

AERONAUTICAL ENGINEERING SERIES

GROUND ENGINEERS

ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT

INCLUDING THE REPAIR, OVERHAUL
AND TESTING OF MAGNETOS

("X" LICENCE)

BY

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The Air Ministry, whilst accepting no responsibility for the contents of this book, recognizes it as a textbook that should prove to be of value to intending applicants for Ground Engineers' licences

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INTRODUCTION

IN the Air Navigation Directions, Section 11c, it is laid down that "The constructor shall ensure by suitable inspection that all engines, instruments, and parts (including wiring for electrical equipment other than wireless apparatus) that are fitted into the aircraft are so installed as to function correctly, and, if wireless telegraphy or wireless telephony apparatus is fitted, that the installation of such apparatus, including bonding and screening, is not such as to prejudice the operation of the aircraft . . . the individuals responsible for such inspection shall be indicated by signatures on the inspection record. . . ."

A motorless glider is probably the only form of heavier-than-aircraft which has no electrical installation of any kind. The smaller types of light aeroplane may incorporate no electrical system beyond the ordinary engine ignition system, or they may be also equipped with electrical night flying equipment, which includes navigation lights, instrument lights, and electric landing lights or electrically ignited flares. The medium and larger types of civil passenger carrying aeroplanes will have, in addition, a wireless transmitting and receiving installation, and, possibly, wireless direction-finding equipment. They may also have such auxiliary services as cabin lighting, cockpit lighting, cooling fans, etc. On military types of aircraft we meet, in addition to the foregoing, such essentially military electrical equipment as bomb release gear, bomb fusing gear, torpedo release gear, identification lights, electrically heated clothing and guns, signalling lamps, cameras, etc. In both civil and military types of aircraft we may meet inter-connected electrical and wireless systems, i.e. where both systems draw energy from one common source.

Apart from the various electrical services referred to above, we may meet individual instruments which are electrically operated apart from any general electrical system installed on the aircraft. We have examples of these in the electrically operated engine revolution counters, electrically operated contents gauges, etc.

In discussing the electrical and wireless installations in use on aircraft, all calculations and problems in design will be carefully avoided. The primary object is to indicate to ground engineers, in broad outline, the basic principles of design, together with notes on the care and maintenance of equipment, fault localization, and repair. For these reasons a reference to the various electrical definitions and units which we shall be compelled to use is essential. There are a number of official publications dealing with various individual aspects of our subject, and in compiling this section free use has been made of the information contained in these, the principal of which are—

Air Publication 1208: *Airworthiness Handbook of Civil Aircraft.*
Inspection Instructions of the Aeronautical Inspection Directorate, Air Ministry.
Admiralty Handbook on Wireless Telegraphy.

Acknowledgment has also to be made of the courtesy and assistance received from The British Thomson-Houston Company Ltd.; Marconi Ltd.; Rotax Ltd.; Smith's Aircraft Instruments; Batteries Ltd.; The Plessey Co.; Record Electrical Co. Ltd.; Vickers Ltd., and the Edison Storage Battery Co. Ltd., in supplying information regarding their products.

One general observation remains to be made before proceeding to deal with the subject in further detail. Ground Engineers must realize that, apart from routine tests of the continuity of wiring and insulation resistance of an installation in an aircraft, their duties also include a visual examination of all the various components, instruments, and wiring comprising the various circuits, for correctness to specification requirements, drawing requirements, and standard of workmanship. In Air Publication 1208, *Airworthiness Handbook of Civil Aircraft*, is published a list of officially approved items of equipment, but the appearance of the name of any specific item of equipment in such a list does not absolve a ground engineer from the necessity for obtaining adequate documentary evidence, by way of an approved release note or equivalent means, of the correct manufacture, inspection and test of the item in question in accordance with the specification and/or drawings quoted in Air Publication 1208.

ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT

CHAPTER I

ELECTRICITY AND ELECTRIC CURRENTS

The Aether

THE aether is a universally diffused medium, which inter-penetrates all matter and extends immeasurably beyond the confines of the earth's atmosphere. It therefore occupies space, but research has not so far been able to show that it possesses weight, and for this reason it cannot be regarded as "matter." Our reasons for so confidently assuming the existence of this entirely intangible medium may be briefly summarized.

Enormous quantities of energy are radiated from the sun to the earth in the form of light and heat, and this energy travels through space which is known to be devoid of air or ordinary matter. Similarly, light and heat are radiated from incandescent lamps, although the bulbs of those lamps may have been exhausted of air and any other gas or matter. The question is, how does this energy travel across an apparently empty space? It is only reasonable to suppose that it has been "conveyed" across that space in a manner somewhat similar to the manner in which sound is conveyed from, say, an electric bell, across an intervening air space, to our ear. If we place an electric bell in a glass jar we shall find that as we exhaust the air from the jar we shall cease to hear the bell ringing, although we can see through the glass that the bell is still in operation. The reason for our ceasing to hear the bell when the air is exhausted from the jar is that we have removed the medium through which the sound waves are conveyed, viz. the air. The sun's energy must be conveyed to us either as an actual molecular movement, like the movement of individual molecules of water from the source of a river to its mouth, or as a wave motion, like the passage of sound through air. All experience and measurements go to show that light and electro-magnetic energy generally are conveyed or transmitted through space with a definite velocity, and we are led to the conclusion that all space is occupied by a medium which conveys the energy, and that this medium has properties different from those of ordinary matter. This medium is called the *aether*.

Movements of the aether are produced by the electric fields associated with electrons, and the **speed of propagation** of electro-magnetic disturbances of the aether is 186,000 miles per second.

All movements of the aether consist of electric and magnetic forces alternating in direction, and they produce a disturbance spreading outwards, which is called an electro-magnetic wave, or simply an *aether wave*. These waves produce different effects which require different methods of reception according to their frequency. The term "frequency" must not

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be confused with the "speed of propagation." The **frequency** of a wave form simply refers to the number of complete waves or cycles per unit of length (or time, since the length and time are inter-dependent) and is a widely varying factor, whereas the speed of propagation is a fixed quantity, already referred to, of 186,000 miles per second.

Perhaps the difference may be most clearly comprehended by a hypothetical illustration. Suppose it were possible for two men to stand 186,000 miles apart, and each man to be holding one end of a long rope stretched between them. If one man agitates his end of the rope in an up and down direction he will produce ripples or waves in the rope which will travel along the rope to the other end. The first man can vary the size of the waves according to the manner and speed with which he agitates the rope, i.e. he can produce waves which measure, say, 3 ft. from crest to crest, or which measure, say, 6 ft. from crest to crest. These dimensions are analogous to the wave-length of an aether wave, and the number of complete waves which can be produced in a given time is the frequency, but the speed with which the waves travel along the rope from one end to the other is the speed of propagation. If, in this illustration, a wave travelled along the rope from one man to the other in 1 sec., it would travel at the same speed as the waves in the aether. Perhaps it will not be out of place to conclude this description of the aether with a summary of the most important kinds of aether waves known. (See table on opposite page.)

The method of converting wave-length to frequency is to divide 186,000 miles by the length of one wave, which will give the number of waves in that length, i.e. the number of waves propagated per second. For converting frequency into wave-length, the rule is to divide 186,000 miles by the frequency.

In other words

$$\text{Frequency} \times \text{wave length (miles)} = 186,000.$$

It should be remembered that frequency is often referred to in terms of kilocycles,

$$\text{i.e. 1 kilocycle} = 10^3 \text{ cycles.}$$

So that 10^4 cycles is the same as 10 kilocycles.

The term "frequency" is the commonly adopted abbreviation of "frequency per second."

Electricity

The modern theory of electricity is termed the Electronic Theory. It must not be assumed that we have, as yet, any complete theory of the structure of the atom which absolutely and completely sums up all known facts concerning electricity, but the electronic theory of electricity is at present the universally accepted theory, and it is of the greatest possible help in explaining most electrical phenomena and especially in explaining the action of wireless valves. We shall have more to say on the subject under the heading of atoms and electrons.

Matter

Matter is anything which has weight and occupies space. Some kinds of matter are invisible, for example, air, hydrogen, etc. Matter is composed of innumerable separate particles, all of which, however, are spaced apart from each other. The smallest particle of matter which can exist as a separate entity is called a molecule, but this is a relatively large and very complex structure. The molecule of one substance is entirely different, both as regards composition and construction, from the molecule of

Wave-length (millimetres)	Frequency (per second)	Type of Wave	Type of Receiver
.000 000 01	3×10^{19} cycles	Gamma waves	Photographic plate
.000 063 80	4.7×10^{15} "	X rays	or
.000 1 to .000 2	3×10^{15} to 1.5×10^{15} "	Ultra-violet rays	Fluorescent screen.
.000 4	7.5×10^{14} "	Violet light	
.000 45	6.7×10^{14} "	Blue "	
.000 5	6×10^{14} "	Green "	
.000 6	5×10^{14} "	Yellow "	The eye.
.000 65	4.6×10^{14} "	Orange "	
.000 8	3.8×10^{14} "	Red "	
.001 6 to .102 4	2×10^{14} to 3×10^{13} "	Dark heat or infra-red rays	The skin.
.204 8 to 3.276 8	15×10^{11} to 0.9×10^{11} "	Unknown	Unknown.
6.553 6 mm. to 13 312 mm. and up to 30 000 metres	4.6×10^{10} to 2.2×10^7 " and up to 10^4 "	Hertz radiation W/T waves	An aerial and suitable detector circuits.

any other substance. Molecules vary considerably in size and weight, but the largest is far too small to be seen under even the most powerful microscope.

Molecules are structures which are built up from much smaller particles called **atoms**. Both the chemical and physical properties of molecules are entirely different from the chemical and physical properties of any of the atoms which go to make up those molecules, except in the case of certain substances, which are called **elements**. In the case of an element, the molecules are structures consisting of from one to five atoms of exactly similar chemical and physical properties.

Apart from elements, we have other substances called **compounds**, and in these cases the molecules are structures consisting of two or more atoms having entirely different chemical and physical properties from each other and from the molecule which they produce. Thus the molecule of the element sodium consists of a single atom of sodium, the molecule of the element oxygen consists of two similar atoms of the element oxygen, and the molecule of the element nitrogen consists of three atoms of that element, whilst the molecule of the compound water consists of two atoms of the gas hydrogen combined with one atom of the gas oxygen, and the molecule of the compound known as mica consists of 42 atoms of five different kinds (i.e. potassium, oxygen, aluminium, silicon, and hydrogen). Air is neither an element nor a compound, but is a mechanical mixture (in varying proportions) of molecules of the gaseous elements oxygen, nitrogen, argon, and certain other rare gases.

It is believed that there are only ninety-two different kinds of atoms (i.e. elements) and that all other substances are compounds, consisting of molecules constructed from varying numbers and selection of atoms of these elements. Nearly all the ninety-two elements have been identified and isolated, but four or five still remain to be discovered, although our knowledge of this subject is so exact that practically all the chemical and physical properties of the unknown elements have already been forecast with considerable confidence.

Until recent years it was believed that the atom was the final subdivision of matter, but modern physical research has now demonstrated that atoms themselves are complicated structures which probably consist of a positively charged central nucleus together with an associated number of free **electrons** or charges of negative electricity. The electrons are mainly in violent motion in elliptical orbits round the central nucleus, and these orbits are of varying and relatively large dimensions. The central nuclei are presumed to vary in size and structure in the atoms of the different elements, the nucleus of the hydrogen atom being the smallest and simplest and being identical with the positive particle or **proton**. The following figure shows the assumed structure of three typical atoms, those of hydrogen, carbon, and oxygen.

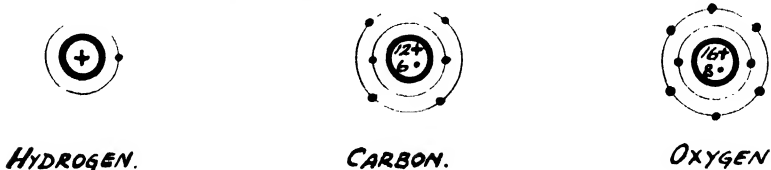


FIG. 1

It will be noted that the hydrogen atom consists of a central nucleus of one proton, together with one free associated electron; that of carbon

of a central nucleus of twelve protons and six "prisoner" electrons together with two free electrons in a small diameter orbit and four free electrons in a larger diameter orbit; that of oxygen of a central nucleus of 16 protons and 8 "prisoner" electrons, together with two free electrons in a small diameter orbit and six free electrons in a larger diameter orbit. There are strong reasons for presuming that there is a maximum of four elliptical orbits which may contain free electrons, but only the heaviest atoms will have free electrons in the outer rings. The smallest orbit is full when it has two electrons, the next when it has eight electrons, the next when it has eighteen, and the largest when it has thirty-two, but it is not necessary for any orbit to be fully occupied. The principal difference between the atom of one element and the atom of any other element is the varying number of free electrons associated with the central nucleus. In the formation of a simple compound there is a gain or loss of electrons by the constituent atoms, the outer electrons of the ions tending to assume an inert gas configuration. In common salt (NaCl), for example, the sodium (Na) loses an electron, the chlorine (Cl) gains one.

The mass of the proton in an atom of hydrogen is 1,800 times greater than the mass of an electron, and thus it will be seen that practically the whole mass of an atom is located in the central proton. In the case of the hydrogen atom there is one electron associated with the proton.

Whilst the proton is regarded as being a body charged with positive electricity, the electron is a particle of negative electricity free from association with anything in the nature of matter as we know it. It not merely has a charge, but it is a charge, and apart from its charge it has no existence. There are 6×10^{18} electrons in a coulomb, and the diameter of an electron is 3.74×10^{-13} cm. These figures are so difficult to grasp mentally that it may be mentioned that if a single drop of water were magnified up to the size of the earth its atoms would be about the size of footballs, and the comparative size of the electron to the atom is about the same as a glass bead to an Atlantic liner.

Electrons can neither be created nor destroyed, but they can be made to move from one location to another, and thus to produce electrical phenomena. From this it will be seen that electricity cannot be produced or generated. A dynamo or battery is merely a device for setting electrons in motion from one locality to another.

As already stated, an atom of an element consists of a central nucleus with a certain number of associated free electrons, and the variation in the number of associated free electrons is the principal factor in determining the chemical properties of the element.

Whilst all electrons are precisely similar to each other, all nuclei are not similar to each other, but vary in size and magnitude of positive electrical charge. Thus, the value of the positive charge of the nucleus is normally neutralized by the aggregate value of negative charges of its associated free electrons, and the atom normally exhibits no electrical properties. But if an atom has an electron too many, or an electron too few, it does exhibit electrical properties, which can be detected by the electrostatic attractive and repulsive effects thereby produced, and the atom is said to be ionized. Thus, when an electron is added to, or taken from, a previously neutral atom or molecule, the charged particle which is thus formed is called an ion. If an electron is added to a normal atom there is a surplus of negative charge, and the resulting atom is known as a negative ion. The superfluous electron may move from a negative ion to a positive ion (i.e. an atom deficient of one electron) to produce two neutral atoms. It should be noted that the movement of

such electrons is away from the negative ion and towards the positive ion, i.e. the movement of electron currents is in the opposite direction from the popular assumption that credits "electricity" with moving from the "positive pole" to the "negative pole," an assumption dating from the time when the structure of the atom was not understood. Since this assumption, however, is still so universal outside the laboratory, and since its use is not likely to involve us in any difficulties, it will be adhered to in this volume, except where it becomes essential to draw special attention to the actual direction of flow of an electron current.

The movement of electrons between two points is normally referred to as an electric current, but a flow of electrons is more easily produced in some substances than in others. If it is a comparatively easy matter to produce a flow of electrons in a substance, that substance is regarded as being a good conductor, whereas a substance whose electrons offer considerable resistance to movement is regarded as being a bad conductor. Thus there is no definite line of demarcation between good conductors and bad conductors, since a flow of electrons can be produced in even a bad conductor if the electric field is sufficiently strong. The only really good conductors of electricity are the various metals, and the atoms of these substances will readily part with an electron under the slightest provocation. Even when there is a total absence of any electric force these electrons will be moving about quite freely, a regular interchange of electrons to and from the various atoms constantly taking place. But, because these electrons are moving aimlessly in all directions, there will be no resulting current. It is only when an electric force is applied to coerce all these electrons to move in one common direction that we have a current of electrons, or, more familiarly, a current of electricity. The individual electrons will not travel the whole way round a circuit. They will only travel to nearby atoms with which they will unite, but other electrons will instantly be liberated from those atoms

Good Conductors	Partial Conductors	Bad Conductors
Silver (annealed) Copper (annealed) Copper (hard drawn) Silver (hard drawn) Gold Aluminium Zinc Platinum Iron Nickel Tin Lead German Silver Platinoid Manganin Mercury Charcoal Graphite Acids Metallic salts Well-water (impure) The body	Cotton Wood Stone Marble Paper Ivory	Oils Porcelain Wool Silk Sealing-wax Sulphur Resin Gutta-percha India-rubber Shellac Vulcanite Mica Paraffin wax Glass Dry air

to start their travels in the same direction as the first ones. Unless the current is flowing in a very good conductor, this interchange of electrons will not be taking place in all the atoms, but only in some of them. In fact, the proportion of free electrons to the total number of atoms is a measure of the conductivity of the medium, as well as of the magnitude of the current which is flowing.

