases) from the heating surface in a given time has been found to result from gas firing, due to the uninterrupted application of the gas flame. This also preserves the boiler from the alternating strains due to expansion and contraction from the heating and cooling actions of coal firing, which are ruinous to the structure of the boiler. The gas for boiler firing is usually taken from the main flue supplying other furnaces, so that it is rarely possible to obtain accurate figures of coal consumption for steam raising, but separate tests have shown an evaporation of 9 lbs., and 10·59 lbs.

of water from and at 212 degrees Fah. per lb. of coal in the producer, cold air being used for combustion. I find that the average of Fichet s results = 9·04 lbs. of water evaporated per lb. of coal; that of Haupt's results = 9·88 lbs. of water evaporated per lb. of coal; and that of D. K. Clark's results = 8·96 lbs. of water evaporated per lb. of coal. Giving a mean of 9·29 lbs. of water per lb. of coal. Boilers at Messrs Hatton & Sons (gas fired) required 2·15 lbs. of coal per I.H.P., whilst some other results noted by me in "Fuel and its Applications," gave a mean of 10·59 lbs. of water per lb. of coal. These are as good results as the average with any careful coal firing, and, except in Haupt's case, they were obtained without any arrangements for heating the air used for combustion.

It is strange that whilst firms rarely grudge the expense of adding mechanical stokers to boilers, the cost of fitting gas firing, which is no greater in many cases, should be considered an obstacle to its adoption.

Boilers of the locomotive type are being gas fired at the works of the L. & N.-W. Railway Co., and of Messrs Neilson, Reid & Co.: Lancashire type, at Butterley Iron Co.'s Works, and elsewhere; and Davey-Paxman type, at R. Stephenson & Co.'s. Babcock-Wilcox boilers are also at work fired by gas (see Figs. 29 and 30), and the Stirling boiler fired by gas, at the Glasgow Exhibition, will no doubt still be remembered.

Other applications of gas to evaporating processes have mainly interest from the chemical engineering point of view, but one of perhaps wider interest is that of the brewers coppers at Messrs Guinness' great brewery in Dublin.

(5). Brick kilns. This district has the honour of having produced the first, and so far the only successful gas regenerative kiln for burning bricks, and also a successful gas pottery kiln. The Dunnachie kiln, which is still in use at Glenboig, and is an element of consequence in the production of the excellent quality of the fire brick goods of that brand, was described to this Institution in two communications by Mr John Mayer (see Transactions, Vols. XXVIII. and XXIX.) Constructive details have been slightly improved since that date, but the principle remains the same, and the low temperature of the escaping gases noted by Mr Mayer—viz., 150 to 300 degrees Fah., with one "green" chamber in circuit, and 90 to 180 degrees Fah., with two "green" chambers—shows how thoroughly the heat is utilized in the kiln chambers. The Murray & Macintyre gas pottery kiln was described to the Glasgow Philosophical Society on 19th April, 1893, by Mr W. F. Murray, and although the form originally chosen for these kilns operated against their ultimate success, they worked long enough to prove the entire practicability and economy of that system of treating pottery ware. As worked at Rutherglen, these kilns were built of the circular form usual in potteries, several of these being grouped together by means of flues. It was, however, found that there were certain drawbacks inherent to that form, and Mr Murray abandoned it in favour of the rectangular chamber form which, of course, makes it almost identical with the Dunnachie kiln.

(6) The only other application of producer gas to furnaces which may be considered as directly connected with engineering and shipbuilding is that of heating the retorts in gas works. Various arrangements have been in use for several years, for utilizing the coke in producers which either formed part of the retort setting or were erected just outside in front of the retort bench and under the floor level of the charging house. Under such circumstances the producers were necessarily small, but our President, Mr Foulis, has introduced with success the novel plan of having large producers erected outside the retort house, the coke being charged into them while still red hot. By his courtesy I am enabled to show an illustration of his plan, Figs. 31—33, and to state that the four producers erected at Dawsholm heat 192 retorts, with a saving of 10 per cent. of the fuel required in the case of the producers placed in front of the retorts. This arrangement of producers is combined with an ingenious blast governor controlled automatically by the pressure of gas in the

gas main from the producers, which causes it to operate upon a valve in the steam pipe leading to the steam-jet blowers. The force of blast entering the producers is thus proportional to the pressure or quantity of gas in the mains, so that the demand regulates the supply. There is also a dust collector in the main circuit near the producers which acts very efficiently.

POWER.

No paper on producer gas would have any claim to completeness of view of the subject if it did not in these days refer to the direct use of producer gas in gas engines. We are here, of course, on somewhat different ground from that on which the value of producer gas in furnace work has to be considered. It is not the direct production of flame that is in question, but the transformation of the potential energy of the fuel into the actual power of the engine. As compared with the steam engine the gas engine saves several steps in the transformation of energy, and this gives to the gas engine and gas producer a decided advantage. Some producers, such as those of Dowson in this country, and Lencauchez and Fichet in France, have been wrought for some years with anthracite or coke as fuel when the object was the production of gas for use in small gas engines. But since large power gas engines have been successfully made the field has become vastly wider, and the employment of producers using bituminous coal slack, combined with appliances for the removal of tar and dust from the gases, and in some cases with plant for the recovery of ammonia as sulphate from the nitrogen of the coal, has become an accomplished fact.

It would lengthen this paper unduly were a minute description of these appliances added, so that I content myself with a reference to Figs. 34—36, which illustrate gas purifying plant designed by Messrs W. F. Mason, Ltd., for Duff producers to supply gas for 2000 H.P., and ammonia recovery plant with Duff producers dealing with 500 tons of slack per week, at the Fleetwood Works of the United Alkali Co., Ltd.

According to Mr Bryan Donkin,* we may take the heat value of illuminating gas roughly at 584 B. Th. U. per cubic foot. That of producer gas made from coal varies, according to one authority, from 144 to 165 B. Th. U., but according to another is properly 190 B. Th. U.—the analysis quoted on page 249 gives a heat value of about 183 B. Th. U. per cubic foot. The gas from Mond and from Dowson producers is given as equal to 150 B. Th. U. That is a favourable estimate of the gas made from Mond producers using slack coal, the ammonia being recovered from the gas (125 being about the usual figure), but is about the normal value of producer gas from coke or anthracite. The gas from blast furnaces using coal is equal to about 137 B. Th. U. and from coke furnaces it averages about from 100 to 110.

In comparison with average steam engines where producer gas is burned under the boilers to generate steam, 100 cubic feet of power gas burned directly in a gas engine cylinder will yield as much power as 400 feet burned under the boilers. The consumption of fuel in larger gas engines using power gas has now been brought under 1 lb. per I.H.P. per hour.

The comprehensive remarks on this part of the subject in the Presidential Address at the opening of this session, and the recent paper by Mr D. Clerk sufficiently indicate the great importance which it has assumed.

Combined with it there arises the question of the distribution and cost of power gas. Schemes are put forward for monopolising large tracts of country in the interests of one form of gas producer, as far as the right to distribute the gas to consumers is concerned. But that need not deter individual consumers within such districts from supplying themselves with producers for their own requirements, especially as by so doing they will obtain much cheaper gas. Our President can tell us the proportion which the cost of distribution bears to that of production in the case of

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* "Motive Power from Blast Furnace Gases." Min. Proc. Inst. C. E., Vol. cxlviii.

illuminating gas. For producer gas that proportion must be very much greater, on account of the immensely larger mains required.

The cost of production is barely above 1 penny per 1000 cubic feet with expensive coal. Thus, if we take coal at 10s per ton in a producer gasifying 10 cwts, per hour and working 60 hours per week, the quantity of gas yielded per ton being taken at 150,000 cubic feet, the labour cost as equal to 1s per ton, and the charges for interest and depreciation at ¼ the cost of the coal, we have per 1000 cubic feet:—

Coal = ·80d
Labour = ·08d
Int. and Dep. = ·20d
Total 1·08d

Of course with the cheaper dross which would most commonly be used, the cost of the gas is less, and as the labour cost has been arrived at by taking 30s per week as the wages of one man for one 10-cwt. producer, in the usual case in which several producers are at work together, the labour charge will be proportionately less. The costs for "labour, interest and depreciation, and sundries" at steel works in Moravia for converting coke into water gas and producer gas with the Essen apparatus, was stated by Sir I. Lowthian Bell to have been 2s 8·18d *per ton of coke*, and these charges were, he considered, very high, so that it is probable that, in taking ¼th of the cost *per ton of coal* for interest and depreciation alone, I have considerably over-estimated the cost there also. In fact the ordinary cost of producer gas with good producers using coal slack amounts to about one halfpenny per thousand cubic feet. The practical advantage, therefore, of giving away to distributing companies from 1d. to 3 pence per 1000 cubic feet of gas used does not readily appear.

This is a somewhat rapid survey of a very large subject, but it may serve to arouse interest and elicit discussion, in the course of which statements will be given of experience in the use of producer gas.

I have only, in conclusion, to tender my thanks to those who have already, as noted in the preceding pages, been kind enough to give some results of their experience with gas furnaces.

Discussion.

The discussion on this paper took place on 18th March, 1902.

Mr Peter N. Cunningham (Member) said he must congratulate Mr Rowan in bringing so fully and clearly before the Institution such an important subject. He thought it was of very great importance to such an Institution as this. So far as the application of gas as a motive power, or its direct application to gas engines, was concerned, he had no experience, but as he had been closely connected with the iron and steel trade for upwards of twenty-five years, and as the production and application of gas formed an important part in the operations carried on in an iron and steel works, he could appreciate the importance of it. He quite agreed with Mr Rowan that a good producer must be capable of being cleaned without interfering with the continuous production of gas, and that no heat or combustible matter should pass away in the ashes made. These advantages were fulfilled, he thought, in the water-sealed gas producer. He had erected twenty-eight gas producers on Mr Duff's principle. The internal size of the hearth was about 9 feet by 7 feet with the Λ-shaped Duff grate, and they had given very satisfactory results, both as to the quality of the gas produced and the combustible matter which passed away in the resultant ash. On the other hand, he had altered quite a number of the old Wilson gas producers, as shown on Fig. 2, to water-sealed bottoms, using a central cone-shaped blower of large diameter with two cones, one placed on the top of the other, with a space left for the air to enter the producer. That arrangement gave a very good distribution of the air, and the producer worked very uniformly. The fire did not work into holes and produce local heating; and there was no clinkering caused. The carbon which passed away in the ash from an altered Wilson producer, with double cone only, amounted to from ·5 to 1 per cent. of the

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fuel consumed; in fact, it could not be noticed in the ash. With the Duff producer, he had had the same uniformly good results, as practically no carbonaceous matter left the producer in the ash. He had had some of the Duff producers continuously running for twelve months without having the fire out, and at the end of that time he found that they were in good condition and needed no repair whatever. He had had the same good results with the altered Wilson producer. Clinkering could be prevented by having the producer built on proper lines and by careful working. He had used dross in these producers containing as much as 24 per cent of ash without any clinkering, and the ash, contained in some of the drosses, was readily fusible. The steam pressure at which producers should be worked should not be high, and when a clinkering dross was met with, to prevent the clinkering taking place, an increased amount of vapour and a decrease in the air would put matters right. The moisture or vapour attacked the hot clinker and disintegrated it, softened it and brought it down. His practice was to use dross of the commonest kind, and with very good results. In regard to the furnaces for heating metals, he might say that he had had several furnaces built for heating finished material for flanging, stamping, and pressing. The gas produced was in a water-sealed bottom, and was used direct at the furnace without passing any regenerator chamber. The size of one of these furnaces was 15 feet in length, by 10 feet 6 inches in width, with gas and air ports alternately on both sides of the furnace. The height of the furnace was 2 feet 6 inches. Two fairly large regenerator chambers for heating the air only were used with these furnaces. The gas from the producer was produced at a high temperature, and used direct, thus doing away with the usual reversing and chimney valves. The results obtained in heating plates for bending, flanging, or pressing into shapes, were all that could be desired, and the consumption of fuel (dross) ranged from 9 to 12½ per cent. of the weight of the material heated. He thought that such furnaces were very well adapted to work in shipyards and stamping and flanging shops, where a welding heat was not required. The addition of a chamber to regenerate the gas would give a furnace that would heat anything up to welding heat. Mr Rowan referred on page 250 to regenerator chambers being underneath the ground. In every case where this could be done it was best, but he had had regenerator furnaces working with their regenerator chambers on the floor level. This overcame the difficulty of sinking a portion of the furnace much below the level of the floor. They had worked very well and given no trouble. He considered gas furnaces were much more economical than coal-fired furnaces, but even though the furnace might be used intermittently, if the damper on the furnace was lowered carefully and the furnace closed up, the regenerator chambers and also the body of the furnace kept a large amount of heat for a long time. There was a great future before the use of gas in the heating of materials, which were at present heated in coal-fired furnaces.

Mr Charles G. Norris (Member) expressed pleasure at having an opportunity of saying a few words on the subject, as he had been able, within the last day or two, to obtain some data which might be of interest. Quite recently the firm of Messrs Ruston, Proctor & Co., Ltd., Lincoln, had been making enquiry with regard to the relative economy of gas-fired and coal-fired furnaces. They intended to build a new works, and the question they wished to decide was whether to put down gas furnaces or coal furnaces. Their representatives came to Scotland, as many people did when they wished to learn how to work on the most economical lines, and, after very close enquiry, they procured figures with regard to the weight of plates that could be heated in a certain number of hours, the quantity of coal used, and the price of coal; with the view of getting the cost of heating each ton of plates, and the manager had been good enough to furnish him with the result of that enquiry. They saw a furnace which was gas-fired of about the same dimensions as the one they were firing with coal at Lincoln, and on the ordinary coal-fired furnace they were heating 17 tons of plates in a week of 53 hours. The coal consumed was

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6 tons 14 cwts., and the price of the coal was 11s 6d per ton. Consequently the cost of heating those plates ran up to 4s 5d per ton. The gas-fired furnace heated 45 tons in the week of 53 hours, the coal consumption being 11 tons 10 cwts., and the price of coal used was 8s 6d per ton, so that the cost of heating the plates in the gas-fired furnace was 2s 2d, as against 4s 5d per ton.

The following gives these figures in tabular form for convenience of comparison:—

	Ordinary Coal-Fired Furnace.	"Weardale" Gas-Fired Furnace.
Size of Furnace, - -	15′ 6″ × 6′ 10″	14′ 10″ × 5′ 6″
Weight of Plates heated 53 hours, - -	17 tons	45 tons
Weight of Coal burned 53 hours, - -	6 tons 14 cwts.	11 tons 10 cwts.
Cost of Coal per ton, -	11s 6d	8s 6d
Cost of Heating per ton of Plates, - -	4s 5d	2s 2d

He scarcely needed to say what would be the result of that investigation. He had that day received some interesting information from Messrs A. Macmillan & Sons, Ltd., of Dumbarton. A test was made there a few days ago with regard to the time required for heating certain angle bars in a new gas-fired furnace recently erected, and it was found that the angle bars could be perfectly heated in from 15 to 16 minutes, whereas previously the usual time for the same class of work was 35 minutes. That was distinctly in favour of the gas-fired furnace. He had obtained very similar information from Messrs Workman, Clark & Co., Ltd., of Belfast. He had been over there recently, and they were heating channel bars 9″ by 3½″

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by $3\frac{1}{2}''$ in twenty minutes, and the length of the bars was about 60 feet. The manager told him that after bending, the bars had to be left on the blocks to cool, they had been so thoroughly heated in the furnace. In fact, he said the only thing that determined the rate of working was the time in which the material could be dealt with after leaving the furnace. The information gleaned from Messrs Ruston, Proctor & Co., Ltd.; Messrs Workman, Clark & Co., Ltd.; and Messrs A. Macmillan & Sons, Ltd., emphasized the fact that reheating by producer gas could be done more thoroughly and in much less time, and also that a cheaper class of fuel could be used than was usually the case with coal-fired furnaces. Mr Cunningham, he thought, also corroborated that. The very practical remarks made by Mr Cunningham suggested one or two other points to which he might refer. With regard to the alteration of other types of gas producers to the Duff patent system, it had invariably been found that when Duff patent grates had been applied to producers of the Wilson or Dawson type, the output had been increased about 25 per cent., and in the case of some of Siemens' gas producers at the Monk Bridge Iron and Steel Works, Leeds, four producers fitted with Duff patent grates did the same work that previously required sixteen producers, and a cheaper coal was used in the Duff grates. Mr Cunningham referred to the question of steam pressure for gas producers. He might state that 40 lbs. was the pressure found to be best suited to the requirements and conditions which prevailed at the Glasgow Exhibition, and he was there frequently congratulated upon the character of the residue, but it depended very much upon the class of coal used in the producer, as to what was the best steam pressure. In any case it was very important that the steam should be dry. Another point referred to by Mr Cunningham he should like to emphasize, namely, that the fuel in the producers should be well pokered. If this was attended to it would often be found that cheaper coal could be used. It was very encouraging to have Mr Cunningham's testimony as to the good results obtained from common dross.

Mr Charles G. Norris.

That day he had visited a works where coal which cost about 4s 3d per ton was being used for the gas producers, and apparently there was no trouble with clinker, as the residue was soft and thoroughly well burnt. In conclusion, he might mention that the gas-fired furnaces already referred to for heating plates and angle bars for engineers and shipbuilders, had no underground regenerators, but were of the "Weardale" type, full particulars of which were given in Mr Rowan's paper.

Mr J. F. MACLAREN (Member) stated that his firm had been using gas producers with anthracite coal and gas coke for some years, but considerable trouble from clinker had been experienced, particularly from gas coke, and they had had further trouble with tar gathering on the gas valves of the engines, putting the engines out of order. Otherwise, with regular attention and careful handling, they found the producers very satisfactory. It was certainly a very economical way of working, and only about one pound of anthracite was used per brake horse power per hour.

Mr ALEXANDER WILSON (Member) observed that the experience of using fuel gas for heating purposes in gas works was a lengthy one, and a great many different forms of producers were used. There were over 200 producers in the works where he was, under the President, although many of them were of a small size. In the South, producers with bars under them were used but in Glasgow the style of furnace employed—the Siemens' with the solid hearth—was new to him. It was, however, a more suitable producer for the fuel used in the North, as there was a great deal more ash in the coke in Glasgow than that in the South. The coke in the South was of a much higher quality, and it was therefore more easily dealt with. All the same, a good deal of trouble with clinker had been experienced, and he was surprised to find that with the high percentage of ash so little clinker was produced in Glasgow. Mr Foulis had put down some large producers to take up the work of those of smaller size, with a view to saving fuel and having fewer attendants. When these producers were started there was trouble with the clinker, and several alterations were made, always, however, on the right lines, and now very good results were obtained both in saving of fuel and of labour. These producers had rose-headed blowers similar to those in use in iron works. The clinker now was very easily dealt with, and the coke that was used produced very clean fuel gas. He was rather surprised to hear of the trouble experienced by Mr Maclaren with the tar from anthracite. He thought that fuel gas from coke was far better to work with than fuel gas from coal. It was a much cleaner gas, and there was no trouble either with the bye products or taking out the tar. A great deal depended upon the way the blowers were used of whatever form they were. If the clinker was going to be troublesome it required that the steam should be put in in proportion to the air to suit the fuel. He did not think pressure meant very much so long as the nozzle was suited to the size of the blower. A few weeks ago he saw some producers that had been working for a good many years. While looking at them he noticed one of the men breaking up a clinker as large as his body. He discovered that this clinker was formed when the fuel gas was used a considerable distance away, and the pressure had to be increased to get the gas the distance wanted. He advised the foreman to reduce the orifice for his air, and allow more steam to go in in proportion to the air. He had not heard since what the effect had been, but he was sure that it would cure the clinker. Producers were often left to men who had very little notion how to treat them, but if a little attention was given there was not nearly so much trouble afterwards.

Mr R. T. Napier (Member) asked if, in the case of the best modern producers, it was necessary to keep up the blast during meal hours; or if the producer could be shut off and started again without loss of time.

Mr Wilson—Steam was shut off for eight hours on the Sunday, and the producers were allowed to rest for the full eight hours. There was a little air going through, but a very small quantity.

Mr Cunningham—They shut down on the Saturday afternoon, and did not light up again till nine o'clock on Sunday.

Mr Cunningham.

Practically the producer was sealed up and nothing was leaving it, so that there could be no loss going on after the hydrocarbons were driven off.

Mr A. S. Biggart (Member) said as supplementary to Mr Napier's question he would like to ask if that could be done when gas was being used for power driving. He believed it was not often done, and in many cases the producer had to be kept at work continuously to get better results.

The President said this was a subject that had engaged his attention for a very long time. It was about the year 1882 when he first began, in conjunction with the late Sir William Siemens, to apply heating to gas retorts. Each oven, which contained at that time eight retorts, had a producer placed in front of it, into which the hot coke was drawn from the retorts. At first there was considerable trouble with the clinker, no steam being used. They tried at first to get the clinker to run, but that was a complete failure, and it was only after a great many experiments that they succeeded in getting the producers to work satisfactorily with great advantage in the saving of fuel. Since that time different producers had been experimented with in many ways. The latest were those which had been mentioned in the paper, and illustrated by Mr Rowan. They were placed outside the retort house, and the gas was conveyed to the ovens in flues and distributed among the different settings of the retorts. This system had proved so successful that it was now being extended. At the new works which he was building at Provan the whole of the retorts were to be heated in that way. There was no difficulty whatever when coke was used in regulating exactly the amount of gas made to what was required, whether that gas was used for heating purposes or for the production of power. The paper referred to a very simple arrangement which he had adopted for regulating the amount of gas produced, and which was merely an adaptation of an appliance which was used in gas works for regulating the speed of the exhauster engines, and consisted of a bell or small gas holder, a pipe from the interior of which was carried to the flue

The President.

somewhere near the point where the gas was required for use. The bell was carefully balanced so as to be moved with the slightest difference of pressure. Something like half-a-tenth of water pressure was quite sufficient to move it. The bell was attached to a very delicate steam governor, and the effect was that as the pressure rose showing that there was more gas made than was necessary, the steam was at once shut off, and so the production of gas was regulated in exact accordance with what was required. That was very easy where coke was used, because the moment the steam and air were off from a coke producer, the combustion was checked and the production of gas reduced. On the other hand, when bituminous coal was used the difficulties were greater, for the reason that the production of hydrocarbons continued from the heat of the producer even after the air and steam were shut off. He believed that several plans had been adopted to overcome this difficulty, but it seemed to him that it could be accomplished by regulating not only the air and gas applied to the producer, but also the rate of fuel feeding the producer, so that at the moment the engines stopped and the gas was not required, not only was the air and gas checked, but also the amount of fuel. In this way he thought it would be possible, even with bituminous coal, to regulate the amount of gas made. With coke, as he had already said, there was no difficulty. He did not think any one who had had experience of heating by means of gas instead of open fires would for a moment think of returning to the latter method. The cleanliness and the regularity with which heat could be obtained with gas fuel were so great and resulted in such an immense saving, not only of fuel, but wear and tear and labour, and in many other ways, that there could be no doubt whatever that fuel gas would be the method in which fuel would be used in the future. He thought that time was coming very fast. He would now ask Mr Rowan to reply to the discussion.

Mr Rowan, in reply, said that he did not seem to have succeeded in introducing any controversial matter into his paper, as all the

Mr Rowan.

criticisms had been favourable. At the same time, he thought that the fact that it had produced from several of the speakers such eminently practical remarks, was of itself a complete justification for such a paper having been read. Before replying to one or two remarks that had been made, he would like to say that he had been asked to point out that on page 244 some figures required a little explanation. In dealing with the heat value of coal on a fair analysis, which was given at the foot of page 243, the heat value of the fixed carbon was given, that quantity of carbon being 53·41 per cent. On page 244 there was a paragraph beginning, "If this coal were turned into producer gas, with only air blast, and the gas was burned cold, then the heat value would be" so and so. The carbon line did not seem to be clearly enough stated. He took the 53·41 per cent. of fixed carbon of the coal from the analysis, and it was there stated as being equivalent to 124·62 per cent. of carbon monoxide. What was meant by that was clearly that that quantity of carbon monoxide was the equivalent of the solid carbon mentioned before, and that quantity of carbon monoxide being multiplied by the thermal units due to its combustion gave the result that was stated. It had been remarked to him that the mere mark of equality was not clear enough, and he should have stated in words that what was meant was that the 124·62 per cent. of carbon monoxide was the equivalent quantity produced from that quantity of fixed carbon. He was very glad that it seemed to be the general opinion that firing by means of gas was coming into favour. It was many years since he had worked pretty hard at the introduction of fuel gas, but he must say that in those early days coal was very much cheaper, so that there was not very much encouragement for the introduction of economical methods, but of late years something like a coal famine had come upon them, and manufacturers had learned to consider what might happen in the case of another coal famine or serious strike; at any rate, the price of fuel was a more serious consideration now than it used to be, especially in this country. He had not the slightest doubt that the opinions which they had heard expressed by Mr Cunningham,

Mr Rowan.

their President, and other practical men that evening, that the use of fuel gas for heating was the best method, would become more general. He felt inclined to go a step further and say that heating by means of fuel gas was the only rational method of using fuel. For power purposes, at present, it had rivals, but from the point of view of economy the time was coming, he had not the slightest doubt, when it would be able to hold its own very distinctly in that field also. Mr Norris had given very important figures, and he was extremely glad to have them on record, because members could not conceive the difficulty of getting results from people who had producers and furnaces. Either they had not kept a record of their coal-fired furnaces, or there was a disinclination to let others know how well they were doing with gas, so that comparative figures, such as Mr Norris mentioned, were of great value. Mr James Rowan had been kind enough to give him the following particulars of a coal-fired plate-heating furnace in his works:—Dimensions of furnace—Length, 18 feet 6 inches; breadth, 10 feet 6 inches; height, 2 feet 3 inches; capacity, 431 cubic feet. Area of floor space, 194·25 square feet; grate surface, 21¼ square feet; coal and splint, at 11s 10d per ton delivered; consumption of coal per week, about 9 tons. The furnace was used for heating plates of thickness varying from ¼ to 1¼ inch, and was kept constantly heated whether plates were charged into it or not. It had been at work for about two years and had cost practically nothing for upkeep. He was extremely sorry that Mr James Rowan could not give him the complete information that he asked for, because that would have been an instance of a plate furnace worked by coal, which could have been compared with gas furnaces. But in the absence of data as to the quantity of material heated per ton of coal, a comparison could not be made. Mr Maclaren's remarks as to the trouble from clinker and tar had been almost entirely answered. He, personally, could not understand how there should be any trouble from tar, where either coke or anthracite coal was used in the producer, there being no hydrocarbons in either form of fuel. Where

Mr Rowan.

bituminous coal was used, there was a distillation of volatile hydrocarbons taking place on the first application of heat to the fuel, and the volatile hydrocarbons formed tar on cooling the gas. Tar had been very successfully removed by condensation in many instances, and he thought it would be the fact very soon that by some modification of the producer itself, the quantity of tarry matter produced from bituminous coal would be very greatly reduced, if not entirely eliminated. He knew of some experiments which had been made towards that end, and he believed with very good prospects of success. With regard to the different forms of blowers, he thought that all the remarks pointed to the fact that the larger the area over which the steam and air blast was distributed in the fuel, the better the chance of safe working; that was working without the danger of clinkers, and working in such a way as to extract the whole of the combustible material from the fuel, and it was that feature of the Duff producer which first of all attracted him to it and convinced him of its value. Mr Wilson's remarks about producers and the President's remarks also about the gradual changes taking place in the equipment of gas works, would be found to point to what would take place, not only in gas works, but in other works where producers were wanted in numbers; that was to say, that the tendency was towards large units. A small producer would certainly give more trouble in working than a large one, and in several cases that he knew of, the desire was becoming very marked to have producers of large individual capacity. It had not been easy in the past to get them. He had been connected with the early use of the Wilson producer, and with it there was the greatest difficulty in getting a size capable of gasifying anything above 8 cwts. per hour satisfactorily. He had no doubt from later experience, that that was due to the method in which the blast was used. He knew that there were instances of Duff producers working at the rate of from 20 to 25 cwts. an hour, and even more than that. There was no difficulty at all, as Mr Napier would have gathered from the discussion, in shutting down a producer for an hour. Certainly, there was no difficulty in

Mr Rowan.

shutting a producer down for a whole night. It was quite easy to stop the production of gas, and in the case of bituminous coal being used the difficulty mentioned by the President applied only to the portion of the charge of coal which was on the surface and was not coked. If, shortly before stopping, fresh coal had been put on the surface of the charge, what was required to be done was to take off the poking hole covers and allow the hydrocarbons to burn on the surface of the producer, but that of course involved a little waste, although extremely little. Where the coal had all been coked there was no difficulty at all. There was no production of gas; at least there was not production of gas enough to generate a pressure inside the producer, and the whole affair could be comfortably shut down and left ready to start as soon as necessary. He would have been glad if Mr Cunningham had given a sketch of his producer blower, because it was an interesting one and slightly different from those he had referred to, although, so far as the general design went, it was practically embraced in the designs that were mentioned.

The **President** proposed a hearty vote of thanks to Mr Rowan for his paper, and said he wished to say one word in supplement to what he said before, more particularly in reference to Mr Maclaren's difficulty. He could quite conceive that a little tar might possibly be mixed with gas coke. Often a small quantity of tar dropped from the mouthpiece, and it was almost impossible to separate it from the coke. It was not much, but might have the effect of clogging the valves of the engines after a time. Where gas was applied for the purpose of heating, it was of great advantage to purify the gas. He had put up a dust chamber in connection with the producers he had, so as to remove the whole or the greater part of the dust from the gas immediately after it left the producer. He thought that was necessary when the gas was carried for any length in flues, more especially when coke was used. In the case of gas engines using producer gas it was necessary to cool the gas to atmospheric temperature, and the best way to cool it was to pass it through a washer, and wash it with

The President.

water. If that were done the whole of the tarry matter would be removed and the gas would be at the same time cooled down to the proper temperature. He had now to ask the members to give Mr Rowan a very hearty vote of thanks for his paper.

The vote of thanks was carried by acclamation.

Correspondence.

Mr J. F. Maclaren (Member) observed that in view of the remarks by Mr Wilson he should like to add in explanation that he referred to Scotch anthracite coal. The tar arising from Scotch anthracite was not nearly so troublesome as the tar arising from gas coke, as the tar from anthracite was liquid or semi-fluid, but the tar from gas coke was a solid more like tough india-rubber, and very readily caused the valves of a gas engine to stick. He presumed the tar which arose from gas coke was due to imperfect distillation or drops from the retort mouths when the coke was drawn; in any case it was only the heavier tars that seemed to be left, and these were the most troublesome in an engine. The amount of tar present in the gas was very small, and it seemed to be carried over in a solid form as a mist; it could be removed from the gas by mechanical washing with water, but it seemed to escape the coke scrubbers which were used in their plant for purifying the gas. His firm had so far been unwilling to complicate the plant by adding mechanical washers, but they might possibly have to do so if they continued to use gas coke as a fuel.

SOME CONSIDERATIONS AFFECTING THE ECONOMY OF MARINE SCREW ENGINES.

By Mr E. HALL-BROWN (Member).

(SEE PLATES XXII., XXIII., XXIV., XXV., XXVI. AND XXVII.)

Read 18th March, 1902.

THE difficulty attending the determination of the mechanical efficiency of marine engines has doubtless been the cause of the comparative neglect of that element in the efficiency of the engine as a prime mover. All the published trials of marine engines with which the writer is acquainted give the steam efficiency of the engines in terms of units of steam (or units of heat) per indicated horse power hour. Although this knowledge is of great importance, it should be borne in mind that the real measure of the efficiency of a marine steam engine is the amount of steam (or the equivalent amount of heat) used per effective horse power hour. In fact that the power delivered at the propeller is the power available for driving the ship, not the power shown on the indicator cards.

It is therefore of the greatest importance that if an accurate determination of the mechanical efficiency cannot be given, at least a reliable estimate should be made in such a manner as to leave no doubt as to the direction in which increased economy lies.

The object with which this paper has been written is to draw attention to this important matter.

The published records of accurate marine engine trials are practically confined to the Reports of the Research Committee on marine engine trials, which are to be found in the Proccedings of the Institution of Mechanical Engineers for the years 1889-1892. These trials are six in number, but only two of them, the trials of the "Meteor" and "Iona," are of direct use for the purpose of this paper. Table I. gives some particulars of the engines of these vessels and of the results obtained on the trials. The columns given in italics have been added by the writer.

TABLE No. I.

s.s. "Meteor," Cylinders 29·37", 44·03", 70·12" diam.; stroke, 47·94"; 2 double-ended boilers, 6648 H.S. Total weight, 390½ tons.

s.s. "Iona," Cylinders, 21·88", 34·02", 56·95" diam.; stroke, 39·00"; 2 single-ended boilers, 3160 H.S. Total weight, 202 tons.

	Boiler Pressure.	H.P. Steam-Chest Pressure.	Barometer.	Vacuum.	Revolutions per Minute.	Mean Pressure Reduced to L.P.	I.H.P.	*E.H.P.*
	Lbs.		Lbs.	Lbs.		Lbs.		
"Meteor,"	145·2	—	14·9	12·17	71·78	29·90	1994·0	*1794*
"Iona,"	165·0	—	14·58	13·88	61·10	21·13	645·4	*553*

	Power Absorbed by Friction, &c. I.H.P. - E.H.P.	*Pressure on L.P. Piston to Overcome Friction, &c. P_f*	*Percentage of I.H.P. Absorbed by Friction, &c.*	*Mechanical Efficiency. $\frac{E.H.P.}{I.H.P.}$*	Pounds of Water used per hour per		Heat Units used per minute per	
					I.H.P.	*E.H.P.*	I H.P.	*E.H.P*
	Assumed	Assumed	Assumed					
"Meteor,"	*200·0*	*3·00*	*10·0*	*·90*	14·98	*16·65*	265·6	*295*
"Iona,"	*92·4*	*3·00*	*14·2*	*·858*	13·35	*15·57*	249·6	*291*

Table II. which, so far as the writer is aware, has not hitherto been published, gives the results of some very interesting trials made by Mr D. Croll upon a set of triple-expansion screw engines having cylinders of 13½", 21", and 35¼" diameter respectively, with a stroke of 21". In this case also the columns in italics have been added by the writer.

TABLE No. II.

M. D. Croll's experiments.

Cylinders, 13½″, 21″, 35¼ diam.; stroke, 21″.

Total number of Expansions.	Boiler Pressure.	H.P. Steam Chest Pressure.	Vacuum.	Revolutions per minute.	Mean Pressure Reduced to L.P.	I.H.P.	E.H.P.	Power absorbed by friction, etc. I.H.P.—E.H.P.	Pressure on L.P. Piston to overcome friction, &c. Pf	Percentage of I.H.P. absorbed by friction, &c.	Mechanical Efficiency. E.H.P./I.H.P.	Pounds of water used per hour per I.H.P.	Pounds of water used per hour per E.H.P.
	Lbs.	Lbs.	Inches.						Assumed.				
8·7	106	94	26	95·6	22·6	215	*186*	*29*	*3·0*	*13·3*	*·867*	19·5	*22·5*
8·7	106	96	25	98·6	23·1	238	*207*	*31*	*3·0*	*13·0*	*·870*	18·9	*21·8*
8·7	112	102	24·5	101·0	25·15	263	*232*	*31*	*3·0*	*11·9*	*·881*	18·2	*20·6*
8·7	155	100	25	109 2	25·9	293	*258*	*35*	*3·0*	*11·6*	*·884*	17·5	*19·8*
8·7	155	98	25	113·6	25·9	305	*270*	*35*	*3·0*	*11·6*	*·884*	16·8	*19·0*
8·7	160	108	25	122·8	26·67	336	*298*	*38*	*3·0*	*11·2*	*·888*	16·0	*18·1*
8·7	164	52	27·5	89·0	21·18	195	*168*	*27*	*3·0*	*14·2*	*858*	17·15	*20·0*
8·7	160	52	24·5	88·6	21·25	195	*168*	*27*	*3·0*	*14·1*	*·859*	18·25	*21·3*
8·7	160	53	20·0	85·3	20·52	182	*155*	*27*	*3·0*	*14·6*	*·854*	20·00	*23·4*
10·0	152	144	24	133·5	31·30	431	*388*	*43*	*3·0*	*9·6*	*·904*	15·05	*16 65*
10·0	144	137	24·5	131·5	30·25	412	*371*	*41*	*3·0*	*9·9*	*·901*	15·00	*16 66*
10·4	146	114	25	111·6	26·05	301	*266*	*35*	*3·0*	*11·5*	*·885*	15·85	*17·91*
10·4	152	120	25	115·6	26 50	316	*280*	*36*	*3·0*	*11·3*	*·887*	15·80	*17·85*
10·9	160	120	25·7	113·0	25·15	310	*273*	*37*	*3·0*	*11·9*	*·881*	15·70	*17·85*

What may be considered the most important contribution to our knowledge of the efficiency of engines of the marine type is to be found in the published results of the trials of the experimental engine at the Durham College of Science, Newcastle-on-Tyne. Records of four important series of tests of this engine are given in the valuable papers by Prof. R. L. Weighton and Mr A. L. Mellanby, published in the Proceedings of the North-East Coast Institution of Engineers and Shipbuilders, 1896 and 1898. Full particulars of these engines, which are of the inverted marine type, slightly modified to suit the purposes of research, and of the trials, will be found in the papers above referred to. The results of the trials are shown in Tables III., IV., V., and VI,, several columns having been omitted from the original tables, and the column giving the pressure upon the L.P. piston necessary to overcome friction and air-pump resistances having been added.

These trials of the Newcastle experimental engine are specially valuable as showing the variation of both steam and mechanical efficiency with an engine of a strictly marine type when worked under varying conditions.

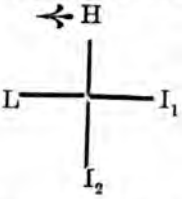
With reference to these tabulated results it will be noted that in the cases of the "Meteor" and "Iona" there is only one trial of each engine.

In Mr Croll's experiments there are fourteen different trials of the same engine under varying conditions as to steam pressure, ratio of expansion, speed of revolution, and power developed, the two last being necessarily related in the case of an engine driving a screw propeller.

The trials of the experimental engine at Newcastle, again, are confined in each case to a practically constant speed of revolution, the other conditions being varied. Table III. gives the results of a series of trials made with a practically constant boiler pressure, at a practically constant speed of revolution, the power developed by the engine being varied by altering the ratio of expansion. Table IV. gives the results of a series of trials made with a practically constant boiler pressure and speed of rotation as he.

nsion.

Sequence of Cranks.



Total Number of Expansions (Moving Piston Rods).	Boiler Pressure.	H.P. Steam-Chest Presure.	Barom	t- f ed n,	Mechanical Efficiency. E.H.P./I.H.P.	Pounds of Water used per hour per I.H.P.	Pounds of Water used per hour per E.H.P.	Heat Units used per Minute per I.H.P.	Heat Units used per Minute per E.H.P.
	Lbs.	Lbs.	Inch						
69·7	209·8	204·7	29·	1	·763	14·6	19·56	270·5	362·6
69·7	208·8	203·2	29·	4		14·1	18·48	261·5	342·6
69·7	210·6	203·1	29·	4		14·1	18·05	261 4	334·5
46·4	211·	204·4	29·	5	·816	13·49	17·05	250·	316·
46·4	211·	206·0	29·	7		12·79	15·59	237·	289·
46·4	210·	204·1	29·	3		12·84	15·44	238·	286
34·8	209·8	203·6	30·	0	·844	12·90	15·38	239·	285·
34·8	210 0	203·9	30·	0		13·06	15·38	242·	285·
34·8	209·7	203·1	30·	2		13·22	15·77	245·	291·
27·87	209·2	205·0	30·	3	·870	13·11	15 00	243	278·
27·87	209·7	205·4	30·	3		13·00	14·94	241·	277·
27·87	208 0	202·4	30·	2		13·11	15·20	243	280
23·2	209·7	204·7	29·	2	·875	12 73	14·62	236·	271·
23·2	209·5	205 0	29·			13·00	14·84	241·	275·
23·2	210 0	205·5	29·	0		13·31	15·00	245·	278·
19·8	208·7	202·0	29·		·904	13·12	14·57	243·	270·
19·8	209·6	202·7	30·			13 17	14·46	244·	268·
19·8	210·1	203·9	30·	0		13 22	14·68	245·	272·
17·4	208·2	199·8	30·	5	·899	12·63	14·20	234·	263·
17 4	208·6	201·72	29·	5		13·06	14·55	242·	269·
17·4	209·1	201·5	29·	0		13·44	14·74	249·	273·
15·46	207·	200·7	30·		·896	12·79	14·25	237·	264·

Sequence of Cranks.

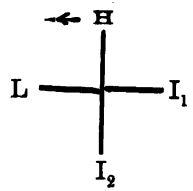


TABLE No. IV.

Trials of Experimental Engine at Durham College of Science, Newcastle-on-Tyne.

Cylinders, ... 7″, 10½″, 15½″, 23″ | Stroke, ... 18″

Power regulated by throttling.

All steam pressures given in lbs. per square inch above atmosphere.

Boiler Pressure.	H.P. Steam-Chest Pressure.	Barometer.	Vacuum.	Revolutions per Minute.	Mean Pressure Reduced to L.P.	I.H.P.	E.H.P.	Power Absorbed by Friction, &c. I.H.P. – E.H.P.	Pressure on L.P Piston toovercomeFriction, &c. Pf	Percentage of I.H.P. Absorbed by Friction, &c.	Mechanical Efficiency. E.H.P./I.H.P.	Pounds of Water Used per Hour, Per I.H.P.	Pounds of Water Used per Hour, Per E.H.P.	Heat Units Used Per Minute, Per I.H.P.	Heat Units Used Per Minute, Per E.H.P.
Lbs.	Lbs.	Inches.	Inches.		Lbs.				Lbs.						
201·1	83·64	29·7	24·05	150·2	11·5	64·82	51·95	12·87	2·26	19·85	·801	15·9	19·9	295	368
201·4	102·14	29·7	24·35	144·5	15·28	82·81	71·02	11·79	2·16	14·23	·857	14·83	17·31	274	320
201·8	133·3	29·65	24·16	143·1	19·77	106·19	92·95	13·24	2·44	12·46	·875	13·83	15·78	256	292
200·7	144·7	29·65	24·15	141·0	21·4	113·21	101·02	12·19	2·28	10·76	·892	13·78	15·46	255	286
200·1	164·38	29·65	24·09	143·6	24·97	134·48	120·07	14·41	2·65	10·71	·892	13·35	14·97	247	277
200·4	192·3	29·65	23·95	141·8	30·08	160·02	141·69	18·33	3·42	11·45	·885	12·86	14·53	238	269
209·3	185·2	30·1	24·07	140·73	30·7	162·	146·23	15·77	2·96	9·73	·902	12·91	14·32	239	265

Sequence of Cranks.

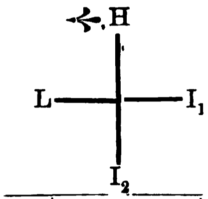
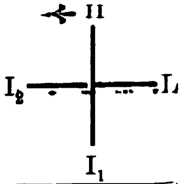


TABLE No. V.

Trials of Experimental Engine at Durham College of Science, Newcastle-on-Tyne.
Cylinders, 7", 10½", 15½", 23"; stroke, 18".

Boiler Pressure.	H.P. Steam Chest pressure.	Barometer.	Vacuum.	Revolutions per minute.	Mean Pressure reduced to L.P.	I.H.P.	E.H.P.	Power absorbed by friction, &c. I.H.P.—E.H.P.	Pressure on L.P. Piston to overcome friction, &c.	Percentage of I.H.P. absorbed by friction, &c.	Mechanical Efficiency.	Pounds of water used per hour per		Heat units used per minute per	
Lbs per sq. in.	Lbs. per sq. in.	Inches.	Inches.						Pf		E.H.P./I.H.P.	I.H.P.	E.H.P.	I.H.P.	E.H.P.
210·6	200·7	29·52	24·09	140·3	30·08	158·4	140·7	17·7	3·34	11·17	·888	12·77	14·39	232	262
190·0	183·5	29·52	24·16	136·3	27·54	140·8	125·2	15·6	3·03	11·07	·889	12·98	14·61	236	265
170·3	162·4	29·32	23·92	141·4	24·01	127·4	113·4	14·0	2·62	10·98	·889	13·21	14·83	239	269
150·0	143·0	29·75	24·26	140·9	21·68	114·5	96·7	17·8	3·34	15·54	·844	13·39	15·85	242	286
130·0	124·0	29·75	24·40	137·2	18·01	92·8	80·7	12·1	2·33	13·03	·869	14·49	16·66	262	301
110·0	107·0	29·75	24·25	140·2	15·70	82·6	68·6	14·0	2·64	16·94	·831	14·51	17·56	263	316
90·0	87·4	29·80	24·27	139·2	12·43	64·9	53·6	11·3	2·14	17·41	·827	15·76	19·07	283	342
70·0	69·4	29·80	24·21	142·3	9·93	53·1	39·5	13·6	2·53	25·61	·744	16·60	22·30	297	399
								14·51 Mean.	2·746 Mean.						



Sequence of Cranks.

TABLE No. VI,

Trials of Experimental Engine at Durham College of Science, Newcastle-on-Tyne.
Cylinders, 7", 10½" 15½," 23"; stroke, 18." Power regulated by boiler pressure.

Boiler Pressure.	H.P. Steam Chest Pressure.	Barometer.	Vacuum.	Revolutions per minute.	Mean Pressure reduced to L.P.	I.H.P.	E.H.P.	Power absorbed by friction, &c. I.H.P.—E.H.P.	Pressure on L.P. Piston to overcome friction, &c.	Percentage of I.H.P. absorbed by friction, &c.	Mechanical Efficiency.	Pounds of water used per hour per		Heat units used per minute per	
Lbs. per sq. in.	Lbs. per sq. in.	Inches.	Inches.						Pf		E.H.P. / I.H.P.	I.H.P.	E.H.P.	I.H.P.	E.H.P.
209·1	200·0	29·77	24·17	138·2	30·29	157·0	140·3	16·7	3·19	10·63	·894	12·53	14·03	227	255
190·0	185·3	30·10	24·49	142·5	27·11	144·9	131·6	13·3	2·47	9·17	·907	13·04	14·36	237	261
170·0	163·1	29·42	24·32	143·1	23·98	128·9	116·0	12·9	2·38	10·00	·900	13·25	14·72	240	267
150·0	146·7	30·10	24·52	143·7	21·91	118·2	103·0	15·2	2 80	12·85	·871	13·31	15·27	241	276
130·0	125 6	29·96	24·47	140·1	18·69	98·3	85·4	12·9	2·43	13·12	·868	13·56	15·61	245	283
90·0	87·0	29·82	24·53	145·7	12·80	69·9	56·1	13·8	2·50	19·74	·802	14·99	18·69	271	337
								14·13 Mean.	2·628 Mean.						

above, but with the power developed by the engine varied by "throttling" the steam before admission to the H.P. steam-chest.

Tables V. and VI. show the results of trials with two different sequences of cranks, the speed of revolution being kept practically constant and the power varied by varying the boiler pressure.

The results of the last five of Mr Croll's experiments are shown in the form of a diagram in Fig. 1., and the results of one set of Prof. Weighton's experiments (Table III., "Expansion" Trials) in Fig. 2.

In these diagrams, the base represents mean pressure referred to the L.P. cylinder. On this base are set up ordinates representing I.H.P. (or to a different scale mean pressure referred to L.P. cylinder), E.H.P., steam used per I.H.P. and per E.H.P. per hour and mechanical efficiencies $\frac{\text{E.H.P.}}{\text{I.H.P.}}$.

As regards the steam consumption shown in the tables and diagrams the following points may be tested:—

The "Meteor" has a boiler pressure of 145 lbs., a total ratio of expansion of 10·6 giving a mean pressure referred to the L.P. cylinder of 29·9 lbs., and a steam consumption of 14·98 lbs. per I.H.P. hour.

In the case of the "Iona" these figures are 165 lbs. boiler pressure, 19 expansions, a mean pressure of 21·13 lbs., and a steam consumption of 13·35 lbs. per I.H.P. hour.

This seems to show the "Iona" to be the more economical engine, but if allowance be made for the probable mechanical efficiencies of the two engines it will be seen that there is very little between them.

In Mr Croll's "expansion" trials (the last five on Table II.) the consumption of steam per I.H.P. hour decreases with decreased ratio of expansion, or, what is the same thing, with increased mean pressure referred to the L.P. cylinder, within the limits of his experiments. Further, if allowance is made for mechanical efficiency it will be seen that the gain is very considerable, and that a still further reduction in the total ratio of expansion would have given a still lower consumption of steam in pounds per E.H.P. hour.

The results of Prof. Weighton's tests confirm all this, although they go much further and show that, with 210 lbs. boiler pressure, steam economy when measured in terms of effective horse power may be expected continually to increase until a mean pressure referred to the L.P. cylinder of 40 lbs. is reached, and probably even beyond that point.

The writer would now direct attention to the question of mechanical efficiency. This question, affecting, as it does, all estimates of the power necessary for the propulsion of ships, has received scant attention at the hands of marine engineers. It is a matter which might profitably occupy many papers, and the writer asks indulgence if he only touches upon such points as are required for his immediate purpose.

It is evident that of the power developed in the cylinder a certain part must be absorbed in driving the engine itself, together with any pumps or connections, and that only what is left is available for propelling the ship. It is manifestly of great importance to know what proportion of the indicated horse power is so available in the case of any engine.

The importance of the matter was fully recognised by Dr Froude, and formed the subject of one of his papers before the Institution of Naval Architects.

In his analysis Dr Froude divided the internal resistance of an engine into three constituents.

1st. The equivalent of the friction due to the dead load.
2nd. The equivalent of the friction due to the working load.
3rd. The equivalent of the air-pump and feed-pump duty.

The power absorbed by these three constituents he estimated, at full power, to be approximately as follows:—

1st. Dead load friction, -	13·0%	of the I.H.P.
2nd. Working load friction,	13·0%	,, ,,
3rd. Air pump resistances, -	6·8%	,, ,
Total,	32·8%	,,

In other words he estimated that at that time approximately one-third of the total power shown on the indicator cards was absorbed by the engine and connected mechanism, leaving only two-thirds available for turning the propeller.

As regards engine resistances at reduced powers, Dr Froude assumed that the "dead load" friction of an engine was constant, and therefore the power absorbed by this constituent of the total resistance varied as the revolutions of the engine. The other two constituents he treated as varying with the developed power or I.H.P. of the engine.

This subdivision of the frictional resistances of a marine engine into the elements of dead load friction and friction due to working load seems to have been adopted by many writers upon screw propulsion. Mr W. F. Durand in his work on "Resistance and Propulsion of Ships" assumes that the total power absorbed by friction may be expressed by an equation of the form

$$Wf = hN \times lW.$$

where

Wf is the total power absorbed by friction.

h is a constant for any given engine.

N is the number of revolutions.

hN is the amount due to what is termed initial friction.

W is the I.H.P.

and l is likewise a constant for any given engine.

This it will be seen is simply Froude's assumption. Mr Durand says "the supposition that the total frictional power may be thus expressed is quite arbitrary, but it seems to answer the purpose required as closely as present data can determine." Further on he states that this "division of the power absorbed by friction is not altogether satisfactory, and the only excuse for its use is our ignorance of a more correct analysis."

Finally, he assumes a case in which he estimates the power absorbed by friction at full power as follows:—

Initial friction, - - - - -	7%	of the I.H.P.
Load friction, - - - - -	7%	,,
Total, - - -	14%	

Mr D. W. Taylor, in his book on "Resistance of Ships and Screw Propulsion," adopts the same method of dealing with engine friction. His estimate for new triple-expansion engines of the present day is, that at full power the amounts are:—

Initial friction.	6 to 10% of	the I.H P.
Load friction,	7%	,,
Total,	13% to 17%	

The writer is of the opinion that with a new triple-expansion engine working with a pressure of 160 lbs. or over, the total engine friction including shafting and air pump need not exceed 12 per cent. at full power, and may be even less.

Leaving the matter at this stage in the meantime the writer would now call attention to the columns relating to engine friction and mechanical efficiency in Tables III. to VI. and also to Tables VII. to XII., which show the results of numerous trials to determine the power absorbed by friction in engines of various types.

It will be noted that most of the experiments have been made at constant speeds of rotation. The absence of a series of trials at constant brake load and varying speeds of rotation are to be regretted.

The general conclusions which may be drawn from the results of these experiments are:—

(*a*) That with constant boiler pressure and constant speed of rotation, the power being varied by varying the ratio of expansion, the amount of power absorbed by friction is practically constant, that is, is independent of the load.

(*b*) With constant boiler pressure and constant speed of rotation, the power being varied by "throttling" the steam before admission to the H.P. cylinder, the power absorbed by friction is slightly less at reduced load than at full power. In other words, the mechanical efficiency is slightly higher at reduced loads when "throttled" than when the power is reduced by "expansion."

(*c*) In every case the mechanical efficiency increases with increased load.

Conclusion (*a*) strikes at the subdivision of engine friction into "initial friction" and "load friction," there being no evidence of anything corresponding to increase of friction due to load. Indeed in many of the experiments the power absorbed by friction is absolutely the same at no load as at full load.

The variation in engine friction with throttled or reduced steam is clearly shown in Prof. Weighton's and in Mr Mellanby's experiments. The pressure on the L.P. piston necessary to overcome friction in these experiments is shown graphically in Figs. 3 and 4.

The base line in these diagrams is mean pressure referred to the L.P. cylinder, the normals representing—to a different scale—the pressure on the L.P. cylinder necessary to overcome friction resistances and air-pump load.

This variation in engine friction with reduced steam pressure is noticed by Prof. Thurston, from whose "Manual of the Steam Engine" Tables X., XI., and XII. are taken.

The only tests given at varying speeds of revolution are those in Table VII. With this engine the power absorbed by friction is actually less in amount and in per centage at 192·4 revolutions than at 176·2 revolutions.

The absence of experimental data prevents any exact conclusio regarding the variation in friction at varying speeds of rotation being drawn, but the writer is of the opinion that for all practical purposes, and until further data is available, it is sufficiently accurate to consider that the power absorbed by friction is independent of the load, and varies as the speed of rotation. In other words that engine friction may be represented by a constant pressure upon the L.P. cylinder. This pressure is called P*f* in

D. K. Clark.

TABLE No. VII.

Messrs R. Garret & Sons—A Compound Portable Engine.

Cylinders, ... 7″ – 10½″
Stroke, ... 10″
Cranks at Right Angles.

Revolutions, - - - - -	176·2	192·4
I.H.P., - - - - - -	30·08	29·14
B.H.P., - - - -	26·13	25·65
Difference Frictional Resistance H.P.	3·95	3·49
Difference % of I.H.P., - -	13·1%	12·0%
Efficiency of Transmission, -	86·9%	88·0%

D. K. Clark.

TABLE VIII.

Speed Constant. Powers Varying.
Corliss Engine. Schlumberger & Co.
Tested by Mm. Walkier-Munier and G. Keller.
Single Cylinder, 24″ × 48″
50 Revolutions.

I.H.P., - - -	72·8	102·0	119·5	133·3	145·4	158·4
Frictional Resistance I.H.P., - -	12·4	12·2	13·5	11·8	12·4	13·6
Frictional Resistance % of I.H.P. - -	17·0%	11·9%	11·6%	8·9%	8·6%	8·5%
Efficiency, - -	83·0%	88·1%	88·4%	91·1%	91·4%	91·5%

D. K. Clark.

TABLE No. IX.

Hirn's Engine. 23¾″ × 67″. 30 Revolutions.

I.H P., - - - -	107	113	125	146	154
B.H.P., - - - -	95	102	114	134	143
Difference, - - -	12	11	11	12	11
Difference % of I.H P., -	11·0%	10%	9%	8%	·7%
Efficiency, - - -	89%	90%	91%	92%	93%

Thurston.

TABLE X.

Conducted by Messrs Aldrich & Mitchell.

8″ Cylinder × 14″ Stroke.

Eccentric Governor.

Revolutions.	Steam Pressure.	I.H.P.	E.H.P.	Difference.	Friction %
232	50	7·41	4·06	3·35	45
230	63	10·00	6·00	4·00	40
230	73	11·75	8·10	3·65	32
230	75	14·02	10·00	4·02	28
230	80	15·17	12·00	3·17	21
230	75	16·86	14·00	2·86	17
231	72	22·07	20·10	2·06	9
229	60	33·04	29·55	3·49	9·5
229	70	43·04	39·85	3·19	7·4
230	90	52·60	50·00	2·60	4·9

Thurston.

TABLE No. XI.
Single Cylinder Engine, $6\frac{7}{8}'' \times 12''$.
Day & Riley.

Revolutions.	Steam Pressure.	I.H.P.	E.H.P.	Difference.	Mean Friction Pressure. Pf	Friction %
282	19	2·26	0	2·26	3·70	100
286	66	10·95	7·61	3·33	5·25	30
285	71	15·99	13·10	2·61	4·25	18
284	74	20·73	18·55	2·65	4·18	12
279	65	25·95	23·61	2·33	3·73	9
280	72	32·22	29·03	3·19	5·15	10

TABLE No. XII.

Thurston.

Same Engine as above.
Experiments to Show Variation of Friction with Variation in Steam Pressure.

Revolutions.	Steam Pressure.	I.H.P.	Mean Pressure.	Mean Friction Pressure. Pf	Friction %	Load on Brake.
				LBS.		LBS.
250	25	6·01	10·84	1·95	18	10
285	42	7·17	11·35	3·63	32	10
271	58	6·81	11·28	3·16	28	10
286	68	7·77	12·25	4·90	40	10
296	82	7·87	12·00	4·68	39	10
279	66·5	1·995	3·22	3·22	100	None.
275	35	1·710	2·80	2·80	100	None
272	25	1·876	3·11	3·11	100	None
270	15	1·712	2·86	2·86	100	None

the Tables I. to VI., XI., XII. and XIV., and it will be noted that in the Newcastle experimental engine the pressure necessary to overcome friction and air-pump resistances is practically 3 lbs. per square inch in the "expansion" trials, with about 210 lbs. boiler pressure. This is rather under 10 per cent. of the total mean pressure at 17·4 expansions.

Although the writer admits that his opinion regarding the variation of friction with speed of rotation may not be accepted without further experiment, he is confident that no one will dispute the fact that the mechanical efficiency of all engines must increase with increase of load.

Further, he thinks that Mr D. Croll's experiments, and still more those of Professor Weighton, show conclusively that, generally speaking, the average engine in the merchant marine is working with a total ratio of expansion which could be considerably decreased without reduction in steam economy when measured in units per I.H.P per hour, and which would show a really substantial gain in steam economy when measured in units per E.H.P. per hour.

This is one of the lessons which Professor Weighton drew from his experiments, and which he set forth in his admirable paper.

At this stage it may be interesting to compare the results obtained from the "Meteor" and "Iona" as set forth in Table I. in the light of the probable mechanical efficiencies of the engines of these vessels. In doing so it should be borne in mind that the engines of the "Meteor" were designed to develop on each alternate voyage a much greater amount of power than was developed on trial. This would in many ways interfere with the economy of the engine at the power at which they were tried, as compared with an engine designed to give the trial power only, at the same ratio of expansion.

If the pressure necessary to overcome the engine friction P_f be taken at 3 lbs. per square inch in each case, the mechanical efficiency of the "Meteor" is seen to be 90 per cent. and that of the "Iona" 85·8 per cent. The amount of heat used per E.H.P.

being 295 and 291 units respectively—a very slight economy in the case of the "Iona," when it is kept in mind that the boiler pressure was 20 lbs. higher than that of the "Meteor."

When it is further noted that the machinery of the "Iona" weighed 6·26 cwts. per I.H.P., while that of the "Meteor" weighed only 3·91 cwts. per I.H.P., it is seen that the machinery of the "Meteor" was commercially the more efficient.

The writer is strongly of opinion that in the case of a triple-expansion engine working with a boiler pressure of 180 lbs. the valve settings should be arranged to give a mean pressure referred to the L.P. cylinder of at least 35·5 lbs. in ordinary working. From the results of his own experience, coupled with the data from Prof. Weighton's experiments, he is thoroughly convinced that this pressure would be obtained without the slightest increase in the steam consumption when measured in units per I.H.P., and with increased economy when measured—as it ought to be—in units per E.H.P.

As an example of modern cargo boat machinery, take that of the s.s. "Indrani" built and engined by Messrs Vickers, Sons & Maxim, of Barrow, particulars of which are given in Mr M'Kechnie's "Review of Marine Engineering during the last ten years," a paper read before the Institution of Mechanical Engineers in July, 1901.

The following are the particulars given:—

Cylinders, 27", 44", 72" diameter.
Stroke, - - 48"
Boiler pressure, 180 lbs.
Piston speed, 640 feet per minute.
I.H.P., 2120.

This power corresponds to a mean pressure referred to the L.P. cylinder of 26·9 lbs. The revolutions per minute corresponding to the piston speed are 80.

The reduction which could be made on the size of these engines upon the lines advocated by the writer is shown in the following table

NAME.	Cylinders.		Revolutions.	Mean Pressure referred to L.P.	I.H.P.	Assumed Value of P_f	Mechanical Efficiency.	E.H.P.	Consumption of water at 14 Lbs. per I.H.P. Hour.
	Diameter.	Stroke.							
									Lbs.
S.S. "Indrani"	27″,43″,72″	48	80	26·9	2120	3·00	·89	1885	29,680
Proposed Engine	24″,40″,64″	45	80	35·5	2070	3·00	·91	1885	28,980

In making out these figures it is assumed that the friction pressure Pf may be taken at 3 lbs. per square inch on the L.P. piston. Upon this assumption the mechanical efficiency of the "Indrani's" engines is—

$$\frac{23\cdot9}{26\cdot9} = \cdot89.$$

It may be objected that this is pure assumption; but consideration shows that (1) it is not likely to be an excessive estimate, but rather the reverse; (2) if the estimate is too low it merely means that the gain to be obtained upon the lines suggested by the writer is somewhat greater than he claims.

A mechanical efficiency of 89 per cent. means that the effective power available at the propeller is—

$$\frac{2120 \times 89}{100} = 1885.$$

Again, as the friction does not increase with the load (the speed of revolution being constant) the same friction pressure Pf may be assumed with the proposed increased mean pressure. The mechanical efficiency of the proposed engine would therefore be—

$$\frac{32\cdot5}{35\cdot5} = \cdot91$$

And the I.H.P. corresponding to 1885 H.P. at the propeller would be—

$$\frac{1885 \times 100}{\cdot91} = 2070$$

At 80 revolutions per minute and with a mean pressure of 35·5 lbs. the engine necessary for 2070 I.H.P. would be—

Cylinders 24″, 40″ and 64″ diameter respectively, and stroke 45″.

This is a considerable reduction in the size of the engines.

The points in favour of the proposed reduction are—

1. A substantial reduction in the first cost of the machinery.
2. A reduction in coal consumption due to the increased mechanical efficiency. In the case stated the gain may be represented by a reduction of ¾ of a ton per 24 hours.
3. Increased deadweight carrying capacity, due to (*a*) reduced weight of machinery and (*b*) to reduced weight of bunker coal. The reduction in weight of machinery may be put at 30 tons, and 60 days less coal at ¾ of a ton per day amounts to 45 tons, or a total gain in carrying capacity of 75 tons.
4. The engines are more moderate in size and consequently more easily overhauled.

When it is considered that increased carrying capacity and diminished coal consumption are claimed in addition to reduced first cost, surely the proposal is worthy of the serious consideration of all marine engineers and shipowners.

Since writing the above, the Second Report of the Committee on Water-Tube Boilers has been published.

This report contains, in addition to other valuable matter, an account of the engine trials of H.M.S.'s "Minerva" and "Hyacinth" and of the R.M.S. "Saxonia."

As the results obtained on these trials seem, at first sight, somewhat at variance with the conclusions arrived at in the paper, the writer has thought it advisable to refer to them.

A few particulars of the engines are therefore given in Table No. XIII., and an abstract from the results of the trials in Table No. XIV. These results are also plotted in the form of curves in Fig. 5.

TABLE No. XIII.

	H.M.S. "Minerva."	H.M.S. "Hyacinth."	R.M.S. "Saxonia."
Date of Contractors' trial -	1896.	1899.	1900.
Description - - -	Vertical triple-expansion.	Vertical triple-expansion.	Vertical quadruple-expansion.
Number of cranks - -	3	4	4
Diameter of cylinders—H.P.	S. $33\frac{3}{32}''$ P. $33\frac{7}{64}''$	26″	29″
" " I.P.	$49\frac{5}{32}''$ $49\frac{17}{32}''$	42″	1st $41\frac{1}{2}''$ 2nd 59″
" " L.P.	74 74	48″ (2 to each set).	84″
Length of stroke - -	3′ 3″	2′ 6″	4′ 6″
Maximum pressure for which engines are designed -	150 lbs.	250 lbs.	210 lbs.
Where auxiliary engines can exhaust to - - -	Auxiliary condensers and atmosphere.	Low pressure receivers, evaporators, auxiliary condensers, and atmosphere.	Low pressure receivers, auxiliary condensers, main condensers, and atmosphere.

TABLE No. XIV.

Name of Vessel.	Steam Jackets in Use.	Pressure in H.P. Steam-Chest. Lbs.	Vacuum. Inches.	Revolutions per Minute.	Mean Pressure reduced to L.P.	I.H.P.	Mean Pressure Absorbed by Friction (P*f*)	Mechanical Efficiency	Pounds of Water Used per Hour,		Heat Units Used per Minute.	
									Per I.H.P.	Per E.H.P.	Per I.H.P.	Per E.H.P.
H.M.S. "Minerva" (*a*)	All	80	27·40	83·3	15·2	2142	*3·0*	*·79*	16·18 (*c*)	*20·5*	293	*371*
,, ,, (*a*)	All	128	26·45	108·2	26·1	4771	*3·4*	*·87*	15·44 (*c*)	*17·7*	283	*325*
,, ,, (*a*)	All	138	26·35	110·7	27·6	5155	*3·4*	*·87*	13·82 (*c*)	*15·9*	253	*290*
,, ,, (*a*)	All	136	26·25	128·55	37·4	8132	*3·5*	*·906*	16·66 (*c*)	*18·4*	305	*337*
H.M.S. "Hyacinth" (*a*)	L.P. only	110	26·45	99·8	18·1	1967	*4·0*	*·78*	17·21 (*c*)	*22·1*	316	*405*
,, ,, (*a*)	None	167	26·75	135·65	33·6	4957	*4·5*	*·865*	15·56 (*c*)	*18·0*	286	*330*
,, ,, (*a*)	None	192	25·85	157·35	45·7	7795	*5·0*	*·89*	15·78 (*c*)	*17·7*	292	*328*
,, ,, (*a*)	None	220	24·55	170·7	54·8	10,180	*5·4*	*·98*	16·40 (*c*)	*18·2*	321	*346*
H.M.S. "Hyacinth" (*b*)	L.P. only	100	26·45	101·55	18·8	2079	*4·0*	*·788*	18·80 (*d*)	*23·8*	346	*438*
,, ,, (*b*)	L.P. only	167	26·4	138·35	33·4	5025	*4·5*	*·865*	17·00 (*d*)	*19·7*	312	*361*
,, ,, (*b*)	None	167	26·65	136·9	33·4	4975	*4·5*	*·865*	16·68 (*d*)	*19·3*	307	*355*
,, ,, (*b*)	None	194	25·15	159·35	47·8	8277	*5·1*	*·892*	17·67 (*d*)	*19·8*	326	*366*
,, ,, (*b*)	None	220	24·55	170·7	54·8	10,180	*5·4*	*·900*	18·23 (*d*)	*20·3*	356	*396*
R.M.S. "Saxonia" (*b*)	None	192	25·35	77·75	39·0	9099	*3·75*	*·908*	13·47 (*c*)	*14·9*	248	*274*
,, ,, (*b*)	None	192	25·35	77·75	39·0	9099	*3·75*	*·903*	14·33 (*d*)	*15·9*	264	*292*

NOTE—(*a*) Open exhausts.
(*b*) Closed exhausts.
(*c*) Steam for main engines and jackets only, no auxiliaries or feed make up
(*d*) Including steam required for auxiliaries but no feed make up.

Before proceeding to discuss these results the writer would emphasize the point that the possible reduction in the size of marine engines advocated in the paper is based upon the assumption that the speed of revolution is not altered. Any alteration in the number of revolutions per minute introduces a new set of conditions.

This is made clear by experiments conducted by Professor Weighton on the following lines:—

The engines were set to develop about 70 I.H.P. at 100 revolutions per minute, the load upon the brake being adjusted accordingly. A set of readings was taken under these conditions.

The engines were left untouched in every way, and readings were taken at reduced brake loads.

As might be expected, each reduction in brake load was accompanied with an increase in the speed of revolution, and with a reduction in the mean pressure referred to the L.P. cylinder. The consumption of steam per both I.H.P. and E.H.P. was gradually less until a certain point was reached; beyond that point the consumption of steam gradually increased.

The reduction in mean pressure referred to the L.P. cylinder amounted, between 100 and 170 revolutions per minute, to 2 lbs. per square inch.

This reduction in mean pressure due to increased speed of revolution and consequent increased friction in the steam passages, coupled, especially in the case of the "Hyacinth," with a reduced vacuum at higher speeds and powers, is sufficient to account for the early points at which maximum economy (as measured in lbs. of steam per I.H.P. hour) was attained in the "Minerva" and "Hyacinth" trials.

The value assigned to P*f* and to the mechanical efficiency of the engines is of course merely an estimate of what the writer considers probable under favourable circumstances, and is intended to show the effect of the mechanical efficiency upon the point of real maximum economy in steam consumption.

The "Saxonia" was tried at one power only—that corresponding to a mean pressure reduced to the L.P. cylinder of 39 lbs. per square inch. The results obtained would probably have been still better at a higher power.

Before proceeding to the discussion on this paper, which took place on 15th April, 1902,

Mr E. HALL-BROWN said that those who had been present during the reading of his paper, or had done him the honour of reading it since, would remember that one point raised was the question of the friction of marine engines at various speeds, and in the paper he expressed the opinion that the pressure on the low pressure engine necessary to overcome the friction in the engine was practically a constant quantity. Through the kindness of Prof. Weighton, he was in a position to supplement the data given in the paper by the record of a series of most important engine trials having a direct bearing upon the question of the mechanical efficiency of marine engines at various powers and speeds. Particulars of these trials were given in Table No. XV., and curves of the results were plotted in Figs. 6, 7, and 8. These trials were made with the experimental engine at Durham College of Science. The engine was arranged as an ordinary three-crank triple-expansion engine, with cylinders 7″, 10½″, and 15½″ in diameter respectively, and a stroke of 18″. The cranks were set at angles of 120° respectively, the sequence being H.P., I.P., L.P. The mean cut-off in each cylinder was 66° of the stroke. This was kept constant throughout the trials, the speed being varied by varying the steam pressure. As in the other trials with that engine, the air pump was driven by the engine in the ordinary way. Table XV. showed the actual results obtained on these trials. It would be noted that—as was invariably the case—there were slight discrepancies in some of the figures. In other words, the "spots" did not all fall, as they should do, on a fair curve. These slight discrepancies might be ascribed to errors of observation, indicator errors, slight variations in steam pressure, and the like. In drawing the curves in Figs.

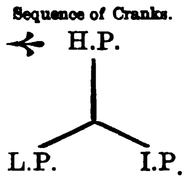
TABLE No. XV.

Trials of Experimental Engine at Durham College of Science, Newcastle-on-Tyne.

Cylinders, .. 7", 10½", and 15½". | Stroke, ... 18".

Constant brake adjustment. Steam pressure varied.

Receivers drained. Cranks at 120°.


Sequence of Cranks.

Cut-Off.			Boile Pressure.	Vacuum.	Revolutions per Minute.	Mean Pressure reduced to L.P.	I.H.P.	E.H.P.	Power absorbed by friction, &c. I.H.P.—E.H.P.	Pressure on L.P. Piston to overcome friction, &c. P/.	Percentage of I.HP. absorbed by friction, &c.	Mechanical Efficiency I.H.P. / E.H.P.	Pounds of water used per hour per		Total Water used per hour.
H.P.	I.P.	L.P.	Lbs.	Inches—about									I.H.P.	E.H.P.	Lbs.
·66	·66	·66	113	24	97·63	34·17	56·3	48·3	8·0	4·79	14·2	·858	16·54	19·28	931·3
·66	·66	·66	133	—	104·3	38·33	67·7	62·3	5·4	3·02	7·9	·921	16·18	17·57	1095·6
·66	·66	·66	161	—	115·2	46·02	89·6	80·0	9·6	4·86	10·7	·893	15·44	17·30	1384·0
·66	·66	·66	177	—	125·8	50·80	107·9	97·8	10·1	4·68	9·4	·906	15·09	16·65	1629·0
·66	·66	·66	196	—	139·4	54·87	129·4	121·6	7·8	3·26	6·0	·940	15·16	16·13	1962·0

6, 7, and 8, an attempt had been made to eliminate these discrepancies, but the actual "spots" from Table XV. were shown on the various diagrams. The curves shown in Fig. 6 were drawn in the same manner as those shown in Fig. 2, but, as the speed of revolution was not constant, the curves of "mean pressure referred to L.P. cylinder" and of "horse-power" were not similar. Fig. 7 showed the same results plotted upon a base of "revolutions per minute." Fig. 8 showed the variation in the values of P*f* upon a base of "revolutions per minute." It would be noted that the special value of these trials lay in the fact that both the load upon the engine and the number of revolutions were varied. The variation in the load was due to the alteration in the speed of revolution, as the resistance of the brake, which was of the turbine type, increased with increased speed of revolution. Thus at 97·63 revolutions per minute, the indicated H.P. was 56·3, while at 139·4 revolutions per minute it was 129·4. It would be noted that the value of P*f* (the pressure per square inch on the L.P. cylinder necessary to overcome the engine friction and air-pump resistance) was practically constant throughout these trials. That was exactly in accordance with the writer's opinion as expressed in the body of the paper. Regarding the steam consumption, it was also worthy of note that the steam consumption per I.H.P. hour and per E.H.P. hour was least at the maximum power attained, corresponding to a mean pressure referred to the L.P. cylinder of 54·87 lbs. per square inch, the initial steam pressure being 196 lbs. per square inch, and the vacuum 24 inches.

Discussion.

Prof. R. L. WEIGHTON, M. A., (Member) said that he had perused Mr Hall-Brown's paper with very great interest indeed, and he could conscientiously say that he concurred in the main with every one of his conclusions. The lesson which he taught as the result of his studies on this question was one which he, (Professor Weighton), thought at the present day was very much needed. He himself had made a great many experiments bearing

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more or less directly on the subject, and the more experiments he made he got the more convinced that if the maximum economy in the true sense of the word was to be attained, that was in terms of water used per brake horse power, then engines must be made considerably smaller than was the custom at the present day. That was the general lesson which was taught by such experiments. The subject was rather a favourite one with him and he was very glad of that opportunity to refer to it further. Reduced to its lowest terms, the question which the writer of the paper had dealt with might be stated thus. A little consideration would show that what was required was to arrive at the maximum-economy degree of expansion for any given boiler pressure and any given type of engine. It was quite obvious that after that was determined, the dimensions of the cylinders would follow for a given horse power and piston speed, so that if they could ascertain the number of expansions they had determined all they required, the mean pressure being one of the results which would follow from the number of expansions, and the diagram factor depending upon the type of valve gear of the engine designed. It used to be a very prevalent opinion that it was scarcely possible to carry expansions too far in a multiple-expansion engine, or at any rate that the limit of expansions was not reached until the terminal pressure of the last cylinder fell very nearly to the back pressure. That had been proved by experimental research to be an absolute fallacy, and very wide of the mark indeed, and theoretical considerations were found to support the results of experimental research. In addition to the back pressure in the low pressure cylinder, there were several other considerations which had to be taken into account in determining the best number of expansions used; for instance, in addition to the back pressure, there was the friction of the mechanism, which was, like back pressure, waste power. There was also condensation throughout the cylinders. Any condensation represented waste power in the shape of disappearance of heat. And there were also the leakage of pistons and valves, and the effects of clearance spaces. There might be other factors, but these at least must be taken into account in fixing the most economical number of expansions. Hitherto he submitted that at least the three last had been overlooked as a rule. The larger the engines were for a given power, it was quite obvious that the greater would be the loss from all those several sources of loss, and therefore if engines were built needlessly large for their power, greater and greater losses were incurred from those several sources; and a little consideration would show that if in any case the terminal pressure in the low pressure cylinder fell below that pressure in lbs. per square inch, which was equivalent to back pressure, initial friction, condensation, clearance and leakage, then that engine was working less economically than it would do if it were worked with less expansions and at higher power in order to raise the back pressure a little above this limit. As he had mentioned he had made a great many experiments bearing upon this subject, and to emphasize the point he would call attention to Fig. 10, which showed results from the same engine worked in three different ways. Curve A referred to cylinders 7″ and 15½″ diameter; Curve B referred to cylinders 7″, 10½″, 15½″ diameter, and Curve C referred to cylinders 7″, 10½″, 15½″ diameter. The stroke was the same in all, viz., 18″. It would be noticed that maximum economy occurred in A and B when the expansions were 12 times, and in C when the expansions were 7 times. The notes on the diagram rendered it self-explanatory, but attention might be called to the great influence on maximum-economy expansions, of the increase in back pressure due to working without a vacuum. Curve C was not strictly comparable with A and B, because the pressure was different, but as far as it went, it was instructive. It was a moot question how far results such as these—obtained as they were from engines of comparatively small size—could be applicable without modification to very much larger sizes. Size, of itself, would not affect back pressure per unit of area of piston; but it might reasonably be expected to affect, to some unknown, though probably not great extent, the relative friction, condensation,

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clearance, and leakage losses. The general result would be that the most economical number of expansions would rise in some degree with engine dimensions. How much it was impossible to say, without further experiment. The table annexed was given as a further illustration:—

No.	B.H.P.	Expansions. (rR)	$\frac{\text{B.H.P.}}{\text{I.H.P.}}$	I.H.P.	M.P.	Cylinders.			Water used per	
						″	″	″	B.H.P.	I.H.P.
I.	1000	8	·95	1052	54	18	27	40	16·6	15·7
II.	1000	12	·93	1075	42	18½	29	47	16·0	14·8
III.	1000	20	·90	1111	30	19	33	57	16·6	14·9

r = nominal ratio of expansion in H.P. cylinder = $\frac{\text{stroke}}{\text{cut off}}$.
R = ratio of low pressure cylinder to H.P cylinder.
M.P. = Mean pressure reduced to low pressure cylinder.
Boiler pressure assumed at 200 lbs. above atmosphere.
Stroke, 3 feet; revolutions, per minute, 80.

Taking Curve B in Fig. No. 10 as a basis, it would be seen that an engine of given power—say, 1000 B.H.P.—might be designed in two ways for a given economy—say, for 16·6 pounds of feed-water per B.H.P. per hour. It might be small or large. If small, it would work with eight expansions; if large, with twenty expansions. The resulting dimensions were given in Nos. I. and III. of above Table. The engine in No. II. was the size for maximum economy, *i.e.*, with twelve expansions. He did not think Mr Hall-Brown could reasonably expect any legitimate conclusions from trials of the "Minerva" and "Hyacinth" bearing on the point of his paper. The tables for the "Minerva" and "Hyacinth" showed that the engines were throttled, and they were also linked up to some extent. It was not specially mentioned, but he had made a calculation which showed that it must be so. He knew, as a matter of fact, that engines were worked that way in the Navy, partially linked and partially throttled. The results from these trials could not, therefore, be expected to yield information on the subject of the most economical expansions at given pressures. If these engines had not been linked up the water per H.P. would never have attained a minimum; it would always have been on the down grade, and the fact that they *did* attain a minimum showed that they were expanded to some extent by linking up. He reckoned that the best mean pressure would occur in the "Hyacinth" at 43 lbs , while the best mean pressure in the "Minerva" would occur at about 36 lbs., if the engines of these ships had been tested at maximum boiler pressure, and at various expansions.

Prof. J. H. BILES, LL.D. (Member of Council) said that he had had the opportunity, before the meeting, of reading the figures sent by Sir A. J. Durston.* In addition to the figures of the actual friction test, the horse power and revolutions with the ship in dock were given with no load on, and they had a bearing on Mr Hall-Brown's paper. In the case of the "Hyacinth" for mean revolutions of 179 the horse power was 590, and for mean revolutions of 22·2 the horse power was 51·5, which showed that the horse power did not vary directly as the revolutions in the "Hyacinth." In the "Minerva" the maximum revolutions were 141 and the indicated horse power was 527. At 20 revolutions it was 60, and at about half-way between, namely, at 81 revolutions it was 200. There again the horse power due to friction was not in proportion to the revolutions. It was also interesting to know that the horse power due to engine friction (that was dead load friction) was about 6 per cent. in the case of the "Hyacinth" and about 5 per cent. in the case of the "Minerva." That, he thought, was a common result of horse power due to dead load friction in relation to the maximum horse power. He did not know whether Mr Hall-Brown knew that a great many results had been published in America, by the United

* See page 315.

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States Engineers' Naval Institute, giving details of horse power for different auxiliary engines and also the horse power due to light load, and in all the more recent engines the horse power due to engine friction was, he thought, from 4 to 6 per cent.

Mr James Welsh (Member) wished to say a word on the subject of engine friction. In 1893 he brought before the Graduates' Section curves of friction horse power which closely resembled that shown by Prof. Weighton. The curves were constructed to illustrate the results of a series of trials with a small triple-expansion three-crank marine engine, with a stroke of 10 inches, running at from 100 to 350 revolutions per minute. The method adopted was to run the engine with a steady brake load and vary the revolutions. Data was obtained with four different brake loads, and it was found that for a given speed the horse power absorbed in friction was constant. The greatest discrepancy between the curves occurred at the highest speeds, and was probably due to indicator errors. The conclusions arrived at were that the trials confirmed some remarks by Prof. Thurston published about the same time, and which might be stated as follows:—

1. "The friction of an engine was constant at any given speed at all loads, and was at different speeds entirely independent of the magnitude of the load."
2. "The friction of an engine was variable with variation of speed of engine, increasing as the speed increased in some ratio as yet undetermined but probably different with every engine, and for the same engine with every change of conditions of operation."

It would be interesting if Prof. Weighton would supplement his information by giving additional curves of I.H.P. and E.H.P. with different brake loads, and he had no doubt that the results would bear out the foregoing. The discussion on the most economical ratio of expansion was very instructive and he considered Mr Hall-Brown's conclusions were correct.

Mr Thomas Laidlaw (Member) said that as a rule the practice on the Clyde was to work with a higher referred mean pressure than was the case with the general run of North-East Coast builders, because of the demand on the Clyde for the maximum power in the minimum space for many of the ships built. The builder was compelled to keep a low ratio of cylinders with a late cut-off in the H.P. cylinder, in order to secure the high referred mean pressure, which, together with a high piston speed, gave the maximum power. Now, it would appear from the remarks of a previous speaker, that the greatest economy as well as power, was the result of this high referred mean pressure. The point he should like observed was that on the North-East Coast, where the object aimed at principally was economy, a much greater ratio of cylinders and an early H.P. cut-off, with a correspondingly low referred mean pressure, was adopted.

Mr James Andrews (Member) remarked that Mr Hall-Brown had introduced a subject which was full of interest and he had much pleasure in joining in its discussion. He was exceedingly pleased to see Professor Weighton at the meeting to more fully explain the result of his trials and to give his views on the question generally. He had intended to say something regarding the friction of high speed engines, but as it had been so often referred to there was little room to add anything new. Professor Biles had referred to what the Americans had been doing in that connection, and he himself had brought a diagram which he had constructed, on the same lines as those shown by Mr Hall-Brown, from the results of trials made on an American engine.* The trials of this engine were very complete and were conducted upon similar lines to those of the Durham College engine. The engine had steam cylinders of 9″, 16″ and 24″ diameter respectively by 36″ stroke, running at 87 revolutions per minute, with a boiler pressure of 120 lbs. per square inch and a pressure of 115 lbs. per square inch at the engine. The cylinders were approximately in the ratio of 1, 3, 7, and were combined to form three engines as follows:—(1) A

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* Trials on Sibley College Engine by Thurston and Brinsmade.

Mr James Andrews.

compound engine having steam cylinders 9" and 16" in diameter; (2) a compound engine having cylinders 9" and 24" in diameter; and (3) as a triple-expansion engine having cylinders 9" 16" and 24" diameter respectively. The trials recorded in Fig. 11 were from the triple-expansion engine, and that diagram seemed to him to discount a great deal of the proposal that the number of expansions of a triple-expansion engine must be reduced to such an extent that, they would have 35 lbs. or 40 lbs. per square inch mean pressure reduced to the L.P. cylinder before the point of maximum economy was reached. In this case the point of maximum economy was clearly defined at 16 lbs. mean pressure reduced to the L.P. cylinder, and the number of expansions was 22. A peculiar thing about it was that when worked compound the form of curve for this engine was almost an exact copy of that shown on Professor Weighton's diagram, but the point of maximum economy was different. The 1 to 3 compound engine attained its maximum economy at 16 expansions, while the 1 to 7 compound engine had not quite reached that point, as far as the trials went, down to 20 expansions. It seemed to him that if the steam pressure of this engine was increased from 120 lbs. up to 210 lbs. per square inch, as in the Durham College Engine, it would make a still greater difference between the most economical rate of expansion in the two engines. Professor Weighton had referred to one or two very important points, one of which was cylinder condensation. That he considered was a factor of the utmost importance. What was cylinder condensation? Surely it could not be that the heat was transmitted through the cylinder walls to the outside. It seemed to him that the heat was lost due to the accumulation of water in the cylinder, and that it would make a great difference in those curves if an engine were tested in which water could not accumulate in the cylinder; as, for example, an engine with Corliss valves where the water could be got rid of readily, and he thought that that must have something to do with the difference between the points of maximum economy at 16 lbs. per square inch in the one engine and 40 lbs. per square inch in the other engine. He thought that they would be making a great mistake if the trials of one engine were to be accepted as conclusive, however elaborate and however many experiments were made. He did not think that the problem could be solved until they had had a great many similar tests upon different engines and of different designs, and he thought that Professor Weighton had led the way by laying down a systematic basis. One gentleman had referred to the cylinder ratios which were adopted on the Clyde, as distinct from those on the Tyne. He doubted very much if a ratio of 1 to 5 was very much of an improvement over 1 to 7, which latter was said to be the Tyne practice. It was well known that, in the days when a steam pressure of 150 lbs. was most common in British war vessels, the cylinder ratio was 1 to 5, and it was notorious that they were the least economical engines made; but the argument of Admiralty officials was that those engines were not designed with a view of obtaining maximum economy at full power, but that they were most economical at low powers. What conclusion could be drawn when they were told on the one hand that a cylinder ratio of 1 to 5 was not adopted for economy, and now on the other hand the same ratio was being adopted on the Clyde, because it was economical. It seemed to him that the arguments were rather conflicting.

Mr JOHN RIEKIE (Member) said that the results of the trials made by Professor Weighton, which showed that the efficiency of an engine fell off with increase in expansion, induced him to say a few words. It appeared to him that if a wider range of expansion had been arranged for by cutting off early in the H.P. cylinders, as was done in the simple engine, the results of the trials might have been different. With the engine having the 18-inch, 27-inch and 40-inch cylinders, in place of increasing the range of expansion a stage further by increasing the diameter of the L.P. cylinder, he would advocate the use of two 18-inch high pressure cylinders with a cut-off of 30 per cent. In this way the expansion of steam would be continuous, and not only would a greater number of expansions be obtained, but receiver drop would be reduced to a

Mr John Riekie.

minimum. As still earlier cut-offs could be used with this system, it was more than probable that the efficiency would increase in ratio with the number of expansions. This system of compounding was at work on two locomotives, and one portable engine in India. So far the trials had been made on non-condensing engines only, but as a pressure of steam as low as from 5 to 10 lbs. could be used in the receiver, and this at a constant pressure, it appeared to him that the system was the nearest approach in efficiency to a condensing engine, and when used on a condensing engine should give good results. He would be pleased to read a paper on this improved system if some member such as Mr Hall-Brown would collaborate with him, so that the matter might be clearly set forth.

Mr A. Scott-Younger, B.Sc. (Member), observed that he had, unfortunately, not got the paper in time to study it as he would like to have done, and as it deserved to be studied, but he was very pleased to have heard the discussion, which had been exceedingly interesting. If Mr Hall-Brown was right—and *he* was following the lead of Prof. Weighton—it seemed to him that the design of the great majority of marine engines in existence at the present day must be defective. There was no doubt that, judging from the results submitted to the meeting, the number of expansions at which these engines were worked was considerably too high; and, if these figures were correct, considerable economy would result from reducing the ratio of the cylinders. He had been struck by Professor Weighton's closing remarks, which, he thought, were very much to the point. He (Prof. Weighton) had indicated that it was perhaps hardly correct to reason from the results obtained from one small engine, and apply these results to every type of engine, small and large, with different boiler pressures, and so on. It seemed to him that that statement was thoroughly justified. He could hardly imagine that it was the correct thing to generalise from the results obtained from one individual engine, no matter how many experiments were made from it. He expressed his personal thanks to Mr Hall-Brown for bringing up the matter that evening.

Mr W. B. Sayers.

Mr W. B. Sayers (Member) said he would like to ask Mr Hall-Brown whether he was the initiator of the letters "E.H.P." The reason why he asked was that those who had to do with electrical machinery had used the letters "E.H.P." as meaning "electrical horse power," and, if they had appropriated a term which had already been in use among mechanical engineers, they ought to alter it; but if Mr Hall-Brown had now initiated the use of the letters to indicate "effective horse power," he hoped that he would see his way to alter it, because any electrical engineer would understand it to mean "electrical horse power" at once. With regard to Fig. 8 of Prof. Weighton's experiments, he would like to point out that the curve P*f* was really not justified by the spots at all. He did not know what it ought to be like, but, if he were drawing that curve from the spots, he would certainly think that he had four spots. To select three out of five, and utterly neglect the other two, did not seem to be at all justifiable.

The President said that it occurred to him that perhaps Professor Weighton might like to make some further remarks.

Prof. Weighton said the only point he would like to have further elucidated was about the remarkable diagram put up by Mr Andrews. As he had said already he was a bit of a sceptic of everything till he had had it proved, and although he did not claim that the trials of one type of engine could possibly be applicable in an absolute sense to all types, still he thought they were *fairly* applicable, and that the difference should not be so great as was shown between those diagrams. He would like to ask, if he might, that Mr Andrews should supply full information about the engine so that one might try and follow it up by finding out where the discrepancy lay. He was convinced that there was a discrepancy—it was such a difference—and if that engine was working at anything like 116 lbs. boiler pressure with a maximum economy at expansions of 16 or 20, then certainly there was room for further inquiry into the matter. It was entirely at variance with every individual experiment he had ever made, and he had made experiments not only on a small engine, but on full-sized commercial engines both condensing and non-condensing.

Mr Andrews.

Mr Andrews said that those trials were made on the Sibley College engine by Messrs Thurston and Brinsmade, and were published in the Transactions of the American Society of Engineers; they were also published in this country in "Industries and Iron" for 17th December, 1897. He might also add that the trials of some of the engines were carried out in precisely the same way as those by Professor Weighton; that was to say, the number of expansions in each cylinder was varied independently until the most economical rate of expansion in all the cylinders combined was obtained, and from the best results those curves were made. He would have preferred to show the diagrams in the same form as Professor Weighton had done; namely, with the steam consumption relative to the total number of expansions, not only because that was how they were given in the original paper but because it seemed to him to be far more intelligible; however, he had prepared his diagram to compare with those given in the paper. As he had said the curves from the American engine had the point of maximum economy more clearly defined than those from the Durham College engine. There was none of the flatness in them as shown in Fig. 2, they were more after the nature of the upper curve in Professor Weighton's diagram. It seemed to him that they were just learning how to go about this intricate problem, and it was such experimenters as Professor Weighton who had the facilities and opportunities, which manufacturing engineers had not, that they must look to for its solution.

Mr E. Hall-Brown in reply said that with regard to the tables sent by Sir John Durston it was of course impossible for him to say anything off-hand. Those figures might be absolutely contrary to anything that was in the paper, as Professor Biles seemed to assume, or they might confirm the conclusions arrived at in the paper, but it was impossible for him to say anything regarding them until he had had an opportunity of studying the communication. He had, however, no doubt that if properly analysed they would be found to corroborate the other experiments on engine friction. He was very much indebted to Professor Weighton for his presence there that evening and for his remarks. It had been quite an unexpected pleasure to him. He thought Professor Weighton had been unduly modest in his estimate of the importance of his experiments when he said that, he did not feel justified in saying that the conclusions arrived at could be absolutely applied to engines of very large power, such as 5000 or 6000 H.P. He agreed with him so far, provided there was no misunderstanding regarding what was meant by applying the conclusions arrived at. That was to say that, although the best ratio of expansion for the Newcastle engines might not be exactly the best ratio for much larger engines, it was sufficiently near to point clearly to the direction in which increased economy lay.

Mr Andrews—If he might be allowed to interpose for a moment, he would say that he had had many opportunities of testing small engines of different sizes, both simple and compound, and he had found a very great difference between the steam consumption of the large and the small sizes, whether running at the same speed of revolution or the same piston speed.