The table on page 6 gives a list of some ordinary substances arranged in descending order of conductivity.

Before proceeding to deal with electrical units it is well to point out that there are two principal types of electric currents, viz. conduction currents and convection currents. **Conduction currents** are those currents which flow in a closed circuit consisting of a source of electric force (i.e. E.M.F., or electromotive force) and a continuous conductor. **Convection currents** are those which arise from the ionization of some medium in the circuit, e.g. between filament and anode of a transmitting valve, etc.

CHAPTER II

ELECTRICAL UNITS

HAVING now dealt in a general way with the nature of electricity and electric currents, we may proceed to define the various units which are used to measure electricity, electric currents, and the electrical properties of the various apparatus we shall be concerned with later on. It will be well to point out at the beginning that the various practical electrical units are based on what are known as C.G.S. units. The latter are the units used by scientists and will not directly concern us here. The initials stand for centimetre-gramme-second. The commonest practical units are the volt, ampere, and ohm, and we will deal with these first, afterwards proceeding to the less common ones, like the henry, farad, etc.

The force which moves, or tends to move, electrons in a definite direction is termed an **electromotive force**, or E.M.F., and its unit is the **volt**. For an electron stream to move at all it must move from a region of comparatively high pressure to a region of comparatively low pressure, i.e. there must be a difference of pressure, or **difference of potential**, between the two ends, and the greater this difference of potential the greater is the E.M.F. or voltage tending to move the electron stream. To produce a voltage, or E.M.F., therefore, we must create a difference of potential. In hydraulics, a difference of water level corresponds to our difference of potential, and the water pressure in a connecting pipe is the equivalent of our E.M.F. or voltage. As a greater pressure is necessary to force a given amount of water through a small pipe in a given time than is necessary to force the same amount of water through a larger pipe in the same time, so a greater E.M.F. or voltage is necessary to force a given amount of electricity through a small wire in a given time than is necessary to force the same amount of electricity through a larger wire in the same time. So we see that "potential" is analogous to "level," "difference of potential" to "difference of level," and "E.M.F." or "volts" to "pressure" or "lbs. per sq. inch." The volt, which is the practical unit of electrical pressure, is the E.M.F. or pressure necessary to force a current of 1 ampere through a resistance of 1 ohm. There are three different ways in which an E.M.F. may be produced, viz. (a) by immersing two dissimilar metals, or other substances, in certain liquids, e.g. acids of primary and secondary cells; (b) by heating the junction of two dissimilar metals, i.e. thermo couples; and (c) by cutting a conductor in a certain manner by magnetic lines of force, e.g. dynamo, alternator, transformer.

Having produced a current of electricity, its rate of flow is measured in **amperes**. It is to be specially noted that this unit is a measurement of "rate of flow" and not a measurement of "quantity passed." In hydraulics it is analogous to "gallons per minute," and not simply to "gallons." An ampere is a rate of flow of one coulomb per second, a **coulomb**, which is analogous to "gallon," being 6×10^{18} electrons. From this it will be noted that a current of electricity of 1 ampere is equivalent to a flow of 6×10^{18} electrons per second.

The next most important unit is the unit of resistance, which is called the **ohm**. It is analogous to the friction which is encountered by all moving bodies, and it represents the property of all matter of opposing the free passage of electrons through it. Just as the friction between two bodies

in relative motion will result in the conversion of a certain proportion of the energy of motion into heat, so the resistance of a body to the passage of a current of electricity will result in the conversion of a certain proportion of the energy of the moving electrons into heat. The less the willingness with which molecules receive and release electrons, the greater is the shock given to the atom, and consequently to the molecule, the greater the heat generated. The standard definition of the ohm is "the resistance of a column of mercury 106.3 cm. long, 1 sq. mm. in cross-section, and of a mass of 14.4521 grm. at a temperature of 0° C." A megohm is a million ohms, and a microhm is a millionth part of an ohm. When measuring "insulation resistance," say with a Bridge Megger, it is the passage of a very minute current through the substance that operates the instrument.

The "specific resistance" of a conductor is the resistance between opposite faces of a cm. cube, of that substance. Tables of the specific resistance of various conducting substances are made out usually at 0° C. since resistance alters with a change of temperature. Some examples of specific resistances per cm. cube are approx.—

Insulating rubber	=	1,400 × 10 ¹⁸	microhms
Distilled water	=	7 × 10 ¹⁸	"
Mica	=	4 × 10 ¹⁸	"
Mercury	=	94	"
Platinum	=	11	"
Copper	=	1.6	"

Having now considered the three primary units concerned when a current of electricity is caused to flow in a circuit, we come to the fundamental law which connects those units. This is known as **Ohm's law** and states that the "current is directly proportional to the voltage, and inversely proportional to the resistance" or, more graphically,

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad \text{or} \quad C = \frac{E}{R}$$

This equation may, of course, by simple arithmetical transposition, be expressed as

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

or as

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

It is very important to note, however, that this law only holds good when we are dealing with steady unidirectional currents. When we come to deal with alternating, or oscillatory currents, there are other factors to be considered which will modify the relationship expressed in these equations.

The practical application of Ohm's law to the solution of the problems met during the layout of an installation may be briefly discussed. By far the commonest problem is that dealing with determination of the size of cable required for a particular purpose. To take the simplest form of circuit, i.e. that consisting of a source of potential, such as a battery, in association with a "load," say a lamp, and the necessary connecting wires, we have—

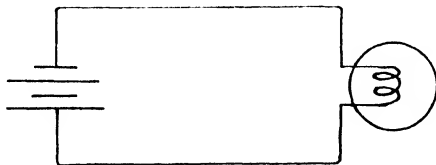


FIG. 2

In this case the resistance of the circuit is the sum of the individual resistances of the lamp, the wires, and the internal resistance of the battery. These factors being known, together with the voltage of the battery, it is a perfectly simple calculation from the formula $C = \frac{E}{R}$ to determine the value of the current which will flow, and hence the suitability of the wires in use. If, now, we consider the same circuit modified to supply two lamps, we are immediately faced with two alternatives, viz. (a) with the lamps wired in series, and (b) with the lamps wired in parallel. In the case of (a) the circuit becomes

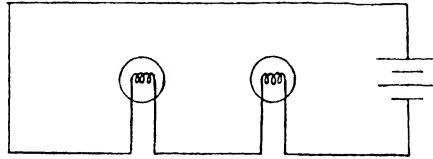


FIG. 3

and the problem is precisely the same as before, i.e. the resistance of the circuit is the sum of the individual resistances of the lamps, the wires, and the internal resistance of the battery. In the case of (b), however, the circuit becomes



FIG. 4

and the total resistance is reduced. Where we have a number of resistances in parallel the rule for obtaining the resultant resistance is given by the formula

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} \text{ etc.}$$

Returning to our diagram, our method of procedure will be to find the resultant resistance of the lamps by means of the above formula, and to this result add the resistance of the wires and the internal resistance of the battery. Perhaps the reason for this procedure will be clearer if we regard the lamps as a compound resistance which is in series with the resistances of the wires and battery.

Where resistances are joined in series there will be a voltage drop at each resistance, and the current flowing is cut down accordingly. The total voltage drop is given by the formula

$$\text{Volts} = CR_1 + CR_2 + CR_3, \text{ etc.}$$

Before leaving the three primary units we should mention one other unit, the **Watt**, which is a derivative of two of them. When we have a current of electricity flowing in a circuit that current has two fundamental characteristics, viz. its voltage and its rate of flow, or amperage. It should be noted that the rate at which that current is capable of doing work will vary in direct proportion to both the voltage and the amperage. The

unit of power, or the rate of doing work, or the rate of producing energy, is the watt, and we therefore have

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$

and the relationship of the watt to certain other fundamental units is—

$$\begin{aligned} 746 \text{ watts} &= 1 \text{ horse-power} \\ &= 550 \text{ ft.-lb. per second} \\ &= 33,000 \text{ ft.-lb. per minute} \\ 1 \text{ watt} &= 1 \text{ Joule per sec.} \\ &= .7373 \text{ ft.-lb.} \\ &= 10^7 \text{ ergs} \end{aligned}$$

Returning for a moment to the formula

$$\text{Watts} = \text{Volts} \times \text{Amperes} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and remembering from Ohm's law that

$$\begin{aligned} \text{Voltage} &= \text{Current} \times \text{Resistance} \\ \text{and Current} &= \frac{\text{Voltage}}{\text{Resistance}} \end{aligned}$$

we can obtain, by simple substitution in (1)

$$\begin{aligned} \text{Watts} &= (\text{Current} \times \text{Resistance}) \times \text{Current} \\ &= C^2 R \quad . \quad . \quad . \quad . \quad . \quad (2) \end{aligned}$$

$$\begin{aligned} \text{and Watts} &= \text{Volts} \times \frac{\text{Voltage}}{\text{Resistance}} \\ &= \frac{V^2}{R} \quad . \quad . \quad . \quad . \quad . \quad (3) \end{aligned}$$

We thus have three equations for calculating electrical power in watts, from a knowledge of any two of the three units—volts, amperes, and resistance. A larger and more commonly used unit of power is the kilowatt = 1,000 watts. The Board of Trade unit is the kilowatt-hour, which is the energy expended by 1,000 watts acting for one hour.

CHAPTER III

MAGNETISM

WE have already referred to the mutual attraction between protons and electrons, which, under favourable circumstances, will unite to produce a neutral atom. It is a universal law of nature that similarly charged particles will repel each other. The phenomenon is explained by saying that the particles have associated with them an electric field, or state of strain in the aether, which is strongest nearest to the particle containing the charge and diminishing with distance. Thus, when a current of electrons is flowing along a conductor, the electric fields due to each electron set up a sort of swirl in the aether, much in the same way that a body moving on the surface of water will produce a swirl in the water. The swirl produced in the aether by the movement of electrons and their associated electric fields is termed a **magnetic field**.

Thus every conductor carrying a current of electrons is surrounded by a magnetic field, which takes the form of a band of concentric circles round the conductor, and both inside and outside it. The direction of rotation of the magnetic swirl depends on the direction of flow of the electron current. If we could hold a wire end on to our line of sight, and an electron stream in the wire was flowing towards our eye, then the positive direction of rotation of the magnetic swirl round the wire would be in a counter-clockwise direction, or, stated in another way, if a straight wire is held in the right hand with the thumb pointing along the wire in the direction of flow of the current then the bent fingers holding the wire indicate the direction of swirl round the wire of the magnetic flux. The whole of the magnetic field is filled with lines of force, i.e. the whole of the surrounding aether is in a state of strain, and there is a magnetic force at any point in the field. In the absence of any outside influence, the circles of magnetic lines of force are true circles concentric with the wire, but these circles may be distorted and drawn to one side by the influence of neighbouring magnetic fields.

When we come to consider the application of this phenomenon to a **solenoid** of wire, we find that the total resultant magnetic field has assumed the shape shown in Fig. 5.

That is, we shall have a strong and concentrated magnetic field within the solenoid, and a relatively weak, attenuated field, outside it. Such a magnetic field will behave in a manner similar to a magnetized bar of steel. We shall have a north pole at the end of the coil from which the lines of force emerge, and a south pole at the end where they enter.

Here, again, we have a simple rule for memorizing the relationship of polarity to direction of current flow, which is as follows: if, when looking at one end of the coil, the current is flowing in a clockwise direction, then the end of the coil which we are looking at is a south pole.

The strength of a magnetic field produced in this manner is directly proportional to the **magneto motive force** applied, which is proportional to the number of turns of wire, and to the current strength, i.e. to the amperes \times turns. The magnetic lines of force in a solenoid produce what is usually referred to simply as a **magnetic flux**, and the density of a magnetic flux is measured in terms of so many lines of force per sq. cm. of cross-sectional area.

The presence of iron, or other magnetic material, within the magnetic field, will result in a further distortion and concentration of lines of force through the material, since iron is by several hundred times a better conductor of magnetic lines of force than is air. In producing a flux in a magnetic circuit, there is a certain opposition to be overcome by the applied magneto motive force (M.M.F.), and this opposition is termed the **reluctance** of the circuit. The reluctance, or magnetic resistance, of a piece of material is proportional to its length, cross-section, and permeability, and is thus seen to be analogous to the ohmic resistance of a wire to the passage of an

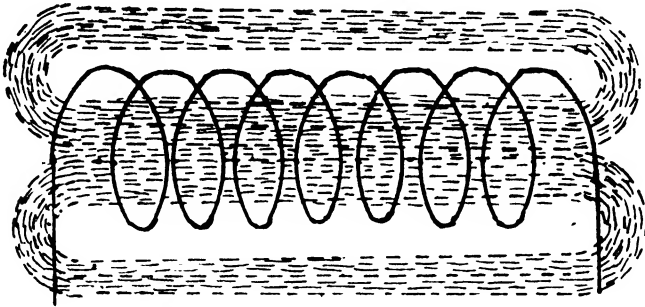


FIG. 5

electric current. It will be noted that the relationship between these terms, viz. $\text{Flux} = \frac{\text{M.M.F.}}{\text{Reluctance}}$, is identical with Ohm's law for electrical circuits, viz. $\text{Current} = \frac{\text{E.M.F.}}{\text{Resistance}}$.

The existence and shape of a magnetic field may be rendered visible by a very simple and beautiful experiment (Figs. 6 and 7). Take an ordinary sheet of glass and support it near its edges in a horizontal plane. On the upper surface of the glass sprinkle evenly a thin layer of iron filings. Now bring a solenoid of wire close up to the underneath surface of the glass. On sending a current through the wire it will be observed that the iron filings will move on the plate, and arrange themselves to form a pattern indicating the direction of flow of the magnetic lines of force. The exact pattern formed will, of course, depend on the disposition of the solenoid relative to the glass. The movement of the filings may be assisted by gently tapping the glass with a pencil.

We have already seen that electrons have associated with them an electric field, and that when an electron is in motion, the movement of its electric field produces a corresponding magnetic field. This statement is equally true whether we are speaking of (a) the movement of electrons from atom to atom along a wire, or of (b) the movement of an electron in its orbit round the proton or nucleus of an atom. In the case of (a) we have already referred to the production of the magnetic field round a wire carrying a stream of electrons. In the case of (b) it will be seen that the resulting magnetic field will be associated only with the single atom under consideration. Thus we are forced to the conclusion that each atom has in itself the properties of a tiny magnet. Why, then, does not a mass, representing a large number of atoms, exhibit always the properties of a magnet? Considering only the case of iron, it is assumed that each atom is a magnet with a north and a south pole, and that in a mass of iron all

these tiny magnets are normally so thoroughly mixed up, the south pole of one atom lying towards the north pole of the next atom, that all their tiny fields are mutually neutralized, and the whole mass thus exhibits no magnetic properties.

In its natural state, iron and the ores of iron normally exhibit no magnetic qualities. In certain localities, however, deposits of iron ore may be found which possess natural magnetic qualities, and these will be retained by the ore even after quarrying. Such an ore is Magnetite (Fe_3O_4), which is found in Spain, Sweden, North America, Asia Minor, etc., although not always in a magnetized condition. The reasons for the phenomenon are obscure, but are probably associated with the disposition of the ore in the ground, in relation to the magnetic lines of force of the earth, which itself behaves as a large but weak magnet.

The magnetic properties of iron or iron ores are destroyed by great heat, such as is encountered in a smelting furnace, although a much lower degree of heat may be effective. The magnetic properties may be restored by bringing the specimen under the influence of a powerful magnetic field, such as is produced by the passage of a strong electric current round a solenoid of wire, or by a strong permanent magnet of steel. A bar of steel, if held so that its axis lies along the natural lines of force of the earth, and tapped with a hammer, will acquire magnetic properties to a certain degree. Conversely, a bar magnet held across the natural lines of force of the earth, and tapped with a hammer, will lose some, or all, of its magnetic properties. Several cases have been known of the steel structure of an aircraft becoming powerfully magnetized due to the machine having encountered a lightning discharge whilst in flight. Incidentally, one of the effects of such an occurrence is to render the aircraft's compass totally ineffective as a navigating device.

When a bar of iron is magnetized it is believed that the constituent atoms have become arranged orderly, so that all the south poles point towards one end of the bar and all the north poles towards the other, so that the resulting magnetism of the bar is the summation of all the individual magnetic fields of those constituent atoms which have responded to the "lining up" process. Although iron will readily become strongly magnetized, it will just as readily lose its magnetic properties when the magnetizing force is removed. Yet there will generally be a certain small amount of residual magnetism left after the magnetizing force is removed, depending principally on the quality and purity of the iron.

The following list shows the relative susceptibilities of different substances to magnetic fields—

Oxygen	17.5	Water	96.6
Air	3.4	Sulphur	118.0
Hydrogen	0.1	Bismuth	1967.0
Zinc	74.6		

It should be noted that magnetic substances exhibit a certain disinclination to become magnetized or demagnetized, i.e. the effect produced will lag slightly behind the cause, and this "lagging behind" property is known as **hysteresis**. The purest soft iron (i.e. Swedish) offers the least resistance to magnetic lines of force, i.e. is the most **permeable**, and it also exhibits the lowest hysteresis effects. Steel, on the other hand, is not nearly so permeable, and exhibits much greater hysteresis effects. For these reasons, soft or well annealed iron is suitable for electro-magnets, transformers, and other forms of apparatus which depend for their operation on rapid reversals of magnetic properties. Similarly, steel is suitable for machines requiring a strong and permanent magnetization. The

presence of certain other metals, such as cobalt, tungsten, nickel, etc., in steel greatly enhances the strength and permanence of a magnet produced from such material.

If two magnetized pieces of steel are placed with the north pole of one

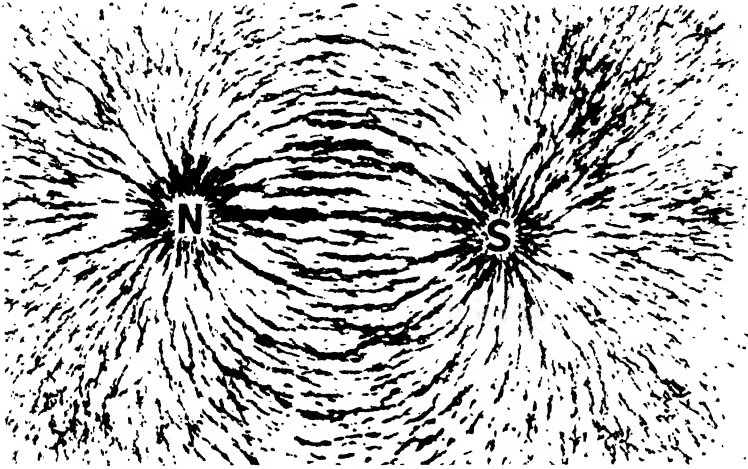


FIG. 6

near the south pole of the other, a strong attractive force between the two will be observed (Fig. 6). Similarly, a strong repulsive effect will be observed when the north pole of one magnet is brought into proximity with the north pole of the other (Fig. 7). From this phenomenon is evolved the law that "like poles repel and unlike poles attract."

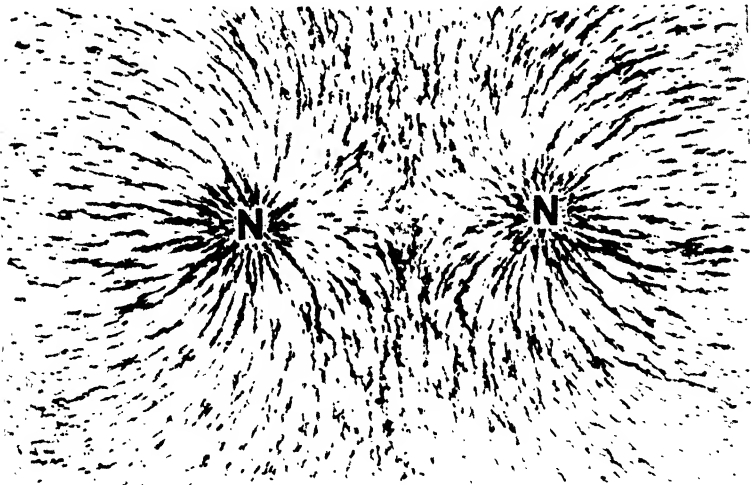


FIG. 7

Whilst iron is strongly attracted by a magnet, nickel and cobalt are also attracted to a feeble extent, and many other substances to a very much lesser extent. Such substances are referred to as having Paramagnetic qualities. Paramagnetism of atoms or ions is an indication of a lack of symmetry—and so of magnetic balance—of the electron orbits.

Copper and bismuth, on the other hand, are feebly repelled by a magnet, and a number of other substances also exhibit the same property, known as Diamagnetism, to a very feeble extent.

Whilst paramagnetism is a particular property of electronic systems possessing unbalanced electronic orbits capable of changing their orientation, diamagnetism is common to all matter.

We have already referred to the fact that when a current of electricity flows along a wire, concentric circles of magnetic lines of force surround the wire. If the current of electricity in the wire is suddenly changed in value, we shall find that there will be a corresponding change in the value of the magnetic field which surrounds the wire. Conversely, if the magnetic field surrounding a wire is suddenly changed in value, there will be a corresponding change in the value of the current flowing in the wire. This reciprocal reaction between magnetic fields surrounding wire and the current flowing in a wire is the basis of design of many forms of electrical machinery, such as dynamos, motors, alternators, transformers, etc., and we will examine this phenomenon a little more closely.

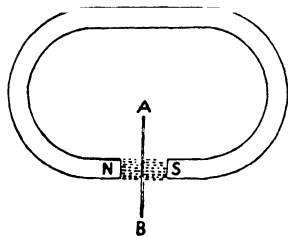


FIG. 8

Suppose that *AB* in Fig. 8 represents a wire lying in the magnetic field between the north and south poles of a horseshoe magnet. If this wire is moved horizontally backwards and forwards between the poles there will be no effect on the wire because it is "sliding" along the lines of force. It is not cutting through them, and the magnetic field round the

wire is not changing in value. If, however, the wire were to be raised and lowered in a plane vertical to the surface of the paper, it would cut through the lines of force, and this would result in an E.M.F. being produced in the wire, i.e. one end of the wire would be raised to a higher potential than the other end, and a current of electricity would flow in the wire if the circuit were completed. Elaborating this process a little further, we will suppose that the poles of our horseshoe magnet are opened further apart, and a separate bar magnet, or piece of iron, introduced between the poles, but not touching them, so that two gaps are produced, one at each end of the bar, with a strong magnetic field in each gap, and our length of wire is now replaced by a loop of wire *AB* capable of being rotated about the axis *CD* (see Fig. 9). It will now be noted that when this loop of wire is rotated there are two sections of the loop which will cut through lines of force as they pass the poles of the magnet, and these sections are connected together at one side, and the ends brought out at the other. The rotary motion of such a loop of wire through the magnetic fields could be maintained indefinitely, and the two open ends would supply an E.M.F. which could be utilized to cause current to flow in an external circuit. Such is the basic design of the dynamo and alternator. The E.M.F. produced in this case would not be a steady E.M.F., but would rise and fall in value as the limbs of the loop approached and receded from the magnetic fields, and would change in polarity as the limbs of the loop passed from one magnetic field to the other, so that the resultant E.M.F. would be an

alternating E.M.F., rising from zero to a maximum value in one direction, then falling again to zero and rising to a maximum value in the opposite direction, and the resultant E.M.F. would be the sum of the E.M.F.s produced in the two limbs of the loop.

In practice, of course, this arrangement is elaborated by increasing the number of turns of wire in the loop, increasing the number of loops and increasing the number of poles. The E.M.F. produced from such machines may, if desired, be "commuted," or rendered unidirectional, by bringing the ends of the loop to a commutator fixed to the shaft, the external circuit being connected to this by means of fixed brushes which rub on its surface as it rotates. The brushes make contact with each loop, through appropriate sectors of the commutator, only during that part of the revolution during which the loop is cutting the maximum number of lines of force, passing then to the next following loop connections. The E.M.F. produced in this manner is directly proportional to the rate of cutting lines of force, and it will be at once apparent that this will be affected by (a) speed of rotation; (b) strength of field, i.e. number of lines of force per unit area; (c) length of "active" conductor, i.e. length of conductor actually cutting lines of force, and neglecting length of dead end connections. The direction of flow of the resultant current may be most conveniently remembered by **Fleming's rule**, which is shown in Fig. 10.

Using the right hand, and holding the thumb and first two fingers so that each is perpendicular to the plane containing the other two, the three directions are given by the rule—

Thumb shows direction of motion of conductor.

First finger shows direction of lines of force.

Second finger shows direction of E.M.F.

In general, it is true to say that a machine designed to produce an E.M.F. by the application of mechanical force to rotate conductors in a magnetic field is capable of the reverse function, i.e. it will produce mechanical force when an E.M.F. is applied to its conductors; thus a dynamo is capable of operating as a motor, and *vice versa*. In certain cases, peculiarities of design will, however, defeat this object and the machine will only operate to the end for which it has been designed.

Mechanical force is required to move a conductor generating an E.M.F. and a current through a magnetic field, because the current flowing through the conductor sets up a flux around it, which reacts on the flux which is being cut, in such a manner as to oppose the motion of the conductor. This fact is expressed in **Lenz's law** which states that "in a case of mutual motion of circuits, or circuits and magnets, the induced effects will always be such as to oppose the motion."

We have referred to the method of producing an induced E.M.F. by means of a stationary magnetic flux and a moving conductor, but similar results may also be obtained by means of (a) a moving flux and a stationary conductor; (b) a variable flux and a stationary conductor; (c) a variable flux and a moving conductor.

We must now consider the case where a conductor is cut by its own lines of force, i.e. when the lines of force associated with its current vary in number due to the current changing its strength, when an E.M.F. will

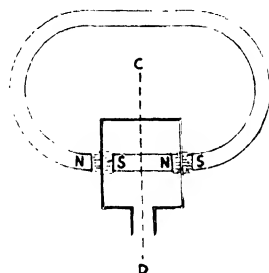


Fig. 9

be induced in the conductor. This can only occur, of course, when the current is either increasing or decreasing in value.

When we start a current in a wire, the current produces a field, which reacts upon the current, by setting up an opposing E.M.F. which delays its growth, the result being that it takes time to cause a current to reach its full value. Similarly, when the current is switched off, the magnetic field is destroyed, and an **induced current** in the same direction as the one cut off is established. These effects are known as **self-induction**. We know that if we apply a steady pull to a heavy body, say a garden roller, we do not at once produce in it the full velocity due to that pull. Time is required to get up speed. Moreover, when the speed has been acquired, a reversed force will not at once bring the heavy body to rest, and time is again required to destroy the motion. This is due to the inertia of the garden

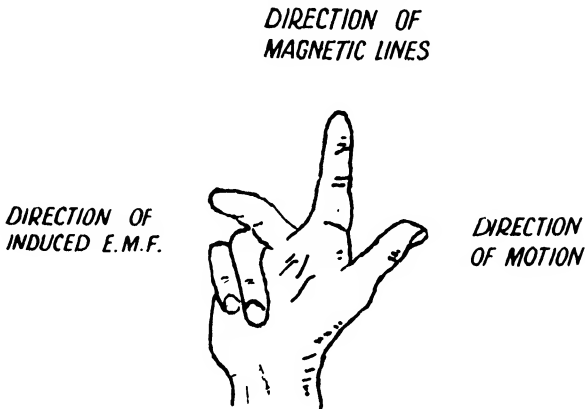


Fig. 10 .

roller and there is an exactly similar inertia effect in connection with conducting circuits, this effect being known as the Inductance of the circuit. As a consequence of these facts, it is found that when we switch a current on, no spark is observed, but when a current is switched off a heavy spark may be obtained at the point of break, this being due to the storage of energy in the magnetic field, which, on collapse, produces the so-called extra current in the same direction as the one switched off. The magnitude of this extra current will vary with the strength of the magnetic field which is broken down. Thus, a plain conductor will have associated with it a comparatively weak magnetic field, which can only produce a weak "extra current" on breakdown, but a circuit containing coiled conductors (solenoid) will have a much stronger magnetic field, which again will be very greatly increased where an iron core is employed, and the extra current at breakdown of such a field will be very considerable, often largely exceeding in value that of the original steady current.

The diagrams shown in Fig. 11 are arranged from left to right in order of their inductance, from nil on the left to maximum on the right. The foregoing explanation will supply the reasons for the provision of special switch gear, etc., in circuits to transformers, motors, etc.

Fig. 11A illustrates a conductor doubled back upon itself in such a way that the inductance of one half of it is neutralized by the inductance in the other half; 11B is a plain straight conductor; 11C is a conductor having one

or two loops in it; 11D is a conductor having a large number of loops; and 11E is a conductor with a large number of loops wound upon an iron core; and 11F is a conductor with a large number of turns wound up one arm of a closed iron circuit.

The practical unit of self-inductance is the **henry**. A coil has an inductance of 1 henry when, if the current through it changes at the rate

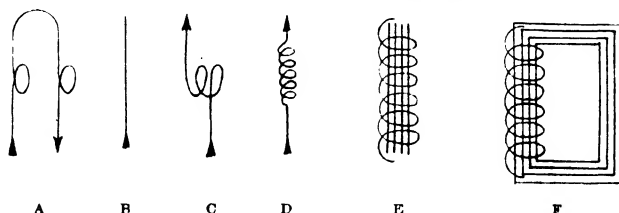


FIG. 11

of 1 ampere per second, an E.M.F. of 1 volt is induced. From this it will be seen that--

$$\text{Induced E.M.F. (volts)} = \text{Rate of change of Current (amperes per second)} \times \text{Inductance (henrys)}$$

We now come to the last electrical unit with which we shall be concerned, viz. the **farad**. Suppose that two insulated metal plates, *A* and *B*,

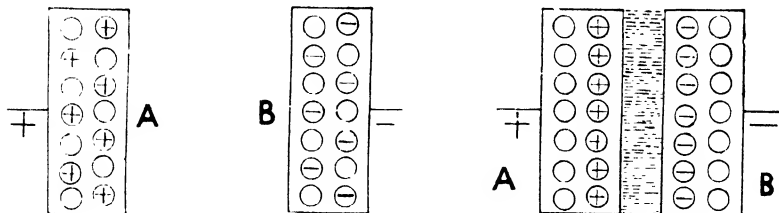


FIG. 12

FIG. 13

some distance apart, are connected to D.C. mains or a battery. Then, the plates being too far apart to influence one another, they will have the potentials of the positive and negative terminals of the mains or battery, and *A* will consist of neutral molecules and positive ions, i.e. molecules deficient of electrons, whilst *B* will consist of neutral molecules and negative ions, i.e. molecules with excess electrons. The plates have "charges," and potentials corresponding to those charges. Now, if these plates are brought near together, an electric field is set up through the dielectric between them, and this dielectric is strained so that there is an urge for the electrons and positive charges to separate from the molecules, and they try to move towards the positive and negative plates respectively. The effect of this strain in the dielectric is to reduce the potential difference between the two plates, and this loss of P.D. has to be made up from the mains or battery. Thus a momentary flow of electrons is produced through the mains until the P.D. of the plates is restored. The magnitude of the charges upon the plates will obviously govern the strength of the electric field and the consequent degree of strain in the dielectric, and the greater the strain in the dielectric the greater will be the amount of electrical energy stored up in the device, which is known as a **condenser**.

We have a parallel in the case of an ordinary steel spring, where the greater the strain in it, the greater the amount of stored up mechanical energy, which will be liberated by the uncoiling of the spring. If our condenser is disconnected from the mains it will retain its electrical charge, which will be liberated into a circuit connecting the two plates together.

A condenser is said to have a capacity of 1 farad when a charge of 1 coulomb (one ampere flowing for 1 sec.) produces a P.D. between the two plates of 1 volt. A small condenser may, perhaps, hold an equal number of coulombs to a large one, but the P.D. (or E.M.F.) must necessarily be higher. Increasing the area of the plates, or decreasing the thickness of the dielectric, will increase the capacity of a condenser.

Different dielectrics act differently as regards the inductive action between the plates. For instance, mica will suffer a greater electric strain than air, and if mica be substituted for air in a condenser, a greater charge must be given to produce the same E.M.F. The mica condenser, therefore, has a larger capacity, other things being equal. This property of the dielectric is termed its **specific inductive capacity**, or dielectric constant.