Mr Hall-Brown—That was quite right, but it did not interfere with what he had said. With regard to the "Minerva's" trials, he had no intention of saying that they were not conclusive as regarded the questions raised in the paper. The steam consumption trials were interesting, as turning up at a time when he was preparing this paper. In drawing the steam consumption curves, Prof. Weighton was quite at liberty to choose the spots which he considered most correct, and to draw the curve accordingly. He did not insist upon his explanation of the discrepancies in the trials being accepted as necessarily the correct one. Prof. Biles had remarked that the American engineers had published a lot of results of trials, but he did not quite gather whether these were brake H.P. trials of full power marine engines. If they were, they were most important, and he hoped that Prof. Biles would find it convenient to give them the results, so as to have them in-

Mr Hall-Brown.

corporated in the Transactions. The results of such trials of engines of 5000 or 6000 H.P. would be well worthy of a place in the Transactions. Prof. Biles had said also that, as the result of experiment, the amount of power absorbed in friction was found to be something between 4 and 6 per cent. He was very glad to hear it. The engines must have been very economical, and a long way ahead of the engines that seemed to have inspired the chapters on friction in Prof. Thurston's book, and several others of the leading writers on the American continent. At the same time, anyone who read the paper would see that he stated very clearly that he considered the friction of marine engines to have been generally overestimated. With regard to the question of engine friction at increased speeds of revolutions, there was no doubt that, theoretically, the friction of an engine *ought* to increase as the revolutions increased. That had been pointed out by Prof. Thurston and others. He had, however, come to the conclusion that in ordinary marine engine practice the pressure required to overcome frictional resistance was, as nearly as they could judge, constant, irrespective of both revolutions and power. There seemed to be considerable misunderstanding as to what the trials of the Newcastle engine meant. One or two of the speakers had said that they could not dogmatise from the trials of a single engine. The Newcastle experimental engine was not one engine, but an unlimited number of engines. The number of cylinders, the ratio of the cylinders, the angles of the cranks and the capacities of the receivers could be altered so that an almost infinite number of engines were available for experimental purposes. With regard to what Mr Laidlaw said about economy on the North-East Coast, he was not sure that he could quite agree with him. He believed that equally economical engines were built on the Clyde and on the North-East Coast, and neither district had a monopoly of well designed engines. This he said after having had considerable experience of both places. He would require more particulars before he could discuss the results put forward by Mr Andrews,

Mr Hall-Brown.

but in any case he would emphasize the fact that all he had had to say, so far, had been absolutely confined to the ordinary type of marine engine. So far as his experience went he had found the conclusions arrived at in the paper completely verified in actual marine practice. For instance, he had designed engines for 160 lbs. working pressure, with a mean pressure as high as 46 lbs. per square inch, and the economy in steam consumption was quite equal to that of engines which, with the hope of obtaining extreme economy, were designed for a mean pressure of 22 lbs. to the square inch, and he would not have the slightest hesitation in repeating, under a penalty, the same process at any other time. He could not say that he had quite followed the remarks of the gentleman who referred to the question of earlier cut-off, but if he had found increased economy in some direction, which was contrary to the accepted notions of engineers in this country, he hoped he would not take his ideas to America until he had given engineers a trial on this side. He had listened to Mr Younger's remarks with considerable pleasure until he became such a very canny Scot, and warned them against dogmatising from the results of a single engine. When he said that, Mr Younger and he parted company. He could only repeat that he did not consider the results given in the paper could in any way be considered the results, merely, of a single engine trial. With regard to Mr Sayers, who asked about the use of the letters, E.H.P.; these letters were used to represent effective horse power by mechanical engineers long before electrical engineering was born, and consequently were no part of the electrical engineers' property. As to the value of P*f* in Fig. 8, the differences were very much magnified, owing to the vertical scale used; and the reasons for neglecting the second and last spots would be clearly seen by referring to Fig. 7. There was no reason why there should have been less friction on the second set of trials than the first, and he thought it was sufficiently evident that the two spots belonging to the second and fifth trials had, for some reason, fallen out of the line. Any slight difference in the condition of the mechanism, or

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in the internal lubrication of the engine would affect those spots to a considerable extent. He thought that the line drawn in the diagram might be taken as representing the actual value of P*f* very closely, especially as the correction, therein shown, agreed with the fair curves in Figs. 6 and 7. He had to thank the members very much indeed for the kind way in which they had received his paper, and he was much indebted to those who had taken part in the discussion, and especially to Professor Weighton for his contributions.

The **President** proposed a very hearty vote of thanks to Mr Hall-Brown for his interesting paper, which had led to a very keen discussion, and he was sure that the discussion would be read with very great pleasure in their Transactions. He thought they were very much indebted to Prof. Weighton for being present that night. Prof. Weighton had been in Glasgow on other matters, but knowing that this paper was to be discussed that evening he had come forward, and his remarks had been very valuable and had been listened to with very great pleasure. He had no need to say more, but just to ask them to give Mr Hall-Brown a very hearty vote of thanks for his paper.

The vote of thanks was carried by acclamation.

The **President** said he had now to intimate that the Members of Council who were proposed at the last meeting had been duly elected. The Council were at present engaged in revising the rules of the Institution, and they hoped to conclude that work in a short time. It was a matter which required a great deal of consideration, and as soon as possible they would submit their proposals in print to the members, and it would be necessary, before the commencement of the next winter session, to call a special meeting for the consideration of these proposed new rules so as to get them approved and put into force during the next session.

Correspondence.

Sir A. J. **Durston**, K.C.B. (Hon. Member), felt, in connection with Mr Hall-Brown's paper, that the information contained in the following tables, which gave the results of recent tests of the machinery of H.M.S's. "Hyacinth" and "Minerva," might be interesting to Members of the Institution. Table XVI. showed the moment of turning the screws and screw alley shafting only, the figures having been obtained when the vessels were in dry dock. Table XVII. gave the I.H.P. of the machinery absorbed in driving the engines and shafting only, at the stated revolutions, when the vessels were afloat with their screw propellers removed.

TABLE No. XVI.

"Hyacinth" and "Minerva."

Friction Test of Propeller Shafting Aft of Thrust Block.

Ship.	Weight in Lbs.		Radius at which Weight acted.
	Port.	Starboard.	
Hyacinth..................	616	784	5′ 4″
Minerva....................	728	784	5′ 6½″

TABLE No. XVII.

Friction Trials of Engines in Dock.

Propeller Blades and Bosses removed.

"Hyacinth" Engines $\frac{26'', 42'', (2)48''}{2'\ 6''}$		"Minerva" Engines $\frac{33'', 49'', 74''}{3'\ 3''}$	
Mean Revs.	I.H.P. (Total).	Mean Revs.	I.H.P. (Total).
179	590·7	141·5	526·9
162·5	440·0	120·5	362·7
141·5	321·15	101·5	256·6
122·0	243·4	81·0	197·8
102 0	201·6	62·0	147·2
81·0	144·95	40·0	109·2
60·0	108·77	19·75	60·9
39·5	78·55		
22·25	51·5		

Mr R. T. Napier.

Mr R. T. Napier (Member) noted that the aim of the author seemed to be to show that in the matter of using steam expansively the limits of economy had been passed; the gain in mechanical work, due to prolonging the expansion, being fully absorbed by the extra expenditure on friction in the larger engine. The author quoted various published opinions as to the probable ratio of useful to indicated power; later experiments seemed to have shown that the 90 per cent. which, years ago, was held as probable, need not be departed from in estimating power. The power required to drive air and feed pumps must be small, as the quantity of air which, in the days of jet condensing, was continually being liberated from the supply water was now reduced to the trifling amount that could be absorbed in the hot well. The net work expended in dealing with the water was simply the weight of such water multiplied by the weight due to boiler pressure + atmospheric pressure. With 180 lbs. boiler pressure and 14 lbs. of feed per I.H.P. per hour, this worked out at 106 foot lbs. per minute, and even taking three times that to cover friction of plungers and gear and resistance of valves and pipes, the total was only 1 per cent. of the I H.P. He considered that there was small value in the experimental testing of engines at speeds other than those for which they were designed. At higher speeds there was wire drawing in the passages, and at lower speeds there was loss through needlessly large clearance spaces. To test engines *underloaded* was of as little use, and in this the author evidently agreed, in that he did not value the trial of the "Iona" as a fair test of the ratio of indicated to effective power. The author advocated working engines with a mean pressure reduced to L.P. cylinder of 35·5 lbs., and instanced the engines of the steamer "Indrani," for which engines he would have substituted others with 23 per cent. less cylinder capacity, 6 per cent. less piston speed, and 32 per cent. greater mean pressure, and claimed that such should be more economical. It is not questioned by anyone that in a *small* engine with high mean pressure there was less actual power absorbed in friction than in a larger engine indicating about the

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same power, but this was not the whole case. The "Indrani's" engines must have worked with a ratio of expansion of about 15 to 1, and could well have done the work they did with the 14 lbs. of feed per I.H.P. per hour estimated by the author; while the proposed engines, having no such high ratio of expansion, would most certainly have required more feed. With no more than 14½ lbs. of feed per I.H.P. per hour the actual daily consumption of coal would be, at 10 lbs. of evaporation per lb. of coal, 8 cwts. more than with the engines as fitted.

Mr E. Hall-Brown, in reply, said he had now had an opportunity of looking into the figures so kindly communicated by Sir A. J. Durston. As the results of these friction trials of the "Hyacinth" and "Minerva" were of considerable interest, he had calculated the corresponding values of P*f* at the various speeds of revolution. These values were given in Table No. XVIII, and they were also

Table No. XVIII.

Values of P*f* from the trials of H.M.S's. "Hyacinth" and "Minerva."

"Hyacinth"			"Minerva"		
Engines $\frac{26'',\ 42'',\ (2)\ 48''}{2'\ 6''}$			Engines $\frac{33'',\ 49'',\ 74''}{3'\ 3''}$		
Mean Revs.	I.H.P. (Total).	Values of P*f*.	Mean Revs.	I.H.P. (Total).	Values of P*f*.
22·25	51·50	4·22	19·75	60·9	3·64
39·5	78·55	3·62	40·0	109·2	3·22
60·0	108·77	3·31	62·0	147·2	2·80
81·0	144·95	3·26	81·0	197·8	2·88
102·0	201·60	3·60	101·5	256·6	2·99
122·0	243·40	3·64	120·5	362·7	3·56
141·5	321·15	4·13	141·5	526·9	4·41
162·5	440·00	4·93			
179·0	590·70	6·02			

Mr Hall-Brown.

shown graphically in Fig. 9. The difficulty of taking indicator diagrams accurately from marine engines with the propeller blades removed was very great, and this might cause some doubt as to whether the "friction horse-power" could be accurately ascertained in this manner. It might be assumed that, with the expert engineers engaged on these trials, every known means were taken to ensure that the actual power required to run the engines at the various speeds was recorded, and that the results, so far as they went, were therefore reliable. The friction so determined was what used to be called "initial" or "dead load friction," to which had to be added the friction due to the working load. One of the chief points of his paper was that, so far as experiment went, there was no such item as friction due to the load. Upon this point the "Minerva" and "Hyacinth" experiments did not throw any light. It was unfortunate that one had not a complete record of the conditions of these trials. The values of "P*f*" deduced from the experiments showed a variation which he had not found in the records of any other experiments. It might be that a complete record of these trials, giving the various conditions as to cut-off, pressure at the H.P. steam chest, vacuum etc., would throw some light upon the reasons for this variation. Thus, it would be noted that in the case of the "Hyacinth" the value of P*f* at 22·25 revolutions was 4·22, at 81 revolutions 3·26, and at 179 revolutions 6·02; that was to say, that the friction did not vary either with the revolutions, or inversely as the revolutions, but attained a minimum at about 80 revolutions, and was greater on each side of that point. A similar result was shown by the trials of the "Minerva." It might also be noted that while the ratio of the lowest number of revolutions to the highest number recorded in the case of the "Hyacinth" was 1 : 8·05, the ratio of the corresponding values of P*f* was only 1 : 1·43. In the case of the "Minerva" the corresponding ratios were 1 : 7·15 and 1 : 1·21 respectively. That was to say that while the revolutions were increased by 800 per cent. and 700 per cent. in the case of the "Hyacinth" and "Minerva" respectively, the corresponding

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increase in the value of P*f* was only 43 per cent. and 21 per cent. respectively. Surely in spite of Professor Biles' remarks these values of P*f* were practically constant. With regard to Mr R. T. Napier's remarks, he would like to point out that one of the chief contentions in the paper was that the reduction of the ratio of expansion would not lead to a reduction in economy but the reverse, so that in addition to the gain in mechanical efficiency there would be a gain in steam efficiency. In other words, the reduction in the size of the machinery would not lead to increased daily consumption of coal as stated by Mr Napier, but if his (Mr Hall-Brown's) contentions were correct to a diminished consumption of coal. This was clearly stated in the paper.

THE "JAMES WATT" ANNIVERSARY DINNER.

The Annual "James Watt" Dinner was held in the Windsor Hotel, St. Vincent Street, Glasgow, on Saturday evening, 18th January, 1902. The chair was occupied by Mr **William Foulis**, President of the Institution, and the croupiers were Mr Archibald Denny, F.R.S.E., Mr Thomas Kennedy, and Mr R. T. Moore, B.Sc. The company numbered upwards of 270 gentlemen, including Members of the Institution and distinguished guests.

The President was supported by—The Honourable Lord Provost Samuel Chisholm, LL.D.; Sir William Arrol, LL.D., M.P.; Captain Francis R. Pelly, R.N., H.M.S. "Benbow;" Bailie John Shearer; Mr William Jacks, LL.D., President, West of Scotland Iron and Steel Institute; Mr J. P. MacLay, Messrs MacLay & MacIntyre; Mr John Ward, Messrs William Denny & Bros., Dumbarton; Mr C. C. Lindsay, President, Glasgow Association of Students, I.C.E.; Prof. Magnus MacLean, D.Sc., President, Institution of Electrical Engineers (Glasgow Section); Councillor H. Carvick Webster; Mr Robert Laidlaw; Mr John Young; Mr James Mollison, Lloyd's Register; Sir Digby Murray, Bart.; Sir David Richmond; Mr Matthew White, Deacon-Convener of Trades House; Bailie Bilsland; Bailie J. M. Thomson; Mr J. G. Dunlop, Messrs John Brown & Co.; Col. J. D. Young; Bailie Robert Sorley; Mr W. R. Copland, Chairman of Governors of the Glasgow and West of Scotland Technical College; Councillor William Burrell; Mr G. Handasyde Dick, President, Chamber of Commerce; Fleet-Engineer C. H. Pellow, H.M.S. "Benbow;" Mr A. B. M'Donald, City Engineer; Mr George Herriot, and Prof. Archibald Barr, D.Sc.

After dinner the loyal toasts were given from the chair, and duly honoured.

Bailie **Shearer** proposed "The Imperial Forces." He remarked that for the maintenance of our empire and the defence of our honour we required a strong navy and a strong and mobile army. We had the first, and every day we were increasing its strength and efficiency. The second he believed we would now get very soon He pointed to the close association of the Institution of Engineers and Shipbuilders with the efficiency of the navy, which was the mainstay and pride of our country. With regard to the South African War, he defended the army against the accusation of using methods of barbarism, and urged that to ensure the increased efficiency of the Volunteers it was necessary that that branch of the Imperial forces should be more liberally treated by the Government in matters of training and equipment.

Captain FRANCIS R. PELLY, R.N., H.M.S. "Benbow," replied for the Navy. He recalled the number of vessels for the Navy that had been built in Scotland. He expressed the hope that our Navy would be required only for keeping the ocean clear for commerce, and for protection purposes. But if by any chance we should have the misfortune to go to war, he believed that the quality of the ships we build, and the mettle of the men that Britannia provides for them, would enable us to preserve our command of the seas.

Colonel J. D. YOUNG, who also replied, said that the toast brought to their minds the hardships and the trials endured by our men in the South African war, and helped to draw out more and more our sympathy for and our interest in the mothers, the wives, and the children who were left at home. He referred with gratification to the fact that Bailie Shearer's son had served with distinction at the front, and that he had two other sons in the regiment which he (Colonel Young) commanded. The war had taught, and would teach, us many things. It had modified very largely our methods of making war. In some respects it had made war a much more terrible thing than it was formerly, when armies fought face to face. Now they had to watch the long line of railway, to stand by during the long eerie nights guarding the fords while the men heard the ping of the bullet, and could

Col. J. D. Young.

not tell where it came from. Under these conditions war was a harder, a more cruel, and a much more unpleasant thing than it was before. Another aspect of the question which this war had brought out—and which he did not think was sufficiently realised—was the way in which the colonies had come to the assistance of the mother country. As a result, the empire was now more closely and more tenderly than ever knit together. As a nation we had many lessons to learn from the war, and we would not be business men if we simply formed ourselves into a mutual admiration society. When we were told that army matters must be left to the experts of the War Department we must not believe it. It was for the business men of the country to consider these questions. If this war could have been carried on by contract, as Sir William Arrol built a bridge or many of those present built a battleship, it would have been finished before this. War was now a serious, hard, difficult business, and must be conducted in a business way. If once we got to the point of carrying on our wars by contract, he thought we would not be far off seeing the absurdity of war altogether.

Sir Digby Murray, Bart., submitted the toast of "The City of Glasgow." He expressed his admiration of the energy, perseverance, and dogged determination of the sons of Glasgow, who had made the city what it is. He attributed the energy and perseverance which characterise the people of the South of Scotland and the North of England to the Border blood which had been transmitted to them by their ancestors, and which had developed their present qualities of body and mind. His first acquaintance with Glasgow was made in 1849. Since that time the city had made gigantic strides. Glasgow was very often spoken of as the third city in rank in the United Kingdom. But, even supposing that was the case, there were some respects in which she stood first—as, for instance, in shipbuilding and engineering. In these respects she stood first not only in the United Kingdom but in the world.

Lord Provost Chisholm replied. That was not, he said, by any means the first occasion on which he had enjoyed the hospitality of the Institution, and he was proud to say that familiarity had not on his part produced its proverbial result. He realised that night more keenly than ever how great an honour it was to be the guest of such a distinguished body as the Engineers and Shipbuilders in Scotland, men who, while engaged in the laudable occupation of amassing their own fortunes were at the same time carrying out a higher and nobler commission, who were subduing the earth and harnessing to the chariot of human progress the elemental forces of nature. The honour and the privilege he enjoyed were greatly enhanced by the fact that his name was coupled with such a toast as that of the city of Glasgow, a city the name and fame of which engineers and shipbuilders had done so much to create, and maintain and extend over all the world. His pleasure and honour were also greatly increased by the fact that they were met under the presidency of one who had attained distinguished eminence as an engineer in his own peculiar walk, and who in that capacity had rendered eminent services to the city. He should like to say, with the permission of Sir Digby Murray, that for the last decade there had not been the shadow of a doubt as to the position Glasgow occupied among the cities of Great Britain. He did not refer merely to what might be called special distinctive features, but in regard to that most elemental feature and aspect of the question, that by which all the cities of the kingdom were measured—the population of the municipal area — Glasgow stood second, distanced by London alone. With regard to the toast, they were all familiar with the phrase that while God made the country man made the town. If that phrase was meant to shut out the thought of the presence and power of God in the town, or of the presence and power and operation of man in the country, then, of course it was simply a colossal fiction. But if it only meant—as he presumed it did—that to the superficial observer the presence of the one was more obvious than the presence of the other, he wished to say that it seemed to him that among the cities of the world there were few,

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if any, which stood out more clearly as man-made than Glasgow. They knew who made the Hudson; it was man that made the Clyde. Whether they referred to the great central highway which Glasgow men made for themselves or to those gigantic works which the deepening and the straightening and the widening of the Clyde had rendered possible, those vast shipbuilding yards which line the river, or whether they thought of the railway systems which had their termini in Glasgow, or that extraordinary series of local intercommunication by the underground railways and the subway, or whether they referred to the electric installation, the electric tramway system which their friend and engineer, Mr Young, managed so admirably on the surface of our streets—whether they thought of these or of other results of engineering skill and science, they saw how much, how wholly, indeed, from that point of view, Glasgow had been built up by the labour, the skill, and the genius of man. When, again, they thought of the city itself—by that he meant the men, women, and children of the population—how largely were they indebted to those vast works which the captains of industry had built up, not only for the means of subsistence, but for the training given to intelligent workmen, and which fitted them to fill important and leading positions in all parts of the world. We were sometimes contrasted with America. If the King were to issue a ukase withdrawing all Scotsmen who were at the head of American institutions and our American brethren had to stand by themselves, we would have very little to fear from them.

Dr. William Jacks proposed "Engineering Interests." It was, he said, a healthy sign of the times that we commemorated great men of the past. This was specially the case in literature and in art. There were Scott Clubs, Burns Clubs, Ruskin Clubs, and a great many others. But it had often occurred to him that the great masters of science had not been equally honoured. He was not aware that there was a Faraday, a Darwin, or a Stephenson Club. They should therefore hail with all the greater enthusiasm an institution such as that of the Engineers and Shipbuilders, which commemorated one whose matchless genius harnessed and handed over to the control of mankind one of the greatest forces of nature, and whose lovable and stainless character had surrounded him with an atmosphere of the sweetest fragrance, which as year succeeded year was wafted down on the unwearied wings of time. We lived in an entirely different time from that of Watt. He questioned if Watt would recognise his own great inventions, except perhaps that of the governor. There was no comparison between the achievements of engineers since the time of Watt with those of any other period. In the interval since Watt lived man had made himself absolutely master of many of the resources of nature, and applied them to the needs of humanity. In no preceding age of the world's history had such progress been made. The possibilities of the future had also been opened up. What had been done was but the earnest of things that would be done.

The President, in replying, said the subject of the toast embraced the application of the discoveries in almost every branch of physical science to practical use and to the advancement of mankind. Dr. Jacks had referred to the progress in all branches of engineering science since the time of James Watt They could scarcely realise now how great had been that advancement. At the beginning of last century Watt was just completing those labours, which extended over a long series of years, by which he almost created, he might say, the steam engine. They sometimes heard it said that Watt's great achievement was his separate condenser. To his mind that was only one incident in his career. He thought Watt's great achievement was the result of the long series of years in which he strove with imperfect tools and under many disadvantages and much discouragement to perfect the whole details of his engine, and to make it a workable machine; and without all his labour and all the detail of invention which he brought to bear upon it the engine might have been little more than a scientific toy. It was that which made his memory so revered by them. It was sometimes said that our engineers of the present day were falling behind, or at all events

The President.

that other nations were outstripping them, and it was said that this was owing to technical education. No one could deny that a thoroughly sound education was an absolute necessity for an engineer in whatever branch of the profession he might be. But he would like to say that a nation's greatness and advancement did not depend so much upon the facilities for obtaining technical education as upon the individual efforts made in applying the knowledge that was acquired. It was this individual exertion, this individual effort in applying their knowledge, that had made our engineers what they were among the profession in the world, and he did not believe that that spirit of application and of earnest work was in the slightest degree less than it was in previous years. Therefore he did not take the view that the engineers of this country were likely in the least to take a second place among the engineers of the world. Dr. Jacks had referred to the great advancement that had still to be made in the future. That was a matter upon which he thought they would all agree with Dr. Jacks. A great deal had been done, but he ventured to predict that at the end of this century it would be found that engineers had made much greater progress than they had done during the last century.

Mr JOHN WARD, in proposing "Educational Interests," referred to the growing industrial competition of foreign countries, and said that educational training which had produced in recent years such capable business rivals, especially in Germany and America, was worthy of our serious study and, if necessary, of our imitation. The city had as its motto, "Let Glasgow flourish by the preaching of the Word." To that noble motto we might add "and by the spread of educational interests." In America, a few years ago, he had been struck by seeing the widespread character of technical training. There were free schools, specially staffed and equipped for this work by Boards of Education, throughout the country. The result of this training was telling in their favour in the competition with other countries. The great interest that was now being taken in educational matters was one of the most hopeful signs for the continued prosperity of our country. The university had done a great and a good work in the past, and with men like Professor Barr in the chair there was little doubt that its power would continue to grow. Doubtless, all the financial aid being asked for would ultimately be obtained. The West of Scotland Technical College and Allan Glen's School were also doing excellent work in the matter of technical education. The governors of the Technical College in their recent appeal for funds for the building of the new college had had their hands strengthened and their hearts comforted by the magnificent response that had been made in so short a time. Why, he asked, should so much be left to be supplied by private generosity when it was almost a matter of life and death in the maintenance of our position as an industrial nation? Germany and America had shown the importance they attach to technical education, and only in proportion to the encouragement that we give it as a nation and as individuals, could we hope to successfully face our industrial competitors and uphold our national and commercial supremacy before the world.

Professor **Archibald Barr**, D.Sc., in replying, said that anyone who visited America could not help being struck with the enormous development of scientific and technical education within the last decade or two. He entirely agreed with all that the President had said, that the commercial and industrial interests of this country depended as much to-day as ever they had done upon the individual exertions of those who were carrying on our industries. The President said that they must apply the education they acquired; but that meant that the education must be there to be applied. The American Ambassador to London stated some time ago that the chief industry of America was education. There was a great deal more truth in that than many of them were apt at first sight to suppose. Now that they had got a great American Scotsman coming forward so liberally to endow education in this country, they felt that the leaders of industry in that country were of the same opinion, at least in essence, as the Ambassador to whose speech he had referred. The late revered Principal on

Prof. Archibald Barr, D.Sc.

one occasion said with regard to the University of Glasgow that it had no danger of falling yet awhile into the condemnation—"Woe unto ye when all men speak well of you." After 450 years of educational work by the University of Glasgow, and after all they had seen this year in connection with the celebration of its Jubilee and the gathering within the walls of the University of the International Engineering Congress, and the British Association, he thought people were beginning a little more to understand the position which the University desired at least to hold in the West of Scotland. With the help that the Carnegie money ought to give to the Universities, it would more and more come to have a great influence on the education not only of the wealthy, but of those who were struggling to better themselves. He could not agree with many enthusiasts who believed that education would do everything. He did not believe that a man would dig a ditch better, even the great ditches that were so commonly seen in the streets of Glasgow—because he had a knowledge of geology—nor did he believe that a knowledge of science was necessary for everyone. But he believed heartily that for engineers—not men who used their hands, that was not the function of an engineer; the function of an engineer was to use his head—education would come to be an absolute necessity.

Mr W. R. Copland also acknowledged the toast. He remarked that as a member of the Court he had a connection with the University as well as with the Technical College, and though his efforts had been directed more towards the Technical College, they had not lessened his interest in the great institution on Gilmorehill. When he became a governor of the Technical College in 1886 it had about 2000 students, including the scholars of Allan Glen's School The students, including the scholars from Allan Glen's School, now numbered about 5500. The Technical College was therefore not standing still. The public had responded heartily to the call for funds for a new college, the subscriptions at present amounting to £173,000, which had been obtained in the course of twelve or fourteen months. Within the next few months they would begin building on a part of the site of the old Andersonian College, and he hoped that the structure they would raise would be an ornament to the city and an institution that would benefit succeeding generations.

In the course of the evening an interesting programme of vocal and instrumental music was submitted, the artistes including Miss Margaret Horne, violinist, and Messrs Walter Harvey and J. M. Crawford.

MINUTES OF PROCEEDINGS.

FORTY-FIFTH SESSION

The First General Meeting was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 29th October, 1901, at 8 P.M.

Professor **Archibald Barr**, D.Sc., occupied the chair.

The Minutes of the Annual General Meeting, held on 23rd April, 1901, were read, confirmed, and signed by the Chairman.

ANNUAL REPORT OF THE COUNCIL.

The **Chairman** said a telegram had been received from Dr. Caird regretting his inability to be present, and as senior Vice-President of last session he (Dr. Barr) had been called upon to take the chair. The first business was to place before the meeting the annual report of the Council, but as it had been circulated it was perhaps hardly necessary to read it in full, and he thought he need only remark on one or two points. The very gratifying increase in membersnip for several years had been conspicuous in the session just closed. In passing he would refer to the expression in the Council's report of the loss the Institution had sustained in the death of several of its prominent members. The death of Lord Armstrong, one of their Honorary Members, had removed from the engineering world one of its greatest ornaments. The Clyde district had sustained great loss in the death of Sir Andrew MacLean, Dr. Andrew Stewart, and other members of the Institution whose names were recorded in the report. With regard to the International Engineering Congress, he might say that it had been successfully carried through, and he could assure those present that the impression on all the delegates from whom they had heard, was that the Congress had been a conspicuous success. He moved the adoption of the report.

The motion was agreed to.

TREASURER'S STATEMENT.

In moving the adoption of the Treasurer's Statement, the **Chairman** remarked that the year's work had a very gratifying financial result, and he thought a vote of thanks was due to the gentlemen who had audited the accounts.

The report was adopted.

Mr C. C. **Lindsay** proposed a vote of thanks to the auditors, Mr R. T. Napier and Mr F. J. Rowan.

The proposal was cordially responded to.

The Awards made at the Annual General Meeting of 23rd April, 1901, were presented as follows, viz.:—

PREMIUM OF BOOKS.

To Mr A. B. **McDonald** for his paper on "Glasgow Main Drainage," and to Mr **David Cowan** for his paper on "Workshop Administration: With Special Reference to Tracking Work and Promptly Ascertaining Detailed Costs and Profits."

VOTE OF THANKS TO DR. CAIRD.

Thereafter the **Chairman** observed that in closing the business of last session, he was sure they would all agree that they could not allow their new President to be welcomed amongst them without a word or two being put on record to mark their appreciation of the services which the retiring President had rendered to the Institution. It was well known how Dr Caird had adorned the position to which he had been elected, how he had given the Institution, by his eloquence, the benefit of his scientific knowledge and practical skill. The period of his Presidentship had been one of unexampled prosperity to the Institution, and no one had occupied the chair of the Institution with more grace and acceptance than Dr. Caird had done. He asked the members to accord Dr. Caird a hearty vote of thanks.

The motion was carried by acclamation.

INTRODUCTION OF PRESIDENT.

The **Chairman** then said it now only remained for him, as representing the retiring President, to express their welcome to his successor. No words were needed to introduce Mr Foulis to a Glasgow audience. All appreciated the importance of the great work which he had done and was doing for Glasgow, and they recognised the ability which he had displayed in the management of one of the most important and prominent departments of their municipal enterprise. In that branch of engineering which Mr Foulis specially professed he was one of the leading authorities, and they were proud to have the services of one so widely recognised for his ability, his inventive genius, and his devotion to the interests of the community. He was certain that they all heartily welcomed Mr Foulis to the chair of the Institution, and he now, in the name of the retiring President, asked Mr Foulis to take the Chair of the Institution, and to deliver the address which he had come to offer them.

The President delivered his Introductory Address.

On the motion of Mr A. Denny, senior Vice-President, a vote of thanks was awarded the President for his Address.

Thereafter a paper was read by Mr A. MARSHALL DOWNIE, B.Sc., on "The Design and Construction of Fly-Wheels for Slow Speed Engines for Electric Lighting and Traction Purposes."

A paper by Mr GEORGE JOHNSTONE on "Notes on the Serious Deterioration of Steel Vessels from the Effects of Corrosion" was held as read.

The following candidates were balloted for and duly elected, viz.:—

AS MEMBERS.

BROWN, JAMES D., Engineer, Rosebank Iron Works, Edinburgh.
BULLARD, E. P. Jun., Mechanical Engineer, Bridgeport, Conn., U.S.A.
CHISHOLM, ROBERT, Engineer, Ferniehurst, Bertrohill road, Shettleston.
FERGUSON, DAVID, Shipbuilder, Glenholm, Port-Glasgow.
HÖK, W., Naval Architect, 4 Vasagatan, Stockholm, Sweden.
HUTCHISON, M., Superintending Engineer, 70 South Woodside road, Glasgow.
JONES, ARTHUR J. E., Mechanical Engineer, 118 Napiershall street, Glasgow.
M'DOWALL, JOHN JAMES, Engineer, Vulcan Engine Works, Piraeus, Greece.

Mathieson, James H., Machine and Tool Maker, Saracen Tool Works, Glasgow.

Norris, Charles G., Engineer, 504 Stockport road, Manchester.

Pocock, J. Herbert, Mechanical Engineer, 98 Barrington drive, Glasgow.

Riekie, John, Locomotive Superintendent, Indian State Railways, Argarth, Dumbreck, Glasgow.

Roberts, W. G., Marine Engineer, 100 Bothwell street, Glasgow.

Sommerville, Robert G., jun., Mechanical Engineer, Aldergrove, Port-Glasgow.

Sothern, John W., Teacher of Marine Engineering, 59 Bridge street, Glasgow.

Taylor, Thomas, Engineer, Messrs Smith, Bell & Co., Manila, Phillipine Islands.

AS ASSOCIATES.

Allan, James A., Steamship Agent, 25 Bothwell street, Glasgow.

Brown, Thomas J., Metal Merchant, 233 St. Vincent street, Glasgow.

Gillespie, A. W. W., Engineer and Iron Merchant, 75 Bothwell street, Glasgow.

Hogarth, Samuel C., Shipowner, 70 Great Clyde street, Glasgow,

Hogarth, Hugh, Shipowner, 70 Great Clyde street, Glasgow.

Kirsop, James Nixon, Iron Merchant, 31 St. Vincent place, Glasgow.

Stewart, Charles R., Agent, Messrs J. Stone & Co., 46 Gordon street, Glasgow.

AS MEMBERS FROM GRADUATES' SECTION.

Goudie, William J., B.Sc., Engineer, 92 Albert drive, Crosshill, Glasgow.

Smith, Alexander, Engineer, 16 Courthill, Bearsden.

Watson, Robert, Manufacturing Chemist, 10 East Nelson street, Glasgow.

AS GRADUATES.

Anderson, Thomas, Draughtsman, 326 Cumberland street, Glasgow.

Jackson, Wm. S., Draughtsman, 3 Walmer Crescent, Glasgow.

The Second General Meeting was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 26th November, 1901, at 8 P.M.

Mr **William Foulis**, President, occupied the Chair.

The Minutes of the First General Meeting, held on 29th October, 1901, were read, confirmed, and signed by the President.

Thereafter the discussion on Mr MARSHALL DOWNIE's paper on "The Design and Construction of Fly-wheels for Slow Speed Engines for Electric Lighting and Traction Purposes" was begun and concluded.

On the motion of the President a vote of thanks was awarded Mr Downie for his paper.

The Discussion on Mr GEORGE JOHNSTONE's paper on "Notes on the Serious Deterioration of Steel Vessels from the Effects of Corrosion" was begun and adjourned.

A paper by Mr WILLIAM BROWN (Member of Council), on "Dredging and Modern Dredge Plant" was read.

The following candidates were balloted for and duly elected—

AS A LIFE MEMBER.

ANDERSON, JAMES, Engineer, 1 Marlborough Terrace, Glasgow.

AS MEMBERS.

HAY, JOHN, Assistant Superintendent Engineer, 24 Leadenhall Street, London, E.C.

HUNTER, JOSEPH M., Chief Draughtsman, Byars Terrace, North Orchard Street, Motherwell.

LAIDLAW, THOMAS, Mechanical Engineer, 15 Lennox Avenue, Scotstoun.

McLAREN, WILLIAM, Chief Draughtsman, 9 Westbank Quadrant, Hillhead, Glasgow.

MILNE, CHARLES W., Engineer, Fairmount, Scotstounhill.

MORTON, ROBERT C., Ship Draughtsman, 16 Vinicombe Street, Hillhead, Glasgow.

ROBERTSON, DAVID, W., Manager, Dalziel Bridge Works, Motherwell.

SMITH, HERBERT GARDNER, Lloyd's Surveyor (Engineer), Leewood, Helensburgh.

THOMSON, JOHN, Engineer and Marine Superintendent, 44 St. Vincent Crescent, Glasgow.

WALKER, ARCHIBALD, Superintending Engineer, 24 Leadenhall Street, London, E.C.

AS AN ASSOCIATE.

BUCHANAN, JAMES, Cashier, Dalziel Bridge Works, Motherwell.

AS MEMBERS FROM GRADUATES' SECTION.

Ferguson, Louis, Naval Architect, 8 Belhaven Terrace, Kelvinside, Glasgow.

Ferguson, Peter, Engineer, Gilmourlea, Paisley.

Judd, Edwin H., Engineer, Sentinel Works, Glasgow.

Mowat, Magnus, Jun., Civil Engineer, 12 Randolph Gardens, Partick.

AS GRADUATES.

Ainslie, James William, Engineer, 377 Bath Street, Glasgow.

Anderson, George, Engineering Draughtsman, 2 Parkhead Street, Motherwell.

Brown, William, Mechanical Engineering Draughtsman, c/o Mrs Walker, 5 Princes Street, Pollokshields, Glasgow.

Crighton, John, Ship Draughtsman, 42 Stewartville Street, Partick.

Fairweather, George, A. E., Mechanical Engineering Draughtsman, Elmwood, Avon Street, Motherwell.

Hannah, John A., Mechanical Engineering Draughtsman, 22 Govanhill Street, Glasgow.

Kolvig, William, Engineer. c/o Miss Jenkins, 3 Minerva St., Glasgow.

Learmonth, Robert, Draughtsman, 75 Waterloo Street, Glasgow.

Martin, George H., Draughtsman, c/o London, 102 Byres Road, Hillhead, Glasgow.

Service, William, Marine Engineer, 173 West Graham Street, Glasgow.

Stevenson, Allan, Draughtsman, 69 Cadder Street, Pollokshields, Glasgow.

THE THIRD GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 24th December, 1901, at 8 P.M.

Mr WILLIAM FOULIS, President, occupied the Chair.

The Minutes of the Second General Meeting, held on 26th November, 1901, were read, confirmed, and signed by the President.

Thereafter the discussion on Mr GEORGE JOHNSTONE'S paper on "Notes on the Serious Deterioration of Steel Vessels from the effects of Corrosion" was resumed and concluded.

On the motion of the President, Mr Johnstone was awarded a vote of thanks for his paper.

The discussion on Mr WILLIAM BROWN's paper on "Dredging and Modern Dredge Plant" was begun and concluded.

On the motion of the President, Mr Brown was awarded a vote of thanks for his paper.

The reading of Mr FOSTER KING's paper on "Rudders" was postponed.

The following candidates were balloted for and duly elected:—

AS MEMBERS.

BINNIE, R. B. JARDINE, Engineer, Carntyne Works, Parkhead.
NAGAO, HANPEI, Engineer, c/o Messrs Okura & Co., 53 New Broad Street, London, E.C.
RUTHERFORD, A. K., Civil Engineer, 4 West George Street, Glasgow.
SAYERS, JAMES EDMUND, Electrical Engineer, 189 St. Vincent Street, Glasgow.
SINCLAIR, D. S., Engineer, London Road Iron Works, Glasgow.
STEWART, JAMES C., Engineer, 54 George Square, Glasgow.
WISHART, THOMAS, Engineer, London Road Iron Works, Glasgow.

AS ASSOCIATES.

BORLAND, JOHN G., Coal Merchant, 93 Hope Street, Glasgow.
TAYLOR, FRANK, Managing Clerk, Messrs Alexander Young & Co., 50 Wellington Street, Glasgow.

AS GRADUATES.

CALLANDER, WILLIAM, Apprentice Engineer, 100 Bothwell Street, Glasgow.
COCHRANE, JOHN, Civil Engineer, 15 Ure Place, Montrose Street, Glasgow.
HOTCHKIS, MONTGOMERY H., Student, Crookston House, near Paisley.
SMITH, ALEXANDER, Draughtsman, 12 Fairlie Park Drive, Partick.
WATSON, JAMES, Engineer, 35 Regent Moray Street, Glasgow.
YOUNG GEORGE M., B.Sc., Marine Engineer, 268 Kenmure Street, Pollokshields, Glasgow.

The FOURTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 21st January, 1902, at 8 P.M.

Mr WILLIAM FOULIS, President, occupied the Chair.

The Minutes of the Third General Meeting, held on 24th December, 1901, were read, confirmed, and signed by the President.

Thereafter Mr DUGALD CLERK read a paper on "Gas and other Internal Combustion Engines."

The Discussion on Mr CLERK's paper was begun and concluded.

On the motion of the President, Mr Clerk was awarded a vote of thanks for his paper.

The following candidates were balloted for and duly elected :—

AS MEMBERS.

CRAN, JOHN, Engineer and Shipbuilder, Albert Engine Works, Leith.
DAWSON, CHARLES E., Marine Engineer, 571 Sauchiehall Street, Glasgow.
REID, JOHN WILSON, Mechanical Engineer, 5 Grove Road, New Southgate, London, N.
WARNOCK, WILLIAM FINDLAY, Ship Draughtsman, 274 Bath Street, Glasgow.

AS AN ASSOCIATE.

LOUDON, JAMES M., Electrical Engineer, 22 Clarendon Street, Glasgow.

AS GRADUATES.

CRAN, J. DUNCAN, Apprentice Engineer, 11 Brunswick Street, Edinburgh.
SEMPLE, WILLIAM, Engineer, West End, Bellshill.

The FIFTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 18th February, 1902, at 8 P.M.

Mr WILLIAM FOULIS, President, occupied the Chair.

The Minutes of the Fourth General Meeting, held on 21st January, 1902, were read, confirmed, and signed by the President.

Thereafter Mr J. FOSTER KING read a paper on "Rudders."

The Discussion on Mr J. FOSTER KING'S paper was begun and adjourned.

A paper on "Producer Gas and its use in Engineering and Shipbuilding" was read by Mr F. J. ROWAN.

The following candidates were balloted for and duly elected:—

AS MEMBERS.

BROWN, ROBERT, Engineer, 7 Church Road, Ibrox, Glasgow.

CAMERON, ANGUS, Marine Superintendent, Union Steam Ship Company, Dunedin.

MACKAY, HENRY JAMES, Engineer, 24 Willowbank Street, Glasgow.

WALLACE, JAMES LOCH, Marine Engineer, 15 Clifford Street, Glasgow, S.S.

WRAY, THOMAS HENRY ROBERTS, Electrical Engineer, Clun House, Surrey Street, Strand, London, W.C.

AS AN ASSOCIATE.

SOTHERN, ROBERT M., Teacher of Mathematics, 59 Bridge Street, Glasgow.

AS GRADUATES.

BARNWELL, FRANK SOWTER, Shipbuilder, Elcho House, Balfron.

BARNWELL, RICHARD HAROLD, Engineer, Elcho House, Balfron.

BROOKFIELD, JOHN W., Ship Draughtsman, 21 Peel Street, Partick.

FISH, N., Apprentice Engineer, 480 Springburn Road, Glasgow.

MACGREGOR, J. GRAHAM, Civil Engineer, 4 West George Street, Glasgow.

MILLIKEN, GEORGE, Apprentice Engineer, Milton House, Callander.

The SIXTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 18th March, 1902, at 8 P.M.

Mr WILLIAM FOULIS, President, occupied the Chair.

The Minutes of the Fifth General Meeting, held on 18th February, 1902, were read, confirmed, and signed by the President.

The following nominations for Office-bearers (Sessions 1902-04) were then made:—

Vice-President, Prof. J. H. BILES, LL.D.; *Members of Council*, Messrs. ARCHIBALD DENNY, C. P. HOGG, GEORGE McFARLANE, MATTHEW PAUL, and WILLIAM BROOKS SAYERS.

Thereafter the Discussion on Mr J. FOSTER KING'S paper was resumed and concluded.

On the Motion of the President, Mr King was awarded a vote of thanks for his paper.

The Discussion on Mr F. J. ROWAN'S paper on "Producer Gas and its use in Engineering and Shipbuilding" was begun and concluded.

On the motion of the President, Mr Rowan was awarded a vote of thanks for his paper.

A paper on "Some Considerations affecting the Economy of Marine Screw Engines," by Mr E. HALL-BROWN was read.

The following candidates were balloted for and duly elected:—

AS MEMBERS.

DICK, JAMES, Steel Works Engineer, 12 Ronald Street Coatbridge.
LAIDLAW, D., Engineer and Founder, 147 East Milton Street, Glasgow.
LAIDLAW, T. K., Engineer and Founder, 147 East Milton Street, Glasgow.
MACILWAINE, GEORGE W., Assistant Ship Yard Manager, 5 Osborne Place, Copeland Road, Govan.
MACMURRAY, WILLIAM, Civil and Mechanical Engineer, Taller Bisayas, Yloilo, Philippine Islands.
MUIR, PETER GILLESPIE, Ship Yard Manager, 2 Osborne Place, Govan.
NEEDHAM, JAMES H., Shipyard Manager, Storra Lee, Round Riding Rd., Dumbarton.
STRACHAN, ALLAN, Engineer and Iron Founder, Taller Bisayas, Yloilo, Philippine Islands.
TORRIE, JAMES, Mechanical Engineer, Stewarton.
WILSON, JOHN, Manager Tradeston Gas Works, 11 Regent Park Square, Glasgow.

AS MEMBER FROM GRADUATES' SECTION.

SEEDDON, RICHARD, M., Draughtsman, 45c Whifflet Street, Coatbridge.

AS AN ASSOCIATE.

MURRAY, JOHN BRUCE, Shipowner, 24 George Square, Glasgow.

AS GRADUATES.

KERMEEN, ROBERT, W., Apprentice Engineer, Hanley Terrace, N. Ramsey, I.O.M.

MARSHALL, ALEXANDER, Marine Engineer, Brightons, Polmont Station.

TURNER, ANDERSON, Junr., Draughtsman, Sunnybank, Crosshill.

THE ANNUAL GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, 15th April, 1902, at 8 P.M.

Mr WILLIAM FOULIS, President, occupied the chair.

The Minutes of the General Meeting, held on 18th March, 1902, were read, confirmed, and signed by the President.

Mr F. J. ROWAN and Mr JOHN M'NEIL were appointed to scrutinise the ballot papers.

The scrutineers retired, and, after submitting their report, the President announced that Professor J. H. BILES, LL.D., had been elected as Vice-President; and Messrs ARCHIBALD DENNY, C. P. HOGG, GEORGE MCFARLANE, MATTHEW PAUL, and WILLIAM BROOKS SAYERS, Members of Council for Sessions 1902-03 and 1903-04.

On the motion of Mr A. S. BIGGART, Messrs F. J. ROWAN and R. T. NAPIER were appointed Auditors of the Annual Accounts.

On the motion of the President, Mr JAMES M. GALE was re-elected Hon. Treasurer.

On the motion of Mr R. T. MOORE, B.Sc., seconded by Mr A. S. BIGGART, it was unanimously agreed to award a Premium of Books to Mr WILLIAM MELVILLE for his paper on "The City Union Railway Widening and Extension of St. Enoch Station," read during Session 1900-01.

ENGINEERING CONGRESS, GLASGOW, 1901.

Mr A. S. BIGGART said that he thought the reference to the Engineering Congress in the last Council Report was inadequate, and asked the President if it was intended to make any further reference to the Congress in the Minutes of Proceedings.

Mr SINCLAIR COUPER also considered the report inadequate.

On the suggestion of the President the matter was left to the consideration of the Council.

The discussion on Mr HALL-BROWN's paper on "Some Considerations Affecting the Economy of Marine Screw Engines" was begun and concluded.

On the motion of the President, Mr Hall-Brown was awarded a vote of thanks for his paper.

The following candidates were balloted for and duly elected:—

AS MEMBERS.

DUNCAN, GEORGE THOMAS, Manager, Tangyes Ltd., Glasgow, Cumledge, Uddingston.