The following are puncturing voltages for various dielectrics between plates 1 mm. apart—

Dielectric	Puncturing Voltage	Corresponding Sparking Distance between Plates in Air
Crystal glass	28,500	9 mm.
India-rubber	40,000	13 mm.
Ebonite	50,000	14 mm.
Mica	60,000	20 mm.
Oil (vaseline)	7,000	2.5 mm.

The above values will be influenced by the shape of the electrodes, the duration of application, and the frequency and wave form of the applied voltage (if alternating).

If several condensers are joined in series, the combined capacity is given by the equation

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ etc.}$$

Where several condensers are joined in parallel, the total capacity is obtained by adding together their individual capacities.

It will be noted that these formulae are the reverse of those used when calculating resistance.

When a condenser is discharged by short-circuiting the plates, the flow of current does not consist of a single unidirectional surge of current, but is of an oscillatory character. The first surge of current appears to be carried by its impetus beyond the point necessary to establish equilibrium, and there is a diminishing flow backwards and forwards until equilibrium is established. The frequency of the discharge is affected by the magnitude, not only of the condenser capacity, but also of the inductance in circuit, being determined directly as the square roots of those quantities, and assuming that any pure resistance present is small enough to be neglected. The combination of capacity and inductance in a circuit with negligible resistance produces an **oscillatory circuit**, but if the resistance present is too high in value the oscillatory nature of the discharge is destroyed, and a gradual leak only is produced.

CHAPTER IV

ELECTRICAL EQUIPMENT OF AIRCRAFT

Accumulators

As it is often necessary to operate some part of the electrical equipment of an aircraft when the dynamo is not functioning, an alternative source of current has to be provided, and this normally takes the form of an "accumulator." A supply of current may be obtained from various kinds of voltaic cells, which may be divided into two main classes according to their principle of operation. In the first class the electrical energy is obtained solely as a result of chemical reaction in the cell, involving the wastage of one of the constituents of the cell. The action is therefore direct, and cells operating on this principle are termed **primary cells**, the commonest example being the ordinary Leclanché cell.

As primary cells, or batteries of primary cells, are now seldom used on aircraft we will proceed at once to deal with the second main class, with which we shall be intimately concerned. In this class, electrical energy is first supplied to the cell, and produces certain chemical changes in the constituents of the cell. These chemical changes are capable of reversal, and during this reversal the cell will itself supply electrical energy. The action is therefore indirect and reversible, and is considered as a secondary action. Cells of this type are known as **secondary cells** or "accumulators." Common examples of secondary cells are those of the lead-acid type, and of the nickel-iron-alkali type. It is a common fallacy that accumulators are devices for accumulating and storing electrical energy, but it will be obvious that what really happens is that the electrical energy supplied to the accumulator is converted into chemical energy, and is stored in that form. On completing the external electrical circuit of an accumulator a current will flow from it as long as the chemical action persists, i.e. until the constituents of the cell have regained their initial state.

A secondary cell consists essentially of two metal plates immersed in a liquid, which is known as the electrolyte. The commonest form of accumulator is that known as the "Lead-Acid" type, in which the plates are of lead, and dilute sulphuric acid is used as the electrolyte. During charging, one plate (the anode, or positive plate) is connected to the positive terminal of a source of direct current supply of suitable voltage, the other plate (the cathode, or negative plate) being connected to the negative terminal. The current thus flows, during charging, through the electrolyte from the anode to the cathode. During discharge, however, the current flows through the electrolyte from the cathode to the anode. An accumulator constructed with plain lead plates would, however, have very small capacity, as the chemical reactions occur only on the surface of the plates, and do not penetrate to an appreciable depth. The capacity would gradually increase with the number of times it was charged and discharged, as each successive cycle of operations would increase the depth of active surface material.

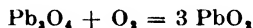
In order to speed up the process, and to give the accumulator an initial high capacity, the surfaces of the lead plates are specially prepared. There are two principal methods of preparing the plates, each named after the original inventor. One type is known as the *Fauré* or "pasted" type, and the other as the *Planté* or "formed" type. Plates of the *Fauré* type are made in the form of a grid, the interstices of which are filled under hydraulic

pressure with a paste made from certain lead oxides which readily lend themselves to the chemical processes which take place during charging and discharging. The paste used for the positive plates is usually red lead (Pb_3O_4) mixed with dilute sulphuric acid (H_2SO_4), and the paste for the negative plates consists of litharge or lead monoxide (PbO) also mixed with dilute sulphuric acid. The mechanical strength of the lead grid into which the paste is forced is usually increased by the admixture of 5 per cent to 10 per cent of antimony. Accumulators constructed on the Fauré principle are very robust but suffer from the disadvantage that high rates of charging or discharging tend to disintegrate the plates.

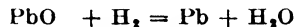
In the Planté principle of construction the positive plates are made from pure lead, and are deeply grooved to give a maximum surface area. Such plates are "formed" by immersing them in a forming bath and passing a current between them until a fairly thick film of lead peroxide (PbO_2) is formed over the whole surface of the plates. No paste is used with these positive plates, the active material being produced from the pure lead of the plate by chemical action during "formation." The negative plates in a Planté cell are usually of the pasted type and similar to those used in the Fauré cell. Planté type plates are not so mechanically strong as Fauré type plates, but they can be successfully charged and discharged at higher rates than similar sized plates of the Fauré type.

In order to grasp the main principles of operation of an accumulator, some explanation of the complex changes produced by charging and discharging is necessary. Before the initial charge of a new cell, the active material of the positive plate consists of red lead (Pb_3O_4) and the negative plate of lead monoxide (PbO). The plates are immersed in dilute sulphuric acid and a current is passed from the positive to the negative plate. The electrolyte is thereby ionized, oxygen being liberated at the positive plate and hydrogen at the negative plate. Both of these gases are very strongly active when in the nascent ("just born") condition, and their action on the paste in the plates may be represented by the following equations—

POSITIVE



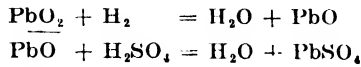
NEGATIVE



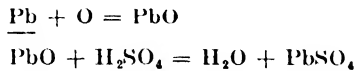
We thus see that the red lead of the new positive plates takes up oxygen to form lead peroxide, whilst the litharge of the negative plates gives up oxygen and is reduced to pure lead. The products of these chemical changes form very porous coatings on the plates, and the reactions go on so long as material is exposed to them. In time, of course, the products of the reactions completely cover the remainder of the original active material, and the action stops. Where the charging operation is carried out slowly, the formation of a thicker surface covering of porous material is favoured, and, because a larger surface area is thereby produced, a larger amount of energy may be stored up. The depth of porous active surface material in a well-cared-for accumulator will increase with age, and therefore its capacity will increase, until the time comes when the plates begin to disintegrate.

On discharging an accumulator by connecting the plates externally, the flow of current through the electrolyte is in the opposite direction, and we therefore have oxygen liberated at the negative plate, and hydrogen at the positive plate. The ensuing chemical reactions are very complex, but may be regarded as occurring in two stages simultaneously. At the

positive plate, the hydrogen first reduces the lead peroxide to lead monoxide, the latter then being immediately transformed into lead sulphate, thus—



Thus the peroxide, which is a deep chocolate colour, is gradually removed and the plate becomes partly coated with white lead sulphate. At the negative plate, the oxygen first combines with the lead to form lead monoxide, and the acid of the electrolyte then converts the latter into white lead sulphate, thus—



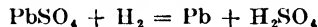
The lead sulphate thus formed on both plates is soft and soluble until the cell is discharged down to 1.8 volts on closed circuit. If discharge is continued beyond this limit the sulphate becomes hard and insoluble, and adversely affects the subsequent working of the cell.

When the cell is fully charged the electrolyte (dilute H_2SO_4) has a specific gravity of 1.220 to 1.270. The specific gravity falls during discharge to about 1.150. This weakening of the electrolyte is due to the breakdown of a certain proportion of the H_2SO_4 to form lead sulphate and water.

The chemical changes associated with the second and subsequent charging operations differ materially from those associated with the initial charge as outlined above. After the initial charge and discharge operations are completed, subsequent charging operations again produce oxygen at the positive plate and hydrogen at the negative plate, but both of these plates are now coated with PbSO_4 . The reaction at the positive plate now may be represented by the following reaction



whilst that at the negative plate may now be represented by



From these reactions it will be noted that both plates are brought back to the same chemical state as that obtaining before discharge, accompanied by the formation of H_2SO_4 , which goes to raise the specific gravity of the electrolyte.

On open circuit, a fully charged cell should show about 2.2 volts. This voltage will fall as the cell is discharged, the rate of fall being dependent on the rate of discharge. Comparative curves showing the fall of voltage on discharge at the 10 hour rate, and the rise in terminal voltage during charging at the same rate are given in Fig. 14. The similarity in form of the voltage characteristics on charge and discharge is at once apparent from the curves.

The capacity of an accumulator is its output expressed in ampere-hours, i.e. the product of the current (amperes) and the time (hours) for which that current can be taken from a fully charged cell, up to the time the terminal voltage has fallen to 1.8 volts on load. The capacity of a cell is normally based on the 10-hour rate of discharge, i.e. the current which will discharge the cell to 1.8 volts in 10-hours. If this rate of discharge is reduced, the apparent capacity will be somewhat increased, and similarly if the rate of discharge is exceeded, the apparent capacity will be reduced.

Considering a 20 ampere-hour accumulator, we shall find that its capacity at different rates would be—

$$\begin{array}{rcl} 10\text{-hour rate} & = & 20 \text{ amp. hours} = 2 \text{ amps.} \times 10 \text{ hours} \\ 5 \text{ " " " } & = & 15 \text{ " " " } = 3 \text{ " " } \times 5 \text{ " " } \\ 1 \text{ " " " } & = & 10 \text{ " " " } = 10 \text{ " " } \times 1 \text{ " " } \end{array}$$

From the foregoing it will be observed that the capacity of a cell is not a constant quantity, but depends on the amount of active material in the plates, and the rate of discharge. The operating temperature also has a large influence on the capacity, which will fall with a fall in temperature. The capacity of a cell based on the 10-hour rate is its actual

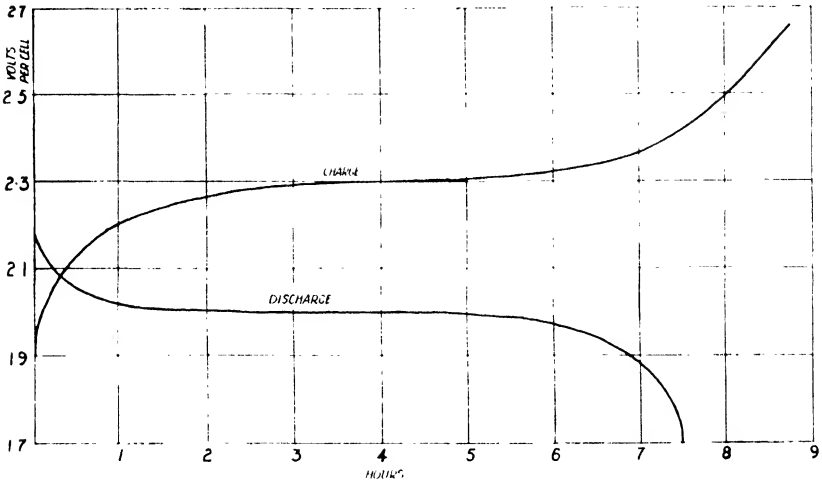


FIG. 14

capacity, and this is approximately half of its capacity when based on "ignition" rating.

A cell in good condition should yield on discharge from 85 per cent to 90 per cent of the energy (ampere-hours) expended in charging it. The useful life of a cell for aircraft purposes may be taken as terminated when its capacity has fallen by about 40 per cent. A cell designed for heavy rates of discharge is usually provided with thin plates, since their capacity does not fall away so rapidly as with plates of average thickness, when the 10-hour rate of discharge is exceeded. Cells with very thick plates are only intended for slow rates of discharge, and they may be considerably damaged, or their effective life reduced, if subjected to any discharge above the 10-hour rate.

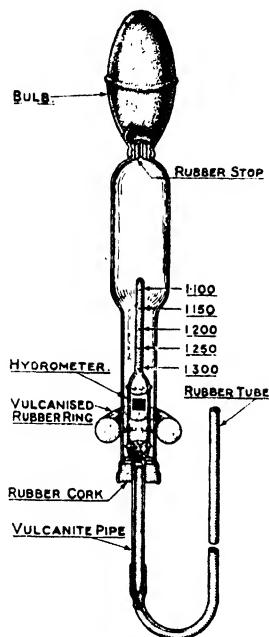
To obtain cells of large capacity it is necessary to increase the area of the plates, and in order to facilitate manufacture and handling this is normally accomplished by using several small plates in place of one large one. Thus a cell may have several positive and several negative plates, and in order to take advantage of both sides of each plate, the positive and negative plates are interleaved alternately, the plates being formed with lugs which extend upwards and are connected to bus-bars, all the positive plates to one bar and all the negative plates to the other bar. It is normal practice to have one more negative plate than positive, so

that the two outside end plates are always negatives, and both sides of every positive are opposite a negative and therefore active. This arrangement is necessary, since during the chemical actions of charging and discharging positive plates tend to buckle readily if the active material of the plate is acted on from one side only.

The plates are prevented from touching by separators, which are constructed either of corrugated celluloid, ebonite, or grooved partitions of specially prepared wood. In certain cases glass tubes are used as separators and, where glass containers are used, grooves and ribs moulded on to the interior walls of the container are common. Celluloid separators are largely disappearing, since after they have been in use some time they tend to promote frothing towards the end of the charging operation, when the plates are gassing freely. Separators must be designed so that free circulation of the electrolyte is permitted. Restriction of this circulation will cause unevenness of density of the electrolyte, resulting in uneven discharge and promoting buckling of plates and shedding of active material. Plates should not rest on the bottom of the container, but a liberal space should always be left for the collection of sediment. Sediment at the bottom of the container consists mainly of active material which has fallen from the plates, and this will short-circuit the cell if it bridges the gap between the plates.

The electrolyte in ordinary types of accumulator cells should consist of pure brimstone sulphuric acid, having a specific gravity of 1.800 to 1.900, diluted to the correct density by means of distilled water. The strong acid should always be added very slowly and very carefully to the water, and not *vice versa*, and mixing should be done in a glazed earthenware, glass, or lead vessel. No other vessel should be used for this purpose owing to the introduction of harmful impurities by the action of the acid on any other common form of metal container. The usual proportions are $3\frac{1}{2}$ to 4 parts of water to 1 part of acid, but the exact specific gravity must always be measured by means of an hydrometer. (Fig. 15.)

Considerable heat is generated during the process of dilution, and the mixture must be allowed to cool before using the hydrometer, or filling into a cell. The specific gravity of the dilute acid should be in accordance with the makers' instructions for the particular type of cell which is being filled. Hydrometers are of various types, but probably the best type for use with small portable cells consists of a hydrometer proper which is enclosed in a glass outer shell having a rubber bulb at the upper end and a short rubber tube at the lower end. By means of the bulb, acid may be drawn up through the tube into the shell and the hydrometer thus floated. After taking a reading on the instrument the acid may be returned to the cell.



* FIG. 15. SYRINGE
HYDROMETER

* Reproduced by kind permission of the Controller, His Majesty's Stationery Office.

The first charge given to an accumulator cell is a special charge required to complete the "formation" of the plates, and to bring them to the required condition for normal working. If this initial charge is improperly carried out, serious damage may be done to the cell. If the full capacity and normal life are to be obtained from an accumulator cell, the makers' instructions given for first charge procedure must be carried out in every detail. As soon as the voltage of any accumulator falls to 1.8 volt per cell on closed circuit, it should be recharged immediately. A cell should never be allowed to stand for any appreciable period in a partly discharged state, if sulphation troubles are to be avoided. Loss of electrolyte should be made good with new dilute acid (1.220 sp. gr.) if the loss was sustained by spilling, or by distilled water if the loss was occasioned by evaporation. Free use should be made of the hydrometer to check the actual specific gravity of the electrolyte, but readings should always be taken immediately after charging, when the specific gravity should be 1.250 or as advised by the makers of the accumulator.

The use of weak electrolyte will result in loss of capacity, and will promote sulphation. The use of too strong electrolyte will also promote sulphation, local chemical action, self-discharge, and possibly damage to the container, if this is of celluloid, particularly if the specific gravity exceeds 1.300.

Particular care should be given to the correct connection of accumulators for charging. The positive terminal of the accumulator should always be connected to the positive terminal of the source of supply, and the negative terminal to the negative side. The polarity of the charging circuit may be determined in various ways, but the two following methods are common and convenient. The first method consists of pressing the ends of the two wires on to damp litmus paper (red or blue). The positive wire will turn blue litmus paper pink, and the negative wire will turn red litmus paper blue. The second method consists of pressing the two wires on to damp blue print paper. The negative wire will leave a white mark.

It is a good general rule, in the absence of makers' instructions, to charge cells at the 10-hour rate until the cells are gassing freely and the specific gravity of the electrolyte has reached a steady maximum as indicated above. It will usually be found necessary to include an adjustable resistance in circuit in order to be able to control the current, and an ammeter should always be included in the circuit in order that the amount of current passing may be ascertained. Such a resistance may take the form of a bank of lamps or an ordinary wire-wound resistance. In any case, the use of any resistance in circuit represents wastage of current and inefficiency in operation. It is better to control the current by connecting a suitable number of cells in series for charging. Where this is done, however, particular care has to be taken, where the cells are not all of equal capacity, to ensure that the charging rate is suitable for the smallest cell, and that small cells are not overcharged nor large cells undercharged. In order to determine the maximum number of cells which may be charged from a fixed voltage supply, 2.8 volts should be allowed for each cell. By cell is meant 1 unit of an accumulator. A 12-volt battery would contain 6 units or cells. Thus on ordinary 220 volt mains the number of cells which could be charged in series would be $\frac{220}{2.8}$ or 78 cells or thirteen 12-volt batteries. If it is desired

to charge a larger number of cells than can be arranged in one set connected in series, the cells may be divided into groups, all the cells in one group being connected in series, and the various groups in parallel. This arrangement, however, requires careful preparation if the cells are of

different types and capacities in order to avoid the dangers of overcharging some cells and undercharging others. All the cells in a group should be of approximately the same capacity, and each group should have its own ammeter and regulating resistance in circuit.

It is important to note that charging from mains can only be carried out where the supply is direct current. An alternating current supply is obviously useless for recharging accumulators. It is often found that where the number of cells to be charged at any one time is never large, but recharging operations are required at frequent intervals, it is more economical and efficient to install a motor-driven generator for the purpose. The motor, of course, would be of a type suitable for running off the mains, and in this case may be either a direct current or alternating current machine. The motor is used to drive a generator giving a direct current of suitable voltage for the general needs of the station, and 50-60 volts is often specified. The initial cost of a motor-driven generator may be a large item, but against this may be set the saving in cost of current otherwise wasted in large resistances or banks of lamps, as the overall efficiency of a motor generator is relatively high. For alternating current mains there are also available various devices for transforming the current to direct current suitable for battery charging purposes. Such devices include thermionic valve rectifiers, metal oxide rectifiers, synchronous motors fitted with commutators, etc.

The faults and troubles with lead-acid accumulators may be conveniently summarized as follows—

SULPHATION

Sulphation is the most common fault to which acid accumulators are liable. As a general rule, it is directly caused by neglect, as is shown by the following list of causes of this fault—

- (i) Discharging an accumulator below 1.8 volts per cell.
- (ii) Allowing a discharged or partly discharged cell to stand in that condition.
- (iii) Persistent undercharging.
- (iv) The use of too strong electrolyte.
- (v) The use of too weak electrolyte.

By the term "sulphation," in connection with accumulators, is understood the formation of the white and almost insoluble sulphate of lead ($PbSO_4$). Whereas the normal chemical action of the cell during the discharge period involves the formation of lead sulphate, it should be remembered that this sulphate is soft and soluble during the period of discharge down to 1.8 volts per cell. This soluble sulphate turns hard and insoluble either after further discharge or from lack of recharging. The effect of bad sulphation is completely to prevent the chemical action taking place during charging and discharging, and therefore a cell in this condition is practically useless. In addition, the mechanical effect of this fault is to render the plates extremely brittle.

The successful treatment of cells for hard sulphation depends entirely on the amount of sulphation present. The procedure in removing the hard sulphate is as follows—

- (i) Empty out the electrolyte and thoroughly wash out the cell with weak electrolyte.
- (ii) Refill with weak electrolyte at a specific gravity of about 1.150.
- (iii) Put on charge at one-quarter normal charging rate.
- (iv) Allow the cell to gas steadily for a long period, since gassing tends to dislodge the insoluble sulphate which falls to the bottom of

the cell as a sediment. It may be necessary to continue this charge for a period of 100 hours or more.

(v) If this treatment is successful, empty out the electrolyte, thoroughly wash out all sediment with weak electrolyte and fill up with fresh acid at a specific gravity of 1.270 at 61° F.

(vi) Charge the cell at normal charging rate for a short period.

If the treatment outlined in the previous paragraph is not successful in removing all the insoluble sulphate, the cell may be carefully dismantled, and the plates taken out and carefully scraped or brushed in order to remove the hard sulphate. This operation requires considerable care since it is essential that the active material of the plates should not be disturbed in any way. The cell is then reassembled and placed on slow charge until it has been restored to normal condition as indicated in the previous paragraph. It must be noted that either form of treatment indicated above will tend to reduce the capacity and effective life of the cell.

HYDRATION

Hydration is the name given to the formation of white lead hydrate in lead-acid cells. This fault is caused by allowing water to remain in contact with the active material of the plates for an appreciable time. For this reason new accumulators should never be rinsed out with distilled water before filling with electrolyte for the first charge, since the tendency to hydration is thereby considerably increased. Hydration, like sulphation, considerably impairs the capacity of a cell, since it interferes with the chemical changes taking place during charging and discharging. Unlike sulphation, however, it is fairly easy to remove by prolonged charging. Cells exhibiting hydration are capable of restoration to a fairly good condition by following the procedure given in sub-para. (iii) and (iv) under sulphation.

BUCKLING OF PLATES

This fault is generally due to excessive rates of charge and discharge. If the normal rate either of charge or discharge is considerably exceeded, the result is uneven chemical action in the active material of the plates. The chief reason for this is that the density of the electrolyte will not be uniform through the cell, as the normal circulation of the electrolyte is not sufficiently rapid to produce uniform conditions when heavy charge or discharge rates are employed. The effect of this uneven chemical action in the plates is to produce unequal strains, and the plates therefore buckle. The tendency of plates to buckle under the above conditions is greatly increased if the cell is overheated.

The only remedy for this fault is to dismantle the cell and to straighten out the buckled plates by pressing them gently between two pieces of board. It is clear that great care must be exercised in carrying out this operation as the plates are very brittle and there is considerable likelihood of loosening the active material, thus causing shedding.

DISINTEGRATION OF PLATES

This fault, like buckling of plates, is radical in its importance, and the capacity of any cell is very considerably impaired by shedding of active material. Amongst the many causes of disintegration are general neglect, prolonged overcharging, and long continued charging at current strengths much less than normal rate as indicated on the instruction labels. These causes, combined with abnormal heat, result in peroxidation of the lead grids and materially shorten the life of the cell. For continuous disintegration of plates there is no cure. Care should be taken to see that the

sediment collecting in the bottom of the container does not rise sufficiently high to short-circuit the bottom of the plates. The cell should be carefully shaken and the electrolyte and sediment poured out, the cell then being filled with fresh electrolyte and placed on charge at half-normal charging rate.

INTERNAL SHORT-CIRCUITS

Any cell in which there is an internal short-circuit will not gas even after prolonged charging. When this occurs, the accumulator should be dismantled and the plates examined in order to ascertain the cause of the short-circuit. Short-circuits may be produced by neglect, resulting in hydration and severe sulphation. Also lead "trees" may be formed round the edges of adjacent plates, generally due to long continued charging at currents much below normal charging rate. These trees form more or less permanent short-circuits between two or more plates. High temperatures assist the formation of these growths and often cause expansion of the plates, thereby providing a further contributory cause of short-circuits.

ALKALINE TYPE BATTERIES*

Another class of accumulator frequently met with on aircraft has an alkaline solution and either makes use of the elements nickel and cadmium or uses the elements nickel and iron for the active materials in the plates. These two distinct types of alkaline accumulators are being manufactured commercially. The former is generally known as the "NIFE" or Jungner type (see Fig. 16), while the latter is frequently referred to as the Edison type (see Fig. 17). The construction of both types is essentially the same in principle, the various manufacturers adopting differences in detail only. The active material is enclosed in steel tubes or pockets which are perforated with a very large number of minute holes over the whole of their surface, a number of these pockets being assembled into steel retaining frames to form complete positive or negative plates (see Figs. 18, 19, and 20). The required number of plates of the same polarity are mounted on collecting bolts with suitable steel spacing washers and terminal pillars, and are then firmly bolted together. The positive and negative plates are separated by means of ebonite rod insulators and the whole assembly mounted in a sheet steel container having welded joints, the terminals being brought through the cover in suitably insulated glands or stuffing boxes. This container is usually plated on the outside to prevent corrosion. The electrolyte used is a solution of pure potassium hydroxide having a normal specific gravity of about 1.19. In certain makes of cells a small quantity of other constituents is added, but these have no direct effect on the action of the cells. The strength of the solution, apart from evaporation, does not vary during either discharge or charge, and the electrolyte has no action on iron or steel, so that there is no possibility of internal corrosion.

It is seen that steel is used throughout in the construction of the cell; this is of very great advantage in view of the fact that all parts of the cell can be made with mathematical precision. The mechanical strength, durability, and robustness are much in advance of what can be obtained even in the best designs of lead cells—vibrations and shocks cannot dislodge the active material, with the result that there is a total absence of sludge and deposit—the steel plates cannot twist, buckle, break off or grow—the active material and other parts of the cells do not suffer any damage by overcharging, heavy discharging, or idleness.

* See Paper read before the Rugby Engineering Society by D. Kirkman, B.Sc. and F. Watson Mann, B.Sc. (27th January, 1932).

In both types the active material in the positive plates is essentially the same, and consists of nickel hydroxide, the action that takes place on discharge being a reduction from a higher form of nickel hydroxide to a lower form, and *vice versa* on charge. In the nickel iron cell the active material in the negative plate is metallic iron which is oxidized on discharge

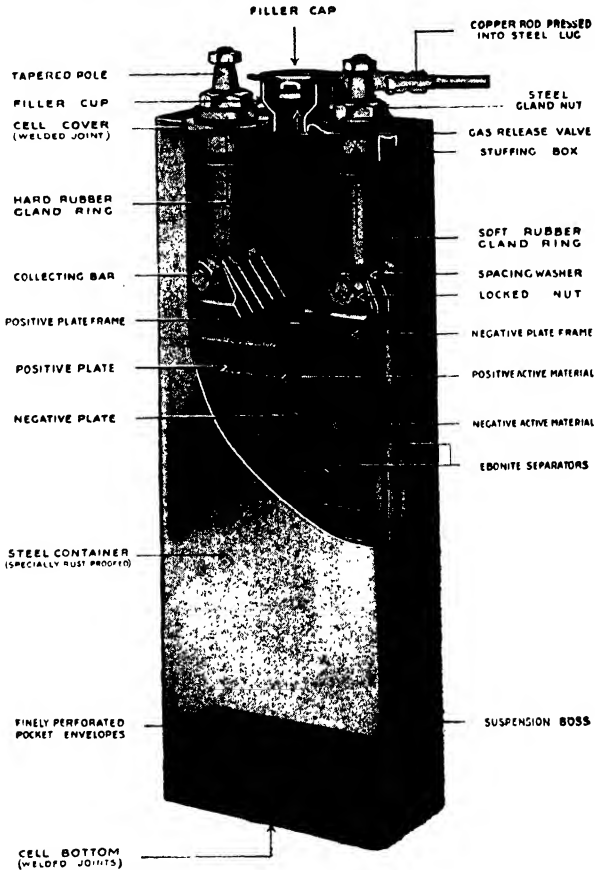


FIG. 16. "NIFE" NICKEL CADMIUM CELL
(By courtesy of Batteries, Ltd.)

to iron oxide (or hydroxide), and *vice versa* on charge, while in the nickel cadmium cell the iron is replaced with cadmium.

One of the biggest difficulties that had to be faced in the manufacture of alkaline cells was the high electrical resistance of the actual active materials, and this was overcome in various ingenious ways. In one example, the nickel hydroxide is mixed with flakes of pure nickel $\frac{1}{8}$ in. square and 0.0004 in. thick, the method being to have alternate layers of nickel hydroxide and flake nickel. Another method is that of mixing the nickel hydroxide intimately with a specially prepared flake graphite, which is chemically inert.

With the nickel iron cell the high resistance of the iron oxide formed on discharge is overcome by mixing the material intimately with about 6 per cent of yellow mercuric oxide. The resistance of the cadmium oxide

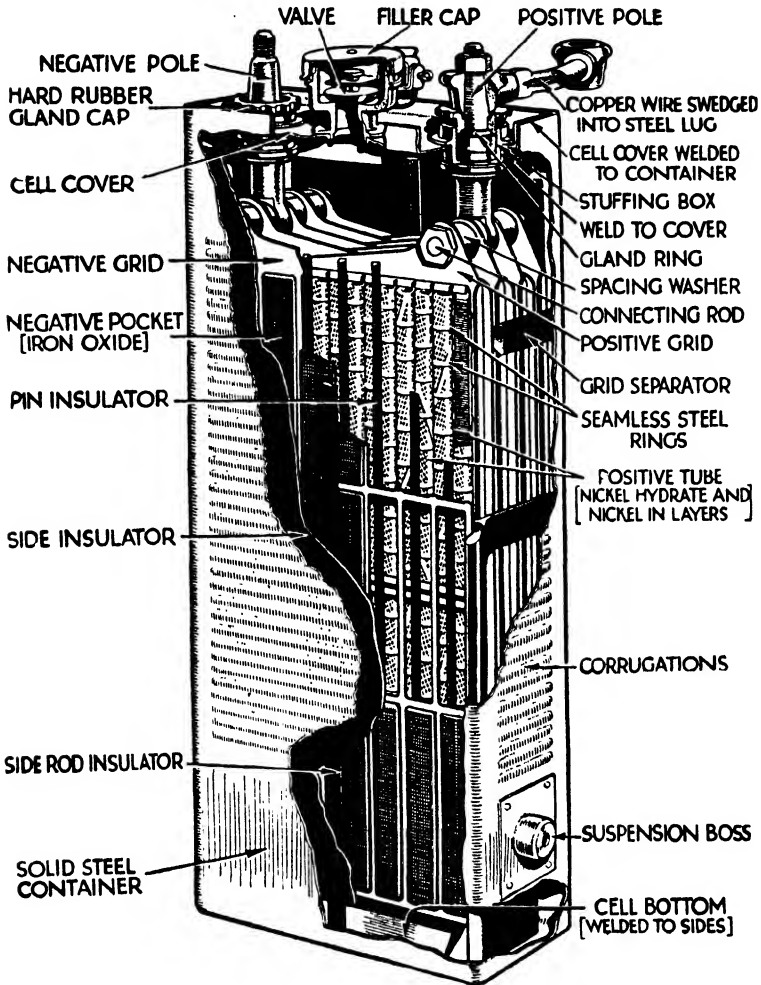


FIG. 17. EDISON NICKEL IRON CELL
 (By courtesy of Edison Storage Battery Distributors, Ltd.)

in the nickel cadmium cell, however, is very much lower and it is unnecessary to add any special conducting material. There is, however, a tendency for the cadmium oxide to cake and lose porosity, and in order to overcome this the cadmium is mixed intimately with a small quantity of iron, the mixture retaining all the advantages of the cadmium and having none of the disadvantages of the iron. This mixture is of very special

interest, as both the constituents of the active material so formed take a useful part in the reactions of the cell, and it is the only case where a mixture of elements has proved a definite success as an accumulator electrode.

The theoretical discharge voltage of the cadmium negative plate is roughly 0.03 volts lower than that of the iron negative plate. This is, however, more than counterbalanced by the lower resistance of the cadmium plate; and the resulting voltage on discharge, except in the very

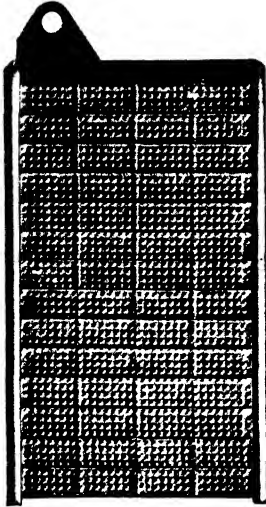


FIG. 18. "NIFE"
POSITIVE OR
NEGATIVE PLATE

(By courtesy of Batteries, Ltd.)