MACTAGGART, JOHN, Consulting Engineer and Naval Architect, 30 Rue Pericleos, Piree, Greece.

TOD, ROBERT P., Engineer, Shawmuir Cottage, Pollokshaws.

AS MEMBER FROM GRADUATES SECTION.

YOUNG, DAVID HILL, Marine Engineer, Marine Engineers' Institute, Shanghai, China.

AS GRADUATES.

ROBERTSON, ROBERT M., Draughtsman, 1 Holmhead Terrace, Cathcart.

RUSSELL, ALEXANDER C., Engineering Draughtsman, 142 Eastfield Street, Springburn.

REPORT OF THE COUNCIL.

Session 1900-1901.

The Council has to report that the membership of the Institution continues to increase, and that its financial position is satisfactory.

The changes which have taken place in the Roll are shown in the following statement:—

	Session 1899-1900.	Session 1900-1901.	Increase.
Honorary Members,	9	8	-1
Members,	832	928	96
Associates,	74	85	11
Graduates,	328	353	25
	1243	1374	131

The meetings held during the Session were six in number, at which the subjoined list of papers, in addition to the President's Address, were read and discussed:—

"A New Gas Producer"—by Mr John A. Purves, D.Sc., F.R.S.E.

"Marine Engine Shafting"—by Mr J. D. M'Arthur.

"Rolling of Ships and the Effect of Water-Ballast"—by Mr B. C. Laws.

"The Engineering Crisis in the Navy"—by Mr D. B. Morison.

"Temporary Work on the Canadian Pacific Railway"—by Mr J. Grant MacGregor.

"The Marine Steam Turbine and its Application to Fast Vessels"—by the Hon. C. A. Parsons, M.A., F.R.S.

"The City Union Railway Widening and Extension of St. Enoch Station"—by Mr William Melville.

"Administration of Workshops"—by Mr David Cowan.

The Meetings held by the Graduates' Section were five in number, at which, in addition to the Chairman's Address, the undermentioned papers were read and discussed:—

"Some Notes on the Longitudinal Strength of Ships"—by Mr W. H. Riddlesworth, B.Sc.

"The Influence of Thickness of Blades on the Performance of Screw Propellers"—by Mr George M. Welsh.

"Compound Slide Rules for Facilitating the Provisional Design of Marine Engines"—by Mr W. J Goudie, B.Sc.

"The Velocity of Application in Different Motive Powers"—by Mr Campbell MacMillan, B.Sc.

The Silver Medal for the best paper in this Section was awarded to Mr Campbell MacMillan, B.Sc.

The Council records with regret the deaths of the following gentlemen:—Honorary Member—The Right Hon. Lord Armstrong, C.B.; Members—Messrs J. R. Allen, W. A. Charlton, J. Currie, J. C. Cameron, J. Donald, Thomas Elsee, Hugh M'Intyre, Sir Andrew Maclean, Frank M'Culloch, A. R. Paton, John D. Scott, Andrew Stewart, LL.D., Joseph Moore, James Wilson, and Thomas Wingate; and Associate—Mr J. A. Webster.

The Institution was represented during the Session on the Board of Trade Consultative Committee by Mr James Denny, Mr John Duncan, Mr James Hamilton, and Mr James Weir.

Only one meeting of the Committee was held, at which future procedure was discussed, and the question of how the Shipbuilding and Engineering interests might best be served, was debated. At that meeting it was stated that the Committee had every prospect of being freed from the financial difficulties which had hitherto hampered it. No real business, as between the Committee and the Board of Trade, was entered upon during the year.

The Institution was represented on Lloyd's Technical Committee by Mr Sinclair Couper, Mr James Gilchrist, Mr John Inglis, LL.D., and Mr John Ward, and the following report from these gentlemen has been received by the Council:—

"During the past Session, the usual Consultative as well as Statutory Meetings of the Committee were held in London, and as an outcome, many details affecting the scantling and construction of hulls and machinery were discussed, and decisions arrived at.

"Two meetings were held during the Session, at White Lion, Court, London, which your Representatives attended. The first on the 13th November, 1900, and the second on the 26th March, 1901, when the following were some of the matters brought forward for consideration:—

Watertight Bulkheads.
Hatches, Coamings, and Ventilators.
Tests of Steel Castings.
Head and Stern Pumps.
Formula for Brown's Cambered Furnace.
Requirements regarding the Testing of Steel.
Tests for Steel Shafting.
Stiffeners to Bridge House Bulkheads.
Rudders of Steam Trawlers.
New form of Corrugated Furnace proposed to be made by Messrs Wm. Beardmore & Co., Limited.

"The results of these deliberations can be seen by comparing the New Edition of Lloyd's Rules with the old ones.

"It is very gratifying to your Representatives to be able to report that the united labours of the 14 gentlemen who constitute the Technical Committee have given much satisfaction to the General Committee of Lloyd's Register, and on more than one occasion they have been thanked for their services.

"The following changes have occurred in the Committee during the Session:—Mr F. P. Purvis having retired, the Institution were fortunate in again securing Mr John Inglis, LL.D., to fill the vacancy. Mr James Riley also retired, and Mr William Beardmore was elected by the Iron and Steel Institute to take his place."

The Institution was represented on the Board of Governors of the Glasgow School of Art by Mr James Mollison.

The Glasgow School of Art has recently been recognised by the Scottish Education Department as the central institution in the district for higher edncation in Art, and as it holds a very important position in relation to the many industries in the city and throughout the country, the Council commends it as worthy of all the support and encouragement that the Institution can give it.

The Institution was represented on the Board of Governors of the Glasgow and West of Scotland Technical College by Mr T. W. M'Intyre.

The advantages of this college are being increasingly appreciated by the public, the number of students enrolled last session being the largest ever recorded. It is a matter of regret that for want of accommodation at present, a large number of applicants for admission to the college cannot be enrolled. Every endeavour, however, is being made to overcome this state of matters until such a time as the new buildings, which it is pleasing to note are about to be commenced, are ready for occupation.

The Council desires to express the thanks of the Institution to these gentlemen for their services in these Institutions.

A Conversazione was held in the St. Andrew's Halls, Glasgow, on the 2nd November, 1900, at which all the branches of engineering embraced by the Institution were represented. An interesting collection of mechanical models and scientific apparatus was exhibited in the Berkeley Hall. The company numbered about 1000, and the meeting was thoroughly enjoyed by those present.

The "James Watt" Dinner was held at the Windsor Hotel, on Saturday, 19th January, 1901, and was well attended by Members and their friends.

An International Engineering Congress, which was supported by the leading Engineering and kindred Institutions, was held in Glasgow from the 3rd to 6th September, 1901, inclusive. The University authorities kindly placed the use of their various Class Rooms at the disposal of the Congress for its meetings.

The surplus revenue for the Session ending 30th September, 1901, as shown by the Treasurer's Statement appended hereto, is £415 6s 10d.

TREASURER'S
INCOME AND EXPENDITURE ACCOUNT
GENERAL

ORDINARY INCOME.			1900-1901.	*1899-1900*
I. *Annual Subscriptions received—*				
842 Members	at £1 10 0	£1263 0 0		
1 Member	,, 0 10 0	0 10 0		
77 Associates	,, 1 0 0	77 0 0		
311 Graduates	,, 0 10 0	155 10 0		
			£1496 0 0	*£1270 0 0*
II. *Arrears of Subscriptions recovered, less expenses*			114 17 0	*39 0 0*
III. *Sales of Transactions,*			43 11 6	*10 13 0*
IV. *Interests and Rents—*				
Interest on Clyde Trust Mortgage for £300, less tax, ...		£9 5 0		*9 8 1*
Students' Institute C.E., for use of Library, ...		12 3 9		*11 12 6*
Interest on Deposit Receipts, *less* on account current, ...		12 10 3		*9 8 11*
			33 19 0	*[30 9 0]*
EXTRAORDINARY INCOME.				
Surplus from Excursion, ...			. . .	*5 4 2*
Surplus from Conversazione, ...			1 2 7	
Surplus from "James Watt" Dinner,... ...			1 3 3	
			£1690 13 4	*£1355 6 2*

STATEMENT.

FOR YEAR ENDING 30TH SEPTEMBER, 1901.

FUND.

ORDINARY EXPENDITURE.		1900-1901.	*1899-1900.*
I. *General Expenses—*			
Secretary's Salary, ...	£300 0 0		*£300 0 0*
Institution's proportion of net cost of maintenance of Buildings, etc.	150 18 10		*106 7 4*
Interest on Medal Funds on loan to Building Fund, ...	21 12 0		*21 12 0*
Library Books, ...	24 1 2		*28 3 10*
Binding Periodicals and Papers,	9 12 6		*6 3 0*
Stationery and Postages, etc.,	44 15 11		*36 5 1*
Office Expenses, ...	43 6 2		*35 4 3*
Advertising, Insurance, etc., ...	7 16 0		*5 7 6*
Assistance at Meetings, ..	6 11 9		*. . .*
		£608 14 4	*[539 3 0]*
II. "*Transactions*" *Expenses—*			
Printing and Binding,	£367 15 7		*372 3 10*
Lithography, ...	117 18 2		*118 6 0*
Postages, ...	66 17 2		*66 17 5*
Reporting, ...	13 7 6		*16 18 0*
Delivery of Annual Volume, ...	12 10 0		*11 10 0*
		578 8 5	*[585 15 3]*
III. *Awards*—Premiums for Papers, ...		12 9 2	*24 0 11*
EXTRAORDINARY EXPENDITURE.			
Deficit on "James Watt Dinner,"		. . .	*6 13 11*
Institution's proportion of rearrangement of Heating Apparatus and Extension of Library, ...	£56 4 1		
Catalogue Cabinet for Library, ...	10 16 0		
Photo of Members and Associates of the Institution, ...	5 14 6		
Address to the King, ...	3 0 0		
		75 14 7	
Surplus carried to Balance Sheet, ...		415 6 10	*199 13 1*
		£1690 13 4	*£1355 6 2*

BALANCE SHEET, AS AT

LIABILITIES.			As at 30th Sept., 1901.	*As at 30th Sept., 1900.*
I. *Sundry Creditors,*			£620 7 1	*£604 19 0*
II. *Subscriptions paid in advance,*			19 10 0	*23 10 0*
III. *Medal Funds—*				
Marine Engineering—				
Balance as at 1st Oct., 1900,	£526 17 5			
Interest received during year,	14 0 2	540 17 7		*526 17 5*
Railway Engineering—				
Balance as at 1st Oct., 1900,	£329 16 1			
Interest received during year,	8 10 4	338 6 5		*329 16 1*
Graduates'—				
Balance as at 1st Oct., 1900,	£25 3 4			
Cost of medal, £1 7s 6d; *less* interest received during year, 16s 3d,	0 11 3	24 12 1		*25 3 4*
			903 16 1	*[881 16 10]*
IV. *Capital Accounts—*				
General Fund—				
Balance as at 1st Oct., 1900,	£1484 1 6			
Surplus, 1900-1901,	415 6 10	1899 8 4		*1484 1 6*
Building Fund—				
Balance as at 1st Oct., 1900,	£2206 10 1			
Life Members' Subscriptions, £53 10/; Life Associate's Subscription, £15; Entry money, £54 10/	123 0 0	2329 10 1		*2206 10 1*
			4228 18 5	*[3690 11 7]*
			£5772 11 7	*£5200 17 7*

30TH SEPTEMBER, 1901.

ASSETS.			As at 30th Sept., 1901.	*As at 30th Sept., 1900.*
I. *Heritable Property*—				
Total Cost,	£7094 16 3			
Of which one-half belongs to the Institution, ...			£3547 8 1	*£3547 8 1*
II. *Investment*—				
Clyde Trust Mortgage, ...			300 0 0	*300 0 0*
III. *Books in Library*—				
Valued at, say			500 0 0	*500 0 0*
IV. *Furniture and Fittings*—				
Valued at, say			65 10 0	*65 10 0*
V. *Sundry Debtors*—			12 6 4	*26 0 0*
VI. *Arrears of Subscriptions*—				
Session 1900-1901—				
39 Members at £1 10/,		£58 10 0		
1 Member at £1,		1 0 0		
6 Associates at £1,		6 0 0		
54 Graduates at 10/,		27 0 0		
		£92 10 0		
Previous sessions—				
22 Members,	£59 10 0			
5 Associates,	13 0 0			
37 Graduates,	47 0 0			
		£119 10 0		
Total,		£212 0 0		
Valued at, say			50 0 0	*50 0 0*
VII. *Cash*—				
In Bank,				
On Deposit Receipt, ..		£79 17 11		
On Current Account, ...		1207 10 9		
In Secretary's hands, ...		9 18 6		
			1297 7 2	*711 19 4*
			£5772 11 7	*£5200 17 5*

ABSTRACT OF "HOUSE EXPENDITURE" ACCOUNT FOR SESSION 1900-1901

INCOME.	12 months, to 30th Sep., 1901.	*12 months, to 30th Sep., 1900.*	EXPENDITURE.	12 months, to 30th Sep., 1901.	*12 months, to 30th Sep., 1900.*
Rents for Letting Rooms, ...	£62 15 0	*£121 7 6*	Salary to Curator, ...	£135 0 0	*£135 0 0*
Balance, being excess Expenditure.	414 5 10	*234 7 8*	Salary to Attendant at Library, Cleaning, etc., ...	67 7 10	*70 9 2*
Payable by Institution, ... £207 2 11			Feu-duty, Taxes, and Insurance.	42 0 3	*36 11 2*
			Interest on Bond, ...	. . .	*47 19 0*
Payable by Philosophical Society, 207 2 11			Alterations, Repairs & Renewals,	186 0 3	*25 1 6*
			Coal, Gas, and Electric Light,	44 2 10	*37 19 6*
			Stationery, Postages, and Incidental Expenses, ...	2 0 8	*2 14 10*
	£477 0 10	*£355 15 2*		£477 0 10	*£355 15 2*

Note.—The Account of the House Committee, of which the above is an abstract, is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Philosophical Society.

EDWARD H. PARKER, *Secretary to the House Committee.*

GLASGOW, *17th October, 1901.*—We have examined the foregoing Financial Statement of the Treasurer, the Accounts of the Marine and Railway Engineering Medal Funds, the Graduates' Medal Fund, the Building Fund, and the "House Expenditure" Account, and find the same duly vouched and correct, the Amounts in Bank being as stated.

The Capital of the Medal Funds is on loan to the Building Fund at interest.

(Signed) F. J. ROWAN, } AUDITORS.
R. T. NAPIER, }

REPORT OF THE LIBRARY COMMITTEE.

THE additions to the Library during the year include 42 volumes and 2 parts by purchase; 26 volumes and 1 part by donation; while 78 volumes and 121 parts were received in exchange for the Transactions of the Institution. Of the periodical publications received in exchange, 26 were weekly, and 15 monthly. Two hundred and twenty-six volumes were bound during the year, including 101 volumes of Illustrated Abridgments of Specifications of Patents.

As the proceedings of the most important engineering societies are to be found in the Library of the Institution, the Committee begs to draw the attention of Members to the existence of this particular section.

The Institution possesses a complete set of the Abridgments of Specifications of Patents dating from 1617, which is available for reference purposes in the Library.

DONATIONS TO THE LIBRARY.

Association of Assistant Engineers in Glasgow. Committee Minute Book, 1860. From Mr Robert Harvey.

Barker, H. A course of six lectures (with discussions) on the Management of Engineering Workshops, February to April, 1901. From Institution of Junior Engineers.

Beare, T. H. The Education of an Engineer: An Inaugural Lecture delivered at the University of Edinburgh, November, 1901. Pamphlet. From the Author.

Berly's Universal Electrical Directory, 1900-1901.

Brewer, Griffith and Alexander, P.Y., Aëronautics: an Abridgment of Aëronautical Specifications filed at the Patent Office from 1815-1891. 1893. From Mr J. A. Brewer.

Brewer & Son. Property in Trade Marks. 1901. From Mr J. A. Brewer.

Brewer & Son. United States Motor-Cars: being an Index of Specifications of United States Patents issued on the Subject of Motor-Vehicles from 1860-1900. From Mr J. A. Brewer.

Electrical Trades' Directory, 1899.

Handbooks—British Association, Glasgow Meeting, 1901. Archæology, Education, Medical, and Charitable Institutions of Glasgow. Edited by Magnus Maclean. Glasgow, 1901.

Local Industries of Glasgow and the West of Scotland. Edited by Angus Maclean. Glasgow, 1901. From the Executive Committee.

Horner, J. G. English and American Lathes, 4to., 1900. From Mr James B. Reid.

International Engineering Congress: Meeting in Glasgow, 1901. Proceedings. Section I., Railways. Section II., Waterways and Maritime Works. 1902.

Lloyd's Register of Shipping (2 vols.); and 1 volume of Rules and Regulations, 1901-02. From Lloyd's Committee.

MacColl, Hector. Strength of Cylindrical Boiler Shells (From Transactions of the Institution of Engineers and Shipbuilders in Scotland, January, 1875). From the author.

MacColl, Hector. Shafting of Screw Steamers (From Transactions of the Institution of Engineers and Shipbuilders in Scotland, January, 1887). From the author.

MacColl, Hector. Universal Corrosion of Marine Machinery (From Proceedings of the Institution of Mechanical Engineers, July, 1896). From the author.

Macoun, John. Catalogue of Canadian Birds, Part I. Ottawa, 1900. From Geological Survey of Canada.

Murphy, W. S. Captains of Industry. Glasgow. From the Author.

Phillips, W. B., Texas Petroleum. Austin, 1900. From University of Texas Mineral Survey.

Proceedings of the Incorporated Municipal Electrical Association, 1901.

Queen's College, Galway; Calandar, 1901-02, and 1902-03.

Report on the Coals, Lignites, and Asphalt Rocks of Texas. 1902. From the University of Texas.

Sothern, J. W., Verbal Notes and Sketches for Marine Engineers. Second and Third editions. 1901-1902.

Thackeray, Sir Edward T., K.C.B., V.C. Biographical Notices of Officers of the Royal Bengal Engineers, 1900. From the Author.

Wannan, A. C., and Sothern, J. W., Elementary Questions, New and Revised, by the Board of Trade for Marine Engineers. 1901.

BOOKS ADDED TO THE LIBRARY BY PURCHASE.

Aitken, Thomas. Road Making and Maintenance; a Practical Treatise for Engineers, Surveyors, and others. 1900.

Bessley, Carl. Marine Steam Engine; its Construction, Action, and Management. Translated by H. A. B. Cole. 3rd edition, Part 3, with Part 3 4to Atlas of Plates. Kiel, 1902.

Björling, P. R. Pumps and Pump Motors. 2 vols.; 4to. 1895.

Blair, A. A. Chemical Analysis of Iron. 3rd edition. Philadelphia, 1898.

Brassey's Naval Annual, 1902.

Butterfield, W. J. A. Gas Manufacture: The Chemistry of. 2nd edition, 1898.

Chatelier, H. Le, and O. Boudouard. High Temperature Measurements. Translated by G. K. Burgess. New York, 1901.

Clark, D. K. Manual of Rules, Tables, and Data for Mechanical Engineers. 7th edition, 1897.

Dalby, W. E. Balancing of Engines. 1902.

Fidler, T. C. Practical Treatise on Bridge Construction. 3rd edition. 1901.

Gillespie, W. M., and Staley Cady. Treatise on Surveying. 2 vols. 1901.

Goldingham, A. H. Design and Construction of Oil Engines, with full directions for Erecting, Testing, Installing, Running, and Repairing. 1900.

Graham, John. Elementary Treatise on the Calculus for Engineering Students. 2nd edition, 12 mo., 1900.

Harcourt, L. F. Vernon. Civil Engineering, as applied in Construction. 1902.

Hutton, F. R. Mechanical Engineering of Power Plants. New York, 1901.

Hutton, F. R. Heat and Heat Engines. New York, 1899.

James, Alfred. Cyanide Practice. 4to. 1902.

Kemp, Dixon. Manual of Yacht and Boat Sailing. 9th edition. 1900.

Kent, William. Steam Boiler Economy. New York. 1901.

Lupton, Arnold, Practical Treatise on Mine Surveying. 1902.

Merrett, H. S. Practical Treatise on the Science of Land and Engineering Surveying, Levelling, Estimating quantities, etc. 5th edition, with an Appendix by G. W. Ushil. 1897.

Peters, E. D. Modern Copper Smelting. 11th edition. New York, 1901.

Pullen, W. W. F. Experimenting Engineering, Vol. I.: a Treatise on the Methods and Instruments used in Testing and Experimenting with Engines, Boilers, and Auxiliary Machinery. Manchester, 1900.

Rankine, W. J. M. Manual of Applied Mechanics. 16th edition, 1901.

Rankine, W. J. M. Manual of Civil Engineering. 21st edition, 1900.

Rankine, W. J. M., and Bamber, E. F. Mechanical Text-Book: or Introduction to the Study of Mechanics. 5th edition, 1900.

Rankine, W. J. M. Manual of the Steam Engine. 14th edition, 1897.

Rankine, W. J. M. Useful Rules and Tables. 7th edition, 1899.

Richardson, M. T. Practical Blacksmithing. 4 vols., New York, 1899.

Robertson, L. S. Water-tube Boilers, based on a short course of lectures delivered at University College, London, 1901.

Sexton, A. H. The Chemistry of Materials of Engineering. Manchester, 1900.

Sharp, John. Modern Foundery Practice. 1900.

The Engineering Index, 1896-1900.

Thearle, S. J. P. Theoretical Naval Architecture. Vol. II. Plates and Tables.

Walton, Thomas, Steel Ships; their Construction and Maintenance. 1901.

White, Sir W. H. Manual of Naval Architecture. 5th edition. 1900.

Year-Book of the Scientific and Learned Societies of Great Britain and Ireland. 1901.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &C. :—

Aberdeen Association of Civil Engineers, Aberdeen.
American Institute of Electrical Engineers.
American Institute of Mining Engineers, New York.
American Philosophical Society.
American Society of Civil Engineers, New York.
American Society of Mechanical Engineers, New York.
Association des Ingénieurs des Écoles Spèciales de Gand, Belgium.
Association Technique Maritime, Paris.
Austrian Engineers' and Architects' Society, Wien.
Bristol Naturalists' Society, Bristol.
British Association for the Advancement of Science, London.
Bureau of Steam Engineering, Navy Department, Washington.
Canadian Institute, Toronto.

Canadian Society of Civil Engineers, Montreal.
Edinburgh Architectural Association.
Engineering Association of New South Wales, Sydney.
Engineering Society of the School of Practical Science, Toronto.
Engineers' and Architects' Society of Naples, Naples.
Franklin Institute, Philadelphia, U.S.A.
Geological Survey of Canada, Ottowa.
Hull and District Institution of Engineers and Naval Architects, Hull.
Institute of Marine Engineers, London.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Junior Engineers, London.
Institution of Mechanical Engineers, London.
Institution of Naval Architects, Japan.
Institution of Naval Architects, London.
Iron and Steel Institute, London.
L'Association Technique Maritime, Paris.
Liverpool Engineering Society, Liverpool.
Literary and Philosophical Society of Manchester, Manchester.
Lloyd's Register of British and Foreign Shipping, London.
Magyar Mérnök es Épitesz-Egylet, Budapest.
Manchester Association of Engineers, Manchester.
Midland Institute of Mining, Civil, and Mechanical Engineers, Barnsley.
Mining Institute of Scotland, Hamilton.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Patent Office, London.
Royal Dublin Society, Dublin.
Royal Philosophical Society of Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Sanitary Institute of Great Britain, London.

Schiffbautechnischen Gesellschaft, Berlin.
Scientific Library, U.S. Patent Office, Washington, U.S.A.
Shipmasters' Society, London.
Smithsonian Institution, Washington, U.S.A.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Ingénieurs Civils de France, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Société Industrielle de Mulhouse, Mulhouse.
Society of Arts, London.
Society of Arts, Massachusetts Inst. of Technology, Boston.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, New York, U.S.A.
South Wales Institute of Engineers, Cardiff.
Technical Society of the Pacific Coast, San Francisco, U.S.A.
West of Scotland Iron and Steel Institute, Glasgow.

COPIES OF THE TRANSACTIONS ARE FORWARDED TO THE FOLLOWING COLLEGES, LIBRARIES, &C. :—

Advocates' Library, Edinburgh.
Bodleian Library, Oxford.
British Corporation for the Survey and Registry of Shipping, Glasgow.
British Museum, London.
Cornell University, Ithaca, U.S.A.
Coatbridge Technical School.
Dumbarton Free Public Library, Dumbarton.
Glasgow and West of Scotland Technical College, Glasgow.
Glasgow University, Glasgow.
Lloyd's Office, London.
Mercantile Marine Service Association, Liverpool.
M'Gill University, Montreal.
Mitchell Library, Glasgow.
Royal Naval College, Greenwich.

Stevens Institute of Technology, Hoboken, U.S.A.
Stirling's Library, Glasgow.
Trinity College, Dublin.
Underwriters' Rooms, Glasgow.
Do. Liverpool.
University College, London.
University Library, Cambridge.
Yorkshire College, Leeds.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS:—

American Machinist.
American Manufacturer and Iron World.
Automotor and Horseless Vehicle Journal.
Cassier's Magazine.
Colliery Guardian.
Contract Journal.
Engineer.
Engineering.
Engineering Magazine.
Engineering Times.
Engineering and Mining Journal, New York.
Engineers' Gazette.
Feilden's Magazine.
Indian Engineering.
Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Journal de l'École Polytechnic.
L'Industria.
Light Railway and Tramway Journal.
Machinery Market.
Marine Engineer.
Marine Engineering.
Mariner.

Mechanical Engineer.
Mechanical World.
Nature.
Nautical Gazette.
Portefeuille Économique des Machines.
Practical Engineer.
Revue Industrielle.
Scottish Electrician.
Shipping World.
Stahl und Eisen.
Steamship.
The Indian and Eastern Engineer.
Tramway and Railway World.
Transport.

The Library is closed for the Summer Holidays from the 11th July till 31st July inclusive.

Except during holidays and Saturdays, the Library is open each lawful day from 1st May till 30th September inclusive, from 9.30 A.M. till 5 P.M. On Saturdays the Library is open from 9.30 A.M. till 1 P.M.

On the 1st October and thereafter throughout the Winter Session the Library will be open each lawful day from 9.30 A.M. till 8 P.M., except on Meeting Nights of the Institution and Royal Philosophical Society, when it is open till 10 P.M., and on Saturdays, when it is closed at 2 P.M.

Members have the privilege of consulting the Books in the Library of the Royal Philosophical Society.

The use of the Library and Reading Room is open to Members, Associates, and Graduates.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signatures to the bottom of Carte.

The Library Committee are desirous of calling the attention of

Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

A List of the Papers read and Authors' Names, from the First to the Thirty-Third Sessions, will be found in Vol. XXXIII. of the Transactions.

As arranged by the Council, a Register Book for Graduates now lies in the Library for the inspection of Members, the object being to assist Graduates of the Institution in finding suitable appointments.

R. T. MOORE,
Hon. Librarian and Convener.

Annual Subscriptions are due at the commencement of each Session: viz.:—

MEMBERS, £1 10s; ASSOCIATES, £1; GRADUATES, 10s.
LIFE MEMBERS, £20; LIFE ASSOCIATES, £15.

Membership Application Forms can be had from the Secretary or from the Sub-Librarian, at the Rooms, 207 Bath Street.

The Council, being desirous of rendering the Transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such Papers should be sent to the Secretary, so that the dates of reading may be arranged.

Copies of the reprint of Vol. VII., containing a paper on "The Loch Katrine Water Works," by Mr J. M. Gale, C.E., may be had from the Secretary; price to Members, 7s 6d.

Members of this Institution, who may be temporarily resident in Edinburgh, will, on application to the Secretary of the Royal Scottish Society of Arts, at his office, 117 George Street, be furnished with Billets for attending the meetings of that Society.

The Meetings of the Royal Scottish Society of Arts are held on the 2nd and 4th Mondays of each month, from November till April, with the exception of the 4th Monday of December.

OBITUARY.

Members.

George McLellan Blair was born in Glasgow on 30th April, 1841. He commenced his business career with Messrs P. & W. McLellan as a boy, and remained associated with the firm for the long period of forty-seven years. In 1861 he was assumed a partner by his uncle, the founder of the firm, and on the retirement of the late Mr Walter McLellan, he became senior partner, and continued as such until the formation of the concern into a limited company in 1890, when he was appointed chairman and managing director, a position he held until his death.

Messrs P. & W. McLellan commenced business in Trongate, from whence their works were removed to the south side of the city, in Adelphi Street and Rose Street, Hutchesontown. Thirty years ago the present works were built on the line of the Glasgow and Paisley Railway opposite Pollokshields, at which establishment large Government contracts, as well as the equipment for railways in India and other parts of the world, the building of iron and steel bridges and other structural work of importance, were carried out under the directorship of Mr Blair.

Mr Blair was a Justice of the Peace for the Lower Ward of Lanarkshire for upwards of twenty years. He was well known in the engineering community in London and the Midlands, but being of a somewhat retiring disposition, he took little active interest in the municipal affairs of his native city. Declining health caused him to seek rest and retirement at his country residence, Clifton Hall, Ratho, but after a two months' absence from business he died on 4th January, 1902, leaving a widow and five sons and three daughters to mourn his loss.

Mr Blair became a member of the Institution in 1869.

Frank McCulloch, London.

Mr Frank McCulloch became a Member of the Institution in 1891.

Henry John McDowall was born at Johnstone in the year 1857. He was the youngest son of the late Mr John McDowall, founder of the well-known sawmill-engineering firm of John McDowall & Sons, Walkinshaw Foundry, Johnstone, and received his early education at the Glasgow High School, and Lausanne. On returning from Switzerland he entered the Walkinshaw foundry as an apprentice, and acquired a practical knowledge by working in the various departments associated with the business. He eventually became a partner in the concern, and in connection with its affairs travelled in various parts of the world.

Mr McDowall was a Justice of the Peace for the county of Renfrew, and was president of the Johnstone Conservative Association, at the time of his death. He was also an enthusiastic volunteer and held the colonelcy of the 3rd Lanark R.V. for some time. He was known as a genial large hearted gentleman, and was an accomplished musician besides being a trained vocalist.

Mr McDowall died at his residence, Sunnyhill, Johnstone, on 30th January, 1902, in the 46th year of his age.

He became a member of the Institution in 1899.

Thomas McLaren was born in Perthshire in the year 1841. He was educated in Glasgow, and served his apprenticeship as an engineer with Messrs Tod & MacGregor, of which firm his uncle, Mr David Tod, was a partner. Shortly after completing his apprenticeship he was appointed to the Khedive of Egypt's yacht, which was built by Messrs Tod & MacGregor, as second engineer. Leaving the Khedive's service, he was engaged for some years with Messrs M. Langlands & Sons, and during the latter part of his career with that firm was chief engineer of the well-known steamer "Princess Royal." Subsequently he became superintendent engineer with Messrs James Little & Co. About the year 1889 Mr McLaren established himself in Glasgow as a consulting engineer. He died suddenly in Glasgow on 3rd May, 1902.

Mr McLaren became a member of the Institution in 1898.

ALFRED MUIR was the fourth of the five sons of the late William Muir, founder of the firm of Messrs Wm. Muir & Co., Engineers' Tool Makers, Manchester. He was born on the 29th May, 1840, at Pimlico, London, where his father was engaged at that time as manager for Mr Bramah, the inventor of the celebrated Bramah lock and of the important improvements which made the hydraulic press commercially useful.

The subject of this memoir was brought up in Manchester, and after completing his education at the Chester College, of which the late Rev. Arthur Rigg was then the Principal, he served his time in his father's works. On completing his apprenticeship he worked for some time as a journeyman mechanic at Messrs Penn's Marine Engineering Works, Greenwich, to gain experience. On leaving that firm, he was appointed manager of his father's works, and when his father retired from business he succeeded him, and eventually, on its being converted into a private limited company, he was appointed chairman and managing director of the company, which position he held at the time of his death.

Alfred Muir, like his father before him, was a splendid workman, and took great pride in turning out work only the best of its kind, in finish, accuracy of workmanship, and detail, and so continued the high reputation that "Muir's Tools" had acquired for such qualities. He was also a clever inventor, and patented several of his inventions, notably improvements in cutters for milling, in couplings for drilling and milling machines, and in capstan slide rests for lathes.

Shortly before his death he was selected by the War Office as a member of the Screw Committee appointed to make experiments, and to report on a standard screw, with a view to its general adoption by the country, and if he had been spared his special experience would have been of the greatest value. He took no prominent part in politics or municipal work, but devoted himself unremittingly to his business, to which he was devotedly attached, and he died in harness, being called away suddenly on the 10th May, 1902, at Harrogate, where he was staying for the benefit of his health, after having sojourned for three months in Egypt for the same purpose without experiencing any improvement in his condition.

He became a member of the Institution on 23rd February, 1897.

Alexander R. Paton was born on 18th December, 1860, and received his education at the Glasgow Academy. He acquired his early training as an engineer with the firm of Messrs J. & J. Thomson, Finnieston, Glasgow. Shortly after the expiration of his apprenticeship he entered the service of Messrs Patrick Henderson & Co., and eventually became chief engineer on one of their steamers. Subsequently he was appointed as an engineer surveyor to Lloyd's Register, and after a few years resigned to start business on his own account as a consulting engineer.

Mr Paton was esteemed by all who knew him for his kindly disposition and obliging manner. He died at his residence, Redthorn, Partick, on 14th July, 1901.

Mr Paton joined the Institution as a graduate in 1879, and became a member in 1894.

John Paton was born at Old Kilpatrick on the 2nd April, 1861. After leaving school he served an apprenticeship of five years in the civil and mining engineer's department of Messrs William Dixon, Limited. During that period, by private tuition and evening classes, he qualified himself to become a capable assistant. In 1882 he entered the office of Mr John Strain, Glasgow, where he had a varied experience in railway surveying and in the design of bridges and other works. While in Mr Strain's employment he acted as resident engineer during the construction of the Killin branch of the Callander and Oban Railway, and the Airdrie, Gartness, Chapelhall, and Newhouse branches of the Caledonian Railway.

After the completion of these works he acted as engineer to Mr A. H. Boyle, railway contractor, carrying out various important works. His bent being strongly for the practical work of construction, he began business as a contractor on his own account about 1891. Beginning in a modest way, he was able, by careful personal attention, to undertake larger and larger contracts. He successfully carried out various sewage and water-works' contracts and several bridges—among them being Haddington bridge over the Tyne, Cambuslang bridge over the Clyde, and Bonhill bridge over the Leven. Some years ago he carried out for the Caledonian Railway Company the remodelling of Crieff station, and in 1899 he undertook the first section of the Lochearnhead, St. Fillans, and Comrie Railway, which was opened from Comrie to St. Fillans for public traffic in 1901. So well did he perform this work that the engineers, Messrs Crouch & Hogg, recommended him for the second section (nine miles in length), which was under construction at the time of his death on the 27th January, 1902. He was laid down with scarlet fever only a week before, but some kidney trouble complicated the issue, and he passed away suddenly at the age of 40, in the prime of life.

Mr Paton was a man of quiet and reserved disposition, strong and self-reliant, who enjoyed the full confidence of all those for whom he carried out work, and had he lived he would have risen to a foremost place as a constructor of public works. He left a widow and four young children.

Mr Paton became a member of the Institution in 1889.

WILLIAM T. PHILP, Belfast.

Mr William T. Philp joined the Institution as a Graduate in 1881, and became a Member in 1891.

Associate.

William Young was born in Glasgow on 16th April, 1825, and served an apprenticeship of seven years with his father, Mr William Young. He started in business as a brass founder with his brother, Mr John Young, under the name of Messrs J. & W. Young, in 1850, and remained in the business until his death, which took place on 25th October, 1902.

Mr Young was an Associate of the Scottish Shipbuilders' Association at incorporation with the Institution in 1865.

Graduates.

Turner Dunn died at Durban, Natal, on 18th December, 1901. Mr Dunn joined the Institution as a graduate in 1893.

Andrew M'Nair, son of Mr James M'Nair, was born at Glasgow on 17th November, 1879, and received his education at the Partick Academy and Allan Glen's School, Glasgow.

He completed his apprenticeship with Messrs D. & F. Reid, engineers, Ayr, in May, 1901, and thereafter entered the service of Messrs D. Rowan & Son, Glasgow. In August of that year his health suddenly failed, and he died at Norwood, Ayr, on the 21st December, 1901, aged 22 years.

Mr M'Nair joined the Institution in 1901.

LIST OF HONORARY MEMBERS, MEMBERS, ASSOCIATES, AND GRADUATES

AT CLOSE OF SESSION 1901-1902.

HONORARY MEMBERS.

	DATE OF ELECTION.
KELVIN, Lord, A.M., LL.D., D.C.L., F.R.SS.L., and E., Netherhall, Largs,	1859
BRASSEY, Lord, K.C.B., D.C.L., 4 Great George street, Westminster, London, S.W.,	1891
BLYTHSWOOD, Lord, Blythswood, Renfrewshire,	1891
KENNEDY, Professor A. B. W., LL.D., F.R.S., 17 Victoria street, London, S.W.,	1891
MURRAY, Sir DIGBY, Bart., Hothfield, Parkstone, Dorset,	1891
WHITE, Sir WILLIAM HENRY, K.C.B., F.R.S., LL.D., D.Sc., 39 Rowland Gardens, Brompton, London, S.W.,	1894
DURSTON, Sir A. J., K.C.B., Westcomlea, Park Road, Blackheath, London, S.E.,	1896
FROUDE, R. E., F.R.S., Admiralty Experiment works, Gosport,	1897

MEMBERS.

	DATE OF ELECTION.
AAMUNDSEN, JENS L., 57 Classensgade, 2 Sal, Copenhagen, Denmark,	24 Jan., 1899
ABERCROMBIE, ROBERT GRAHAM, Broad Street Engine Works, Alloa,	21 Mar., 1899
ADAM, J. MILLEN, Ibrox Iron works, Glasgow,	G. 25 Mar., 1890 M. 22 Jan., 1895
ADAMSON, ALEX., St. Andrews, Chislehurst,	20 Feb., 1900
ADAMSON, JAMES, St. Quivox, Stopford road, Upton Manor, Essex,	23 Apr., 1889
ADAMSON, PETER HOGG, 11 Fairlie park drive, Partick,	19 Mar., 1901
AILSA (*The most Honourable the Marquis of*), Culzean castle, Maybole,	25 Jan., 1898

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

AITCHISON, WILLIAM, 6 Midlothian drive, Shawlands, Glasgow,	22 Oct., 1889
AITKEN, H. WALLACE, 140 Bath Street, Glasgow,	G. 24 Jan., 1888 M. 24 Jan., 1899
AITON, J. ARTHUR, Western Works, Hythe Road, Willesden Junction, London, N.W.,	24 Nov., 1896
ALEXANDER, JOHN, Engineer, Barrhead,	19 Mar., 1901
ALLAN, JOHN M.,	21 Jan., 1890
ALLAN, ROBERT, Demerara foundry, George Town, Demerara,	30 Apr., 1895
ALLAN ROBERT, 93 Hope Street, Glasgow,	26 Apr., 1898
ALLAN, Sir WILLIAM, M.P., Scotia Engine works, Sunderland,	20 Jan., 1869
ALLEY, STEPHEN E., 8 Woodside terrace, Glasgow,	23 Nov., 1897
†ALLIOTT, JAMES B., The Park, Nottingham,	21 Dec., 1864
ALSTON, WILLIAM M., 24 Sardinia terrace, Hillhead, Glasgow,	G. 15 Feb., 1865 M. 18 Dec., 1877
†AMOS, ALEXANDER, Public Library of N.S.W., Sydney, New South Wales,	21 Dec., 1896
†AMOS, ALEXANDER, Jun.,	21 Dec., 1886
†ANDERSON, E. ANDREW, c/o Clinton, 13 Holmhead street, Glasgow,	21 Feb., 1899
ANDERSON, F. CARLTON, 53 Bothwell street, Glasgow,	23 Apr., 1901
ANDERSON, J. GODFREY, B.SC., c/o Messrs James Templeton & Co., Greenhead, Glasgow,	19 Mar., 1901
ANDERSON, JAMES, 100 Clyde street, Glasgow,	G. 24 Feb., 1874 M. 23 Nov., 1880
†ANDERSON, JAMES, 1 Marlborough terrace, Glasgow,	26 Nov., 1901
ANDERSON, JAMES H., Caledonian Railway, Glasgow,	20 Dec., 1892
ANDERSON, ROBERT, Clyde Street, Renfrew,	26 Jan., 1897
ANDERSON, WILLIAM MARTIN, Engineer, 100 Clyde street, Glasgow,	18 Dec., 1900
ANDERSON, WILLIAM SMITH, Bogie Wood, Port-Glasgow,	21 Nov., 1899
ANDREWS, H. W., 128 Hope street, Glasgow,	A. 21 Dec., 1897 M. 24 Oct., 1899
ANDREWS, JAMES, Blythswood Chambers, 180 West Regent street, Glasgow,	22 Nov., 1898
ANGUS, ROBERT, Lugar, Ayrshire,	28 Nov., 1860
ANIS, Professor MOHAMED, Bey, Ministère des Travaux Publics, Cairo,	24 Apr., 1894
ARCHER, W. DAVID, 47 Croham road, Croyden, Surrey,	20 Dec., 1887
ARNOT, WILLIAM, 79 West Regent street, Glasgow,	23 Jan., 1894
ARNOTT, HUGH STEELE, 99 Clarence drive, Hyndland, Glasgow,	G. 26 Oct., 1897 M. 22 Jan., 1901
ARROL, THOMAS A., Germiston works, Glasgow,	21 Dec., 1875

ARROL, THOMAS, Jun., Oswald gardens, Scotstounhill, Glasgow,	20 Nov., 1894
†ARROL, Sir WILLIAM, LL.D., M.P., Dalmarnock Iron works, Glasgow,	27 Jan., 1885
AULD, JOHN, Whitevale foundry, Glasgow,	28 Apr., 1885
AUSTIN, WM. R., 11 University avenue, Glasgow,	23 Feb., 1897

BAILLIE, ROBERT, c/o Stirling Boiler Company, Limited, 75 Bath street, Glasgow,	20 Nov., 1900
BAIN, WILLIAM N., 40 St. Enoch square, Glasgow,	24 Feb., 1880
BAIN, WILLIAM P. C., Lochrin Iron works, Coatbridge,	28 Apr., 1891
BAIRD, ALLAN W., Eastwood villa, St. Andrew's drive, Pollokshields, Glasgow,	25 Oct., 1881
BALDERSTON, JAMES, Anchor mills, Paisley,	25 Jan., 1898
BALDERSTON, JOHN A., Vulcan Works, Paisley,	18 Dec., 1900
BALFOUR, GEORGE, Messrs Lowdon Bros. Temple Electric Works, Dundee,	21 Mar., 1899
BALLINGALL, DAVID, c/o Richard Hornsby & Son, Ltd., Spittlegate Iron Works, Grantham,	27 Oct., 1896
BAMFORD, HARRY, M.Sc., The University, Glasgow,	24 Nov., 1896
BARCLAY, GEORGE, Vulcan works, Paisley,	25 Jan., 1898
BARMAN, HARRY D. D., 27 University avenue, Glasgow,	G. 24 Apr., 1888 M. 24 Oct., 1899
BARNETT, J. R., Westfield, Crookston,	22 Dec., 1896
BARNETT, MICHAEL R., Engineer's Office, Laurel Bank, Lancaster,	22 Nov., 1887
BARR, Professor ARCHIBALD, D.Sc., Royston, Dowanhill, Glasgow,	21 Mar., 1882
BARR, JOHN, Glenfield Company, Kilmarnock,	A. 28 Oct., 1883 M. 25 Jan., 1898
BARROW, JOSEPH, Messrs Thomas Shanks & Co., Johnstone,	19 Feb., 1901
BAXTER, GEORGE H., Clyde Navigation works, Dalmuir,	22 Mar., 1881
BAXTER, P. M'L., Copland works, Govan,	G. 22 Dec., 1885 M. 15 June, 1898
BEARDMORE, JOSEPH, Parkhead Forge, Glasgow,	27 Oct., 1896
BEARDMORE, JOSEPH GEORGE, Parkhead Forge, Glasgow,	22 Nov., 1898
BEARDMORE, WILLIAM, Parkhead forge, Glasgow,	27 Oct., 1896
BEGBIE, WILLIAM, P.O. Box 459, Johannesburg, South Africa,	15 June, 1898
*†BELL, DAVID, 19 Eton place, Hillhead, Glasgow,	
BELL, IMRIE, 49 Dingwall road, Croydon, Surrey,	23 Mar., 1880

Bell, Stuart, 65 Bath street, Glasgow,	26 Feb., 1895
Bell, Thomas, Messrs John Brown & Co., Ltd., Clydebank,	G. 26 Apr., 1887 M. 27 Apr., 1897
Bell, W. Reid, Headquarters, Railway Pioneer Regiment, Johannesburg, South Africa,	22 Jan., 1889
Bennie, H. Osbourne, Clyde Engine works, Cardonald, Glasgow,	25 Jan., 1898
Bennie, John, Auldhousfield, Eastwood, Pollokshaws,	22 Feb., 1898
Bergius, W. C., 77 Queen street, Glasgow,	23 Jan., 1900
Beveridge, Richard James, 53 Waring street, Belfast,	22 Feb., 1898
Biggart, Andrew S., 279 Nithsdale road, Pollokshields, Glasgow,	G. 20 Mar., 1883 M. 25 Nov., 1884
Biles, Professor John Harvard, LL.D., The University, Glasgow,	25 Mar., 1884
Binney, Wm. H., Marine Superintendent, Holyhead,	26 Jan., 1897
Binnie, R. B. Jardine, Carntyne Works, Parkhead,	24 Dec., 1901
Bird, John R., 10 Morrison street, Glasgow,	25 Mar., 1890
Bishop, Alexander, 3 Germiston street, Glasgow,	G. 24 Mar., 1885 M. 24 Jan., 1899
Blair, David A., Scotland street Copper works, Glasgow,	23 Mar., 1897
Blair, George, B.Sc., 16 Albert road (East), Crosshill, Glasgow,	21 Nov., 1899
Blair, George, Jun., 38 Queen street, Glasgow,	G. 22 Jan., 1884 M. 23 Feb., 1897
Blair, H. Maclellan, Obbe, Skye,	G. 22 Jan., 1884 M. 22 Oct., 1869
Blair, James M., Williamcraigs, Linlithgowshire,	27 Mar., 1867
Bone, William L., Ant and Bee works, West Gorton, Manchester,	23 Oct., 1883
Borrowman, William C., Newstead, West Hartlepool,	G. 27 Oct., 1887 M. 26 Oct., 1895
Bost, W. D. Ashton, Adelphi house, Paisley,	25 Jan., 1898
Bow, William, Thistle works Paisley,	27 Jan., 1891
Bowser, Charles Howard, Charles street, St. Rollox, Glasgow,	21 Mar., 1899
Boyd, William, The Tharsis Sulphur and Copper Co., Ltd., Hebburn-on-Tyne,	24 Oct., 1899
Brace, George R., 25 Water street, Liverpool,	25 Mar., 1890
Bray, E. N., 81 St. George's place, Glasgow,	22 Nov., 1898
Breingan, W. D., Barns place, Clydebank,	22 Jan., 1901
Brewer, J. Alfred, 249 West George street, Glasgow,	20 Nov., 1900
Brier, Henry, 1 Miskin road, Dartford Kent,	22 Dec., 1891
Broadfoot, James, Lymehurst, Jordanhill,	G. 23 Dec., 1873 M. 22 Jan., 1884