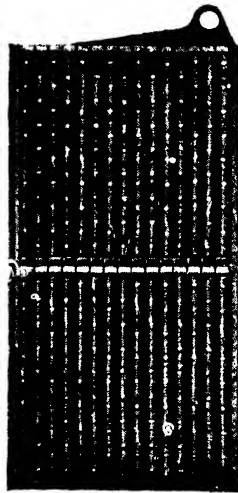


FIG. 19. EDISON
POSITIVE PLATE

(By courtesy of Edison Storage Battery Distributors, Ltd.)

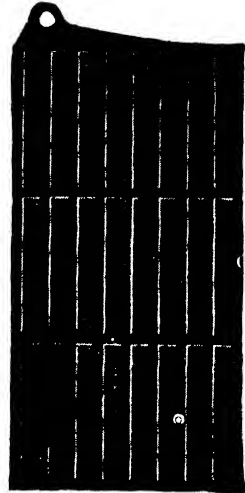


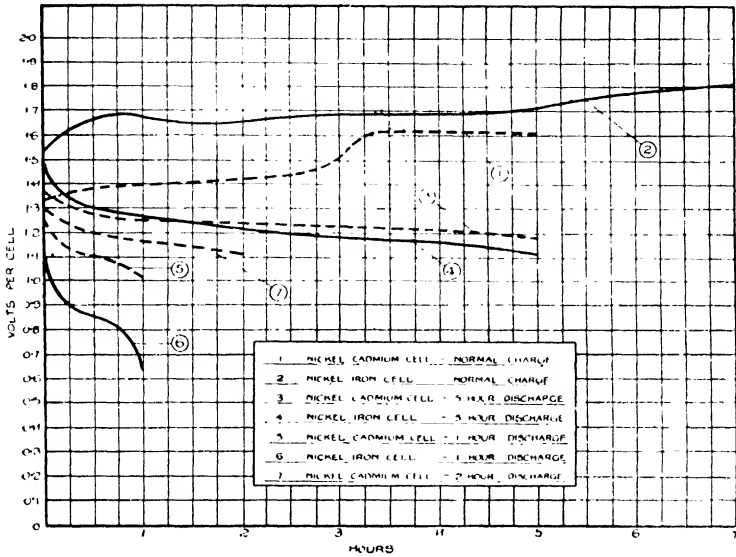
FIG. 20. EDISON
NEGATIVE PLATE

early stage, is actually slightly higher, this being particularly noticeable at higher discharge rates.

The charging voltage of cadmium oxide is very much lower than that of iron oxide, and this is one of the more important advantages of the cadmium plate. The voltage required for the conversion of cadmium oxide to cadmium (with a nickel hydroxide positive plate) is from 1.35 to 1.5 volts, while that for converting iron oxide to iron is 1.55 to 1.8 volts, these figures assuming approximately normal charging rates.

Another interesting point arises here. It would be thought on consideration of the above voltages that there would be a definite break in both the charge and discharge curves of a nickel cadmium cell having a negative plate consisting of a mixture of cadmium and iron. As the discharge potentials of cadmium and iron are very close together, the expected break in the discharge curve is smoothed over and is not apparent. On charge, however, there is a distinct break, which occurs after the cadmium oxide portion of the material has all been converted, and the position of this break is found to vary with the percentage of iron present in the plate (see Figs. 21 and 22).

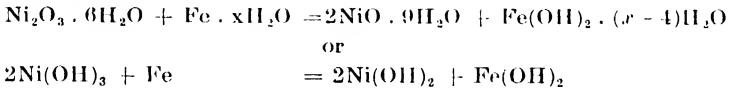
The chemical reactions occurring in alkaline cells are extremely involved,



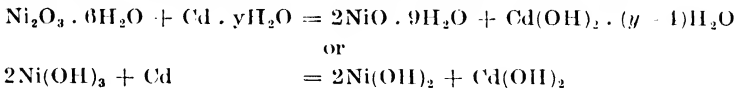
COMPARATIVE CHARACTERISTICS OF NICKEL-CADMIUM AND NICKEL-IRON CELLS
 Fig. 21

and it is very difficult to give anything really conclusive, as various oxides of nickel, iron, and cadmium appear to be formed almost simultaneously in different degrees of hydration; but for a very rough approximation the following equations may be considered -

For the Nickel Iron Cell

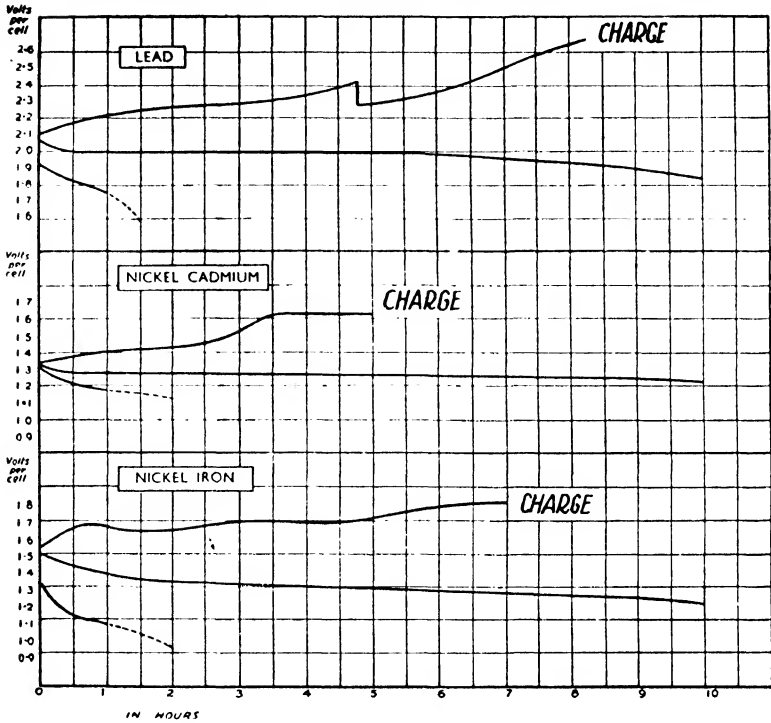


and for the Nickel-Cadmium Cell a combination of the above and



The electrolyte appears to take no active part in the reactions of the cell, and to function merely as a conductor. Apart from considerations of temperature rise and alteration in gravity due to electrolysis on charge, the quantity of electrolyte can thus be reduced to a minimum and the plates placed very closely together.

It will also be seen that although oxygen plays a part in the reaction, being transferred from one plate to another, no free oxygen is liberated on discharge, and therefore as no gases are evolved it would appear that a cell could be made absolutely unspillable by fitting solid stoppers. The iron present in a fully charged nickel iron cell, however, is not completely stable and tends to become oxidized slowly when standing idle; this is accompanied by the evolution of hydrogen and by a self-discharge of the cell. The cadmium negative, on the other hand, is completely stable and has in addition a stabilizing effect on the small quantity of iron, with the



VOLTAGE CHARACTERISTICS OF LEAD, NICKEL CADMIUM AND NICKEL-IRON CELLS
 Fig. 22

result that in the nickel cadmium cell there is no gassing, either on discharge or when standing idle, and no self-discharge. A nickel cadmium cell can therefore be made completely unspillable by fitting solid stoppers and thousands of batteries so fitted are giving excellent results in service. A very short period, however, should elapse after the completion of charge before inserting the solid stoppers in order to allow the gases generated during charge to escape completely.

The charging voltage of a pure nickel cadmium cell is from 1.35 to 1.50 volts, compared with 1.55 to 1.80 for a nickel iron cell, and the open circuit voltage of both types is between 1.25 and 1.40 volts, depending on the state of charge. Let us consider what this means. The voltage necessary to decompose the water content of a potassium hydroxide solution is of the order of 1.40 volts, which is appreciably below the charging voltage necessary to charge a nickel iron cell. A high degree of polarization is required to reduce the iron oxide, and the evolution of oxygen and hydrogen occurs during the whole of the charge, making the efficiency well below the theoretical figure. With the nickel cadmium cell, however, the evolution of gas is much less and the efficiency correspondingly higher, particularly as the cadmium oxide can be reduced with a low degree of polarization.

From this it is obvious that a nickel iron cell cannot be charged at very low rates and, on account of the large variation between charge and

discharge voltage, cannot be "floated." The characteristics of the nickel cadmium cell, however, are such that it can be trickle charged or "floated" in a similar way to the lead cell.

Although the actual resistance of the active materials in alkaline cells has been brought within satisfactory limits by the various means outlined earlier, the internal resistance of the normal alkaline cell of both types is appreciably higher than that of a lead cell. The nickel cadmium cell is by

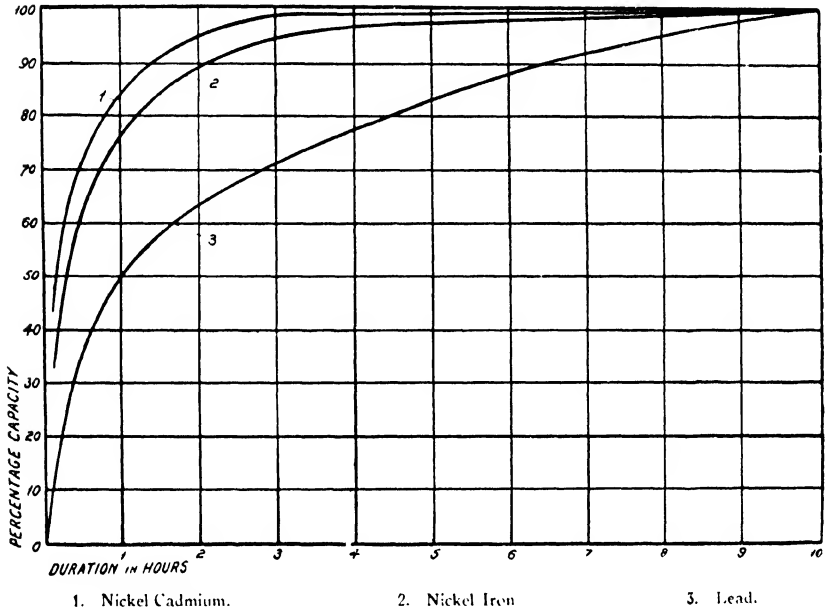


FIG. 23

far the better of the two types and has an internal resistance which is only about half that of the nickel iron cell.

Fig. 23 shows the percentages of rated capacity obtainable at various discharge rates. If a battery is required for heavy discharge only, the capacity is frequently determined by considerations of terminal voltage only, and in this case it is almost always possible to install a nickel cadmium battery of much smaller rated capacity than would be necessary with lead. Switch closing and Diesel engine starting are examples of this class of duty.

All types of cells, lead, nickel iron, and nickel cadmium are affected in a similar manner by temperature. Normal temperature is usually taken as 15° C., and the capacity and voltage of cells on discharge increase as they are operated above normal. Beyond 45° C. the active materials may become adversely affected, and all battery manufacturers give a limit of about this figure above which cells should not be worked.

At temperatures below normal there is a very rapid falling off in both capacity and voltage, the lead cell being almost equally as bad as the nickel iron, while the nickel cadmium cell shows up comparatively well. Freezing of the electrolyte has no permanent effect on either the nickel iron or the

nickel cadmium cell, and only results in an inertness which is removed when the temperature is raised again, but in a lead cell it is often disastrous to the plates.

PERCENTAGE CAPACITY AVAILABLE AT NORMAL RATE

	15° C.	5° C.	- 5° C.	- 15° C.
Lead	100	84	65	43
Nickel cadmium	100	96.5	92	74.5
Nickel iron	100	79	52.5	15.8

Generators—Motors

The movement of a metallic conductor through—not along—the lines of force in a magnetic field creates a difference of electrical pressure between the ends of the wire, and if the two ends are joined together by means of a suitable conductor, so long as relative motion is maintained between the conductor and the magnetic field, a current of electricity due to this difference of electrical pressure will flow through the system. It is important to note that it is a difference of electrical pressure, and not a current, that is created. Such a machine requires the application of mechanical force to obtain the relative motion of conductors and magnetic field, producing in return the difference of electrical pressure which may be used to cause a current of electricity to flow, and is called a generator. A machine designed to operate in the reverse sense, viz. to produce mechanical force by the application of a difference of electrical potential to the conductor, is called a motor. In many cases the same machine can be made to operate either as a motor or as a generator, but this is not an invariable rule, due to peculiarities of design.

The magnetic field of either a generator or a motor may be produced by the use of either permanent magnets or electro-magnets. Permanent magnets are used in some classes of small machine, such as magnetos and the generators used in connection with certain makes of electrical revolution counters. The use of permanent magnets, of course, involves the use of hardened alloy steel in the construction, but with electro-magnets it is permissible to use soft or malleable iron or mild steel. The current used to energize the coils of the electro-magnets is usually obtained from the machine itself, if of the direct current type, but in certain cases it is obtained either from another and smaller generator, which is often incorporated in the main generator, or from storage cells.

Alternators, or generators designed to produce alternating current, are a class of machine which requires such separate outside excitation, since they require a source of direct current for field excitation purposes. A self-exciting generator operates by reason of the fact that even soft iron will retain a certain small amount of residual magnetism, sufficient to enable the armature coils to produce a small E.M.F. This small E.M.F. will cause a small current to flow in the field coils, which will in turn increase the magnetic flux, thus increasing the E.M.F. in the armature, which again increases the field excitation, and thus a building-up process goes on until the magnetic circuit reaches saturation point. A new generator may require the application of a magnetizing current from an outside source on its first run up, but thereafter there will normally be sufficient residual magnetism to enable it to be self-exciting.

After allowing a small amount of energy to compensate for friction losses and heat losses, the amount of mechanical energy required to drive a generator is directly proportional to the amount of electrical energy—watts—which the machine is giving out. Where the source of mechanical energy is an engine fitted with a governor, it will be easy to watch the action of the governor respond to the varying output of the generator. In the case of an electric motor, on account of certain electrical reactions within the machine, the nature of which it is unnecessary to consider here, the motor will only take that amount of electrical power from the supply mains which is proportional to the actual

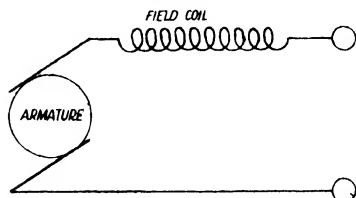


FIG. 24

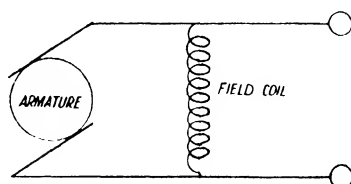


FIG. 25

load on the machine, apart from small inherent losses due to inefficiency of conversion.

In direct current generators, the portion in which the electrical difference of pressure is produced, and whether it be stationary or rotary, is termed the **armature**. The other portion is usually designated the **field magnets**. Direct current dynamos are divided into four main classes, viz.—

- Separately excited dynamos.
- Series-wound dynamos.
- Shunt-wound dynamos.
- Compound-wound dynamos.

Reference has already been made to the first class. On aircraft, it is only met with in the case of certain high voltage generators used for wireless purposes. In such machines the high voltage main armature current would be unsuitable for field excitation, therefore, a small secondary armature, mounted on the same shaft as the main armature, is caused to rotate in a secondary magnetic field system attached to the main field framework. The low tension current from the small secondary armature is used to excite the main field system. In some cases this secondary armature is designed on a sufficiently generous scale to enable it to supply low tension current for battery charging, and general purposes on the aircraft, apart from wireless.

In **series-wound** dynamos the field coils are wound with a comparatively few turns of thick wire, through which the whole of the current given off by the armature flows. The arrangement is illustrated diagrammatically in Fig. 24. The value of the resultant E.M.F. depends on the strength of the magnetic field, the speed of rotation, and the number of wires joined in series on the armature. Dynamos of this type are only satisfactory under conditions of constant speed and constant load, and are therefore quite unsuitable for use on aircraft. In a series-wound motor, the E.M.F. of the supply being constant, the speed will decrease as the load increases, and, conversely, the speed will increase as the load decreases. The starting torque of a series-wound motor is high, but, in general, it is unsuitable for aircraft use.

In the third class of dynamo, the **shunt-wound** type, in place of passing the whole current from the armature through a few turns of thick wire, only a small proportion of the total armature output is used to excite the field coils, which, in this case, consist of a greater number of turns of finer gauge wire, having a high resistance. For a given size of field magnet it is necessary to have a given number of ampere-turns to obtain the desired maximum magnetic flux. Whereas in the series-wound machine this is attained by few turns and many amperes, in the shunt-wound type it is attained by many turns and few amperes. Hence the thick wire in the former case and the fine wire in the latter. The arrangement of a shunt-wound machine is shown diagrammatically in Fig. 25. The E.M.F. will now be almost independent of the load, provided the speed be kept constant, because the resistance of this part of the circuit will remain constant, and, in accordance with Ohm's law, the same amount of current will flow through the shunt coils at all times. Hence the magnetic field will remain steady, and so, theoretically, will the resultant E.M.F. of the dynamo as a generator, or, if the dynamo be run as a motor, the speed will remain practically constant at all loads. As a matter of fact the E.M.F. of a shunt-wound dynamo tends to drop slightly as the load is increased, owing to the effect of armature reaction, and this is compensated for by means of a small adjustable external resistance, or by other means which will be referred to later.

The fourth class of dynamo (**compound-wound**) is really a combination of the characteristics of the series-wound and shunt-wound machines.

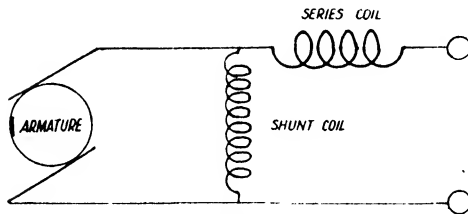


Fig. 26

The field magnets are provided with two separate windings. One winding consists of a few turns of heavy gauge wire, and carries the whole output of the armature. The other winding consists of many turns of finer gauge wire, and is connected straight across the armature, but on account of

its high resistance it absorbs only a small proportion of the total output of the armature. The arrangement is illustrated diagrammatically in Fig. 26.

COMMUTATION

It has already been stated that the basic principle of the dynamo is the cutting of magnetic lines of force by a moving conductor. In its simplest form, such a conductor would take the form of a plane rectangular loop of wire, having its ends connected to two insulated metallic rings mounted on the armature shaft. By arranging fixed "brushes" to rub on these rings it is possible to make contact with the ends of the wire whilst the loop is rotating at high speed. But as each ring is connected to one arm of the loop, which is cutting alternately the magnetic lines of force first at a north pole and then at a south pole, each ring in turn becomes the negative and then the positive pole of the armature circuit, and the E.M.F. produced is an alternating one. This alternating E.M.F. may be "commuted" to a direct E.M.F. by the use of a device called a commutator.

The commutator consists of a series of insulated metal bars, segmental in section, mounted in a framework fixed to the armature shaft, all the

metal bars being parallel to the axis of the shaft, and arranged concentrically round it. In a bipolar machine, the ends of the armature loops are connected to diametrically opposite bars of the commutator, and a pair of diametrically opposite fixed brushes are arranged to rub on the surfaces of the bars as they rotate with the armature shaft. Thus, when one arm of a loop is sweeping past a north magnetic pole its end is connected to a commutator bar passing under one of the fixed brushes, and the polarity of that brush will be positive, and the other brush must therefore be negative. By the time the arm of the loop has completed half a revolution it is sweeping past a south magnetic pole, but the commutator bar to which it is connected has also completed half a revolution and is now under the second brush. Thus, although the E.M.F. in the arm of the loop has reversed, the commutator bar to which it is connected is now passing under the other brush, and hence the polarity at the brushes is maintained constant. This is the basic principle of commutation, but in practice it is elaborated by increasing the number of loops of wire on the armature, and by increasing the number of poles in the magnetic system.

Considering the case of a single commutator bar, we see that its E.M.F. will rise from zero to a maximum in one direction, then die away to zero and rise to a maximum in the opposite direction, and die again to zero, all in the course of a single revolution.

The coils of wire which carry the field exciting current are highly inductive, and so, to a lesser extent, are those on the armature. Since the current flowing in these coils passes through the commutator bars and brushes, the circuit is necessarily broken twice in each revolution of the armature. The precautions which have to be taken when breaking a highly inductive circuit have already been referred to, and in the case of the dynamo the avoidance of heavy inductive sparking at the commutator brushes is effected by so placing the brushes in relation to the commutator that at the moment a commutator bar is passing from under the brush the E.M.F. of the armature winding is passing through zero potential. It will be appreciated, however, that the effects of self-induction prohibit this change from being effected instantaneously, although the reversal of current has practically to be done during the very limited time each coil is short-circuited under the brush. How short this period is, is evident when it is considered that a dynamo making 4,800 r.p.m., or 80 rev. per sec., and fitted with a commutator containing only 20 sections, has any set of coils under the action of a brush for the 1/1600 part of a second only. This time is too limited to permit of the reversal of current, and were the brushes set precisely at the neutral position, sparking would inevitably occur. To overcome this difficulty the brushes are set a little forward from the neutral position in the case of a generator, and a little behind the neutral position in the case of a motor. The result of this adjustment of the brushes is that during the time the coil is short-circuited it is acted upon by the magnetic field into which it is about to be thrown, and, therefore, there is a reverse E.M.F. generated in the coil while still under the action of the brush. The angle through which the brushes are set forward is termed the **angle of lead**, and similarly the angle through which the brushes are set back—in the case of a motor—is termed the **angle of lag**. These settings vary with the load on the machine.

The output of a generator is controlled largely by the permissible temperature rise of the windings. The passage of a current of electricity along a wire has a heating effect on the wire, which increases as the current density in the wire is increased. This heating effect will obviously be

most marked in the case of well protected windings, and least marked in the case of open and well ventilated windings. For this reason aircraft generators are usually installed in such a position that they receive the full cooling effects of the slipstream of the airscrew. By this means the output may be increased by about 100 per cent over what the same machine could safely give if deprived of the cooling advantages of an air blast.

When considering the output marked by the makers on an aircraft dynamo, therefore, it is necessary also to consider where it will be installed in the aircraft, and to regulate the permissible load to be taken from it accordingly.

A 12-volt system for lighting and general low tension supplies on aircraft is practically universal, and this voltage has been fixed as offering the

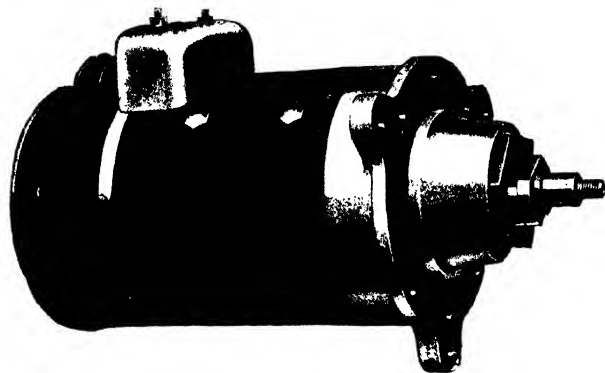


FIG. 27. ENGINE-DRIVEN TYPE A.T. 149

24 volts. 350 watts at approx. 3,600 r.p.m. Overall length 12 $\frac{1}{2}$ in.
Diameter 5 in. Weight 28 $\frac{1}{2}$ lb.

Also designed to give its output over a wide range of speeds, this constant current machine is adapted for flange mounting. The switching is so arranged that this dynamo gives full output only when the navigation lamps are in use. As shown, this machine is arranged for mounting vertically, but it can be supplied for horizontal drive either by engine or by means of an airscrew.

(By courtesy of Rotax Ltd.)

best compromise and economy of weight. A lower voltage would involve the use of much heavier cables, terminal blocks, switchgear, etc., and would give practically no corresponding saving in weight of the generator itself. A higher voltage would show some saving in weight of cables, but the problem of weight of a suitable accumulator then arises.

The particular types of generator in general use may be classified as follows—

1. Approximately 200 watt, plain shunt-wound machines, requiring an external regulator to maintain constant voltage under all conditions of speed and load.
2. Approximately 200 watt shunt-wound machines, fitted with a third brush and additional field winding for voltage regulation over a fairly wide range of speed and load.
3. Approximately 500 watt plain shunt-wound machines, similar to (1) above.
4. Dual purpose high and low tension generators of the Marconi-Newton type.



FIG. 28. WIND-DRIVEN TYPE A.T. 153

12 volts. 150 watts at approx. 3,500/4,000 r.p.m. Overall length 12½ in. Diameter 4½ in. Weight 11½ lb.
(By courtesy of Rotax Ltd.)

The methods of driving aircraft generators include (a) windmill drive, with wooden or metal windmills having fixed blades. The windmill chosen for use with any particular generator will depend on the generator speed and output, the position of the generator on the aircraft, i.e. in or out of the slipstream, and the normal speed of the aircraft; (b) direct drive from the main aircraft engine, either by fixed gearing or by flexible shaft; (c) by windmills of the automatically variable pitch type, such as are usually fitted on the Marconi-Newton dual purpose generators.

Windmills for use with electrical generators which are constructed to the designs shown on the table appended hereto are approved for use on civil aircraft.

Type	Drg. No.	Range of Total Airspeeds over Windmills*	Corresponding Range of r.p.m.	Generator for which Approved
Fixed pitch wooden windmills— Vickers . . .	{ A.305	80-110 m.p.h.	4,500-6,300	} Vickers D.P.A. 150 watt generator
	{ A.342	110-140 „	4,700-6,150	
Rotax . . .	{ H.9	90-162 „	3,500-7,500	} Rotax generators Types AT. 153 and AT. 157 120 watt DP. generator (A.M. Type)
	{ H.10	93-171 „	3,500-7,500	
	{ H.11	110-198 „	3,500-7,500	
	{ H.17	75-110 „	3,500-5,500	

* Including slipstream if any.

In the case of (a) and (b) above, it will be obvious that the speed of the generator will vary considerably under different conditions met with in ordinary flight, and therefore some means of regulating the generator voltage becomes essential. There are types of automatic voltage regulators, installed remote from the generator, which will be described later. There is also the type of generator provided with compensator windings designed to regulate the current over a wide speed range. The automatically variable pitch windmill is a very successful fitment for obtaining a steady voltage, because of its governing action, which maintains the speed of the generator practically constant over wide ranges of load and air speed.

On the whole, aircraft generators are very reliable machines, and their maintenance requirements are not great. The armatures are normally mounted in ball bearings, which call for occasional lubrication only, and for this purpose anti-freezing grease is usually specified by the makers. The brush position is usually fixed, and no adjustments of this are possible. The brushes will wear with use, and should be inspected regularly, and renewed as necessary. The commutator may become dirty and worn with use. Only fine grade carborundum cloth should be used for cleaning purposes. If deep burning or pitting has occurred, or the commutator has worn oval, or if flat spots have developed, the whole armature should be removed from the generator, mounted in a lathe, and the surface of the commutator cleaned up with a very sharp narrow-nosed tool, and the insulation between the bars then slightly recessed. The interior of the generator should be kept clean, and especially should it be kept free of moisture and carbon dust, which will otherwise accumulate from worn

brushes. Should a definite fault, not attributable to ordinary lack of maintenance, develop in a generator, the following notes may be of assistance.

1. *Brush vibration*, may be due to rough commutator surface, commutator worn oval, loose commutator bars, or projecting insulation material between the commutator bars.

In each of these cases the remedy will be obvious. It should be remembered that the insulating material between the bars of the commutator should be recessed slightly below the surface of the bars.

2. *Sparking at brushes*, may be due to unsuitable material of the brushes, badly "bedded" brushes, unsuitable spring pressure behind the brushes, brushes may be covered with dust, or grease, or oil, etc., a loose

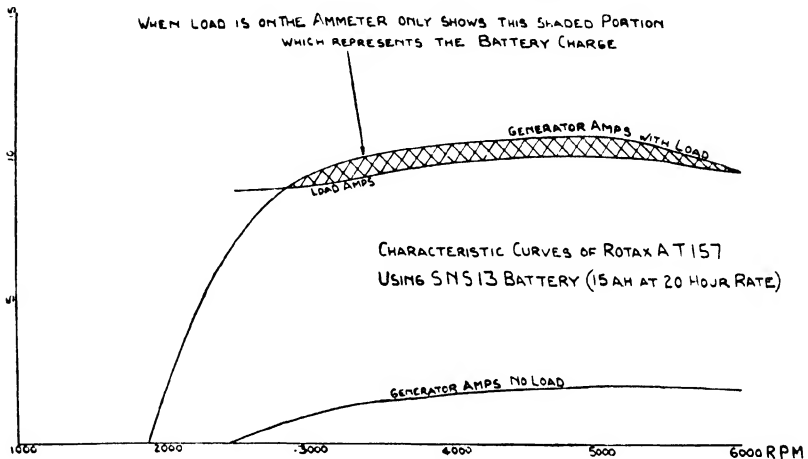


FIG. 29

connection between a commutator bar and the armature winding, a break in the armature winding, or too high a generator speed.

3. *Commutator burnt* or covered with a black coating. This fault is often due to the brushes being of too soft material, which is decomposed, and covers the commutator with a film which increases the contact resistance, thus heating the brushes and commutator. The treatment of the commutator and carbon brushes, and the quality of the latter, will have a great influence on the sparkless running of a continuous current machine. The different sorts of carbon brushes show great differences in quality, hardness, and conductivity, so that a machine will work best with a particular sort of brush. Generally speaking, machines for high voltages will work best with hard carbons, while for low voltage machines soft carbons are more suitable.

4. *Failure to generate* is often due to loss of residual magnetism, which may be caused by violent vibration, or a reversal of the magnetism which has been insufficient to build up a residual field in the opposite direction. To build up the magnetism again, send a current from an external source through the field coils. A reversal of field connections, or change in direction of rotation, will produce similar symptoms of a failure to generate, as also will poor contact between brushes and commutator, or too low a speed of rotation.

Whilst the foregoing may be regarded as a résumé of the usual type of faults found in machines of standard design, it will be appreciated that proprietary makes of dynamo and allied electrical equipment may be liable to disorders peculiar to each, and due to the special feature of design introduced by the makers. The following notes on location and remedy of troubles are therefore reproduced in full by courtesy of Rotax Ltd., from their Instruction Booklet No. 229.

CONSTANT CURRENT TYPE DYNAMOS

Symptoms	Probable Fault	Remedy
Ammeter fails to indicate charge when running with no lights in use, or gives heavy discharge with lights on.	Dynamo not charging, due to: broken or loose connection in charging circuit causing field fuse to blow.	Examine charging circuit wiring. Tighten loose connection or replace broken lead. Particularly examine battery connections. Fit replacement fuse.
	Commutator greasy or dirty.	Clean with soft rag moistened in petrol.
	Reversed polarity due either to dynamo having been motored with field switch (charge) "off" or the battery being accidentally connected the wrong way round.	Move charge switch and lighting switch to "on" position, and run dynamo normally. If trouble is not cured, short field fuse with a length of wire, and with lighting switch and charge switch still "on," motor the armature by shorting terminals 5 and A on the cut-out. The dynamo should then function correctly. Remove short circuiting wires and replace fuse.
Ammeter gives low or intermittent charge reading.	Dynamo giving low or intermittent output, due to—	
	Loose or broken connections in dynamo circuit.	Examine charging circuit wiring. Tighten loose connections or replace broken lead. Particularly examine battery connections.
	Commutator or brushes greasy.	Clean.
	Brushes worn, not fitted correctly, or wrong type.	Replace worn brushes. See that brushes "bed" correctly.

CONSTANT CURRENT TYPE DYNAMOS—(contd.)

Symptoms	Probable Fault	Remedy
Ammeter gives high charge reading.	Dynamo giving high output due to—	
	Loose connections in dynamo charging circuit.	Examine charging circuit wiring. Particularly battery connections. Tighten loose connections.
	Battery acid level low.	"Top up" cells with distilled water.
	Brushes not fitted correctly.	See that brushes "bed" correctly.
	Control brush position altered.	Have control brush adjustment re-set.
Lamps give insufficient illumination.	Battery discharged.	Charge battery either by a long period of daytime running or from independent electrical supply.
	Bulbs discoloured through use.	Fit new bulbs.
Lamps light when switched on, but gradually fade out.	Battery discharged.	As above.
Brilliance varies with speed of plane.	Battery discharged.	As above.
	Battery connection loose or broken.	Tighten connections or replace faulty cables.
Lights flicker.	Loose connection.	Locate loose connection and tighten.
Failure of lights.	Fuse blown.	Examine wiring for faulty cables and remedy. Fit replacement fuse.
	Battery discharged.	As above.
	Loose or broken connections.	Locate and tighten loose connections or remake broken connection.