Broadfoot, William R., Inchholm works, Whiteinch, 25 Jan., 1898

Brock, Henry W., Engine works, Dumbarton, 30 Apr., 1895

*__Brock__, Walter, Engine works, Dumbarton, 26 Apr., 1865

Brock, Walter, Jun., Levenford, Dumbarton, 27 Oct., 1896

Broom, Thomas M., Oakfield, East Greenock, 25 Apr., 1893

Brown, Alex. D., Dry Dock, St John's, Newfoundland, 22 Dec., 1896

Brown, Alexander T., 18 Glencairn drive, Pollokshields, Glasgow, G. 25 Feb., 1879; M. 27 Oct., 1891

†*__Brown__, Andrew, London works, Renfrew, 16 Feb., 1859

Brown, Andrew M'N., Strathclyde, Dalkeith avenue, Dumbreck, Glasgow, G. 25 Jan., 1876; M. 24 Nov., 1885

Brown, Ebenezer Hall-, Helen street Engine works, Govan, Glasgow, G. 18 Dec., 1883; M. 26 Feb., 1895

Brown, George, Darvel Graving Dock, Greenock, 23 Mar., 1886

Brown, James, Palmer's Shipbuilding Co., Jarrow-on-Tyne, G. 26 Oct., 1886; M. 26 Jan., 1892

Brown, James D., Rosebank Iron Works, Edinburgh, 29 Oct., 1901

Brown, James M'N., Glenfruin, Renfrew, 26 Jan., 1897

Brown, Matthew T., B.Sc., 233 St. Vincent street, Glasgow, G. 25 Jan., 1881; M. 18 Dec., 1894

Brown, Robert, 7 Church road, Ibrox, Glasgow, 18 Feb., 1902

Brown, Walter, Monkdyke, Renfrew, 28 Apr., 1885

Brown, William, Meadowflat, Renfrew, G. 27 Jan., 1874; M. 22 Jan., 1884

Brown, William, Albion works, Woodville street, Govan, Glasgow, 21 Dec., 1880

Brown, William, Messrs Dubs & Co., Glasgow Locomotive works, Glasgow, 17 Dec., 1889

Brown, William Dewar, 22 Ranelagh villas, Hove, Sussex, 25 Mar., 1890

Brown, William S., Junr., 67 Washington street, Glasgow, 21 Dec., 1897

Bruce-Kingsmill, J., Capt., R.A., The Ordnance College, Woolwich, 21 Dec., 1897

Bruhn, Johannes, D.Sc., 49 Sydenham park, Sydenham, London, G. 24 Oct., 1893; M. 22 Feb., 1898

Bryson, William Alexander, Chambers, 16 Charlotte street, Leith, 27 Oct., 1896

Buchanan, John H., 5 Oswald street, Glasgow, 23 Jan., 1900

Buckwell, George W., Board of Trade Offices, Sunderland, 27 Apr., 1897

Budenberg, Christian Frederick, 31 Whitworth street, Manchester, 20 Dec., 1898

Bullard, E. P., Jun., Bridgeport, Conn., U.S.A., 29 Oct., 1901

Burden, Alfred George Newkey, Box 953, Johannesburg, South Africa, 20 Feb., 1900

Burt, Thomas, 60 St. Vincent crescent, Glasgow,	22 Mar., 1881
Butters, Michael W., 20 Waterloo street, Glasgow,	24 Oct., 1899
Butters, James Thomas, Percy Crane & Engine Works, Glasgow,	19 Mar., 1901

Caird, Arthur, Messrs Caird & Co., Ltd., Greenock,	27 Oct., 1896
†Caird, Edward B., 777 Commercial road, Limehouse, London,	29 Oct., 1878
†Caird, Patrick T., Messrs Caird & Co., Ltd., Greenock,	27 Oct., 1896
Caird, Robert, LL.D., Messrs Caird & Co., Ltd., Greenock,	20 Feb., 1894
Calderwood, William T., Stanley villa, Kilmailing, Cathcart,	25 Jan., 1898
Caldwell, James, 130 Elliot street, Glasgow,	17 Dec., 1878
Cameron, Angus, Union Steam Ship Company, Dunedin,	18 Feb., 1902
Cameron, Donald, City Surveyor's office. Exeter,	25 Feb., 1890
Cameron, John B., 111 Union street, Glasgow,	24 Mar., 1885
Campbell, Duncan, Carntyne foundry and Engineering works, Parkhead, Glasgow,	23 Jan., 1900
Campbell, George, Albany villa, Orrell lane, Aintree, Liverpool,	22 Mar., 1898
Campbell, Hugh, The Campbell Gas Engine Company, Halifax, Yorkshire,	18 Dec., 1900
Campbell, James, 104 Bath street, Glasgow,	18 Dec., 1900
Campbell, John, 8 Broomhill drive, Partick,	21 Jan., 1890
†Campbell, Thomas, Maryhill Iron works, Glasgow,	20 Nov., 1900
Campbell, Walter Hope, 42 Krestchatik, Kieff, South Russia,	25 Apr., 1899
Carey, Evelyn G., 4 Sunnyside avenue, Uddingston,	22 Oct., 1889
Carlaw, Alex. L., 11 Finnieston street, Glasgow,	24 Dec., 1895
Carlaw, David, Jun., 11 Finnieston street, Glasgow,	24 Dec., 1895
Carlaw, James W., 11 Finnieston street, Glasgow,	24 Dec., 1895
Carmichael, Angus T., 3 Harvey street, Paisley road, W., Glasgow,	19 Mar., 1901
Carruthers, John H., Ashton, Queen Mary avenue, Crosshill, Glasgow,	22 Nov., 1881
Carver, Thomas, A. B., B.Sc., 118 Napiershall street, Glasgow,	19 Feb., 1901
Chalmers, Walter, 24 Claremont Gardens, Milngavie,	23 Jan., 1900
Chamen, W. A., 75 Waterloo street, Glasgow,	22 Feb., 1898
Chisholm Robert, Ferniehurst, Bertrohill road, Shettleston,	29 Oct., 1901

Christie, John, Corporation Electricity Works, Brighton,	22 Nov., 1898
Christie, R. Barclay, Messrs M'Lay & M'Intyre, 21 Bothwell street, Glasgow,	25 Apr., 1893
Christison, George, 13 Cambridge drive, Glasgow,	22 Feb., 1898
Clark, George Alexander, 34 Ann street, Glasgow,	22 Nov., 1898
Clark, James Lester, Dublin Dockyard Company, Northwall, Dublin,	24 Nov., 1896
Clark, John, British India Steam Navigation Co., 9 Throgmorton avenue, London, E.C.,	23 Jan., 1883
Clark, William, 208 St. Vincent street, Glasgow,	25 Apr., 1893
Clark, William, 88 Renfield street, Glasgow,	22 Dec., 1896
Clark, William Graham, 29 Church road, Waterloo, Liverpool,	22 Feb., 1898
Clarkson, Charles, 20 Macaulay road, Birkby, Huddersfield,	27 Oct., 1891
Cleghorn, Alexander, 10 Whittinghame drive, Kelvinside, Glasgow,	22 Nov., 1892
Clyne, James, Messrs Clyne, Mitchell, & Co., Commercial road, Aberdeen,	18 Dec., 1900
Coats, Allan, Jun., B.Sc., Hayfield, Paisley,	23 Oct., 1900
Coats, James, Talara, Katharine drive, Govan,	21 Dec., 1897
Cochran, James T., Messrs Cochran & Co., Annan, N.B.,	26 Feb., 1884
Cochrane, John, Grahamston foundry, Barrhead,	25 Mar., 1890
Cockburn, George, Cardonald, near Glasgow,	25 Oct., 1881
Cockburn, Robert, Cumbrae House, Dumbreck, Glasgow,	25 Jan., 1898
Collie, Charles, 19-21 Eaglesham street, Plantation, Glasgow,	26 Apr., 1898
Colville, Archibald, 51 Clifford street, Bellahouston, Govan,	23 Jan., 1900
Colville, Archibald, Motherwell,	27 Oct., 1896
Colville, David, Jerviston house, Motherwell,	27 Oct., 1896
Connell, Charles, Whiteinch, Glasgow,	G. 19 Dec., 1876 M. 25 Mar., 1884
Conner, Alexander, 6 Grange Knowe, Irvine road, Kilmarnock,	G. 26 Feb., 1884 M. 24 Jan., 1899
Conner, Benjamin, 196 St. Vincent street, Glasgow,	G. 22 Dec., 1885 M. 26 Oct., 1897
Conner, James, Lancashire, Derbyshire, and E. Coast Rly., Locomotive Supt.'s Office, Tuxford, Newark,	G. 18 Dec., 1877 M. 24 Nov., 1885
Conner, James, English Electric Manufacturing Co., Limited, Preston,	20 Nov., 1900
Cooper, James, Aberdeen Steam Navigation Company, Aberdeen,	19 Dec., 1893
Cooper, Henry B.,	19 Feb., 1901

Copeland, James, 24 George square, Glasgow,	17 Feb., 1864
Copestake, S. G. G., Glasgow Locomotive works, Little Govan, Glasgow,	11 Mar., 1868
†Copland, William R., 146 W. Regent street, Glasgow,	20 Jan., 1864
Cormack, John Dewar, B.Sc., University College, Gower street, London, W.C.,	24 Nov., 1896
Coulson, W. Arthur, 47 King street, Mile-end, Glasgow,	15 June, 1898
Couper, Sinclair, Moore Park Boiler works, Govan, Glasgow,	G. 21 Dec., 1880 M. 27 Oct., 1891
Courtier-Dutton, W. T., Shipbuilder and Engineer, 121 St. Vincent street, Glasgow,	22 Dec., 1896
Coutts, Francis, 25 Roslin Terrace, Aberdeen.	G. 27 Oct., 1885 M. 24 Jan., 1899
Cowan, David, Coulport house, Loch Long, Dumbartonshire,	24 Apr., 1900
Cowan, John, 16 Carlton Terrace, Kelvinside, Glasgow,	27 Apr., 1897
†Cowie, William, Cazenove works, Dunstable, Bedfordshire,	20 Feb., 1900
Craig, Archibald Fulton, Belmont, Paisley,	25 Jan., 1898
Craig, James, Lloyd's Registry, 14 Cross-shore street, Greenock,	G. 20 Dec., 1892 M. 21 Dec., 1897
Craig, John, Broom, Newton Mearns,	22 Jan., 1900
Cran, John, Albert Engine works, Leith,	21 Jan., 1902
Crawford, James, 30 Ardgowan street, Greenock,	27 Oct., 1896
Crawford, Samuel, c/o Garston Graving Dock & Shipbuilding Co., Ltd., Garston, near Liverpool,	18 Dec., 1883
Crichton, James L., 3 East Park terrace, Maryhill, Glasgow,	18 Dec., 1894
Crockatt, William, 179 Nithsdale road, Pollokshields, Glasgow,	22 Mar., 1881
Crosher, William, 31 Great Wellington street, Kinning Park, Glasgow,	24 Jan., 1899
Crow, John, Engineer, 236 Nithsdale road, Pollokshields, Glasgow,	25 Jan., 1898
Cumming, Wm. J. L., Motherwell Bridge Co., Motherwell,	24 Jan., 1899
Cunningham, Peter N., Easterhouse, Kennyhill, Cumbernauld road, Glasgow,	23 Dec., 1884
Cuthill, William, Beechwood, Uddingston,	24 Nov., 1896

Darroch, John, 27 South Kinning place, Paisley road, Glasgow,	24 Jan., 1899
Davidson, David, 17 Regent Park square, Strathbungo, Glasgow,	G. 22 Mar., 1881 M. 18 Dec., 1888

Davie, James, 92 Albert drive, Crosshill, Glasgow,		19 Dec., 1899
Davies, Charles M., Leslie house, Pollokshields, Glasgow,		24 Apr., 1900
Davis, Charles H., 99 Cedar street, New York, U.S.A.,		20 Nov., 1900
Davis, Harry Llewelyn, Messrs Cochran & Co., Ltd., Newbie, Annan,	G. M.	18 Dec., 1888 23 April, 1901
†**Davison**, Thomas, 248 Bath street, Glasgow,		11 Dec., 1861
Dawson, Charles E., 571 Sauchiehall street, Glasgow,		21 Jan., 1902
Delacour, Frank Philip, Baku, Russia,		24 Apr., 1900
Delmaar, Frederick Anthony, Sourabaya, Netherlands East Indies,	G. M.	24 Apr., 1883 24 Oct., 1899
Dempster, James, 7 Knowe terrace, Pollokshields,		24 Jan., 1899
Dempster, John, 49 Robertson street, Glasgow,		22 Feb., 1898
Denholm, James, 5 Derby terrace, Sandyford street, Glasgow,		21 Nov., 1883
Denholm, William, Meadowside Shipbuilding yard, Partick, Glasgow,	G. M.	18 Dec., 1883 21 Nov., 1893
Denny, Archibald, Braehead, Dumbarton,		21 Feb., 1888
Denny, James, Engine works, Dumbarton,		25 Oct., 1887
Denny, Col. John M., M.P., Garmoyle, Dumbarton,		27 Oct., 1896
Denny, Leslie, Leven Shipyard, Dumbarton,		30 Apr., 1895
Denny, Peter, Bellfield, Dumbarton,		21 Feb., 1888
Dewrance, John, 165 Great Dover street, London, S.E.,		19 Feb., 1901
Dick, Frank W., c/o The Parkgate Steel & Iron Co., Ltd., Parkgate, Rotherham,		19 Mar., 1878
Dick, James, 12 Ronald street, Coatbridge,		18 Mar., 1902
Dickson, William, Lanarkshire Steel Co., Motherwell,		15 June, 1896
Dimmock, John Wingrave, Lloyd's Register of Shipping, 342 Argyle street, Glasgow,		22 Mar., 1898
Dixon, James S., 127 St. Vincent street, Glasgow,	G. M.	24 Dec., 1873 22 Jan., 1878
Dixon, Walter, 59 Bath street, Glasgow,		26 Feb., 1895
Dobson, William, The Chesters, Jesmond, Newcastle-on-Tyne,		17 Jan., 1871
Dodd, T. J., Lloyd's Register of Shipping, 342 Argyle street, Glasgow,		20 Nov., 1900
D'Oliveira, Raphael Chrysostome, Campos Rio de Janeiro, Brazil,		20 Feb., 1900
Donald, B. B., 275 Onslow drive, Dennistoun, Glasgow,	G. M.	20 Mar., 1888 24 Jan., 1899
Donald, David P., Johnstone,		21 Mar., 1899
Donald, Robert Hanna, Abbey works, Paisley,		22 Nov., 1892
Donaldson, James, Almond villa, Renfrew,		25 Jan., 1876

Downie, A. Marshall, B.Sc., London road Iron works, Glasgow,		21 Nov., 1899
Doyle, Patrick, F.R.S.E., 7 Government place, Calcutta, India,		23 Nov., 1886
Drew, Alexander, 14 Talbot House, St. Martin's lane, London, W.C.,		29 Apr., 1890
Drummond, Walter, The Glasgow Railway Engineering works, Govan, Glasgow,		26 Mar., 1895
Drysdale, John W. W., 37 Westercraigs, Dennistoun, Glasgow,		23 Dec., 1884
Dubs, Charles R., Glasgow Locomotive works, Glasgow,		24 Oct., 1882
Duncan, George F., 12 Syriam terrace, Broomfield road, Springburn, Glasgow,	G. M.	23 Nov., 1886 20 Mar., 1894
Duncan, George Thomas, Cumledge, Uddingston.		15 Apr., 1902
Duncan, Hugh, 11 Hampden terrace, Mount Florida, Glasgow,		15 June, 1898
Duncan, John, Ardenclutha, Port-Glasgow,		23 Nov., 1886
Duncan, Robert, Whitefield Engine works, Govan, Glasgow,		25 Jan., 1881
Duncan, Robert, Maarowa crescent, Wellington, New Zealand,		24 Oct., 1899
Duncan, W. Lees, Partick foundry, Partick, Glasgow,		18 Dec., 1900
Dunlop, David John, Inch works, Port-Glasgow,		23 Nov., 1869
Dunlop, John G., Clydebank, Dumbartonshire,		23 Jan., 1877
Dunlop, Thomas, 156 Hyndland road, Glasgow,		19 Dec., 1899
Dunlop, Wm. A., Harbour Office, Belfast,		23 April, 1901
Dunlop, William, N. Odero fu Alesso, Sestri Ponento, Italy,	G. M.	22 Jan., 1884 24 Jan., 1899
Dunn, James, Engineer, Collalis, Scotstounhill, Glasgow,		23 April, 1901
†Dunn, Peter L., 815 Battery street, San Francisco, U.S.A.,		26 Oct., 1886
Dyer, Henry, D. Sc., M. A., 8 Highburgh terrace, Dowanhill, Glasgow,		23 Oct., 1883

Edwards, Charles, The Greenock Foundry Company, Greenock,		26 Oct., 1897
Elgar, Francis, LL.D., F.R.SS., L.& E., 34 Leadenhall street, London, E.C.,		24 Feb., 1885
Elliott, Robert, B.Sc., Lloyd's Surveyor, Greenock,	G. M.	24 Mar., 1885 21 Feb., 1898
Ewen, Peter, The Barrowfield Ironworks, Ltd., Craigielea, Bothwell,		21 Mar., 1899

Faickney, Robert, 3 Thornwood terrace, Partick,		20 Nov., 1900
Fairweather, Wallace, 62 St. Vincent st., Glasgow,		24 Apr., 1894
Fedden, Samuel Edgar, Corporation Electric Supply Department, Commercial street, Sheffield,		21 Mar., 1899
Ferguson, Daniel, 27 Oswald street, Glasgow,		26 Apr., 1898
Ferguson, David, Glenholm, Port-Glasgow,		29 Oct., 1901
Ferguson, J. Strathearn, 126 Ingleby drive, Dennistoun, Glasgow,		23 Nov., 1897
Ferguson, John James, Blax-Tulloch, Kirn,		24 Jan., 1899
Ferguson, Louis, 8 Belhaven terrace, Kelvinside, Glasgow,	G. M.	22 Jan., 1895 26 Nov., 1901
Ferguson, Peter, Gilmourlea, Paisley,	G. M.	22 Jan., 1895 26 Nov., 1901
Ferguson, Peter, Phœnix works, Paisley,		22 Oct., 1889
Ferguson, Wilfred H., 4 Thornwood terrace, Partick,		22 Nov., 1898
Ferguson, William D., Albert villa, Ravenhill road, Belfast,	G. M.	27 Jan., 1885 20 Mar., 1894
Ferguson, William R., Messrs Barclay, Curle & Co., Ltd., Whiteinch, Glasgow,	G. M.	22 Feb., 1881 22 Jan., 1895
Ferrier, James, Retreat Cottage, Links parade, Carnoustie,		22 Dec., 1896
Fielden, Immer, 66 Gordon avenue, Southampton,		24 Feb., 1874
Findlay, Alexander, Parkneuk Iron works, Motherwell,		27 Jan., 1880
Finlayson, Finlay, Laird street, Coatbridge,		23 Dec., 1884
Fisher, Andrew, St. Mirren's Engine works, Paisley,		25 Jan., 1898
Fleming, Andrew E., Kandy, Ceylon,		23 Jan., 1894
Fleming, George E., Messrs Dewrance & Co., 163 St. Vincent street, Glasgow,		27 Oct., 1896
Fleming, John, Dellburn works, Motherwell,		24 Jan., 1899
Fleming, William, 10 Heathfield terrace, Springburn Glasgow,		25 Jan., 1898
Fletcher, James, 15 Kildonan terrace, Paisley road, Ibrox, Glasgow,	G. M.	28 Jan., 1896 23 Nov., 1897
Flett, George L., 5 Abercromby terrace, Ibrox, Glasgow,		22 Jan., 1895
Forsyth, Lawson, 97 St. James road, Glasgow,		18 Dec., 1883
Foster, James, 42 Herriet street, Pollokshields, Glasgow,		26 Jan., 1897
Foulis, William, City Chambers, John Street, Glasgow,		18 Jan., 1870
Fox, Samson, Grove House, Harrogate,		2 Nov., 1880
Frame, James, 6 Kilmailing terrace, Cathcart, Glasgow,		28 Feb., 1897
Fraser, William, 121 North Montrose street, Glasgow,		19 Dec., 1893
Fryer, Tom J., "Brookdean" Hope, Sheffield,	G. M.	18 Dec., 1894 20 Dec., 1898

FUJII, TERUGORO, c/o Admiralty, Tokio, Japan,	21 Feb., 1899
FULLERTON, ALEX., Vulcan Works, Paisley,	22 Dec., 1896
FULLERTON, JAMES, Abbotsburn, Paisley,	19 Mar., 1901
FULLERTON, ROBERT A., 1 Strathmore gardens, Hillhead, Glasgow,	19 Mar., 1901
FULTON, NORMAN O, Woodbank, Mt. Vernon, Glasgow,	G. 23 Feb., 1892 M. 19 Mar., 1901

GALE, EDMUND WILLIAM, c/o H. Baker, Esq., Castle Buildings, Cape Town, South Africa,	23 Nov., 1897
†GALE, JAS. M., Corporation Water works, City Chambers, Glasgow,	24 Nov., 1858
GALE, WILLIAM M., 18 Huntly gardens, Kelvinside, Glasgow,	24 Jan., 1893
GALLETLY, ARCHIBALD A., 10 Greenlaw avenue, Paisley,	22 Jan., 1901
GALLOWAY, CHARLES S., Greenwood City, Vancouver, B.C.,	22 Jan., 1895
GARDNER, WALTER, 8 Percy street, Ibrox, Glasgow,	20 Dec., 1898
GEARING, ERNEST, Fenshurst, Clarence drive, Harrogate,	20 Mar., 1888
GEMMELL, E. W., Board of Trade Offices, 7 York street, Glasgow,	18 Dec., 1888
GEMMELL, THOMAS, Electric Lighting Department, St. Enoch Station, Glasgow,	24 Oct., 1899
GIBB, ANDREW, Garthland, Westcombe Park road, Blackheath, London, S.E.,	G. 23 Dec., 1873 M. 21 Mar., 1882
GIFFORD, PATERSON, c/o Messrs Bell, Brothers & M'Lelland, 135 Buchanan street, Glasgow,	23 Nov., 1886
GILCHRIST, JAMES, Stobcross Engine works, Finnieston quay, Glasgow,	G. 26 Dec., 1866 M. 29 Oct., 1878
GILLESPIE, ANDREW, 65 Bath street, Glasgow,	20 Nov., 1894
GILLESPIE, JAMES, 21 Minerva street, Glasgow,	G. 24 Feb., 1874 M. 24 Mar., 1891
GILLESPIE, JAMES, Jun., Margaretville, Orchard street, Motherwell,	18 Dec., 1900
GILMOUR, JOHN H., River Bank, Irvine,	20 Feb., 1900
GLASGOW, JAMES, Fernlea, Paisley,	25 Jan., 1898
†GOODWIN, GILBERT S., Alexandra buildings, James street, Liverpool,	28 Mar., 1866
GORDON, A. G., c/o Messrs Shewan, Tomes, & Co., Hong kong, China,	23 April, 1901
GORDON, JOHN, 152 Craigpark street, Glasgow,	26 Mar., 1895
GORRIE, JAMES M., 1 Broomhill terrace, Partick, Glasgow,	22 Nov., 1893

Goslin, Ernest T., 88 Renfield street, Glasgow,		20 Nov., 1900
Goudie, William J., B.Sc., 92 Albert drive, Crosshill, Glasgow,	G. M.	21 Dec., 1897 29 Oct., 1901
Gourlay, H. Garret, Dundee foundry, Dundee,		25 Apr., 1882
Govan, Alexander, The Sheiling, Craigendoran,		24 Oct., 1899
Gow, George, c/o Messrs J. M. McFarlane & Co., Wallace Buildings, Greenock,		20 Mar., 1900
Gowan, A. B., Byram, Maxwell drive, Pollokshields, Glasgow,	G. M.	24 Jan., 1882 22 Jan., 1895
Gracie, Alex., Fairfield Shipbuilding and Engineering Company, Govan,	G. M.	26 Feb., 1884 24 Nov., 1896
Graham, David R., Messrs A. Stephen & Sons, Engine Department, Linthouse, Glasgow,		25 Apr., 1893
Graham, John, 60 Cambridge drive, Kelvinside, Glasgow,		25 Jan., 1898
Graham, John, 25 Broomhill terrace, Partick,		23 Oct., 1900
Graham, Walter, Kilblain Engine works, Nicholson street, Greenock,	G. M.	28 Jan., 1896 15 June, 1898
Grant, Thomas M., 222 St. Vincent street, Glasgow,		25 Jan., 1876
Gray, David, 77 West Nile street, Glasgow,		21 Nov., 1899
Gray, James, Riverside, Old Cumnock, Ayrshire,		8 Jan., 1862
Gretchin, G. L., 10 Tschernomorskaia street, Odessa, Russia,		25 Jan., 1898
Grieve, John, Engineer, Motherwell,		25 Jan., 1898
Groves, L. John, Engineer, Crinan Canal, Ardrishaig,		20 Dec., 1881
Guthrie, John, The Crown Iron works, Glasgow,		27 Oct., 1896

Haig, Robert, The Mechanical Retorts Co., Limited Murray street, Paisley,		22 Jan., 1901
Haigh, William R., 6 Elmwood gardens, Jordanhill,		22 Dec., 1896
Halket, James P., Glengall Iron works, Millwall, London, E.,		26 Oct., 1897
Hall, William, Shipbuilder, Aberdeen,		25 Jan., 1881
Halley, William Lizars, Lennoxlea, Dumbarton,		21 Dec., 1897
Hamilton, Archibald, Clyde Navigation Chambers, Glasgow,	G. M.	24 Feb., 1874 24 Nov., 1885
Hamilton, Claud, 247 St. Vincent street, Glasgow,		15 June, 1898
Hamilton, David C., Clyde Shipping Company, 21 Carlton place, Glasgow,	G. M.	23 Dec., 1873 22 Nov., 1881
Hamilton, James, Messrs William Beardmore & Co., Govan, Glasgow,	G. M.	26 Dec., 1863 18 Mar., 1876
Hamilton, James, 6 Kyle park, Uddingston,		20 Nov., 1900

†*HAMILTON, JOHN, 22 Athole gardens, Glasgow,	
HAMILTON, JOHN K., 53 Waterloo street, Glasgow,	15 May, 1900
HAND, HENRY, Lloyd's Register, 342 Argyle street, Glasgow,	22 Jan., 1901
HARMAN, BRUCE, 35 Connaught road, Harlenden, London, N.W.,	G. 2 Nov., 1880 M. 22 Jan., 1884
HARRISON, J. E., 160 Hope street, Glasgow,	G. 26 Feb., 1889 M. 22 Feb., 1898
HART, P. CAMPBELL, John Finnie street, Kilmarnock,	24 Nov., 1896
HARVEY, JAMES, 224 West street, Glasgow,	24 Jan., 1899
HARVEY, JOHN H., Messrs Wm. Hamilton & Co., Port-Glasgow,	22 Feb., 1887
HARVEY, ROBERT, 224 West street, Glasgow,	24 Nov., 1896
HARVEY, THOMAS, Grangemouth Dockyard Co., Grangemouth,	19 Dec., 1899
HASTIE, WILLIAM, Kilblain Engine works, Greenock,	17 Jan., 1871
HAY, JOHN, 7 Linden Mansions, Hornsea lane, Crouch End, London, N.,	26 Nov., 1901
HAY, RANKIN, 44 Windsor terrace, St. George's road, Glasgow,	18 Dec., 1900
HAYWARD, THOMAS ANDREW, 18 Carrington street, Glasgow,	22 Mar., 1898
†HENDERSON, A. P., 30 Lancefield quay, Glasgow,	25 Nov., 1879
HENDERSON, FREDERICK N., Meadowside, Partick, Glasgow,	26 Mar., 1895
HENDERSON, J. BAILIE, Government Hydraulic Engineer, Brisbane, Queensland,	18 Dec., 1888
HENDERSON, JAMES BLACKLOCK, D.Sc., 146 Cambridge drive, Glasgow,	20 Nov., 1900
†HENDERSON, JOHN L.,	25 Nov., 1879
HENDERSON, ROBERT, 777 London road, Glasgow,	19 Mar., 1901
HENDERSON, WILLIAM STEWART, Belwood, Coatbridge,	24 Nov., 1896
HENDRY, JAMES C., 8 Fleming terrace, George street, Shettleston,	18 Dec., 1900
HENRY, ERENTZ, 13 Ann street, Hillhead, Glasgow,	20 Feb., 1900
HERRIOT, W. SCOTT, 19 Keir street, Pollokshields, Glasgow,	28 Oct., 1890
HETHERINGTON, EDWARD P., Messrs John Hetherington & Co, Ltd., Pollard street, Manchester,	22 Nov., 1892
HIDE, WILLIAM SEYMOUR, Messrs Amos & Smith, Albert Dock works, Hull,	18 Dec., 1888
HINES, JAMES, Dunedin lodge, Lenzie, Glasgow,	28 Jan., 1896
HODGART, JOHN, Lumsburn, Paisley,	22 Dec., 1896
HOGARTH, W. A., 293 Onslow drive, Glasgow,	20 Nov., 1900
HOGG, CHARLES P., 53 Bothwell street, Glasgow,	2 Nov., 1880

Hogg, John, Victoria Engine works, Airdrie,	20 Mar., 1883
Hollis, H. E., 40 Union street, Glasgow,	A. 20 Nov., 1897 M. 24 Oct., 1899
Holmes, F. G., Town Hall, Govan,	23 Mar., 1880
Holmes, Matthew, Netherby, Lenzie,	20 Mar., 1883
Holms, A. Campbell, Lloyd's Register, 56 John street, Sunderland,	24 Apr., 1894
Hök, W., 10 Karlaplan, Stockholm, Sweden,	29 Oct., 1901
Homan, William M'L., c/o D. M'Call, Esq., 10 Rosslyn terrace, Kelvinside, Glasgow,	G. 26 Jan., 1892 M. 26 Oct., 1897
Home, Henry, 208 St. Vincent street, Glasgow,	23 Feb., 1897
Horne, George S., Retreat, Kilmalcolm,	21 Feb., 1899
Horne, John, Rokeby villa, Carlisle,	23 Nov., 1897
†Houston, Colin, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890
Houston, James, Junr., Brisbane house, Bellahouston,	25 Jan., 1898
Howard, John Rowland, Parkside place, Johnstone,	18 Dec., 1900
Howat, William, 21 Kirkland street, Glasgow,	22 Feb., 1898
†Howden, James, 195 Scotland street, Glasgow,	Original
Hubbard, Robert Sowter, 3 Downie place, Crow road, Partick,	19 Dec., 1899
Hume, James Howden, 195 Scotland street, Glasgow,	22 Dec., 1891
Hummel, Horace James Jordan, c/o Pintsch's Patent Lighting Co., 38 Leadenhall street, London, E.C.,	23 April, 1901
*†Hunt, Edmund, 121 West George street, Glasgow,	Original
Hunter, Gilbert M., Newyards, Maybole, Ayr,	G. 26 Oct., 1886 M. 19 Nov., 1889
Hunter, James, Aberdeen Iron works, Aberdeen,	25 Jan., 1881
Hunter, James, 34 Ancaster drive, Glasgow, W.,	20 Feb., 1900
Hunter, John, 13 Queen's Gate, Dowanhill, Glasgow,	A. 22 Jan., 1895 M. 21 Mar., 1899
Hunter, Joseph Gilbert, P.O. Box 671, Newport News, Va., U.S.A.,	24 Feb., 1891
Hunter, Joseph M., Byars terrace, North Orchard street, Motherwell,	26 Nov., 1901
Hunter, Matthew, Burnbank, Whiteinch,	19 Mar., 1901
Hutcheon, James, 46 Park drive south, Whiteinch,	19 Mar., 1901
Hutcheson, Archibald, 37 Mair street, Plantation, Glasgow,	22 Dec., 1896
Hutcheson, John, 37 Mair street, Plantation, Glasgow,	22 Mar., 1898
Hutchison, James H., Shipbuilder, Port-Glasgow,	26 Mar., 1895
Hutchison, John S., 126 Bothwell street, Glasgow,	24 Apr., 1900
Hutchison, M., 70 South Woodside road, Glasgow,	29 Oct., 1901

HUTSON, ALEXANDER, Westbourne house, Kelvinside, Glasgow,		19 Dec., 1899
HUTSON, GUYBON, Kelvinhaugh Engine works, Glasgow,	G. M.	23 Dec., 1873 24 Nov., 1885
HUTSON, GUYBON, Junr., 3 Bute mansions, Glasgow,		21 Mar., 1893
HUTSON, JAMES, 117 Balshagray avenue, Partick,		19 Dec., 1899
†INGLIS, JOHN, LL.D., Point House Shipyard, Glasgow,		1 May, 1861
IRELAND, WILLIAM, 7 Ardgowan terrace, Glasgow,		25 Feb., 1890
JACK, ALEXANDER, 164 Windmillhill, Motherwell,		21 Nov., 1893
JACK, JAMES R., Mavisbank, Dumbarton,		27 Apr., 1897
JACKSON, DANIEL, Thornbank, Dumbarton,		24 Oct., 1899
JACKSON, HAROLD D., Westdel, Dowanhill, Glasgow,	G. M.	24 Mar., 1891 20 Dec., 1898
JACKSON, WILLIAM, Govan Engine works, Govan,		21 Dec., 1875
JAMIESON, Professor ANDREW, F.R.S.E., 16 Rosslyn terrace, Kelvinside, Glasgow,		26 Mar., 1889
JARDINE, JOHN, 8 Courtland terrace, Port Talbot, Glamorgan,		26 April, 1898
JEFF, WILLIAM, 38B Byars terrace, N. Orchard street, Motherwell,		18 Dec., 1900
JEFFERY, ARTHUR W., 71 Dixon avenue, Glasgow,		23 April, 1901
JOHNSTON, DAVID, 9 Osborne terrace, Copland road, Glasgow,		25 Feb., 1879
JOHNSTON, ROBERT, Kirklee, Wallace street, Kilmarnock,		22 Mar., 1898
JOHNSTONE, GEORGE, F.R.S.E., Marine Superintendent, British India Stem Navigation Co., Ltd., 16 Strand road, Calcutta,		21 Mar., 1899
JONES, ARTHUR J. E., 118 Napiershall street, Glasgow,		29 Oct., 1901
JONES, LLEWELLYN, Chesterfield house, 98 Great Tower street, London, E.C.,		25 Oct., 1892
JUDD, EDWIN H., Sentinel works, Glasgow,	G. M.	20 Dec., 1898 26 Nov., 1901
KEEGAN, THOMAS J., 41 Margaret street, Greenock,		22 Jan., 1901
KEELING, THOMAS, 42 Prospecthill road, Langside, Glasgow,		19 Feb., 1901

Kelly, Alexander, 100 Hyde Park street, Glasgow,	28 Feb., 1897
Kemp, Daniel, 129 Kenmure street, Pollokshields, Glasgow,	G. 23 Nov., 1886 M. 20 Dec., 1898
Kemp, Ebenezer, D., Birkenhead Iron works, Birkenhead,	G. 20 Feb., 1883 M. 25 Oct., 1892
Kempt, Irvine, Jun., 37 Falkland mansions, Hyndland, Glasgow,	G. 26 Feb., 1895 M. 27 Apr., 1897
Kennedy, Alexander M'A., Rosslea, Dumbarton,	30 Apr., 1895
Kennedy, John, Messrs R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.,	23 Jan., 1877
Kennedy, Robt., B.Sc., Messrs Glenfield & Kennedy, Kilmarnock,	23 Mar., 1897
Kennedy, Thomas, Messrs Glenfield & Kennedy, Kilmarnock,	22 Feb., 1876
Kennedy, William, 13 Victoria crescent, Dowanhill, Glasgow,	24 Apr., 1894
Kerr, James, Lloyd's Register of Shipping, Hull,	22 Feb., 1898
Key, William, 109 Hope street, Glasgow,	20 Feb., 1900
Kincaid, John G., 30 Forsyth street, Greenock,	22 Feb., 1898
King, A. C., Motherwell Bridge Co., Motherwell,	24 Jan., 1899
King, Donald, 1 Montgomerie cottages, Scotstoun, Glasgow,	G. 21 Dec., 1886 M. 20 Mar., 1894
King, J. Foster, The British Corporation, 121 St. Vincent street, Glasgow,	26 Mar., 1895
Kinghorn, A. J., 59 Robertson street, Glasgow,	24 Oct., 1899
Kinghorn, John G., Tower Buildings, Water street, Liverpool,	23 Dec., 1879
Kinmont, David W., Contractor's Office, Larkhall,	G. 20 Feb., 1894 M. 19 Mar., 1901
†**Kirby, Frank** E., Detroit, U.S.A.,	24 Nov., 1885
Knight, Charles A., c/o Messrs Babcock & Wilcox, Ltd., Oriel House, Farringdon st., London, E.C.,	27 Jan., 1885
Knox, Robert, 10 Clayton terrace, Dennistoun, Glasgow,	24 Nov., 1896
Krebs, Frederick, 22 Amaliegade, Cophenhagen,	23 Mar., 1880

Lackie, William W., 75 Waterloo street, Glasgow,	22 Nov., 1898
Lade, James A., 7 Rue Lagrange, Bordeaux, France,	27 Jan., 1891
Laidlaw, D., 147 East Milton street Glasgow,	18 Mar., 1902
Laidlaw, John, Kippilaw, Newton, St. Boswells,	25 Mar., 1884
Laidlaw, Robert, 147 East Milton street, Glasgow,	26 Nov., 1862
Laidlaw, Thomas, 15 Lennox avenue, Scotstoun,	26 Nov., 1901
Laidlaw, T. K., 147 East Milton street, Glasgow,	18 Mar., 1902

Laing, Andrew, The Wallsend Slipway Company, Newcastle-on-Tyne,	20 Mar., 1880
Laird, Andrew, 190 West George Street, Glasgow,	22 Nov., 1898
Lambert, John, Corporation Electricity Works, Perth,	18 Dec., 1900
Lamberton, Andrew, Sunnyside Engine works, Coatbridge,	27 Apr., 1897
Lambie, Alexander, Ravenshall, Port-Glasgow,	19 Mar., 1901
Lang, C. R., Holm Foundry, Cathcart, Glasgow,	G. 20 Nov., 1888 M 26 Nov., 1895
Lang, James, Messrs George Smith & Sons, 75 Bothwell street, Glasgow,	24 Feb., 1880
Lang, John, Jun., Lynnhurst, Johnstone,	26 Feb., 1884
Lang, Robert, Quarrypark, Johnstone,	25 Jan., 1898
Laurence, George B., Clutha Iron works, Paisley road, Glasgow,	21 Feb., 1888
Laws, Bernard Courtney, 52 Fern avenue, Jesmond, Newcastle-on-Tyne,	26 Oct., 1897
Le Rossignol, A. E., Corporation Tramway Office, City road, Newcastle-on-Tyne,	22 Nov., 1898
Lee, Harrison Wm., 62 Sisters avenue, Clapham Common, London, S.W.,	25 Apr., 1899
†Lee, Robert,	G. 21 Dec., 1886 M. 22 Mar., 1898
Leitch, Arch., 40 St. Enoch square, Glasgow,	22 Dec., 1896
Lemkes, C. R. L., 5 Wellington street, Glasgow,	A. 26 Feb., 1884 M. 22 Mar., 1898
Lennox, Alexander, 34 Glasgow street, Hillhead, Glasgow,	G. 23 Jan., 1894 M. 19 Mar., 1901
Leslie, James T. G., 148 Randolph terrace, Hill street, Garnethill, Glasgow,	25 Apr., 1893
Leslie, William, Resident Engineer, Coolgardie Water Scheme, Resident Engineer's Office, Mundaring, West Australia,	24 Feb., 1891
Lester, William R., 11 West Regent street, Glasgow,	G. 21 Nov., 1883 M. 24 Jan., 1899
Lewin, Harry W., 154 West Regent street, Glasgow,	20 Dec., 1898
†Lindsay, Charles C., 217 W. George street, Glasgow,	G. 23 Dec., 1873 M. 24 Oct., 1876
Lindsay, W. F., 203 Nithsdale road, Pollokshields, Glasgow,	19 Mar., 1901
Lithgow, William T., Port-Glasgow,	21 Feb., 1893
Livesey, Robert M., c/o Messrs Topham Jones & Railton, H.M. Dockyard Extension, Gibraltar,	26 Jan., 1897
†Lobnitz, Fred., Clarence house, Renfrew,	G. 24 Mar., 1885 M. 20 Nov., 1896
Lockie, John, Wh.Sc., 2 Custom House Chambers, Leith,	26 Jan., 1897

Lonergan, Alfred E., Whitefield Engine works, Govan, Glasgow,	17 Dec., 1889
Longbottom, John Gordon, Technical College, 38 Bath street, Glasgow,	22 Nov., 1898
†Lorimer, William, Glasgow Locomotive works, Gushetfaulds, Glasgow,	27 Oct., 1896
†Loudon, George Findlay, 10 Claremont Terrace, Glasgow,	25 Jan., 1896
Luke, W. J., Messrs John Brown & Co., Ltd., Clydebank,	24 Jan., 1898
Lusk, Hugh D., c/o Mrs Nelson, Larch villa, Annan,	21 Feb., 1880
Lusk, James, Southdean, Colinton road, Edinburgh,	18 Dec., 1905
Lyall, John, 34 Randolph gardens, Partick,	27 Oct., 1888
Macalpine, John H., Viewfield, Kilmalcolm,	20 Dec., 1898
M'Arthur, James D., Oriental avenue, Bangkok, Siam,	26 Apr., 1898
McAulay, W., 34 Ann street, Glasgow,	22 Nov., 1898
†M'Call, David, 160 Hope street, Glasgow,	17 Feb., 1858
M'Callum, H. Malcolm, c/o Mrs Craighead, 191 Kilmarnock road, Shawlands, Glasgow,	24 Oct., 1899
M'Coll, Peter, 284 Dumbarton road, Partick,	G. 18 Dec., 1883 M. 24 Jan., 1899
†MacColl, Hector, Bloomfield, Belfast,	24 Mar., 1874
†MacColl, Hugo, Wreath Quay Engineering works, Sunderland,	G. 20 Dec., 1881 M. 22 Oct., 1889
M'Creath, James, 208 St. Vincent street, Glasgow,	23 Oct., 1883
Macdonald, D. H., Brandon works, Motherwell,	24 Mar., 1896
Macdonald, John, 146 West Regent street, Glasgow,	21 Mar., 1899
Macdonald, John Dron, 3 Rosemount terrace, Ibrox, Glasgow,	19 Mar., 1901
Macdonald, Thomas, 9 York street, Glasgow,	25 Jan., 1898
M'Dougall, Robert Melvin, 86 Dale street, Glasgow,	20 Nov., 1900
M'Dowall, John Jas., Vulcan Engine Works, Piraeus, Greece,	29 Oct., 1901
M'Ewan, James, Cyclops Foundry Co., Whiteinch, Glasgow,	26 Feb., 1884
M'Ewan, Joseph, 35 Houldsworth street, Glasgow,	27 Jan., 1891
Macfarlane, James W., 12 Balmoral villas, Cathcart, Glasgow,	2 Nov., 1880
Macfarlane, James, Annieslea, Motherwell,	15 June, 1898
†Macfarlane, Walter, 22 Park Circus, Glasgow,	26 Oct., 1886
M'Farlane, George, 34 West George street, Glasgow,	G. 24 Feb., 1874 M. 24 Nov., 1885

M'Farlane, Hugh,		21 Feb., 1899
Macfee, John, Castle Chambers, West Regent street, Glasgow,		22 Jan., 1901
M'Gee, David, The Cottage, Clydebank,		22 Dec., 1896
†M'Gee, Walter, Stoney brae, Paisley,		25 Jan., 1898
M'Geoch, David Boyd, Lilybank, Port-Glasgow,		28 Jan., 1896
M'Gibbon, W. C., 2 Carlton Court, Bridge st., Glasgow,		18 Dec., 1900
MacGregor, J. Grant, Office of Chief Engineer, Hamilton & Dayton Railway Co., Cincinnati, U.S.A.,	G. M.	21 Dec., 1886 28 Apr., 1891
M'Gregor, John B., 19 Bell street, Renfrew,	G. M.	18 Dec., 1883 27 Apr., 1897
M'Gregor, Thomas, 10 Mosesfield terrace, Springburn, Glasgow,		26 Jan., 1886
M'Ilvenna, John, 13 Caird drive, Partickhill, Glasgow,		19 Mar., 1901
MacIlwaine, George W., 5 Osbourne place, Copeland road, Govan,		18 Mar., 1902
M'Indoe, John B., 2 Park terrace, Underwood, Paisley,		21 Mar., 1899
M'Intosh, Donald, Dunglass, Bowling,		20 Feb., 1894
M'Intosh, John F., Caledonian Railway, St. Rollox, Glasgow,		28 Jan., 1896
MacKay, Henry James, 24 Willowbank street, Glasgow,		18 Feb., 1902
MacKay, Robert, 7 Leslie st., Pollokshields, Glasgow,		23 Jan., 1900
M'Keand, Allan, 1 St. James terrace, Hillhead, Glasgow,	G. M.	19 Dec., 1882 20 Mar., 1894
Mackechnie, John, 342 Argyle street, Glasgow,		20 Dec., 1898
M'Kechnie, James, Messrs Vickers, Sons, & Maxim, Barrow-in-Furness,		24 Apr., 1888
MacKenzie, James, 8 St. Alban's road, Bootle,	G. M.	25 Oct., 1881 24 Jan., 1899
Mackenzie, Thomas B., Ellenslee, Wilson street, Motherwell,	G. M.	23 Jan., 1885 26 Nov., 1893
M'Kenzie, John, Messrs J. Gardiner & Co., 24 St. Vincent place, Glasgow,		25 Apr., 1893
M'Kenzie, John, Speedwell Engineering works, Coatbridge,		25 Jan., 1898
Mackie, William A., Falkland bank, Partickhill, Glasgow,		22 Mar., 1881
M'Kie, J. A., Copland works, Govan,		25 Jan., 1898
†MacKinlay, James T. C., 110 Gt. Wellington street, Kinning park, Glasgow,		27 Oct., 1896
M'Kinnel, William, 234 Nithsdale road, Pollokshields, Glasgow,	A. M.	21 Feb., 1893 22 Feb., 1898
MacKinnon, James D., 93 Hope street, Glasgow,		24 Nov., 1896
M'Lachlan, Ewen, 4 Abbotsford place, Glasgow,		21 Feb., 1899
M'Lachlan, John, Saucel Bank House, Paisley,		26 Oct., 1897

M'Laren, Thomas, 342 Argyle street, Glasgow,		20 Dec., 1898
Maclaren, John F., B.Sc., Eglinton foundry, Canal street, Glasgow,		23 Feb., 1892
Maclaren, Robert, Eglinton foundry, Canal street, Glasgow,	G. M.	2 Nov., 1880 22 Dec., 1885
McLaren, John Alex., 34 Ann street, Glasgow,		22 Nov., 1898
McLaren, William, 9 Westbank quadrant, Hillhead, Glasgow,		26 Nov., 1901
McLaurin, Duncan, Cartside, Milliken park, Renfrewshire,		23 Oct., 1900
Maclay, Prof. Alex., B.Sc., Camptower, Bearsden,		28 Apr., 1891
Maclay, David M., Dunourne, Douglas street, Motherwell,		18 Dec., 1900
Maclean, Prof. Magnus, D.Sc., 51 Kersland street, Hillhead, Glasgow,		21 Nov., 1899
Maclean, William Dick, 3 Weymouth terrace, Cessnock, Glasgow,		25 Jan., 1898
McLellan, Dugald, Caledonian Railway, 2 Oswald street, Glasgow,		22 Jan., 1901
M'Lellan, Archibald, Carron Co., Carron, Stirlingshire,		25 Apr., 1899
†Maclellan, William T., Clutha Iron works, Glasgow,		21 Dec., 1886
M'Master, Robert, Linthouse, Glasgow,		25 Feb., 1890
Macmillan, Hugh Millar, B.Sc., Messrs Wigham, Richardson, & Co., Newcastle-on-Tyne,		18 Dec., 1900
*†MacMillan, William, Holmwood, Whittinghame drive, Kelvinside, Glasgow,		
M'Millan, John, Corporation Electric Light Station, Dewar Place, Edinburgh,	G. M.	27 Jan., 1885 24 Jan., 1899
M'Millan, W. Macleod, Dockyard, Dumbarton,		22 Jan., 1901
MacMurray, William, Taller Bisayas, Yloilo, Philippine Islands,		18 Mar., 1902
McMurray, Thomas H., Rosetta avenue, Belfast,		22 Jan., 1901
M'Nair, James, Norwood, Prestwick road, Ayr,		26 Nov., 1895
M'Neil, John, Helen street, Govan, Glasgow,		23 Dec., 1884
MacNicoll, Nicol, 6 Dixon street, Glasgow,		19 Mar., 1901
Macouat, R. B., Victoria Bolt and Rivet works, Cranstonhill, Glasgow,		21 Mar., 1899
MacTaggart, John, 30 Rue Pericleos, Piree, Greece,		15 Apr., 1902
M'Whirter, William, 214 Holm street, Glasgow,		24 Mar., 1891
Mack, James, 22 Rutland street, Edinburgh,	G. M.	21 Dec., 1886 20 Dec., 1898
Manson, James, G. & S. W. Railway, Kilmarnock,		21 Feb., 1899
Marriott, Reuben, Plantation Boiler Works, Govan,		23 Feb., 1897
Marshall, David, Glasgow Tube works, Glasgow,		22 Jan., 1895

Marshall, John, Ashgrove, Kilwinning,	18 Dec., 1900
Martin, E. L., 122 Leadenhall street, London, E.C.,	27 Oct., 1896
Mathewson, George, Bothwell works, Dunfermline,	21 Dec., 1875
Mathieson, Donald A., 3 Germiston street, Glasgow,	26 Jan., 1897
Mathieson, James H., Saracen Tool Works, Glasgow,	29 Oct., 1901
Matthey, C. A., c/o W. Hope Campbell, Esq., 42 Krestchatik, Kieff, S. Russia,	26 Oct., 1897
Mavor, Henry A., 47 King street, Bridgeton, Glasgow,	22 Apr., 1884
Mavor, Sam, 37 Burnbank gardens, Glasgow,	20 Nov., 1894
Maxton, James, 4 Ulster street, Belfast,	22 Jan., 1901
May, William W., Woodbourne, Minard avenue, Partickhill, Glasgow,	25 Jan., 1876
Mayer, William, Morwell House, Dumbarton,	23 Feb., 1897
Mechan, Henry, 13 Montgomerie quadrant, Glasgow,	25 Jan., 1887
Mechan, Samuel, 5 Kelvingrove terrace, Glasgow,	27 Oct., 1891
Meldrum, James, 10 Victoria street, Westminster, London, S.W.,	G. 24 Oct., 1876 M. 28 Nov., 1892
Melville, William, Glasgow and South Western Railway, St. Enoch square, Glasgow,	23 Jan., 1883
Middleton, R. A., 20 The Grove, Benton, near Newcastle-on-Tyne,	G. 24 Jan., 1882 M. 28 Oct., 1890
Millar, Sidney, Harthill house, Cambuslang,	G. 26 Feb., 1889 M. 21 Dec., 1897
Millar, William, Towersland, Octavia terrace, Greenock,	19 Dec., 1899
Miller, Arthur C., 12 Caird drive, Partickhill, Glasgow,	19 Mar., 1901
Miller, John F., Greenoakhill, Broomhouse,	G. 23 Dec., 1873 M. 22 Nov., 1881
Milne, Charles W., Fairmount, Scotstounhill, Glasgow,	26 Nov., 1901
Milne, George, 10 Bothwell street, Glasgow,	22 Jan., 1901
Minty, William, Engineering Department, National Boiler and General Insurance Co., Ltd., 22 St. Ann's square, Manchester,	25 Apr., 1899
†**Mirrlees, James B.**, 45 Scotland street, Glasgow,	Original
Mitchell, Alexander, Hayfield house, Springburn, Glasgow,	26 Jan., 1886
Mitchell, George A., F.R.S.E., 5 West Regent street, Glasgow,	25 Jan., 1898
Mitchell, Thomas, Gower street, Bellahouston, Glasgow,	20 Nov., 1888
Moir, Ernest W., c/o Messrs S. Pearson & Son, 10 Victoria street, Westminster, London,	G. 25 Jan., 1881 M. 24 Jan., 1899
Moir, John, Clyde Shipbuilding and Engineering Company, Port-Glasgow,	23 Feb., 1897
Moir, Thomas, 10 Syriam terrace, Springburn, Glasgow,	23 Apr., 1901
Möller, W., 102 Bath street, Glasgow,	22 Jan., 1901

Mollison, Hector A., B.Sc., 30 Balshagray avenue, Partick,	G. M.	22 Nov., 1892 20 Nov., 1900
Mollison, James, 30 Balshagray avenue, Partick,		21 Mar., 1876
Moore, Ralph D., B.Sc., 13 Clairmont gardens, Glasgow,		27 Apr., 1897
Moore, Robert T., B.Sc., 13 Clairmont gardens, Glasgow,		27 Jan., 1891
Morison, William, 41 St. Vincent crescent, Glasgow,		20 Mar., 1888
Morison, William B., 7 Rowallan gardens, Broomhill, Glasgow,		20 Nov., 1900
Morrice, Richard Wood, 24 Battlefield road, Langside, Glasgow,		23 Feb., 1897
Morrison, William, 11 Sherbrooke avenue, Pollokshields,		19 Feb., 1901
Mort, Arthur, Ellenslea, Wilson street, Motherwell,	G. M.	26 Jan., 1897 19 Dec., 1899
Morton, David Home, 130 Bath street, Glasgow,		20 Nov., 1900
Morton, Duncan A., Errol works, Errol,		21 Nov., 1899
Morton, Robert, 237 West George street, Glasgow,	G. M.	17 Dec., 1878 23 Jan., 1883
Morton, Robert C., 16 Vinicombe street, Hillhead, Glasgow,		26 Nov., 1901
Motion, Robert, Ancrum, Lenzie,		23 Feb., 1892
Mott, Edmund, 7 York street, Glasgow,		24 Mar., 1885
Mowat, Magnus, Jun., Civil Engineer, Millwall Docks, London,	G. M.	26 Oct., 1897 26 Nov., 1901
†**Muir**, Hugh, 7 Kelvingrove terrace, Glasgow,		17 Feb., 1864
Muir, James E., 45 West Nile street, Glasgow,		22 Dec., 1896
†**Muir**, John G.,		24 Jan., 1882
Muir, Peter Gillespie, 2 Osborne place, Govan,		18 Mar., 1902
Muir, Robert White, 97 St. James road, Glasgow,		21 Dec., 1897
Muirhead, James A., Natal Government Agency, 39 Victoria street, Westminster, London, S.W.,		19 Feb., 1901
Muirhead, William, 37 West George street, Glasgow,		26 Oct., 1897
Mumme, Carl, 30 Newark street, Greenock,		22 Oct., 1895
Mumme, Ernest Charles, Hajipur-Begam Sarai Railway Extension, Begam Sarai P.O., Tirhoot State Railway, India,	G. M.	22 Nov., 1892 20 Feb., 1900
Munn, Robert A., Twynham, 5 Winn road Southampton,		22 Dec., 1896
Munro, John, 7 Ibrox place, Govan,		23 Apr., 1901
Munro, Robert D., Scottish Boiler Insurance Company, 111 Union street, Glasgow,		19 Dec., 1882
Murdoch, Frederick Teed, Nile House, Mansourah, Egypt,		25 Feb., 1896
Murdoch, J. A., 7 Park Circus place, Glasgow,	G. M.	25 Oct., 1892 20 Nov., 1900

Murphy, B. Stewart, Lloyd's Register, 324-6, Third Floor, Bourse Buildings, Philadelphia, U.S.A.,	G. M.	24 Oct., 1893 20 Nov., 1900
Murray, Angus, Strathroy, Dumbreck,	G. M.	14 May, 1878 19 Nov., 1889
Murray, Henry, Shipbuilder, Port-Glasgow,		22 Dec., 1896
Murray, James, Westfield, Port-Glasgow,		22 Dec., 1896
Murray, James, 94 Washington street, Glasgow,		26 Jan., 1886
Murray, Richard, 109 Hope street, Glasgow,		26 Oct., 1897
Murray, Thomas Blackwood, B.Sc., 3 Clarence drive, Kelvinside, Glasgow,		22 Dec., 1891
Murray, Thomas R., Messrs. Spencer & Co., Melksham, Wilts,		25 Feb., 1896
Myles, David, Northumberland Engine works, Wallsend-on-Tyne,	G. M.	20 Dec., 1887 19 Dec., 1899

Nagao, Hanpei, c/o Taipeifu, Formosa, Japan,	24 Dec., 1901
Napier, Henry M., Shipbuilder, Yoker, near Glasgow,	25 Jan., 1881
†**Napier, Robert T.**, 75 Bothwell street, Glasgow,	20 Dec., 1881
Needham, James H., Storra Lea, Round Riding road, Dumbarton,	18 Mar., 1902
Neilson, James, C.B., Ironmaster, Mossend,	23 Mar., 1897
Nelson, Andrew S., Snowdon, Sherbrooke avenue, Pollokshields, Glasgow,	27 Oct., 1896
Ness, George, 128a Queen Victoria street, London, E.C.,	23 Feb., 1897
Nicol, R. Gordon, 15 Regent Quay, Aberdeen,	20 Nov., 1900
Nish, William, c/o W. L. C. Paterson, Esq., Finnieston Quay, Glasgow,	6 Apr., 1887
†**Norman, John**, 131a St. Vincent street, Glasgow,	11 Dec., 1861
Norris, Charles G., 504 Stockport road, Manchester,	29 Oct., 1901

O'Brien, William, 21 Ibrox terrace, Govan,	27 Jan., 1891
O'Neill, J. J., 5 Westminster gardens, Hillhead, Glasgow,	24 Nov., 1896
Oldfield, George, Atlas Works, Springburn,	22 Nov., 1898
Oliphant, William, Belvidere, 10 Kay park terrace, Kilmarnock,	23 Feb., 1897
†**Ormiston, John W.**, Douglas gardens, Uddingston,	28 Nov., 1860
Orr, Alexander T., Marine Department, London and North-Western Railway, Holyhead,	24 Mar., 1883
Orr, John R., Motherwell Bridge Co., Motherwell,	24 Jan., 1899

Paasch, Heinrich, 27 Rue d'Amsterdam, Antwerp,	28 Oct., 1890
Paterson, John, Edradour, Dalmuir,	22 Jan., 1901
Paterson, W. L. C., 5 Elmwood terrace, Jordanhill, Glasgow,	21 Nov., 1883
Paton, Professor George, Royal Agricultural College, Cirencester,	22 Nov., 1887
Patrick, Andrew Crawford, Johnstone,	25 Jan., 1898
Patterson, James, Maryhill Iron works, Glasgow,	22 Nov., 1898
Patterson, James, 130 Elliot street, Glasgow,	18 Dec., 1900
Pattie, Alexander W., Hong Kong & Whampoa Dock Co., Hong Kong,	22 Jan., 1895
Paul, Andrew, Levenford works, Dumbarton,	24 Apr., 1877
Paul, H. S., Levenford works, Dumbarton,	24 Jan., 1899
Paul, Matthew, Levenford works, Dumbarton,	G. 26 Feb., 1884 M. 21 Dec., 1886
Peacock, James, Oriental Steam Navigation Co., 13 Fenchurch Avenue, London, E.C.	G. 22 Nov., 1881 M. 21 Feb., 1899
Peck, Edward C., Messrs Yarrow & Company, Poplar, London,	G. 23 Dec., 1873 M. 23 Oct., 1888
Peck, James J., 9 Broomhill gardens, Partick, Glasgow,	22 Dec., 1896
Peck, Noel E., Newington, Southbrae drive, Scotstounhill, Glasgow,	18 Dec., 1900
Penman, Robert Reid, 16 Annfield place, Glasgow,	25 Jan., 1898
Penman, William, Springfield house, Dalmarnock, Glasgow,	25 Jan., 1898
Petroff, Alexander, 60 Thornton avenue, Streatham Hill, London, S.W.,	19 Mar., 1901
Philip, William Littlejohn, Sherbrooke, Box, Wilts,	24 Jan., 1899
Pickering, Robert Young, Railway Wagon and Wheel works, Wishaw,	24 Nov., 1896
Plummer, W. E., Soho works, Bradford,	19 Mar., 1901
Pocock, J. Herbert, 29 Falkland mansions, Kelvinside, Glasgow,	29 Oct., 1901
Poole, William John, 19 Waverley park, Shawlands, Glasgow,	20 Dec., 1898
Pollock, David, 128 Hope street, Glasgow,	23 Feb., 1897
Pollok, Robt., Messrs John Brown & Co., Clydebank,	22 Dec., 1896
Pope, Robert Band, Leven Shipyard, Dumbarton,	25 Oct., 1887
Pratten, William J., Mornington, Derryvolgie avenue, Belfast,	22 Dec., 1896
Purdon, Archibald, Inch works, Port-Glasgow,	27 Apr., 1897
Purves, J. A., D.Sc., F.R.S.E., 53 York place, Edinburgh,	25 Oct., 1898
Purvis, Prof. F. P., College of Naval Architecture, Imperial University, Tokio, Japan,	20 Nov., 1877

PUTNAM, THOMAS, Darlington Forge Co., Darlington,		15 June, 1898
PYLE, JAMES H., 38 Elliot street, Glasgow,		23 Feb., 1897
RAEBURN, CHARLES E., 1 Hillhead street, W., Glasgow,		24 Oct., 1899
RAINEY, FRANCIS E., c/o Mr F. Nell, 97 Queen Victoria street, London, S.E.,		27 Apr., 1897
RAIT, HENRY M., 155 Fenchurch street, London,		23 Dec., 1868
RAMAGE, RICHARD, Shipbuilder, Leith,		22 Apr., 1873
RAMSAY, CHARLES, 33 Thurlby road, West Norwood, London,		21 Dec., 1897
RANKIN, JOHN F., Eagle foundry, Greenock,		23 Mar., 1886
RANKIN, MATTHEW, Messrs Rankin & Demas, Engineers, Smyrna,	G. M.	2 Nov., 1880 20 Mar., 1894
RANKIN, ROBT., Jun., 6 Brighton place, Govan,		22 Jan., 1901
RANKINE, DAVID, 238 West George street, Glasgow,		22 Oct., 1872
REED-COOPER, T. L., 12 Queen's terrace, Glasgow,		22 Dec., 1896
REID, ANDREW T., Hydepark Locomotive works, Glasgow,	G. M.	21 Dec., 1886 18 Dec., 1894
REID, CHARLES, Lilymount, Kilmarnock,		25 Jan., 1881
REID, GEORGE W., Locomotive Department, Natal Government Railways, Durban, Natal, S. Africa,		21 Nov., 1883
REID, J. MILLER, 110 Lancefield street, Glasgow,		23 Mar., 1897
†REID, JAMES, Shipbuilder, Port-Glasgow,		17 Mar., 1869
REID, JAMES, 3 Cart street, Paisley,		25 Jan., 1898
†REID, JAMES B., Chapelhill, Paisley,		24 Nov., 1891
REID, JAMES G., 58 West Regent street, Glasgow,	G. M.	23 Dec., 1894 21 Feb., 1899
†REID, JOHN, 5 Montague terrace, Kelvinside, Glasgow,	G. M.	21 Dec., 1886 18 Dec., 1894
REID, JOHN,		18 Dec., 1900
REID, JOHN WILSON, Woodlands house, New Southgate, London, N.,		21 Jan., 1902
REID, ROBERT SHAW, 161 Hope street, Glasgow,		21 Mar., 1899
REID, THOMAS, Jun., 6 Bridge street, Abbey, Paisley,		18 Dec., 1900
REW, JAMES H., Ardfern, Victoria place, Airdrie,		27 Oct., 1896
REYNOLDS, CHARLES H., Frederiksgade 27, Copenhagen,	G. M.	23 Dec., 1873 22 Nov., 1881
RICHARDS, T. J., 7 York street, Glasgow,		19 Mar., 1901
RICHMOND, Sir DAVID, North British Tube works, Govan,		21 Dec., 1897
RICHMOND, JAMES, Roselyn, 95 Maxwell drive, Pollokshields, Glasgow,	G. M.	23 Jan., 1894 23 Oct., 1900
RICHMOND, JOHN R., Holm foundry, Cathcart, Glasgow,		28 Jan., 1896

Riddell, W. G., c/o Messrs William Crichton & Co., Abo, Finland,	21 Feb., 1899
Riekie, John, Argarth, Dumbreck, Glasgow,	29 Oct., 1901
Risk, Robert, Halidon Villa, Cambuslang,	23 Mar., 1897
Ritchie, George, Parkhead Forge, Glasgow,	15 June, 1898
Roberts, W. G.	29 Oct., 1901
Robertson, A. W., The Shipyard, Ardrossan,	18 Dec., 1900
Robertson, Alex., Jun., Brae cottage, Kilmarnock,	22 Dec., 1896
Robertson, Andrew R., 8 Park Circus place, Glasgow,	G. 12 Nov., 1892 M. 23 Feb., 1897
Robertson, David W., Dalziel Bridge works, Motherwell,	26 Nov., 1901
Robertson, Duncan, Baldroma, Ibrox, Glasgow,	24 Oct., 1876
Robertson, Robert, B.Sc., 154 West George street, Glasgow,	20 Nov., 1900
Robertson, Thomas, 13 Broomhill avenue, Glasgow,	23 Jan., 1900
Robertson, William, 141 St. Vincent street, Glasgow,	25 Nov., 1863
Robin, Matthew, 48 Dumbreck road, Dumbreck, Glasgow,	G. 20 Dec., 1887 M. 25 Jan., 1898
Robinson, J. F., Atlas works, Springburn, Glasgow,	24 Apr., 1888
Robson, George J., 22 Bath street, Glasgow,	21 Mar., 1899
*†**Robson**, Hazelton R., 14 Royal crescent, Glasgow,	Original
Rodger, Anderson, Glenpark, Port-Glasgow,	21 Mar., 1893
Roger, George Wm., Shipyard, Irvine,	G. 24 Nov., 1896 M. 18 Dec., 1900
Rosenthal, James H., Oriel House, 30 Farringdon street, London,	24 Nov., 1896
Ross, J. MacEwan, Ardenlea, Lenzie,	G. 28 Nov., 1882 M. 27 Oct., 1891
Ross, James R., 7 Ashfield gardens, Jordanhill, Glasgow,	24 Nov., 1896
Ross, Richard G., 21 Greenhead street, Glasgow,	11 Dec., 1861
Ross, William, 101 St. Vincent street, Glasgow,	18 Dec., 1900
Rowan, Frederick John, 71a West Nile st., Glasgow,	26 Jan., 1892
Rowan, James, 231 Elliot street, Glasgow,	G. 21 Dec., 1875 M. 27 Jan., 1885
Rowley, Thomas, Board of Trade Offices, Virginia street, Greenock,	18 Dec., 1888
Rudd, John A., 177 West George street, Glasgow,	G. 24 Jan., 1888 M. 15 June, 1898
Russell, Frederick Alexander, 20 Skirving street, Shawlands, Glasgow,	25 Jan., 1888
†**Russell**, George, Alpha Works, Motherwell,	G. 22 Dec., 1858 M. 4 Mar., 1863
†**Russell**, James, Waverley, Uddingston,	G. 24 Nov., 1891 M. 25 Jan., 1898

RUSSELL, JOSEPH, Shipbuilder, Port-Glasgow,		22 Feb., 1881
RUSSELL, JOSEPH WILLIAM, 50 Charles street, St. Rollox, Glasgow,	G. M.	6 Apr., 1887 25 Jan., 1898
RUSSELL, THOMAS W., Admiralty, 21 Northumberland avenue, London, W.C.,		27 Apr., 1897
RUTHERFORD, A. K., 4 West George street, Glasgow,		24 Dec., 1901
RUTHERFORD, GEORGE, Mercantile Pontoon Company, Cardiff,		23 Mar., 1897
SADLER, Prof. HERBERT C., B.Sc., University of Michigan, Ann Arbor, Michigan, U.S.A.	G. M.	19 Dec., 1893 23 Oct., 1900
SALMON, EDWARD MOWBRAY, Lloyd's Register, 71 Fenchurch street, London, E.C.,		21 Jan., 1890
SALMOND, HENRY, 93 Hope street, Glasgow,		18 Dec., 1900
SAMPSON, ALEX. W., Bonnington, 9 Beech avenue, Bellahouston,		22 Dec., 1896
SAMSON, PETER, Board of Trade Offices, 54 Victoria street, Westminster, London, S.W.,		24 Oct., 1876
SAMUEL, JAMES, Jun., 185 Kent road, Glasgow,		24 Feb., 1885
SANDERSON, JOHN, Lloyd's Register, Royal Exchange, Middlesbro'-on-Tees,		20 Feb., 1883
SAYERS, JAMES EDMUND, 189 St. Vincent street, Glasgow,		24 Dec., 1901
SAYERS, WILLIAM BROOKS, Albrecht, Milngavie,		25 Oct., 1892
†SCOBIE, JOHN, c/o Messrs S. Pearson & Son, Limited, Tehuantepec, Mexico,	G. M.	25 Mar., 1879 23 Oct., 1888
SCOTT, CHARLES CUNNINGHAM, Greenock Foundry, Greenock,		27 Oct., 1896
SCOTT, CHARLES WOOD, Dunarbuck, Bowling,		15 June, 1898
SCOTT, JAMES, Rock Knowe, Tayport, N.B.,		22 Dec., 1896
SCOTT, JAMES, Jun., Strathclyde, Bowling,		15 June, 1898
SCOTT, JAMES E., 52 Coal Exchange, London,		30 June, 1872
SCOTT, JAMES G., 34 Montague street, Glasgow,		19 Mar., 1901
SCOTT, JOHN, Abden works, Kinghorn,		25 Jan., 1881
†*SEATH, THOMAS B., 42 Broomielaw, Glasgow,		28 Nov., 1860
SELBY-BIGGE, D., 27 Mosley street, Newcastle-on-Tyne,		21 Feb., 1899
SEXTON, Prof. HUMBOLDT, Glasgow and West of Scotland Technical College, 204 George st., Glasgow,		25 Feb., 1896
SHANKS, ALEXANDER, Jun.,		26 Apr., 1892
SHANKS, JAS. KIRKWOOD, Engineer, Beechfield, Denny,		23 Apr., 1901
SHANKS, WILLIAM, Tubal works, Barrhead,		15 June, 1898
SHARER, EDMUND, Scotstoun house, Scotstoun, Glasgow,		30 Apr., 1895
SHARP, JOHN, 11 Windsor Terrace, Glasgow,	G. M.	24 Oct., 1882 22 Nov., 1898
SHARPE, ROBERT, Corporation Gas-Works, Belfast,		22 Jan., 1901

Shearer, John, 13 Crown terrace, Dowanhill, Glasgow,	23 Oct., 1900
Shedden, William, 3 Andrew's street, Paisley,	24 Oct., 1899
Shepherd, John W., Carrickarden, Bearsden,	26 Mar., 1889
Sheriff, Thos., 17 Westlands drive, Whiteinch, Glasgow,	22 Dec., 1896
Shute, Arthur E., 12 Clydeview, Partick, Glasgow,	27 Oct., 1896
Shute, Charles W., 38 Rowallan gardens, Partick, Glasgow,	27 Oct., 1896
Shute, T. S., 3 Kensington terrace, South, Sunderland,	G. 19 Dec., 1893 M. 22 Feb., 1898
Sime, John, 96 Buchanan street, Glasgow,	26 Jan., 1897
†Simons, William, Tighnabruaich, Argyleshire,	24 Nov., 1858
†Simpson, Alexander, 175 Hope street, Glasgow,	22 Jan., 1862
Simpson, Robert, B.Sc., 175 Hope street, Glasgow,	25 Jan., 1887
Simpson, William, 15 Regent Quay, Aberdeen,	20 Nov., 1900
Sinclair, D. S., London road Iron works, Glasgow,	24 Dec., 1901
Sinclair, Nisbet, 29 University avenue, Glasgow,	G. 20 Mar., 1877 M. 20 Dec., 1887
Slight, George H., Jun., c/o James Slight, 131 West Regent street, Glasgow,	G. 28 Nov., 1882 M. 22 Oct., 1889
Smail, David, 19 Waterloo street, Glasgow,	22 Jan., 1901
Small, William O., Carmyle avenue, Carmyle,	23 Feb., 1897
Smart, Lewis A., 27 Wind street, Swansea,	22 Mar., 1898
Smillie, Samuel, 71 Lancefield street, Glasgow,	A. 24 Jan., 1888 M. 22 Feb., 1898
Smith, Alexander, 16 Courthill, Bearsden,	G. 24 Nov., 1891 M. 29 Oct., 1901
Smith, Alexander D., Vanduara, Springkell avenue, Pollokshields, Glasgow,	2 Nov., 1880
Smith, Herbert Gardner, Leewood, Helensburgh,	26 Nov., 1901
Smith, Hugh Wilson, Netherby, N. Albert road, Pollokshields, Glasgow,	25 Jan., 1898
Smith, James, c/o Dickie Bros., Box 46, Point, Durban, South Africa,	23 Oct., 1888
Smith, Osbourne, Possil Engine works, Glasgow,	24 Dec., 1895
Smith, Robert, c/o Mrs Chisholm, 229 North st., Glasgow,	20 Mar., 1900
Smith, William J., 7 Newark drive, Pollokshields, Glasgow,	24 Jan., 1899
Sneddon, Richard M., 45c Whifflet street, Coatbridge,	G. 21 Nov., 1899 M. 18 Mar., 1902
Sneddon, W. R., Shipyard, Irvine,	22 Jan., 1901
Snowball, Edward, 10 Broomfield terrace, Springburn, Glasgow,	22 Feb., 1870
Somervail, Peter A., Dalmuir Ironworks, Dalmuir,	25 Jan., 1887
Sommerville, Robert G., jun., Aldergrove, Port-Glasgow,	29 Oct., 1901

SOMERVILLE, THOMAS A., 12 Abbotsford rd., Galashiels,	22 Feb., 1898
SOTHERN, JOHN W., 59 Bridge street, Glasgow,	29 Oct., 1901
SPROUL, A., 34 Union Row, Aberdeen,	19 Mar., 1901
STARK, JAMES, 13 Princes gardens, Dowanhill, Glasgow,	27 Oct., 1896
†STEPHEN, ALEXANDER E., 8 Princes terrace, Dowanhill, Glasgow,	18 Dec., 1883
†STEPHEN, FREDERICK J., Linthouse, Govan,	30 Apr., 1895
STEPHEN, J. M., 12 Campania place, Govan,	19 Mar., 1901
*†STEPHEN, JOHN, Linthouse, Govan,	
STEVEN, JAMES, Eastvale place, Kelvinhaugh, Glasgow,	23 Oct., 1900
STEVEN, JOHN, Messrs Steven and Struthers, Eastvale place, Kelvinhaugh, Glasgow,	26 Oct., 1897
STEVEN, JOHN WILSON, 9 Princes terrace, Dowanhill, Glasgow,	20 Dec., 1898
STEVEN, WILLIAM, 83 Fellows road, North Hampstead, London, S.W.	23 Jan., 1894
STEVENS, JOHN, Ayton, Albert drive, Renfrew,	23 Mar., 1897
STEVENSON, WM. F., 49 Park drive, South, Whiteinch, Glasgow,	18 Dec., 1900
STEWART, ALEXANDER W., 55 West Regent Street, Glasgow,	23 Jan., 1894
†STEWART, JAMES, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890
STEWART, JAMES, Messrs L. Sterne & Co., 155 North Woodside road, Glasgow,	25 Oct., 1898
STEWART, JAMES C., 54 George square, Glasgow,	24 Dec., 1901
STEWART, JOHN GRAHAM, B.Sc., Ault Wharrie, Dunblane,	22 Mar., 1892
STEWART, W. MAXWELL, 55 W. Regent street, Glasgow,	21 Nov., 1899
STRACHAN, ALLAN, Taller Bisayas, Yloilo, Philippine Islands,	18 Mar., 1902
STRACHAN, ROBERT, 55 Clifford street, Ibrox, Govan,	22 Nov., 1898
STRATHERN, ALEXANDER G., Hillside, Stepps, N.B.,	25 Apr., 1899
STUART, JAMES, 115 Wellington street, Glasgow,	22 Oct., 1889
STUART, JAMES, B.Sc., Stanley villa, Langside, Glasgow,	28 Nov., 1897
STUART, JAMES TAIT, 2 Bowmont terrace, Kelvinside, Glasgow,	18 Dec., 1900
SURTEES, FRANCIS VERE, Messrs Lobnitz & Co., Ltd., Renfrew,	19 Feb., 1901
SUTHERLAND, SINCLAIR, North British Tube works, Govan,	21 Dec., 1897
SYME, JAMES 8 Glenavon terrace, Partick,	23 Jan., 1877
TANNETT, JOHN CROYSDALE, Vulcan works, Paisley,	25 Jan., 1898

TATHAM, STANLEY, Montana, Burton road, Branksome park, Bournemouth, W.,	G. M.	21 Dec., 1880 15 June, 1898
TAVERNER, H. LACY, 48 West Regent street, Glasgow,		22 Dec., 1896
TAYLOR, BENSON,		20 Nov., 1900
TAYLOR, PETER, Selby Shipbuilding and Engineering Co., Ltd., Ousegate, Selby,		28 Apr., 1885
TAYLOR, ROBERT, 49 Brisbane street, Greenock,		27 Oct., 1896
TAYLOR, STAVELEY, Messrs Russell & Company, Shipbuilders, Port-Glasgow,		25 Mar., 1879
TAYLOR, THOMAS (Messrs Smith, Bell & Co.), Manila, Phillipine Islands,		29 Oct., 1901
TERANO, SEIICHI, College of Engineering, Imperial University, Tōkyō, Japan,		21 Feb., 1899
THEARLE, SAMUEL J. P., 71 Fenchurch Street, London,		22 Dec., 1896
THODE, GEORGE W., 4 Prince Friedrich-Carl Strasse, Rostock, M.S., Germany,		27 Jan., 1885
THOM, JOHN, 8 Park Avenue, Glasgow,		26 Feb., 1889
THOMSON, Prof. ARTHUR W., D.Sc., College of Science, Poona, India,		26 Apr., 1887
THOMSON, G. CALDWELL, 23 Elisabeth street, Riga, Russia,		24 Oct., 1893
THOMSON, GEORGE, 14 Caird drive, Partickhill, Glasgow,		18 Dec., 1883
THOMSON, GEORGE, 3 Woodburn terrace, Morningside, Edinburgh,	G. M.	23 Nov., 1880 20 Nov., 1894
THOMSON, GEORGE C., 53 Bedford road, Rock Ferry, near Birkenhead,	G. M.	24 Feb., 1874 22 Oct., 1889
THOMSON, JAMES, Hayfield, Motherwell,	G. M.	20 Nov., 1894 20 Nov., 1900
THOMSON, JAMES M., 75 Bothwell Street, Glasgow,		12 Feb., 1868
THOMSON, JOHN, 3 Crown terrace, Dowanhill, Glasgow,		20 May, 1868
THOMSON, JOHN, 44 St. Vincent crescent, Glasgow,		26 Nov., 1901
THOMSON, R. H. B., Govan Shipbuilding yard, Govan, Glasgow,		26 Feb., 1895
THOMSON, ROBERT, Messrs Barr, Thomson & Co., Ltd., Kilmarnock,		25 Jan., 1898
THOMSON, W. B., Ellengowan, Dundee,		14 May, 1878
THOMSON, WALTER M., Inverclyde, Bothwell,	G. M.	20 Nov., 1894 24 Dec., 1895
THOMSON, WILLIAM, 20 Huntly gardens, Kelvinside, Glasgow,	G. M.	23 Dec., 1884 27 Oct., 1896
THUNDERBOLT, EDWARD, 164 Cambridge drive, Kelvinside, Glasgow,		23 Feb., 1897
TIDD, E. GEORGE, 25 Gordon street, Glasgow,		22 Oct., 1895
TOD, ROBERT P., 27 Regent place, Shawlands, Glasgow,		15 Apr., 1902
TODD, DAVID R., 39-40 Arcade Chambers, St. Mary's Gate and Dean's Gate, Manchester,	G. M.	25 Jan., 1887 25 Oct., 1892

Torrie, James, Stewarton,		18 Mar., 1902
Tullis, David K., Kilbowie Iron works, Kilbowie,		23 Nov., 1897
Tullis, James, Kilbowie Iron works, Kilbowie,		23 Nov., 1897
Turnbull, Alexander, St. Mungo's works, Bishopbriggs, Glasgow,		21 Nov., 1876
Turnbull, Alexander Pott, 79 West Regent Street Glasgow,		25 Jan., 1898
†Turnbull, John, Jun., 190 West George street, Glasgow,		23 Nov., 1875
Turner, Thomas, Caledonia works, Kilmarnock,		22 Jan., 1901

Waddell, James, 15 Moray place, Glasgow,		23 Mar., 1897
Walker, Archibald, 24 Leadenhall street, London, E.C.,		26 Nov., 1901
Walker, John, 1 Church road, Ibrox, Glasgow,	G. M.	20 Nov., 1894 19 Dec., 1899
Wallace, Duncan M., 65 Union street, Greenock,		27 Oct., 1896
Wallace, James Loch, 15 Clifford street, Glasgow, S.S.,		18 Feb., 1902
Wallace, John, Jun., 123 East Princes street, Helensburgh,	G. M.	26 Jan., 1892 22 Jan., 1901
Wallace, Peter, Ailsa Shipbuilding Co., Troon,		23 Jan., 1883
Wallace, W. Carlile, Atlas Steel and Iron works, Sheffield,		24 Mar., 1885
Ward, J. C. A., 75 Waterloo street, Glasgow,		22 Nov., 1898
Ward, John, Leven Shipyard, Dumbarton,		26 Jan., 1886
Warde, Henry W., 71 Waterloo street, Glasgow,		15 June, 1898
Warden, Willoughby C., 25 Gordon street, Glasgow,		24 Mar.. 1896
Warnock, William Findlay, 274 Bath street, Glasgow,		21 Jan., 1902
Watkinson, Prof. W. H., The Pines, Crookston,		19 Dec., 1893
Watson, G. L., 53 Bothwell street, Glasgow,		23 Mar., 1875
Watson, Robert, 10 East Nelson street, Glasgow,	G. M.	22 Mar., 1881 29 Oct., 1901
Watson, William, Clyde Shipping Company, Greenock,		24 Nov., 1896
Watt, Alexander, Inchcape, Paisley,		25 Jan., 1898
Webb, R. G., Messrs Richardson & Cruddas, Byculla, Bombay,	G. M.	21 Dec., 1875 26 Oct., 1886
Webster, James, Messrs Sharp, Stewart, & Co., Ltd., Atlas works, Springburn, Glasgow,		21 Mar., 1899
Webster, Thomas Lawson, 53 Dixon avenue, Glasgow,		21 Nov., 1899
Weddell, James, Park villa, Uddingston,		22 Dec., 1896
Wedgwood, A., Jun., Dennystown Forge, Dumbarton,		18 Dec., 1900
Wedgwood, Arthur D., Forgemaster, Dumbarton,		26 Jan., 1897

WEIGHTON, Prof. R. L., M.A., 2 Park villas, Gosforth, Newcastle-on-Tyne,	G. 17 Dec., 1878 M. 22 Nov., 1887
†WEIR, GEORGE, Yass, near Sydney, New South Wales,	22 Dec., 1874
†WEIR, JAMES, Holmwood, 72 St. Andrew's drive, Pollokshields, Glasgow,	22 Dec., 1874
WEIR, JOHN, c/o Messrs D. & W. Henderson & Co., Ltd., 190 Elliot street, Glasgow,	G. 22 Apr., 1884 M. 26 Nov., 1895
†WEIR, THOMAS, China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China,	23 Apr., 1889
WEIR, THOMAS D., Messrs Brown, Mair, Gemmill & Hyslop, 162 St. Vincent street, Glasgow,	G. 19 Dec., 1876 M. 26 Feb., 1884
WEIR, WILLIAM, Holm foundry, Cathcart, Glasgow,	G. 28 Jan., 1896 M. 22 Nov., 1898
WEIR, WILLIAM, 231 Elliot street, Glasgow,	22 Jan., 1901
WELSH, JAMES, 3 Princes gardens, Dowanhill, Glasgow,	G. 24 Nov., 1885 M. 26 Oct., 1897
WELSH, THOMAS M., 3 Princes gardens, Dowanhill, Glasgow,	17 Feb., 1869
WEMYSS, GEORGE B., 57 Elliot street, Hillhead, Glasgow,	G. 28 Nov., 1882 M. 22 Jan., 1901
WEST, HENRY H., 5 Castle street, Liverpool,	23 Dec., 1868
WHITE, RICHARD S., Shirley, Jesmond, Newcastle-on-Tyne,	20 Feb., 1883
WHITEHEAD, JAMES, 6 Buchanan terrace, Paisley,	6 Apr., 1887
WILLIAMS, LLEWELLYN WYNN, B.Sc., Cathcart, Glasgow,	22 Feb., 1898
WILLIAMS, OWEN R., B.Sc., Railway Appliance works, Cathcart, Glasgow,	20 Nov., 1900
WILLIAMS, WILLIAM,	23 Jan., 1900
WILLIAMSON, ALEXANDER, 67 Esplanade, Greenock,	21 Mar., 1899
WILLIAMSON, Sir JAMES, C.B., Admiralty, Whitehall, London, S.W.,	23 Dec., 1884
WILLIAMSON, JAMES, Marine Superintendent, Gourock,	24 Mar., 1896
WILLIAMSON, ROBERT, Ormidale, Malpas, near Newport, Mon.,	20 Feb., 1883
WILSON, ALEXANDER, Dawsholm Gasworks, Maryhill, Glasgow,	28 Jan., 1896
WILSON, ALEXANDER, Hyde Park Foundry, Finnieston street, Glasgow,	23 Feb., 1897
WILSON, ALEX. HALL, B.Sc., Messrs Hall, Russell, & Co., Aberdeen,	23 Oct., 1900
WILSON, DAVID, Arecibo, Porto Rico, West Indies,	25 Oct., 1887
WILSON, GAVIN, 107 Pollok street, S.S., Glasgow,	22 Oct., 1889
†WILSON, JOHN, 165 Onslow drive, Dennistoun, Glasgow,	22 Feb., 1870
WILSON, JOHN, 101 Leadenhall street, London, E.C.,	24 Dec., 1895
WILSON, JOHN, 11 Regent Park square, Glasgow,	18 Mar., 1902

WILSON, W. H., 261 Albert road, Pollokshields, Glasgow,	22 Feb., 1898
WILSON, WILLIAM, Lilybank Boiler works, Glasgow,	30 Apr., 1895
WISHART, THOMAS, London road Iron works, Glasgow,	24 Dec., 1901
WOOD, ROBERT C., c/o Messrs A. Rodger & Co., Shipbuilders, Port Glasgow,	23 Mar., 1897
WOODBURN, J. COWAN, 18 Beechwood drive, Jordanhill, Glasgow,	23 Jan., 1900
WORKMAN, HAROLD, B.Sc., c/o Messrs Barclay, Curle & Co., Ltd., Whiteinch, Glasgow,	21 Dec., 1897
WRAY, THOMAS HENRY ROBARTS, Clun house, Surrey street, Strand, London, W.C.,	18 Feb., 1902
WRENCH, WILLIAM G., 27 Oswald street, Glasgow,	25 Mar., 1890
WRIGHT, ROBERT, 172 Kilmarnock road, Shawlands, Glasgow,	22 Dec., 1896
WYLIE, ALEXANDER, Kirkfield, Johnstone,	26 Oct., 1897
WYLIE, WILLIAM, 33 Maxwell drive, Pollokshields, Glasgow,	26 Apr., 1898
WYLLIE, JAMES BROWN, 134 St. Vincent street, Glasgow,	G. 25 Oct., 1887 M. 26 Jan., 1897
YOUNG, DAVID HILL, Marine Engineers' Institute, Shanghai, China,	G. 20 Nov., 1900 M. 15 Apr., 1902
YOUNG, J. DENHOLM, 2a Tower Chambers, Liverpool,	G. 24 Jan., 1888 M. 23 Jan., 1894
YOUNG, JOHN, Galbraith street, Stobcross, Glasgow,	27 Nov., 1867
YOUNG, THOMAS, Rowington, Whittinghame drive, Kelvinside, Glasgow,	20 Mar., 1894
YOUNG, WILLIAM ANDREW, Millburn House, Renfrew,	26 Mar., 1895
YOUNG, WILLIAM L., 33/35 Stanley street, Kinning Park, Glasgow,	22 Nov., 1898
YOUNGER, A. SCOTT, B.Sc., 8 Walmer crescent, Glasgow,	24 Nov., 1896

ASSOCIATES.

Addie, Frank R., 8 Westbourne gardens, Kelvinside, Glasgow,	18 Dec., 1900
*Aitken, Thomas, 8 Commercial street, Leith,	
Allan, Henry, 25 Bothwell street, Glasgow,	23 Jan., 1900
†Allan, James A., 25 Bothwell street, Glasgow,	29 Oct., 1901
Anderson, James, c/o Masson, 26 Merryland street, Govan,	24 Apr., 1900
Armour, William Nicol, 175 West George street, Glasgow,	24 Nov., 189[illegible]
Baillie, Archibald, 2 Balmoral terrace, Glasgow,	25 Jan., 1898
Bain, Andrew, 17 Athole gardens, Glasgow,	26 Oct., 1897
Bain, W. B., 65 Waterloo street, Glasgow,	22 Jan., 1901
Barclay, Thomas Kinloch, 55 Lochleven road, Langside, Glasgow,	20 Mar., 1900
Begg, William, 34 Belmont gardens, Glasgow,	19 Dec., 1886
Blair, Herbert J., 30 Gordon street, Glasgow,	23 Feb., 1897
Borland, John G., 93 Hope street, Glasgow,	24 Dec , 1901
Brown, Capt. A. R., 34 West George street, Glasgow,	21 Dec., 1897
†Brown, John, B.Sc., 11 Somerset place, Glasgow,	25 Jan., 1876
Brown, Thomas J., 233 St. Vincent street, Glasgow,	29 Oct., 1901
Bryce, John, Sweethope cottage, North Milton road, Dunoon,	18 Jan., 1865
Buchanan, James, Dalziel Bridge works, Motherwell,	26 Nov., 1901
Burns, Hon. James C., 30 Jamaica street, Glasgow.	23 Oct., 1900
Cassels, William, Cairndhu, 12 Newark drive, Pollokshields, Glasgow,	21 Feb., 1893
Claussen, A. L., 118 Broomielaw, Glasgow,	22 Jan., 1892
Clyde, Walter P., Messrs T. S. M'Innes & Co., Ltd., 42 Clyde place, Glasgow,	24 Oct., 1899

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Associates.

Dewar, James, 11 Regent Moray street, Glasgow,	22 Dec., 1897
Dobbie, W. L., 101 Waterloo street, Glasgow,	20 Dec., 1898
Doddrell, Edward E., 11 Bothwell street, Glasgow,	26 Oct., 1897
Donald, James, 123 Hope street, Glasgow,	19 Dec., 1899

Ferguson, Peter, 19 Exchange square, Glasgow,	27 Apr., 1897
Forrest, William, 114 Dixon avenue, Glasgow,	19 Feb., 1901

Galloway, James, Jun., Whitefield works, Govan,	27 Oct., 1891
Gardiner, Frederick Crombie, 24 St. Vincent place Glasgow,	20 Feb., 1900
Gardiner, William Guthrie, 24 St. Vincent place, Glasgow,	20 Feb., 1900
Gillespie, A. W. W., 75 Bothwell street, Glasgow,	29 Oct., 1901

Hardie, Thomas G., 11 Bothwell street, Glasgow,	19 Feb., 1901
Hogarth, Hugh, 70 Great Clyde street, Glasgow,	29 Oct., 1901
Hogarth, Samuel C., 70 Great Clyde street, Glasgow,	29 Oct., 1901
Hollis, John, 29 Alexandra place, Newcastle-on-Tyne,	23 Nov., 1897

Kinghorn, William A., 81 St. Vincent street, Glasgow,	24 Oct., 1882
Kirsop, James Nixon, 31 St. Vincent place, Glasgow,	29 Oct., 1901
Kyle, John, Cathay, Forres, N.B.,	23 Feb., 1897

Loudon, James M., 22 Clarenden street, Glasgow,	21 Jan., 1902

M'Ara, Alexander, 65 Morrison street, Glasgow,	22 Nov., 1892
Macbeth, George Alexander, 65 Great Clyde street, Glasgow,	24 Jan., 1899
MacBrayne, Lawrence, 11 Park Circus place, Glasgow,	26 Mar., 1895
MacDougall, Dugald, 1 Crosshore street, Greenock,	26 Jan., 1897
M'Intyre, John, 33 Oswald street, Glasgow,	23 Feb., 1897

M'Intyre, T. W., 21 Bothwell street, Glasgow,	24 Jan., 1893
M'Leod, Norman, 53 Bothwell street, Glasgow,	20 Feb., 1900
M'Kissock, Peter, 180 Hope street, Glasgow,	19 Mar., 1901
Maclay, Joseph P., 21 Bothwell street, Glasgow,	18 Dec., 1900
M'Pherson, Captain Duncan, 8 Royal crescent, Crosshill, Glasgow,	26 Jan., 1886
Mann, William, Whitecraigs, Giffnock,	20 Feb., 1900
Mercer, James B., Broughton Copper works, Manchester,	24 Mar., 1874
Millar, Thomas, Hazelwood, Langside, Glasgow,	22 Mar., 1898
Miller, T. B., Sandilands, Aberdeen,	18 Dec., 1900
Mowbray, Archibald H., c/o Messrs Smith & M'Lean, Mavisbank, Glasgow,	22 Feb., 1898
Murray, John Bruce, 24 George square, Glasgow,	18 Mar., 1902

Napier, James, 33 Oswald street, Glasgow,	22 Jan., 1901
*Napier, James S., 33 Oswald street, Glasgow,	

Pairman, Thomas, 54 Gordon street, Glasgow,	23 Jan., 1900
Prentice, Thomas, 175 West George street, Glasgow,	24 Nov., 1896

Raeburn, William Hannay, 81 St. Vincent street, Glasgow,	20 Feb., 1900
Reid, John, 30 Gordon street, Glasgow,	22 Dec., 1896
Riddle, John C., 8 Gordon street, Glasgow,	15 June, 1898
Rigg, William, 3 Grantly place, Shawlands, Glasgow,	22 Jan., 1889
Ritchie, James, 40 St. Enoch square, Glasgow,	22 Mar., 1898
Roberts, William Ibbotson, Rawmoor, Sheffield,	15 June, 1898
Robertson, William, Oakpark, Mount Vernon,	27 Apr., 1897
Ross, Thomas A., Glenwood, Bridge-of-Weir,	20 Mar., 1894
Roxburgh, John Archibald, 3 Royal Exchange square, Glasgow,	20 Feb., 1900

Service, George William, 175 West George street, Glasgow,	24 Nov., 1896
Service, William, 54 Gordon street, Glasgow,	23 Jan., 1900

SLOAN, GEORGE, 53 Bothwell street, Glasgow,	20 Feb., 1900
SLOAN, WILLIAM, 53 Bothwell street, Glasgow,	20 Feb., 1900
†SMITH, GEORGE, 75 Bothwell street, Glasgow,	22 Jan., 1901
SMITH, JOHN, 2 Doune quadrant, Kelvinside, Glasgow,	22 Feb., 1898
SOTHERN, ROBERT M., 59 Bridge street, Glasgow,	18 Feb., 1902
STEWART, CHAS. R., Messrs J. Stone & Co., 46 Gordon street, Glasgow,	29 Oct., 1901
STEWART JOHN G., 65 Great Clyde street, Glasgow,	18 Dec., 1900
STRACHAN, G., Fairfield works, Govan,	26 Oct., 1897

TAYLOR, FRANK, Alexander Young & Co., 50 Wellington street, Glasgow,	24 Dec., 1901
TAYLOR, WILLIAM GILCHRIST, 123 Hope street, Glasgow,	23 Jan., 1900
THOMSON, WILLIAM H., 32 Albert Road East, Crosshill, Glasgow,	19 Feb., 1901

WALLACE, H., 544 St. Vincent street, Glasgow,	27 Apr., 1897
WARREN, ROBERT G., 115 Wellington street, Glasgow,	28 Jan., 1896
WATSON, H. J., 134 St. Vincent street, Glasgow,	
WEIR, ANDREW, 102 Hope street, Glasgow,	25 Jan., 1898
WHIMSTER, THOMAS, 67 West Nile street, Glasgow,	24 Oct., 1899
WILD, CHARLES WILLIAM, Broughton Copper Company, Limited, 49-51 Oswald street, Glasgow,	24 Mar., 1896
WREDE, FREDERICK LEAR, 25 Bentinck street, Greenock,	25 Jan., 1898

YOUNG, JOHN D., Scottish Boiler Insurance Company, 111 Union street, Glasgow,	19 Dec., 1882

GRADUATES.

Agnew, William H., Messrs. Laird Brothers, Birkenhead,	28 Nov., 1882
Ainslie, Alexander F., 26 Granville st., W., Glasgow,	21 Nov., 1899
Ainslie, James William, 377 Bath street, Glasgow,	26 Nov., 1901
Aitchison, John Wilson, 213 Watt street, Glasgow,	20 Nov., 1900
Albrecht, J. August, Messrs Reunert & Lenz, Box 623, Cape Town, South Africa,	23 Nov., 1897
Alexander, Robt., 33 Melville street, Portobello,	23 Oct., 1900
Alexander, William, 4 Kelvinbank terrace, Sandyford, Glasgow	19 Mar., 1901
Alison, Alexander E., Devonport, Auckland, New Zealand	22 Nov., 1898
Allan, Frederick Wm., 8 Gillsland road, Edinburgh,	21 Nov., 1899
Allan, James, 144 Buccleuch street, Glasgow,	24 Jan., 1888
Anderson, Adam R., Bank Buildings, Renfrew,	23 Mar., 1897
Anderson, George, 2 Parkhead street, Motherwell,	26 Nov., 1901
Anderson, George C., 2 Florentine gardens, Hillhead, Glasgow,	24 Dec., 1895
Anderson, Thomas, 326 Cumberland street, Glasgow,	29 Oct., 1901
Arbuthnott, Donald S., c/o Messrs Charles Brand & Son, 172 Buchanan street, Glasgow,	23 Oct., 1888
Arundel, Arthur S. D., Penn street works, Hoxton, London, N.,	23 Dec., 1890
Bacon, Henry Douglas,	21 Nov., 1899
Baker, Frederick, W.,	20 Mar., 1894
Barnwell, Frank Sowter, Elcho house, Balfron,	18 Feb., 1902
Barnwell, Richard Harold, Elcho house, Balfron,	18 Feb., 1902
Barty, Thomas, 218 West Regent street, Glasgow,	24 Oct., 1899
Barty, Thomas Patrick William, c/o Messrs. Forman & M'Coll, 160 Hope street, Glasgow,	18 Dec., 1900
Bennett, Duncan, 12 Louis street, Leeds,	26 Oct., 1897
Berry, Davidson, 21 Grange terrace, Langside, Glasgow,	19 Mar., 1901
Bertram, R. M., 9 Walmer road, Toronto, Canada,	24 Jan., 1899
Bianchi, Manuel,	21 Nov., 1899
Binley, William, Jun., Naval Constructor's Office, Brooklyn Navy Yard, Brooklyn, U.S.A.,	21 Mar., 1899
Bissett, John, 35 Harriet street, Pollokshaws, Glasgow,	18 Dec., 1900
Black, James, 3 Clarence street, Paisley,	18 Dec., 1900

Black, W. John, 51 Montgomerie street, Kelvinside, Glasgow,	25 Oct., 1892
Blair, Archibald, 15 Craigmore terrace, Partick,	27 Oct., 1885
Blair, Archibald, 7 Corunna street, Glasgow,	27 Oct., 1891
Blair, Frank R., Ashbank, Maryfield, Dundee,	22 Mar., 1892
Bone, Quintin George, 5 University avenue, Hillhead, Glasgow,	19 Dec., 1899
Bowman, W. D., 21 Kersland terrace, Hillhead, Glasgow,	22 Dec., 1891
Brand, Mark, B.Sc., Barrhill cottage, Twechar, Kilsyth,	24 Jan., 1888
Brookfield, John W., 21 Peel street, Partick,	18 Feb., 1902
Brown, Alexander Taylor, 2 Parkgrove terrace, Sandyford, Glasgow,	26 Oct., 1897
Brown, David A., 57 St. Vincent crescent, Glasgow,	23 Feb., 1897
Brown, J. Pollock, 2 Park Grove terrace, Glasgow,	18 Dec., 1894
Brown, William, c/o Mrs Walker, 5 Princes street, Pollokshields, Glasgow,	26 Nov., 1901
Bryson, William, 21 Cartvale road, Langside, Glasgow,	24 Oct., 1899
Buchanan, Joshua Miller, 7 Glenton terrace, Kelvinside, Glasgow,	21 Nov., 1899
Buchanan, Walter G., 17 Sandyford place, Glasgow,	27 Jan., 1891
Bunten, James C., Jun., Sheriff Riggs, Rutherglen,	20 Nov., 1900
Butler, James S., 21 Peel street, Partick,	22 June, 1901

Caird, William, 12 Avenell road, Highbury, London,	21 Jan., 1890
Calder, John, Lees avenue, Collingswood, New Jersey, U.S.A.,	24 Feb., 1891
Callander, William, 100 Bothwell street, Glasgow,	24 Dec., 1901
Cameron, Angus Johnstone, Greendale, Crossloan road, Govan,	20 Nov., 1900
Cameron, Hugh, 40 Camperdown road, Scotstoun, Glasgow,	25 Oct., 1892
Campbell, Angus, 90 Southgrove road, Sheffield,	24 Jan., 1888
Carslaw, William H., Jun., Parkhead Boiler works, Parkhead, Glasgow,	23 Dec., 1890
Carter, Douglas R., Cockburn Hotel, 141 Bath street, Glasgow,	18 Dec., 1900
Cleland, John, B.Sc., Mansion house, Easterhouse,	26 Feb., 1884
Cleland, W. A., Yloilo, Philippine Islands,	25 Apr., 1893
Cochrane, James, Resident Engineer's Office, Harbour works, Table Bay, Capetown,	27 Oct., 1891
Cochrane, John, 15 Ure place, Montrose street, Glasgow,	24 Dec., 1901

Connell, William, 174 Claythorn street, Glasgow,	20 Nov., 1900
Cowan, D. G., 5 Balgray terrace, Springburn, Glasgow,	24 Oct., 1899
Craig, Alexander, Netherlea, Partick,	26 Nov., 1895
Craig, James, Netherlea, Partick,	22 Feb., 1889
Cran, J. Duncan, 11 Brunswick street, Edinburgh,	21 Jan., 1902
Crighton, J., Rotterdamsche Droogdok, Maatschappy, Rotterdam, Holland,	23 Nov., 1897
Crighton, John, 42 Stewartville street, Partick,	26 Nov., 1901
Cubie, Alexander, Jun., 2 Newhall terrace, Glasgow,	23 Jan., 1900
Cunningham, P. Nisbet, Jun., Easter Kennyhall house, Cumbernauld road, Glasgow,	22 Nov., 1898
Cuthbert, James G., 33 Cartvale road, Langside, Glasgow,	21 Nov., 1899

Davidson, William J. J., 7 Bellevue crescent, Edinburgh,	22 Nov., 1898
Dekke, Kristian S., Bergen, Norway,	22 Dec., 1891
De Keyser, Felix,	19 Dec., 1899
De Sola, Juan Garcia, Sacramento, 57, Cadiz, Spain,	20 Mar., 1900
Deveria, Lewis M. T., c/o Messrs P. M'Intosh & Son, 129 Stockwell street, Glasgow,	10 Feb., 1883
Diack, James A., 4 Rosemount terrace, Ibrox, Glasgow,	22 Jan., 1895
Dickie, James S., San Mateo, California,	19 Dec., 1899
Dobbie, Robert B., 15 Leander Road, Brixton Hill, London, S.W.,	24 Oct., 1899
Dobson, James, Queen street, Kidsgrove, Staffordshire,	22 Dec., 1896
Donaldson, A. Falconer, Beechwood, Partick,	27 Oct., 1896
Douglas, Charles Stuart, B.Sc., "St. Brides," 12 Dalzell drive, Pollokshields, Glasgow,	24 Jan., 1899
Duncan, Alexander, c/o E. G. Fraser Luckie, Esq., Hacienda, Andalusia, Huacho, Sayou, Peru,	23 Apr., 1901
Duncan, James Grieve, 137 Shields road, Glasgow,	22 Nov., 1898
Dunlop, Alex., 14 Derby terrace, Sandyford, Glasgow,	21 Dec., 1897
Dyer, Henry, c/o Mr Elliot, Balshagray avenue, Partick,	18 Dec., 1900

Edmiston, Alexander A., Ibrox house, Govan,	22 Feb., 1898

Fairley, John, 124 Pitt street, Glasgow,	21 Nov., 1899
Fairweather, George A. E., Elmwood, Avon street, Motherwell,	26 Nov., 1901

FAUT, ALEXANDER, 122 Holland street, Glasgow,	19 Dec., 1899
FERGUS, ALEXANDER, 7 Ibrox place, Glasgow,	22 Dec., 1891
FERGUSSON, W. L., 48 Connaught road, Roath, Cardiff,	22 Dec., 1891
FINDLATER, JAMES, 124 Pollok street, Glasgow, S.S.,	19 Dec., 1899
FINDLAY, LOUIS, 50 Wellington street, Glasgow,	21 Feb., 1893
FISH, N., 480 Springburn road, Glasgow,	18 Feb., 1902
FRANCE, JAMES, 8 Hanover terrace, Kelvinside, Glasgow,	26 Oct., 1897
FRASER, J. IMBRIE, 13 Sandyford place, Glasgow,	27 Apr., 1885
FYFE, CHARLES F. A., 38 Burnbank gardens, Glasgow,	18 Dec., 1894

GALBRAITH, HUGH, 75 Waterloo street, Glasgow,	20 Dec., 1898
GALLOWAY, ANDREW, 12 Camphill avenue, Langside, Glasgow,	24 Oct., 1893
GIBB, JOHN, 43 Waterside street, Kilmarnock,	24 Jan., 1899
GIBSON, ROBERT E., Engineer's Department, S. Eastern and Chatham and Dover Railway, 84 Tooley street, London, S.E.,	25 Jan., 1898
GILMOUR, ALEXANDER, Barrhead,	22 Nov., 1898
GILMOUR, ANDREW, 3 Nursery place, Annan,	20 Dec., 1898
GOURLAY, JAMES, B.Sc., Messrs J. H. Carruthers & Co., Hamilton street, Polmadie, Glasgow,	27 Oct., 1891
GOURLAY, R. CLELAND, Endyne, Oakshaw st., Paisley,	24 Dec., 1895
GOVAN, WILLIAM A. W., 15 Renfield street, Glasgow,	18 Dec., 1894
GRAHAM, GEORGE, Ardlui, Freshfield, near Liverpool,	22 Nov., 1898
GRAHAM, JOHN, 15 Armadale st., Dennistoun, Glasgow,	19 Mar., 1901
GRANT, WILLIAM, Croft park, High Blantyre,	24 Oct., 1899

HAMILTON, WALTER, Jun., c/o Crawford, 478 St. Vincent street, Glasgow,	21 Nov., 1899
HANNAH, JOHN A., 22 Govanhill street, Glasgow,	26 Nov., 1901
HENDERSON, CHARLES A., Corporation Electrical Department, Cotton street, Aberdeen,	24 Jan., 1899
HENDERSON, HARRY ESDON, 119 St. John's road, Waterloo, Liverpool,	22 Nov., 1898
HENRICSON, JOHN A., 24 Kergogaten, c/o Miss Beckmiack, Abo, Finland,	19 Dec., 1899
HEPTING, F. W. L.,	20 Nov., 1894
HERSCHEL, A. E. H., 2 Glenavon terrace, Crow road, Partick,	19 Dec., 1899

Holland, Henry Norman, Metropolitan Electric Supply Co., Willesden Works, London, N.W.,	22 Nov., 1898
Horn, Peter Allan, 201 Kent road, Glasgow,	26 Oct., 1897
Hotchkis, Montgomery H., Crookston house, near Paisley,	24 Dec., 1901
Houston, Percival T., 22 Lancaster Gate, London,	22 Nov., 1898
Houston, William C., 4 Abbotsford place, Glasgow,	26 Oct., 1897
Howie, William, Cathkin View, 14 Crossloan road, Govan,	23 Apr., 1901
Howson, George, c/o Mrs Findlay, 5 Craignethan gardens, Partick,	22 Dec., 1891
Hudson, Gerard, 49 Sundorne road, Old Charlton, Kent,	22 Jan., 1895
Hutchison, Robert, c/o Messrs. Burns & Co., Engineers, Howiah, near Calcutta.	24 Oct., 1899
Hutton, W. R., Jun., Lenore, Park Grove, Whiteinch, Glasgow,	23 Apr., 1901

Inglis, John F., Pointhouse Shipyard, Partick,	26 Oct., 1897
Innes, W., 11 Walmer terrace, Glasgow,	22 Feb., 1898
Irons, James Hay, 4 Albert drive, Crosshill, Glasgow,	19 Feb., 1901
Irvine, Archibald B., 8 Newton terrace, Glasgow,	20 Nov., 1894

Jack, Charles, P. M., 17 Albert drive, Pollokshields, Glasgow,	20 Nov., 1900
Jackson, William S., 109 Hope street, Glasgow,	29 Oct., 1901
Johnstone, Alexander C., 167 Langside road, Glasgow,	25 Jan., 1898
Johnstone, Robt., c/o Mrs M'Vicar, 20 Rothesay gardens, Partick,	26 Apr., 1893
Jones, T. C., Kent Avenue, Jordanhill, Glasgow,	23 Nov., 1897

Kay, Alexander J., 21 Endsleigh gardens, Partickhill, Glasgow,	24 Oct., 1893
Kemp, John, 1 Thornwood terrace, Partick,	28 Oct., 1890
Kemp, Robert G., 1 Thornwood terrace, Partick,	28 Oct., 1890
Kermeen, Robert W., Lucania place, S., Govan,	18 Mar., 1902
Kimura, N., 5 Park terrace, Govan,	23 Apr., 1901
King, Charles A., 12 Kew gardens, Kelvinside, Glasgow,	25 Apr., 1893

KING, JOHN, Board of Trade Offices, Liverpool,	26 Jan., 1886
KINGHORN, DAVID RICHARD, c/o Mrs Banks, 57 St. Vincent crescent, Glasgow,	23 Oct., 1900
KIRK, JOHN, Oakfield, University avenue, Glasgow,	20 Nov., 1894
KNOX, ALEX., 10 Westbank terrace, Hillhead, Glasgow,	23 Nov., 1897
KOLVIG, WILLIAM, 19 Steven drive, Linthouse, Glasgow,	26 Nov., 1901

LAMB, STUART, Engineer's Office, St. Enoch Station, Glasgow,	23 Jan., 1900
LAMONT, THOMAS W., Hawkhead works, Paisley,	22 Nov., 1892
LAUDER, THOMAS H., Parkhead forge, Glasgow,	19 Dec., 1893
LAW, ALEXANDER, 138 Cambridge drive, Kelvinside, Glasgow,	26 Apr., 1898
LEARMONTH, ROBERT, c/o H. Drysdale, 590 Dalmarnock road, Glasgow,	26 Nov., 1901
LE CLAIR, LOUIS J., 115 Donore terrace, South Circular road, Dublin,	24 Nov., 1896
LEE, JOHN, 15 St. John street, Mansfield,	26 Jan., 1886
LEITCH, WILLIAM ORR, Jun., Imperial Chinese Railway, Tientsin, North China,	22 Dec., 1891
LESLIE, ALFRED, 148 Hill street, Garnethill, Glasgow,	23 Oct., 1900
LESLIE, JOHN, Struan, Oswald drive, Scotstounhill, Glasgow,	20 Dec., 1892
LLOYD, HERBERT J., Breacan road, Builth, Wales,	21 Dec., 1897
LOADER, EDMUND T., Y.M.C.A. Club, 100 Bothwell Street, Glasgow,	20 Nov., 1900
LORIMER, ALEXANDER SMITH, Kirklinton, Langside, Glasgow,	21 Nov., 1899
LORIMER, HENRY DÜBS, Kirklinton, Langside, Glasgow,	21 Nov., 1899
LOWE, JAMES, c/o Mrs Waddell, 33 Nithsdale road, Glasgow,	24 Oct., 1899
LOWE, ROBERT, 230 Kenmure street, Pollokshields, Glasgow,	22 Jan., 1901

M'ARTHUR, ARCHIBALD, 91 Hyndland street, Partick,	24 Jan., 1893
MACCALLUM, PATRICK F., The Athenæum, Glasgow,	22 Nov., 1880
M'CULLOCH, JOHN, 2 Willowbank crescent, Glasgow,	23 Oct., 1900
MACDONALD, JOHN F., 5 Caird Drive, Partickhill,	21 Dec., 1897
MACDONALD, ROBERT C., 138 Garthland drive, Glasgow,	21 Nov., 1899

MacEwan, Henry, 5 Wendover cres., Mount Florida, Glasgow,	27 Oct., 1891
M'Ewan, John, 3 Norse Road, Scotstoun, Glasgow,	26 Oct., 1887
Macfarlane, Duncan, Jun., 25 St. Andrew's drive, Pollokshields, Glasgow,	26 Oct., 1897
M'Gilvray, John A., 25 Hutton drive, Govan, Glasgow,	26 Oct., 1897
Macgregor, J. Graham, 4 West George street, Glasgow,	18 Feb., 1902
M'Gregor, John L., Coatbank Engine works, Coatbridge,	28 Jan., 1896
M'Harg, W. S., The Grove, Ibrox, Glasgow,	19 Mar., 1901
M'Houl, John B., 2 Windsor terrace, Langside, Glasgow,	24 Jan., 1899
M'Intosh, George, Dunglass, Bowling,	22 Jan., 1895
M'Intosh, John, 5 Douglas terrace, Paisley,	22 Jan., 1895
M'Intyre, James N., Stalheim, Scotstounhill, Glasgow,	20 Nov., 1900
Mackintosh, John, 7 Park quadrant, Glasgow,	18 Dec., 1894
Mackintosh, Robert D., Box 1829, Johannesburg, South Africa,	20 Nov., 1894
Mackay, Harry J. S., Rosemount, Stockport road, Chorlton-cum-Hardy, Manchester,	22 Feb., 1898
Mackay, Lewis C., Jun., 2 Maybank street, Crosshill, Glasgow,	22 Dec., 1896
Mackay, W. Morris, 62 Cromwell street, Glasgow,	22 Jan., 1901
M'Kean, John G., c/o Mrs Elgie, 14 Burnfoot terrace, Whitley Bay,	23 Oct., 1900
Mackie, James, 478 St. Vincent street, Glasgow,	23 Mar., 1897
Mackie, Thomas P., 27 Alexander street, Glasgow,	23 Feb., 1897
Mackie, William, 3 Park terrace, Govan,	21 Dec., 1897
Maclaren, James Ernest, 3 Porter street, Bellahouston, Glasgow,	23 Oct., 1900
M'Laurin, James H., 34 Park circus, Ayr,	18 Dec., 1900
M'Lean, Joseph M., c/o Shaw, 53 South street, Huddersfield,	26 Apr., 1898
McLean, John, 1 Cannon street, Dover,	21 Nov., 1899
Macleod, T. Torq. M., 10 Royal crescent, Glasgow,	27 Oct., 1896
M'Lellan, Alexander, Clyde Navigation Trust, 16 Robertson street, Glasgow,	18 Dec., 1900
Macmillan, Campbell, B.Sc., 17 University avenue, Glasgow,	24 Nov., 1896
MacNicoll, Donald, Griffe Craig, Kilmalcolm,	23 Apr., 1901
M'Rae, John, 47 Palermo street, Springburn, Glasgow,	18 Dec., 1900
M'Vitae, Andrew, Bryce lane, Govan, Glasgow,	21 Dec., 1886
M'Whirter, Anthony C., The General Electric Co., Draughting Department, Schenectady, N.Y., U.S.A.,	21 Dec., 1897
Marshall, Alexander, Brightons, Polmont station,	18 Mar., 1902

MARTIN, GEORGE H., c/o London, 102 Byres road, Hillhead, Glasgow,	26 Nov., 1901
MAITLAND, JOHN M., 13 Rosslyn terrace, Glasgow,	22 Jan., 1901
MATHER, JOHN BOYD, Kirkhill, Mearns,	20 Mar., 1894
MELVILLE, ALEXANDER, Engineer's Office, St Enoch Station, Glasgow,	20 Feb., 1900
MENZIES, GEORGE, 20 St Vincent crescent, Glasgow,	22 Jan., 1889
MERCER, JOHN, c/o Mrs M'Culloch, 25 White street, Partick,	22 Oct., 1895
MILLAR, JOHN S., 22 Rothesay gardens, Partick,	20 Nov., 1894
MILLAR, THOMAS, Messrs Sir W. G. Armstrong, Whitworth & Co., Ltd., Walker Shipyard, Newcastle-on-Tyne,	25 Nov., 1884
MILLAR, WILLIAM P., 4 Parkview gardens, Tollcross, Glasgow,	18 Dec., 1900
MILLER, ALEXANDER, 2 Ailsa terrace, Hillhead, Glasgow,	22 Nov., 1898
MILLER, JAMES, 24 Melrose gardens, Kelvinside, Glasgow,	22 Nov., 1898
MILLER, JAMES WILLIAM, 84 Portland place, London, W.,	20 Dec., 1898
MILLER, JOHN, Etruria villa, South Govan,	23 Apr., 1889
MILLER, ROBERT F., Messrs Wardlaw & Miller, 109 Bath street, Glasgow,	25 Feb., 1890
MILLIKEN, GEORGE, Milton house, Callander,	18 Feb., 1902
MITCHELL, CHARLES, Glenriddell, Dunscore, Dumfriesshire,	25 Jan., 1898
MITCHELL, R. M., 24 Howard street, Bridgeton, Glasgow,	23 Nov., 1897
MORGAN, ANDREW, 20 Minerva street, Glasgow,	18 Dec., 1900
MORISON, THOMAS, 41 St. Vincent crescent, Glasgow,	21 Nov., 1899
MORLEY, JAMES STEEL, 5 Walmer terrace, Copland road, Govan,	20 Feb., 1900
MORRISON, ARTHUR M., Merchiston, Scotstounhill, Glas-Glasgow,	17 Dec., 1889
MORRISON, A., Alt-na-craig, Greenock,	23 Nov., 1897
MORTON, CHARLES C., Ingleside, The Park, Waterloo, Liverpool,	25 Jan., 1898
MORTON, W., REID, Strathview, Bearsden,	26 Oct., 1897
MUIR, ANDREW A, Horshay Engineering Works, Horshay, R.S.O., Shropshire,	22 Nov., 1898
MUIR, JAMES, 9 Garturk street, Govanhill, Glasgow,	21 Nov., 1899
MUIR, JAMES H., 76 Hill street, Garnethill, Glasgow,	26 Jan., 1892
MUIRHEAD, WILLIAM, Cloberhill, Knightswood, Maryhill, Glasgow,	28 Apr., 1891
MUNDY, H. L., Ormsby Hall, Alford, Lancs.,	24 Oct., 1899
MYLNE, ALFRED, 116 Woodlands road, Glasgow,	26 Jan., 1897

NEIL, ROBERT, 116 Forth street, Pollokshields, Glasgow,	20 Mar., 1900
NEILL, HUGH, Jun., 99 Clarence drive, Hyndland, Glasgow,	21 Nov., 1899
NEWTON, CHARLES A., 47 Full street, Derby,	25 Jan., 1898
NIVEN, JOHN, c/o Messrs Lynch, Basreh, Persian Gulf,	22 Nov., 1898
NOWERY, WILLIAM, c/o Fraser, 46 Elderslie street, Glasgow,	21 Dec., 1897

ORR, J., 53 Bentinck street, Glasgow,	22 Oct., 1895
ORR, Prof. JOHN, B.Sc., South African College, Cape Town,	26 Mar., 1895
OSBORNE, HUGH, 31 Broomhill terrace, Partick,	22 Dec., 1891
OSBORNE, MARSHALL, Ashlea, Clooney, Londonderry,	22 Dec., 1891

PATERSON, GEORGE, 27 White street, Partick,	18 Dec., 1900
PATERSON, JAMES V., 307 Walnut street, Philadelphia, U.S.A.,	24 Jan., 1888
PATERSON, JOSEPH BARR, c/o Harvey, 32 White street, Partick,	22 Mar., 1898
PATON, THOMAS, 19 Binnie street, Greenock,	20 Dec., 1892
PIGGOTT, JOSEPH T., 621 Alexandra parade, Dennistoun, Glasgow,	23 Jan., 1900
POLLOCK, GILBERT F., 10 Beechwood drive, Tollcross, Glasgow,	27 Jan., 1891
POLLOK, JOHN, Portland park, Hamilton,	22 Feb., 1898
PORTCH, ERNEST C., 37 Vicars hill, Ladywell, Kent,	26 Oct., 1897
PRENTICE, HUGH, Box No. 105, Postal Station B., Cleveland, Ohio, U.S.A.,	26 Apr., 1898
PRESTON, JOHN C., 343-5 Sussex street, Sydney, New South Wales,	6 Apr., 1887
PRINGLE, WILLIAM S., 15 Elm place, Aberdeen,	24 Oct., 1893

RALSTON, SHIRLEY B., 34 Gray street, Glasgow,	23 Feb., 1897
RAMSAY, JOHN C., 9 Minerva Cottages, Clydebank,	19 Feb., 1901
RAPHAEL, ROBERT A., 150 Renfrew street, Glasgow,	24 Dec., 1895
REID, DAVID H., Beresford Villa, Ayr.	25 Oct., 1887

Reid, Henry P., 12 Grantly gardens, Shawlands, Glasgow,	20 Dec., 1898
Reid, James, 128 Dumbarton road, Glasgow,	22 Oct., 1895
Reid, Walter,	26 Feb., 1894
Richmond, Tom, 4 Rosemount terrace, Ibrox, Glasgow,	20 Feb., 1900
Riddlesworth, W. H., M.Sc., 39 Caird drive, Partickhill, Glasgow,	24 Oct., 1899
Ritchie, James, Wraymont villas, Bloomfield, Belfast,	26 Oct., 1897
Roberts, James, c/o Mrs Pollock, 9 Walmer ter., Ibrox, Glasgow,	23 Apr., 1901
Robertson, Alexander, 272 Darnley street, Pollokshields, Glasgow,	26 Oct., 1886
Robertson, Prof. David, Merchant, Venturers' Technical College, Bristol,	19 Dec., 1899
Robertson, Edward F.,	28 Oct., 1890
Robertson, Robert M., 1 Holmhead terrace, Cathcart,	15 Apr., 1902
Rodger, Anderson, Jun., Glenpark, Port-Glasgow,	15 June, 1898
Ross, J. R., 64 Sandyford street, Glasgow,	25 Oct., 1898
Roy, William, 16 De Vere Gardens, Ilford, Essex,	25 Jan., 1898
Russell, Alexander C., 142 Eastfield street, Springburn, Glasgow,	15 Apr., 1902
Russell, James, 41 Ardgowan street, Greenock,	22 Dec., 1891

Sadler, John, 551 Sauchiehall street, Glasgow,	23 Oct., 1900
Sanguinetti, W. Roger, Public Works Department, Selangor, Malay States,	20 Feb., 1900
Sayers, W. H., 100 Bothwell street, Glasgow,	19 Mar., 1901
Scobie, Alexander, 454 Dumbarton road, Partick,	27 Oct., 1885
Scott, Thomas R., 23 Lismore crescent, Edinburgh,	22 Dec., 1896
Seath, Thomas R., Sunny Oaks, Langbank,	23 Mar., 1886
Seath, William Y., Sunny Oaks, Langbank,	23 Mar., 1886
Semple, William, West End, Bellshill,	21 Jan., 1902
Service, William, 173 West Graham street, Glasgow,	26 Nov., 1901
Sexton, George A.,	24 Nov., 1896
Sharp, James R., 227 Berkeley street, Glasgow,	24 Oct., 1899
Sharpe, William, B.Sc., Engineer-in-Chief's office, Natal Government Railway, Maritzburg, Natal,	24 Dec., 1895
Shaw, John J.,	24 Apr., 1894
Sibbald, Thomas Knight, c/o Messrs Cook & Son, Ltd., Cairo, Egypt,	26 Oct., 1897

SIMPSON, DAVID C., Assistant Mechanical Superintendent, Mersey Dock and Harbour Board Dockyard, Liverpool,	20 Dec., 1892
SLOAN, JOHN ALEXANDER,	25 Jan., 1898
SMITH, ALEXANDER, 12 Fairlie park drive, Partick,	24 Dec., 1901
SMITH, CHARLES, 3 Rosemount terrace, Ibrox, Glasgow,	24 Apr., 1894
SMITH, GEORGE F., c/o Messrs Cramp Shipbuilding and Engineering Works, Philadelphia, U.S.A.,	26 Oct., 1897
SMITH, JAMES, 11 Broomhill avenue, Partick,	18 Dec., 1900
SMITH, JAMES, 23 Barrington drive, Glasgow,	20 Dec., 1892
SMITH, JAMES A., Union Bank house, Virginia place, Glasgow,	18 Dec., 1894
SMITH, JAMES S., 5 Mona Terrace, Gourock,	22 Nov., 1898
SPALDING, WILLIAM, 9 Crown Circus road, Glasgow,	25 Oct., 1892
SPERRY, AUSTIN, 2100 Pacific avenue, San Francisco, U.S.A.,	23 Mar., 1897
SPROULE, Frank, 15 Shaftesbury terrace, Holland street, Glasgow,	19 Feb., 1901
STARK, JAMES, Penang, Straits Settlements,	22 Dec., 1891
STEELE, DAVID J., Davaar, Albert drive, Pollokshields, Glasgow,	20 Dec., 1898
STEVEN, DAVID M., 9 Princes ter., Dowanhill, Glasgow,	15 June, 1898
STEVEN, J. M., Applegarth, Helensburgh,	20 Dec., 1892
STEVEN, JOHN A., 12 Royal crescent, Glasgow,	22 Nov., 1881
STEVENS, CLEMENT H., c/o Messrs Blandy Bros. & Co., Las Palmas, Grand Canary,	22 Dec., 1891
STEVENSON, ALLAN, 69 Cadder street, Pollokshields, Glasgow,	26 Nov., 1901
STEVENSON, GEORGE, c/o Reid, 145 Garthland drive, Dennistoun, Glasgow,	24 Apr., 1900
STEVENSON, GEORGE, Hawkhead, Paisley,	22 Nov., 1898
STEVENSON, WILLIAM, Bank Chambers, Sandhill, Newcastle-on-Tyne,	25 Jan., 1881
STIRLING, ANDREW, Messrs Denny & Co., Engine works, Dumbarton,	21 Dec., 1875
SWAN, JAMES, 1536 Pine street, Philadelphia, U.S.A.,	23 Mar., 1897
SYMINGTON, JAMES R., Messrs Butterfield & Swire, Hong Kong, China,	21 Dec., 1886

TAYLOR, ANDREW P., 47 St. Vincent crescent, Glasgow,	19 Dec., 1899
TAYLOR, J. F., c/o Young, 300 Duke street, Glasgow,	23 Nov., 1897
THOMSON, FREDERICK, 18 Westbank terrace, Hillhead, Glasgow,	26 Jan., 1892
THOMSON, GRAHAME H., Jun., 2 Marlborough terrace, Glasgow,	22 Feb., 1898

TOD, PETER, c/o E. H. Williamson & Co., Engineers, Lightbody street, Liverpool,	27 Oct., 1885
TOD, WILLIAM, c/o Mrs Murray, 187 Dumbarton road, Glasgow,	22 Feb., 1898
TURNBULL, CAMPBELL, 190 W. George street, Glasgow,	27 Oct., 1891
TURNBULL, JAMES, Hillcrest, Mansion-house road, Langside, Glasgow,	22 Mar., 1892
TURNBULL, W. L., 190 West George street, Glasgow,	27 Oct., 1891
TURNER, ANDERSON, Jun., Sunnybank, Crosshill,	18 Mar., 1902
TURPIN, C., 763 Dumbarton road, Partick, W.,	23 Nov., 1897

WALLACF, HUGH, Jun., Bloomfield, Dalmuir,	24 Oct., 1899
WALLACE, JOHN,	21 Feb., 1899
WANNOP, CHARLES H., Messrs Alexander Stephen & Sons, Linthouse, Glasgow,	24 Feb., 1885
WARD, G. K., Rockvilla, Dumbarton,	23 Apr., 1901
WARD, JOHN, Jun., Rockvilla, Dumbarton,	23 Apr., 1901
WATSON, JAMES, 35 Regent Moray street, Glasgow,	24 Dec , 1901
WATSON, JOHN, c/o Alexander Fleming, Esq., 9 Woodside crescent, Glasgow,	22 Nov., 1898
WATT, HARRY, 4 Sharrocks street, Ibrox, Glasgow,	20 Dec., 1892
WATT, ROBERT D., Messrs Butterfield & Swire, French Bund, Shanghai, China,	27 Apr., 1880
WEDDELL, ALEXANDER H., B.Sc., Park villa, Uddingston,	22 Dec., 1896
WELSH, GEORGE MUIR, 3 Princes gardens, Dowanhill, Glasgow,	21 Dec., 1897
WHITE, HEDLEY G.,	24 Jan., 1899
WHITEHEAD, JOHN, Eccleston, Wallace st., Kilmarnock,	18 Dec., 1883
WHITELAW, ANDREW H., 14 West End Park Street, Glasgow,	20 Nov., 1900
WILLIAMS, R. R.,	20 Feb., 1900
WILLIAMSON, ALEXANDER, Craiglarnet, Greenock,	20 Nov., 1900
WILSON, THOMAS, 66 Alexandra parade, Glasgow,	20 Feb., 1900
WOODS, JOSEPH, 58 Dudley road, Ilford, Essex,	25 Feb., 1896

YOUNG, GEORGE M., B.Sc., 268 Kenmure street, Pollokshields, Glasgow,	24 Dec., 1901
YOUNG, JAMES M., 39 King street, Pollokshaws, Glasgow,	22 Jan., 1901
YOUNG, JOHN, Jun., Fernbank, Kirkintilloch,	23 Nov., 1897

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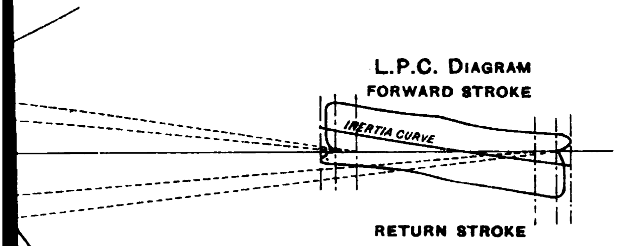

COMBINED CRANK-EFFORT DIAGRAM FOR
COMPOUND VERTICAL CONDENSING ENGINE

CYLINDERS 28" AND 58" x 48" STROKE
I.H.P. 1650—INITIAL PRESSURE 165 LBS. ABSOLUTE
RATIO OF EXPANSION—13
WEIGHTS OF RECIPROCATING PARTS—
H.P. 6600—L.P. 7150 LBS.
CRANKS AT 180° REVOLUTIONS PER MINUTE 84
MEAN ENERGY IN ONE REVOLUTION =
646,000 FOOT-POUNDS
COEFFT. OF FLUCTUATION OF ENERGY = ·14

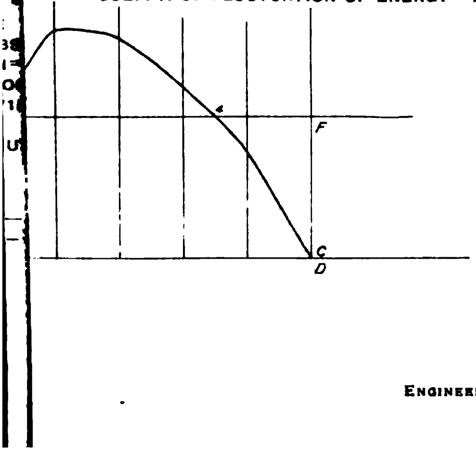

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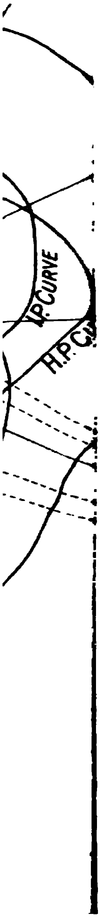
PLATE 11

H.P.C. DIAGRAM.



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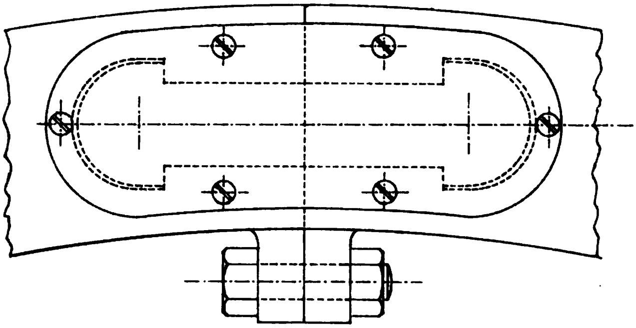
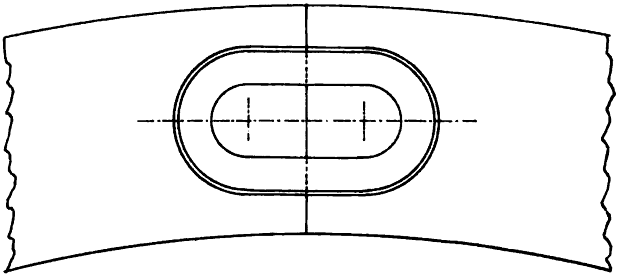


ARROW HEADED BOLTS



LINKS AND LUGS

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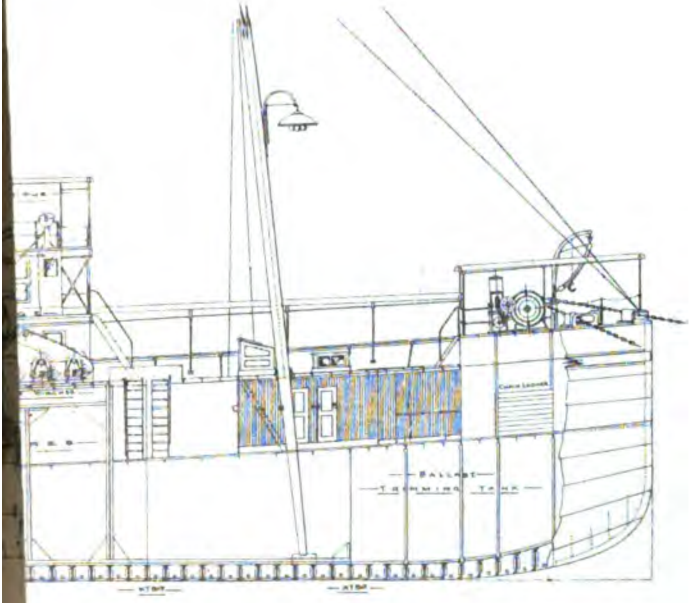
PLATE III.



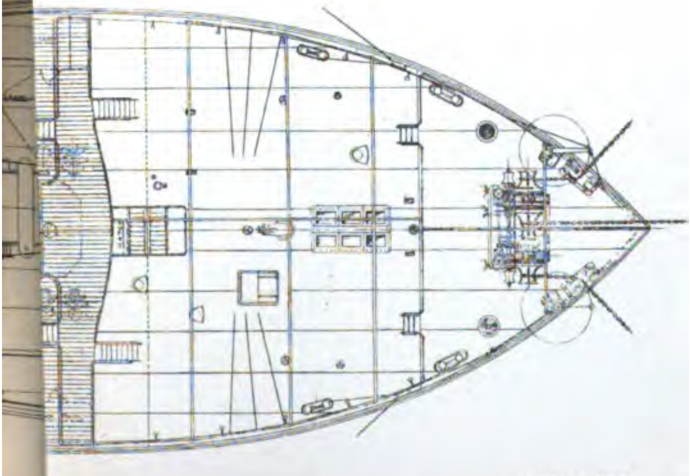


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PLATE IV.

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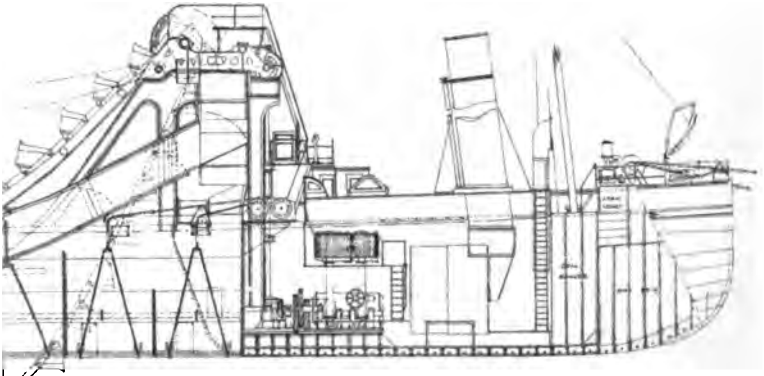

LONGITUDINAL SECTION.

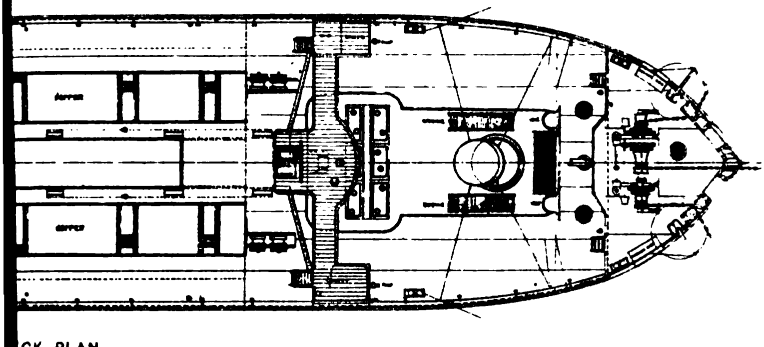

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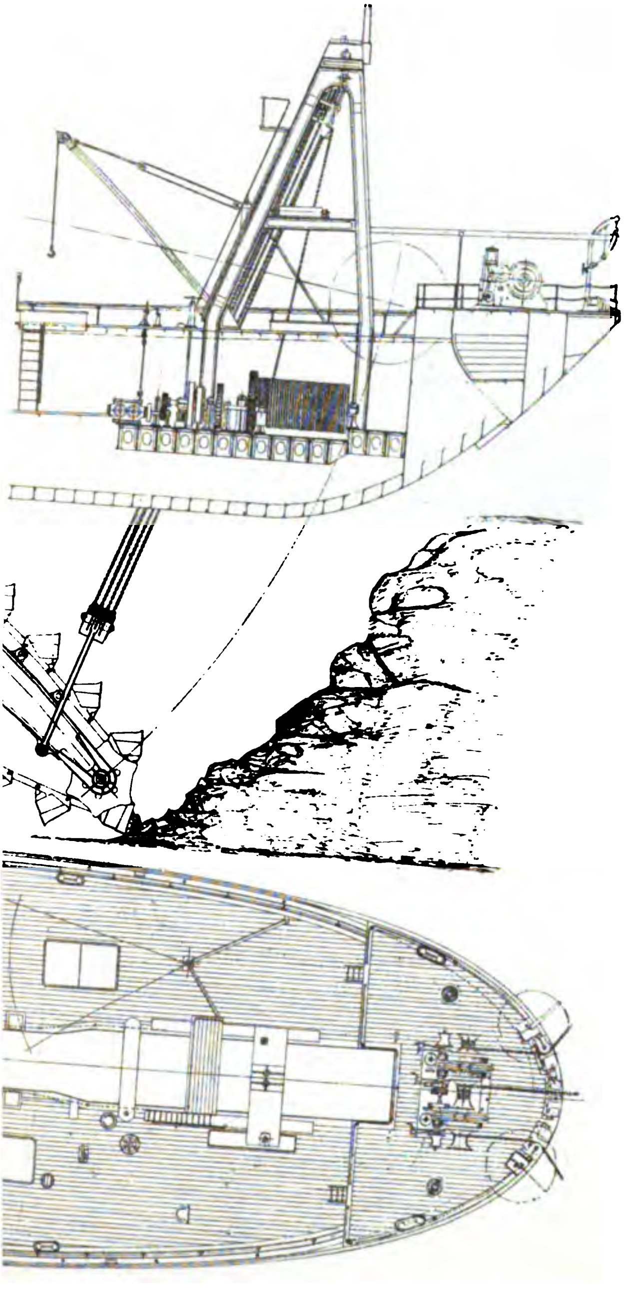
PLATE V.



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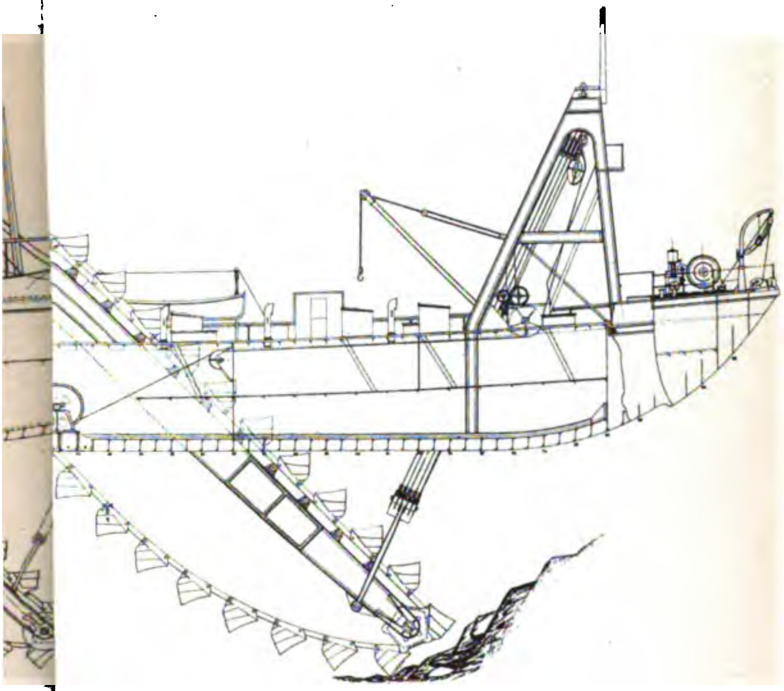

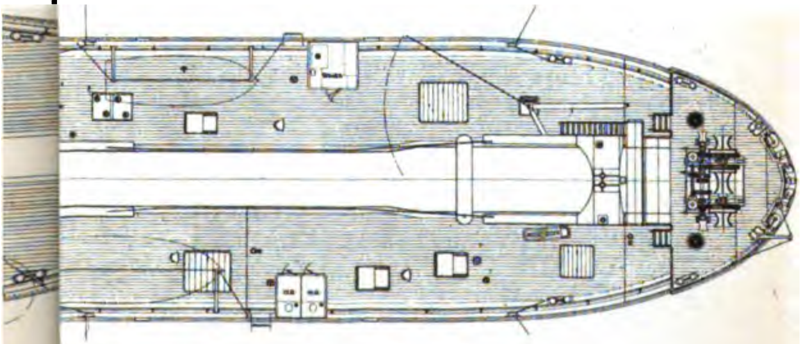

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PLATE VIII.

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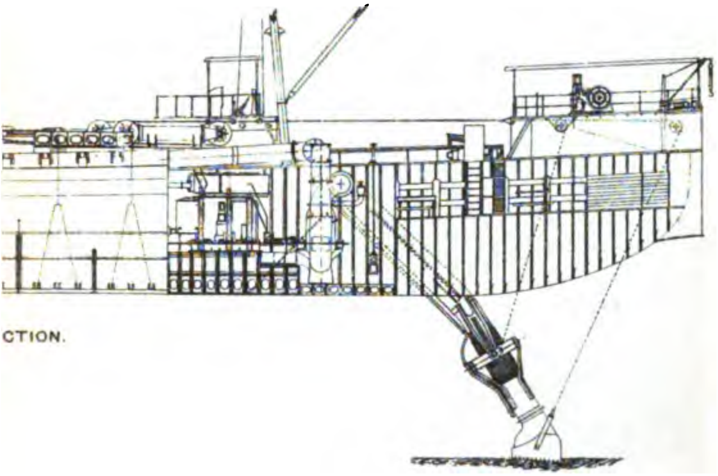

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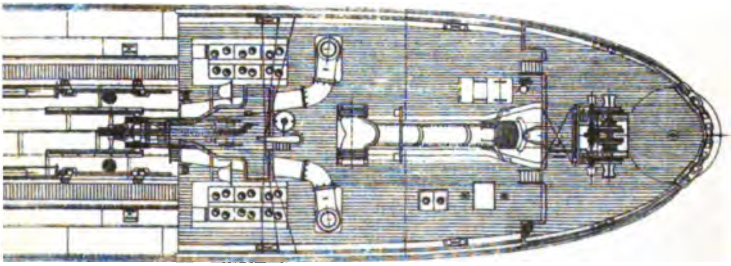

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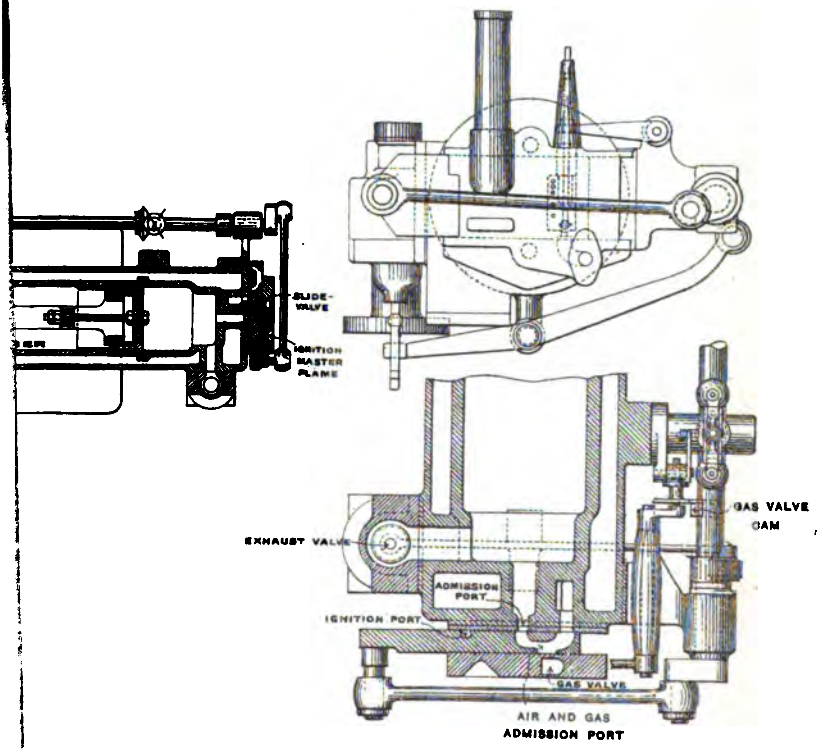

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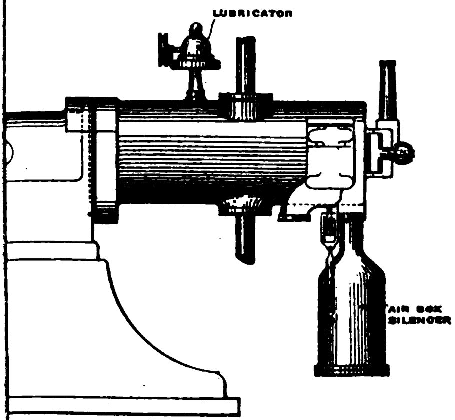

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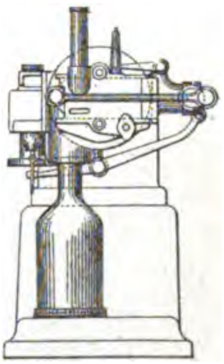

END VIEW

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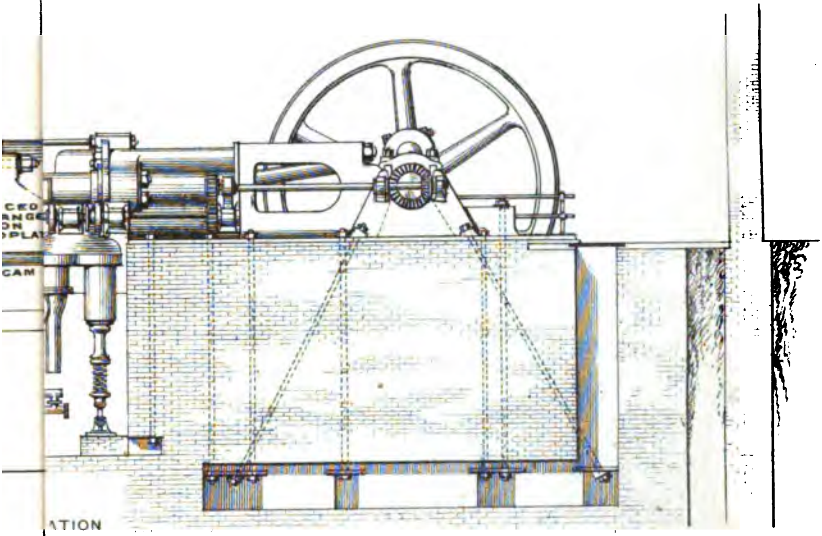
PLATE XI.

12.



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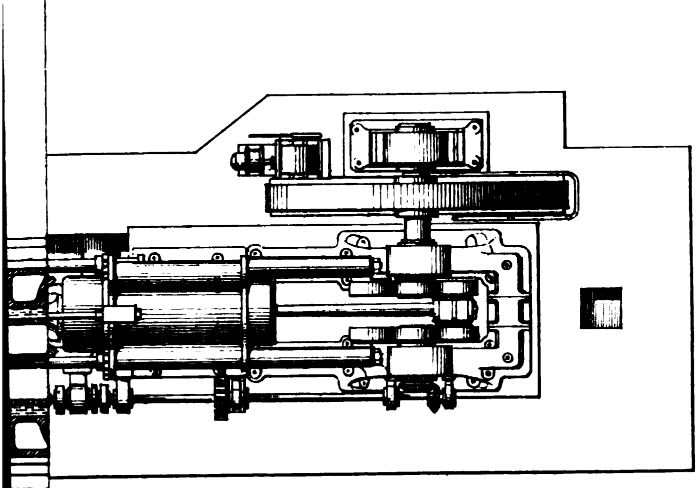

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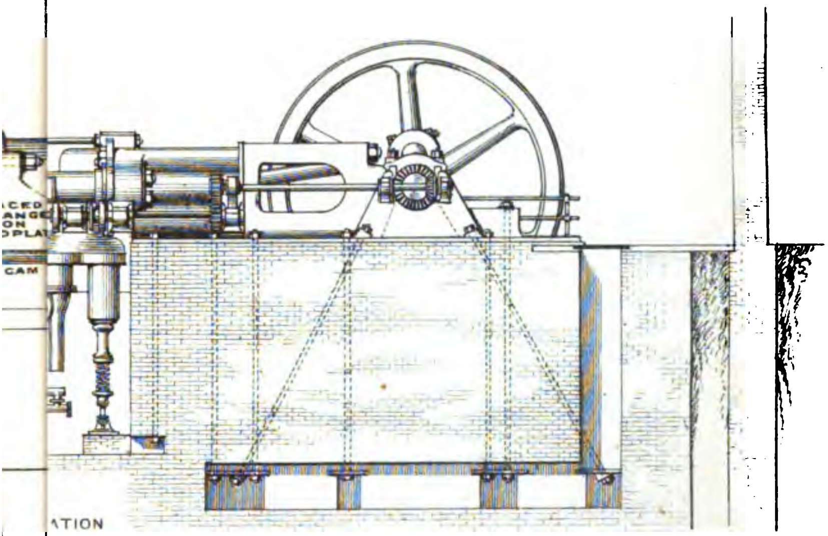

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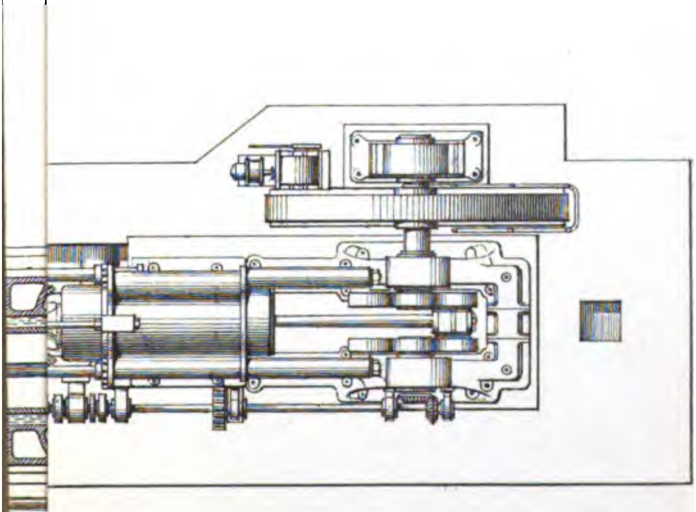

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PLATE XI.

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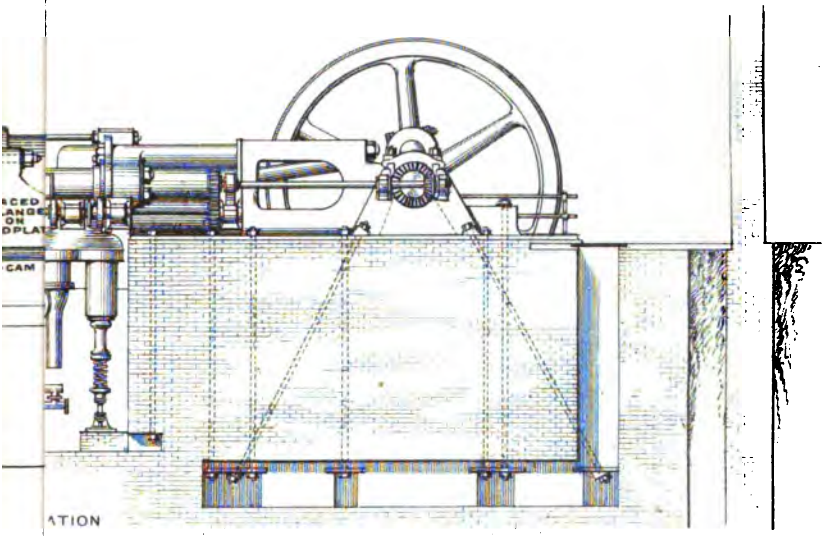

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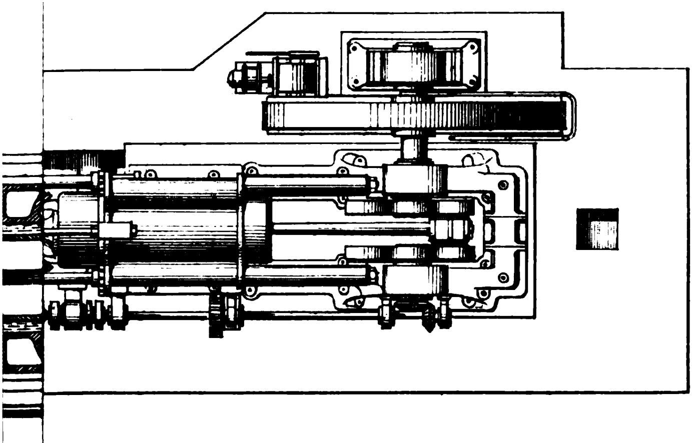

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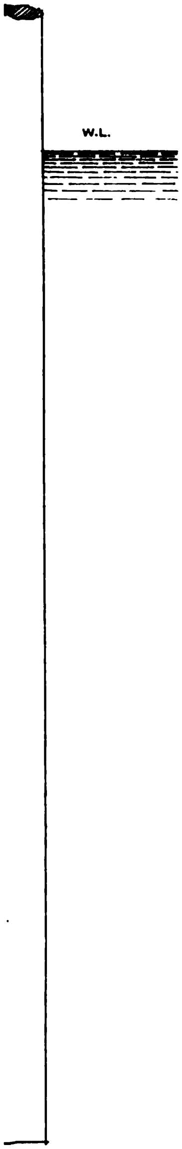

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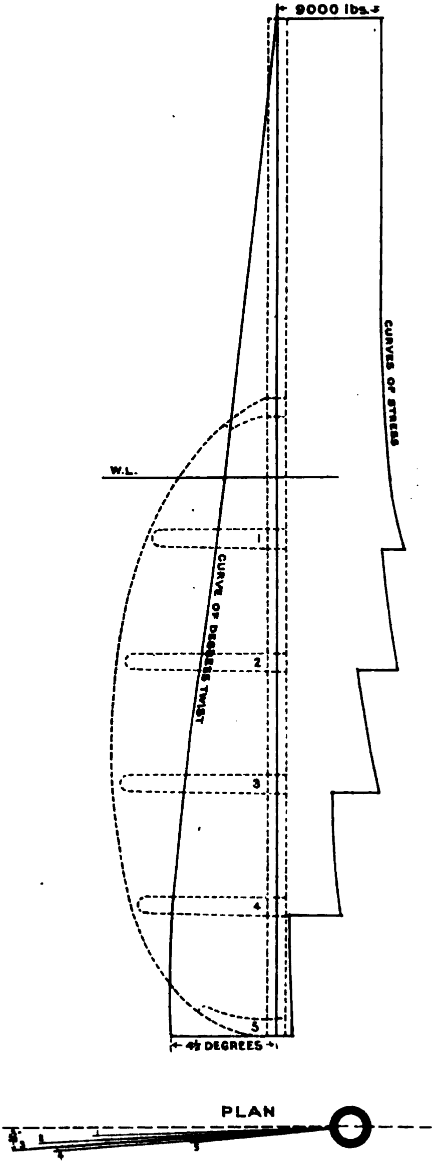

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Fig. 15.

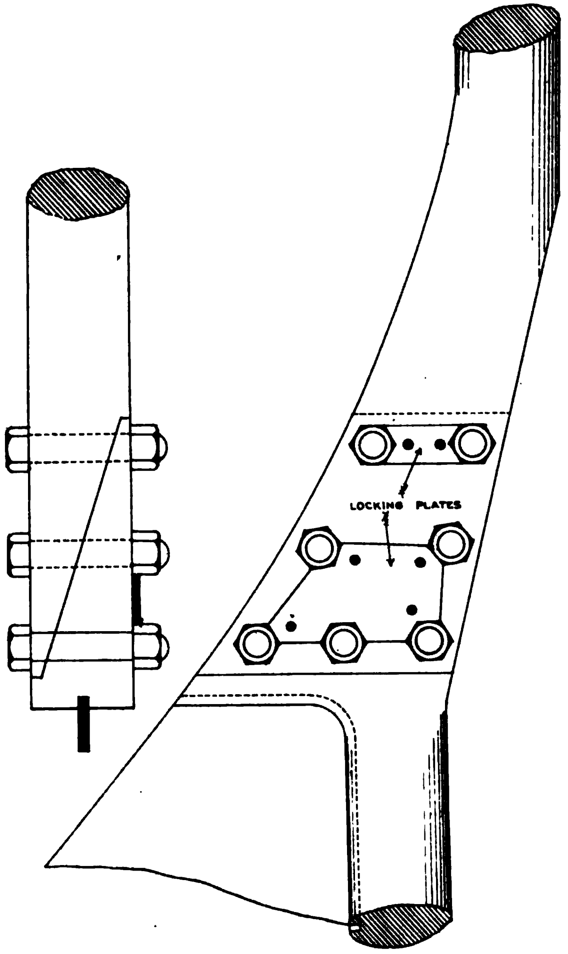

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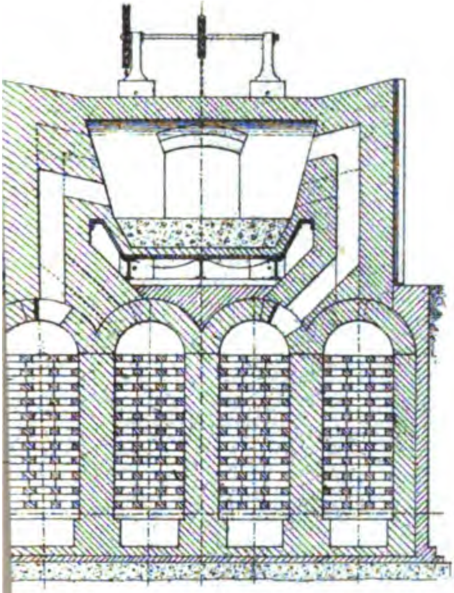
Fig. 13.



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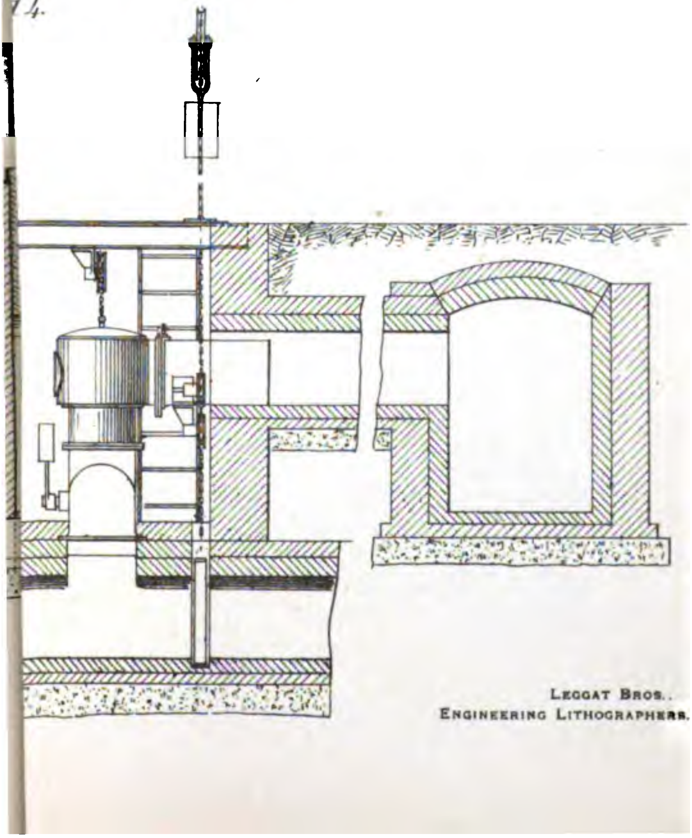

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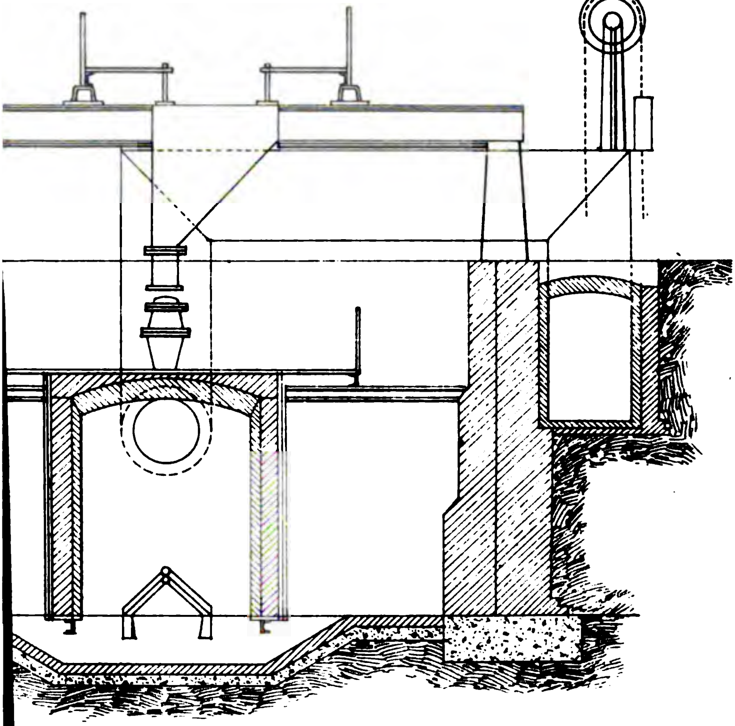
PLATE XVIII.

Fig. 17.



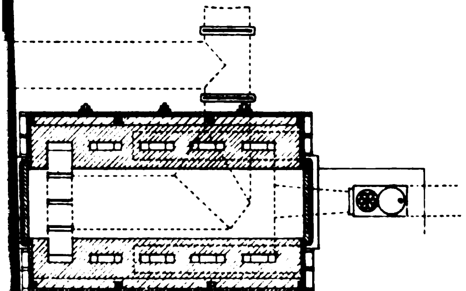


Fig. 28.

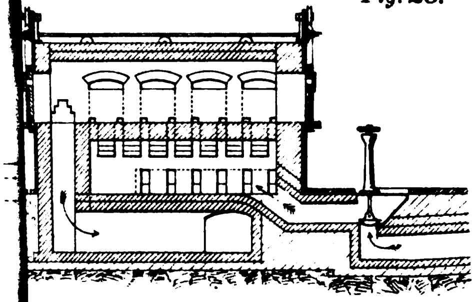


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Fig. 4.

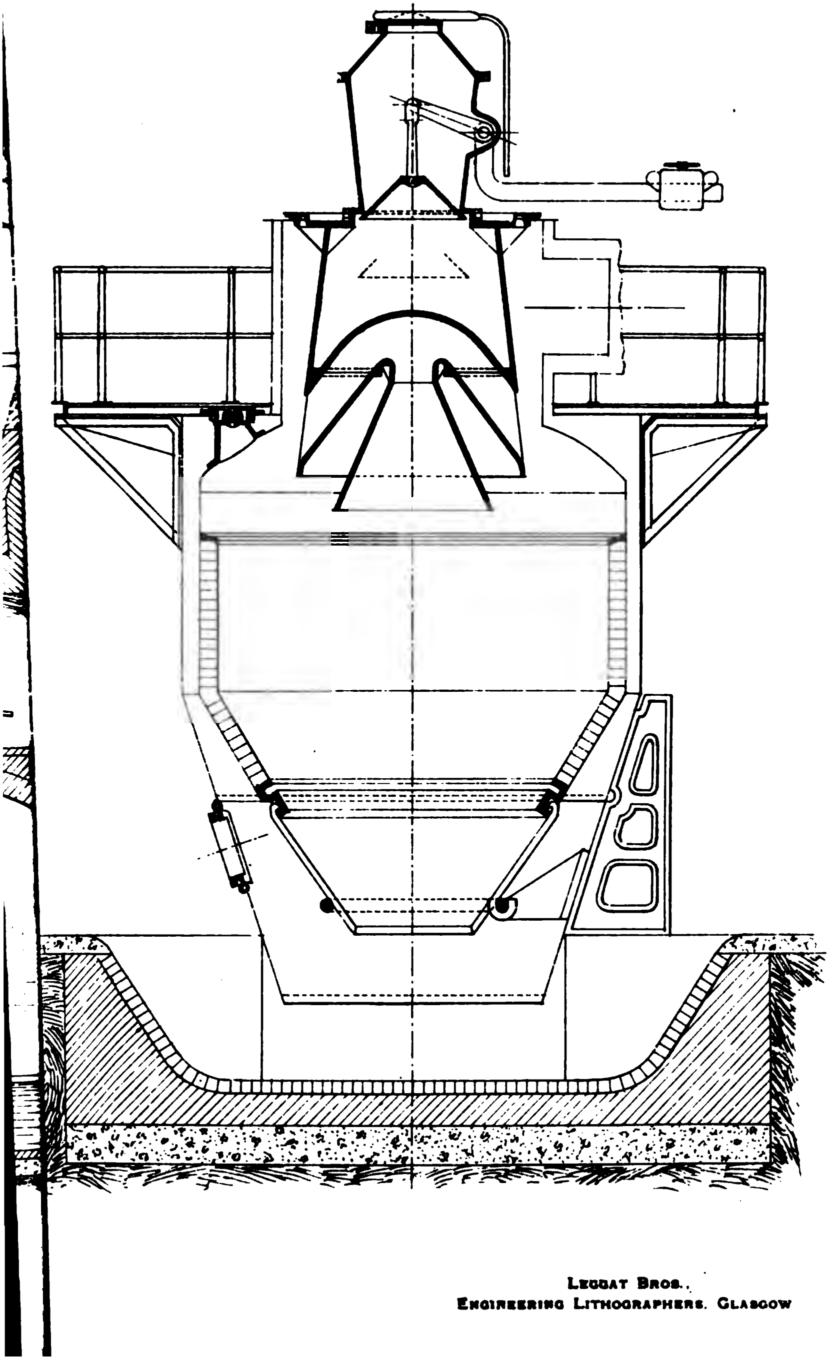

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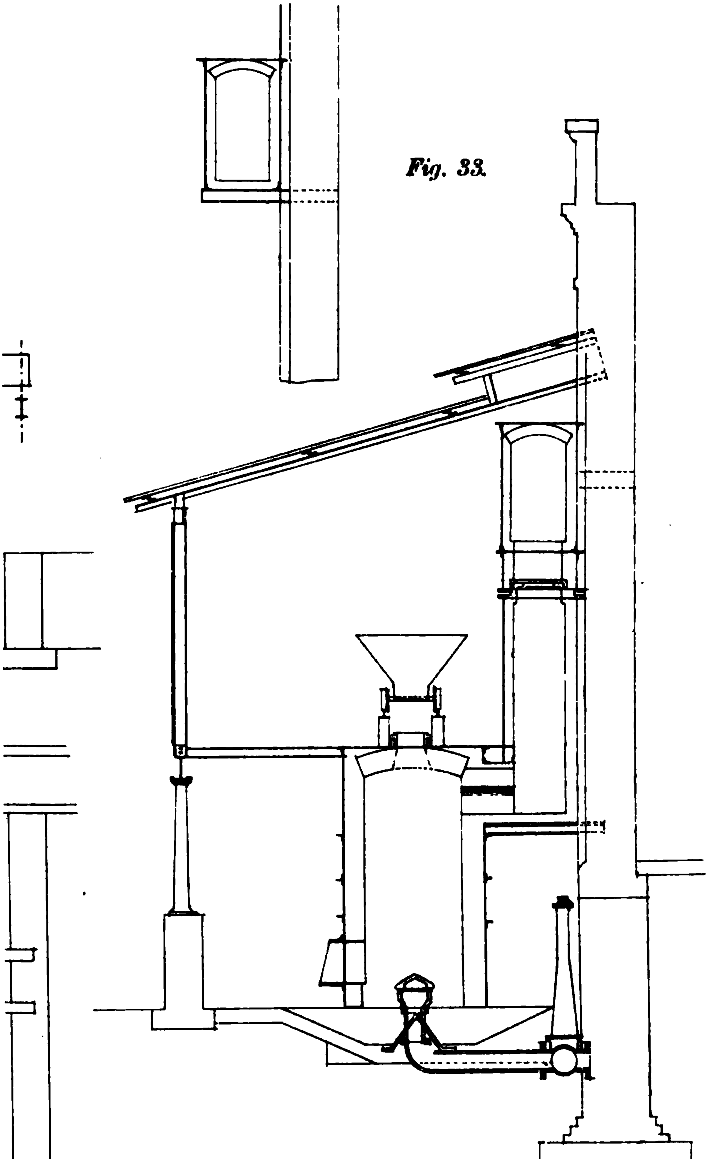
Fig. 33.



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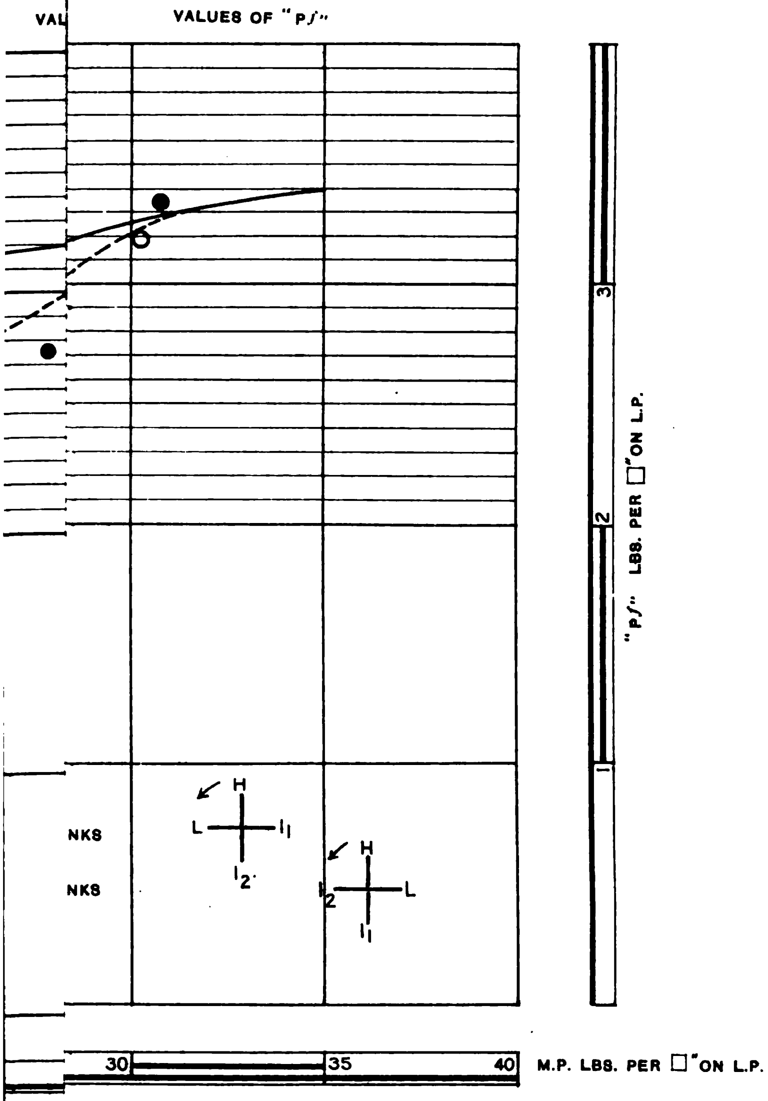
Engineering Lithographers, Glasgow.

PLATE XXIII.



Leggat Bros.,
Engineering Lithographers, Glasgow.

BY MR. E. HALL-BROWN. *PLATE XXIV.*

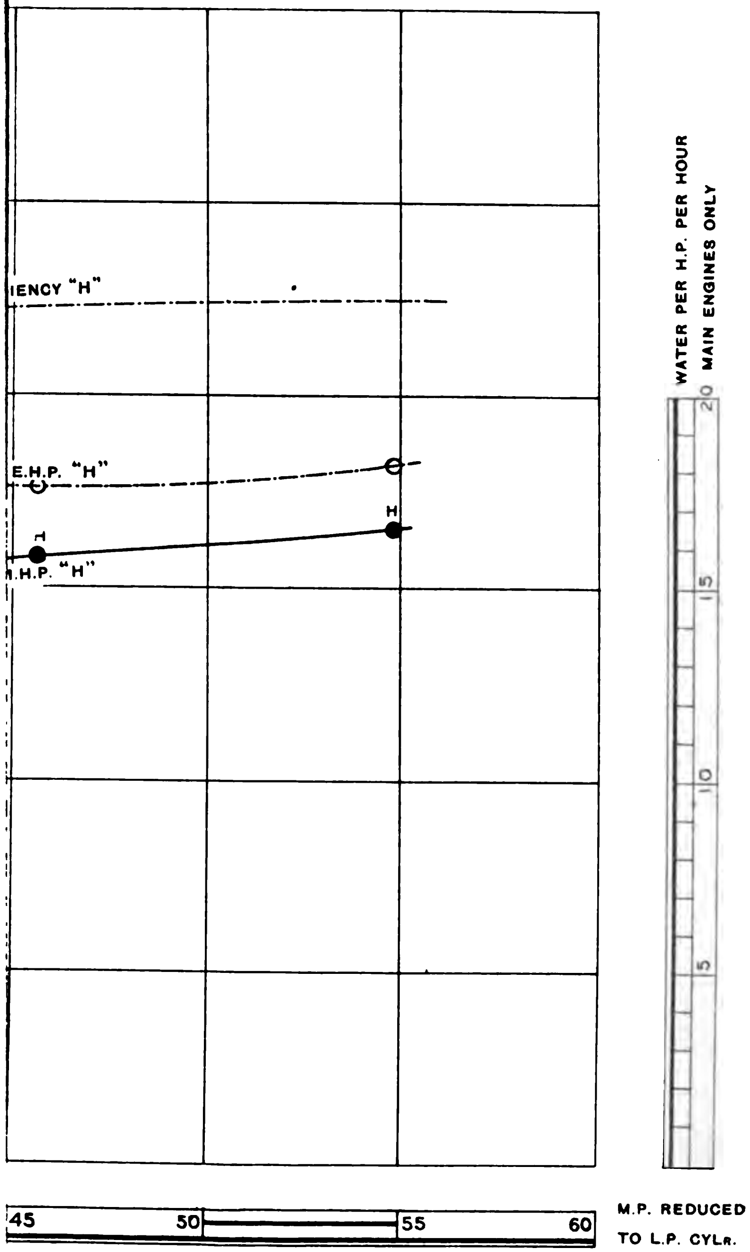


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Fig. 7.

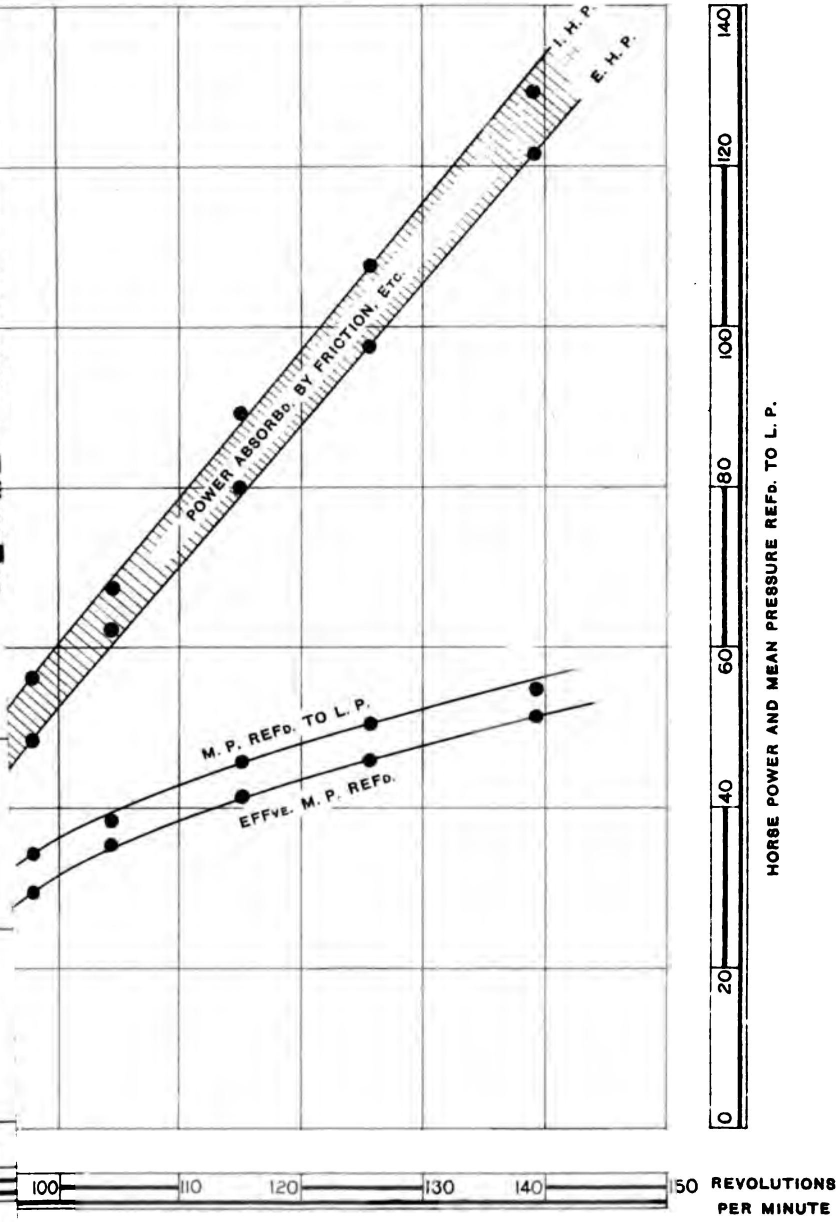

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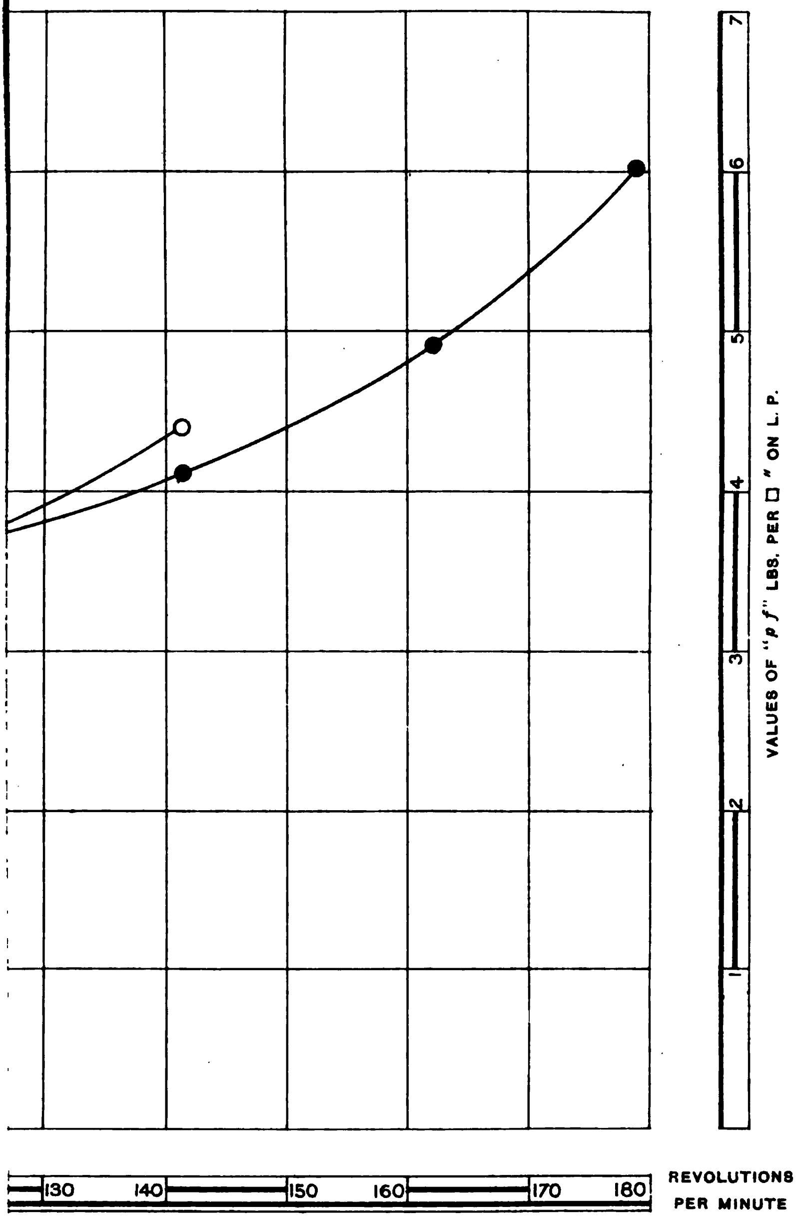
PLATE XXVI.



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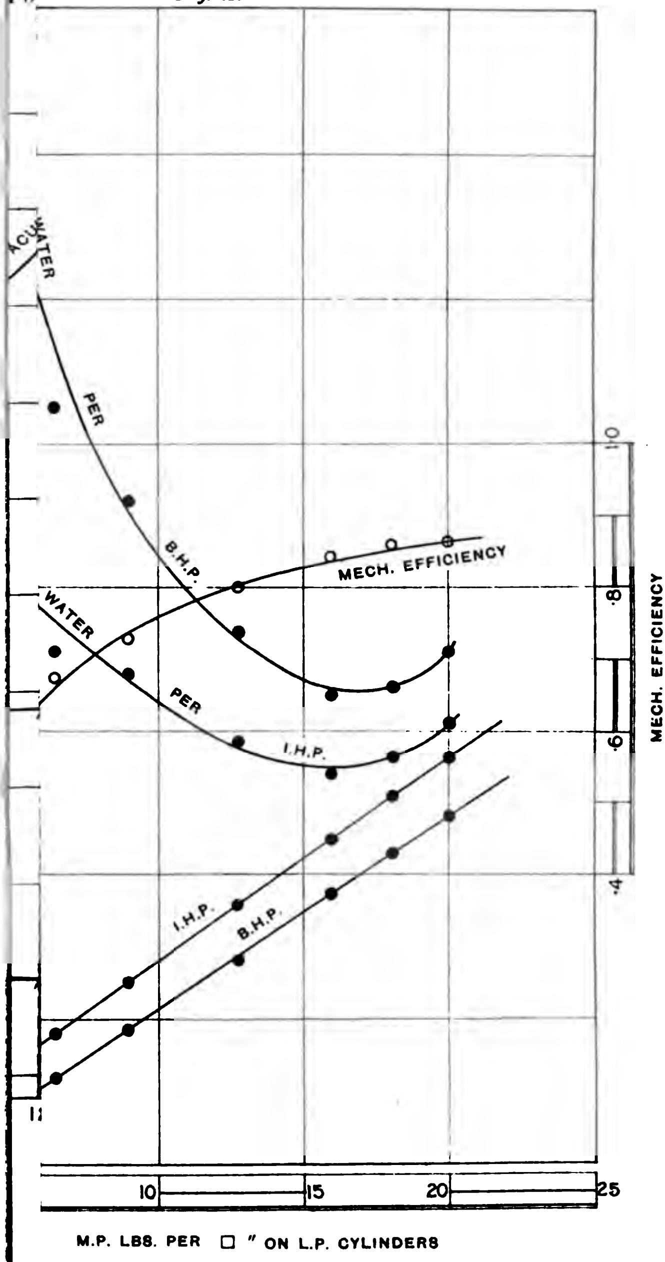
To Illustrate Mr. Andrews' Remarks.

Fig. 11.



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