CONSTANT VOLTAGE TYPE DYNAMOS

Symptoms	Probable Fault	Remedy
Ammeter fails to indicate charge when running with no lights in use, or gives heavy discharge with lights on.	Dynamo not charging due to: broken or loose connection in charging circuit or regulator out of adjustment, causing field fuse to blow.	Examine charging circuit wiring. Tighten loose connection or replace broken lead. Particularly examine battery connections. Fit replacement fuse. Return regulator to Service Depot for adjustment.
	Commutator greasy or dirty.	Clean with soft rag moistened in petrol.
Ammeter gives intermittent charge reading.	Dynamo giving low or intermittent output, due to—	
	Loose or broken connections in dynamo circuit.	Examine charging circuit wiring. Tighten loose connections or replace broken lead. Particularly examine battery connections.
	Commutator or brushes greasy.	Clean.
Ammeter gives excessive charge reading.	Brushes worn, not fitted correctly, or wrong type.	Replace worn brushes. See that brushes "bed" correctly.
	Dynamo giving high output due to—	
	Regulator out of adjustment.	Return regulator to Service Depot for adjustment.
Lamps give insufficient illumination.	Bulbs discoloured through use.	Fit new bulbs.
Brilliance varies with speed of plane.	Battery connection loose or broken.	Tighten connections, or replace faulty cables.
Lights flicker.	Loose connection.	Locate loose connection and tighten.
Failure of lights.	Fuse blown.	Examine wiring for faulty cables and remedy. Fit replacement fuse.
	Loose or broken connection.	Locate and tighten loose connection, or remake broken connection.

Location and Remedy of Troubles

Although every precaution is taken to eliminate all possible causes of trouble, failure may occasionally develop through lack of attention to the equipment, or damage to the wiring. The most probable faults are tabulated, according to the symptoms which are displayed, in the foregoing fault-finding tables.

A few hints on the best way to make use of these tables are given, as the sources of many troubles are by no means obvious. In some cases, a considerable amount of deduction from the symptoms is needed before the cause of the trouble is disclosed.

Much evidence can be gained from the ammeter. If, for instance, no charge reading is indicated when the engine is running with the charging switch in full charge position and the load "off," the dynamo is failing to charge. To ensure that the ammeter is not at fault, the lights should be switched on, while the plane is stationary, when a reading on the discharge side of the scale should be observed. Again, if the maximum ammeter reading is much below normal when the dynamo is charging, or if the needle fluctuates when the engine is running steadily, a low or intermittent dynamo output can be suspected. The dynamo may have been neglected, and the trouble could be caused by, say, worn brushes or a dirty commutator.

Should the intensity of the lights vary, or should they fail entirely, it is probably due to the battery terminals being allowed to corrode and the consequent breaking of a connection. If the cause of the trouble is not located at the battery, the switchboard should next be examined; particularly, see that all the terminals are quite tight. If one particular lamp does not light, look for a broken filament or a loose connection at the lamp. When the plane is stationary and the lamps light when switched on, but gradually go out, the battery is probably exhausted.

Wiring*

All cables and wires used for electrical purposes on aircraft must be manufactured in accordance with an approved specification, and must be installed in accordance with an approved installation drawing or diagram. Cables manufactured in accordance with B.S. Specification E.3. or D.T.D. Specification E. & I. 351 and others are already approved. Only cables consisting of multi-stranded conductors of high conductivity tinned copper wires, with an adequate covering of high-grade insulating material, and a satisfactory external protection against mechanical damage, are likely to obtain official approval. It must be remembered that electrical wiring in aircraft is subject to the very insidious and destructive effects of vibration and extremes of weather and temperature, and for these and other reasons it is essential that the very greatest care be taken with their installation. The principal points to be observed are—

1. No joints in cables are permitted, except by means of approved type terminal blocks.
2. All cable ends must be properly prepared and finished off.
3. Where cable ends are soldered, only flux consisting of resin, or resin dissolved in methylated spirit, may be used. This is to avoid the gradual corrosive effects produced by most other fluxes. Such corrosive effects are very insidious and are often only detected by the gradual breaking off of the strands of wire near to the soldered end, thus resulting in decreased conductivity and heating up of the remaining strands.
4. Every strand of the conductor must be brought into circuit. Under

* Based upon Inspection Leaflet 19 of A.P. 1208 and reproduced by kind permission of the Controller, His Majesty's Stationery Office.

no circumstances may the conductivity of a conductor be reduced by cutting off a certain number of strands in order to accommodate the remainder in a terminal which is really too small for its proper duty. Every care must be taken to protect cables where they pass over sharp edges of wood or metal, or through holes which are not properly flared or bushed. Short lengths of systoflex, or similar protective tubing, may be used.

5. Cables should be cleated at frequent intervals, say 8 in. to 12 in., depending on circumstances. A short piece of systoflex or similar tubing should be slipped over the cables under each cleat.

6. Cables should be cleated sufficiently close to the ends to prevent any mechanical pull coming on to the conductors at the connections in the terminals.

7. Particular care should be taken with cables passing through open cockpits to protect them from accidental damage due to movements of passengers or crew, from petrol, dope, and oil, and from the effects of rain or weather.

8. It is always a good plan to run cables in light metal ducts, which support them throughout their length, but care must be taken to avoid all sharp edges in the ducts, and to provide them with adequate ventilation to avoid any possibility of moisture condensing within them. If necessary, drainage holes should be provided.

9. General service circuits (lighting, heating, etc.), should be installed in the aircraft as remote as possible from the wiring of W/T circuits, in order that the danger of interference with W/T communications may be reduced to a minimum.

10. Items of electrical equipment containing permanent or electro magnets, or strongly magnetic solenoids, must be installed at a sufficient distance from the navigating compass to avoid the introduction of errors into the readings of the latter. For a similar reason, electric cables must be "paired," i.e. positives and negatives run together in such a way that the inductive effects of one are neutralized by the inductive effect of the other, or, if run singly, they must be kept well away from the compass.

After completing the wiring on the aircraft, due care having been given to the foregoing points, and all connections to lamps, instruments, etc., being completed, it is necessary to apply tests to the installation to verify connections and standard of workmanship. The necessary tests are three in number, viz. (a) insulation tests; (b) continuity test; and (c) operational test.

INSULATION TESTS

These should be carried out with a 500-volt megger, and the results obtained in each case, after a continuous application of the test pressure for at least one minute, should not be less than the value obtained from the formula

$$\frac{20 \text{ megohms}}{\text{No. of points in circuit}}$$

subject to a minimum value of the insulation resistance obtained by this formula of 2 megohms. Circuits under test should be closed at the switches, but have lamp bulbs, and similar detachable items, removed. The insulation tests are taken in two stages, viz. (i) a test for insulation resistance "between poles" of all circuits. The test involves the connection of the two megger terminals to the two sides respectively of each circuit or sub-circuit in turn. A number of circuits or sub-circuits may be bunched together if convenient, the object of the test being to verify that the

insulation between positive and negative poles of all circuits is satisfactory. Should a low reading be obtained when testing a "bunch" of circuits simultaneously it will be necessary, of course, to separate the circuits and test each individually in turn to locate the defective one, and then to trace and rectify the fault. (ii) A test for insulation resistance to "earth." For the purpose of this test one terminal of the megger is connected to "earth," i.e. the metallic structure of the aircraft, the other terminal being connected in turn to one end of each separate length of insulated conductor in the installation. A multi-core cable must be tested at one end of each core. In this case, the object of the test is to verify that every conductor is sound and has not been damaged in such a way as to permit connection between that conductor and the structure of the aircraft.

It may be as well to mention here that it is a definite Air Ministry requirement that all electrical circuits on aircraft must be of the double pole insulated type, i.e. "earth return" circuits are not permitted. The single exception to this rule concerns the low tension magneto control circuit, where, under certain circumstances, an "earth return" is permitted.

CONTINUITY TEST

All wiring is to be tested from point to point, using a battery and either a bell or a lamp as indicator, the smaller sizes of wires being subjected to a slight tension whilst undergoing this test. The bell or lamp used for this test should carry a reasonably heavy current, so that, in the event of a poor or intermittent contact occurring anywhere in the circuit, the relatively heavy current required by the bell or lamp will have difficulty in passing, and the chances of detecting the fault thereby increased. A current of 2 to 3 amperes is desirable.

OPERATIONAL TEST

An accumulator of the appropriate voltage is to be temporarily connected to the relevant accumulator leads, and all switches, etc., operated several times to ensure that each circuit of the system is working satisfactorily and is unaffected by the working of any other circuit. On completion of inspection and testing, all necessary records should be made and certified in the aircraft inspection record.

The following table shows the usual types of circuits in use on aircraft, and some of the appropriate approved specifications of wires which may be used in connection therewith.

LOW TENSION CIRCUITS

Unscreened. (1) For general service and wireless circuits in fuselages and wings where special protection against weather, petrol, oil, mechanical damage, etc., is not required.

Spec. B.S. E.3. Section I. (Glazed cotton braided flexible cords and cables.)

Spec. R.D. Inst.I.M. D.3667-4-50 G.B. (Cellulose varnished.)

(2) As for (1) but where a reasonable amount of additional protection is required.

Spec. R.D. Inst.I.M. D.3667-4-50 G.B. (Cellulose varnished.)

Spec. B.S. E.3. Section II. (Flexible cords and cables with water-proof covering.)

(3) As for (1) but where maximum protection is required, e.g. cables exposed outside fuselage to slipstream, also low tension ignition leads.

Spec. B.S. E.3. Section IV. (Flexible cords and cables with cab tyre sheathing.)

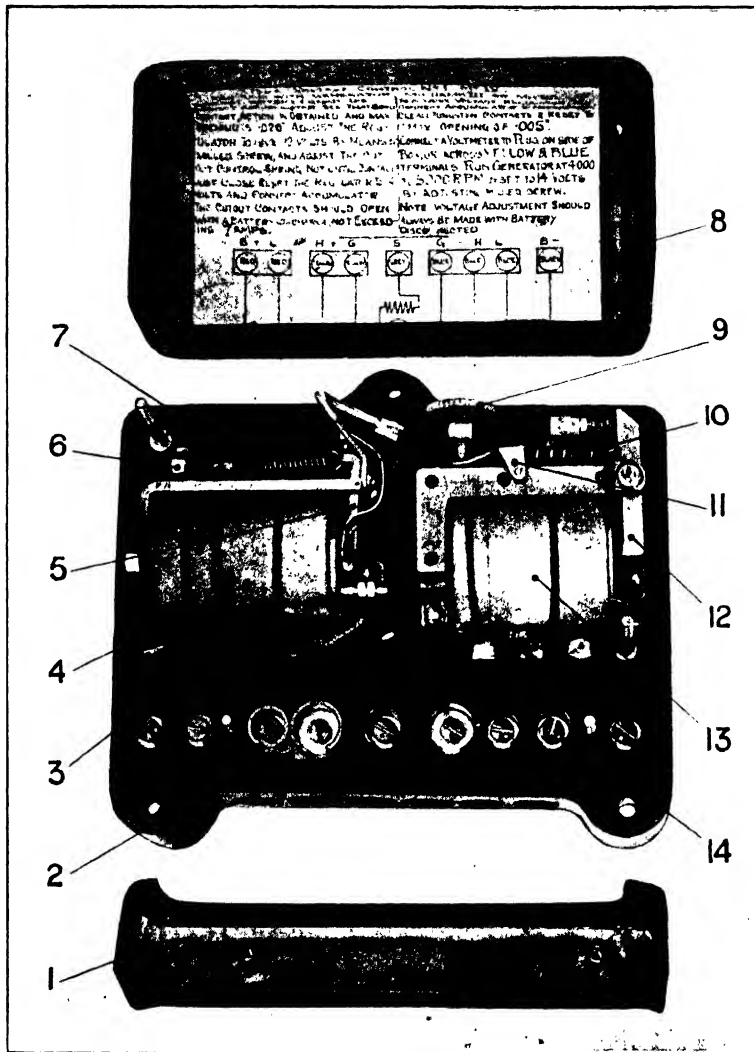


FIG. 30. R.A.F. No. 1, MARK IV, VOLTAGE REGULATOR AND BATTERY CUT-OUT

(From A.P. 1095, by courtesy of the Controller of His Majesty's Stationery Office)

Screened. (1) For general service and wireless circuits in unexposed positions and requiring screening.

Spec. A.M. Specification E. & I. 351. (The "met" series, i.e. all cable names terminate in the suffix "met.")

Spec. A.M. Specification E. & I. 352. (With rubber sheathing over the metal braiding.)

(2) As for (1) but for use in more exposed positions, and for ignition circuits.

Spec. B.S. E.3. Section V. (Flexible cords and cables with cab tyre sheathing and metal braiding.)

HIGH TENSION CIRCUITS

Unscreened. Ignition leads to sparking plugs; aerial reel to transmitter-receiver; starting magneto to main magneto.

Spec. B.S. E.I. Section I. (Plain rubber finish cable.)

Spec. A.M. Specification E. & I. 309. (Rubber and varnished cotton braided.)

Screened. Ignition leads to sparking plugs and starting magnetos to main magnetos.

Spec. B.S. E.1. Section II. (Metal braided cables.)

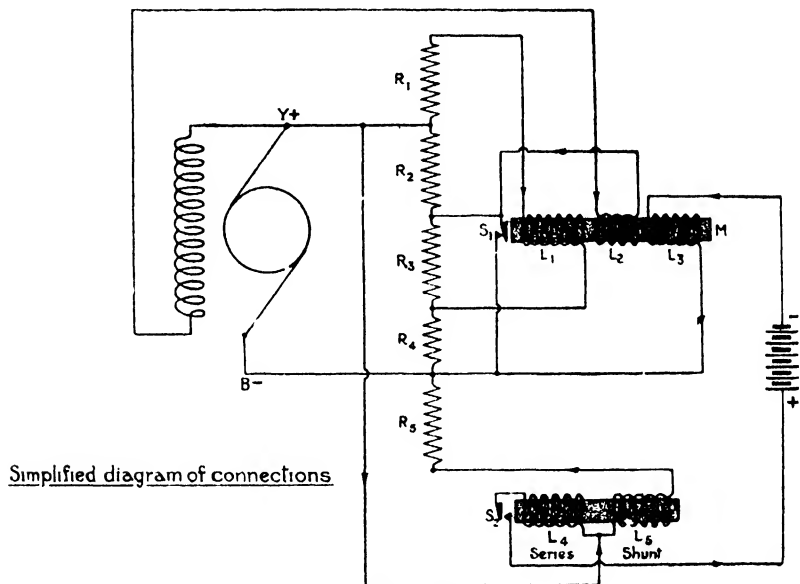


FIG. 31. R.A.F. NO. 1, MARK IV, VOLTAGE REGULATOR
(From A.P. 1095, by courtesy of the Controller of His Majesty's Stationery Office)

Voltage Regulators

A plain shunt-wound dynamo which is driven at a varying speed obviously requires some means of maintaining its voltage at a constant value, or confined within very narrow limits, and on aircraft this object is usually achieved by means of an automatic voltage regulator operating on what is known as the Tirril principle. Such regulators are normally installed in a vertical position in the cockpit, or in some other position where they can be conveniently inspected and adjusted, since they contain a vibrating armature and contact points which require occasional cleaning and adjustment.

The R.A.F. Mark IV type regulator, which is available for use on civil aircraft, consists in its essentials of an electro-magnet, with a spring-loaded armature, and various resistances for smoothing and other purposes. It

also contains a battery cut-out, which will be dealt with separately. Referring to Fig. 31, the electro-magnet is indicated at M , and is energized by the two coils L_1 and L_2 . L_1 is connected across the generator armature through the resistances R_1 and R_4 , while L_2 carries the generator field current and acts in opposition to L_1 . When the generator is started up, the contacts S_1 are closed. The resistances R_3 and R_4 are thus short-circuited, and the negative end of the generator field is connected to "B -" through the coil L_2 , so that the generator builds up on full field except for the negligible voltage drop across L_2 .

When the generator voltage reaches a certain predetermined value, the electro-magnet M attracts a small soft iron armature against the pull of a control spring, thus opening the contacts S_1 . The resistances R_3 and R_4 are thereby inserted in the generator field circuit, thus reducing the generator field current and causing the generator voltage to fall. When the voltage has fallen by a certain amount, the contacts S_1 are closed by the control spring, which overcomes the weakening attraction of the soft iron armature by M . This causes the voltage to rise again, and the cycle of operations is repeated. An approximately constant mean voltage is thus maintained at any load and speed within the capacity of the generator.

By connecting the coil L_1 to the junction of the resistances R_3 and R_4 , a "bucking" effect is obtained. When the contacts S_1 open, an immediate reduction of current in coil L_1 is produced, due to the combined effect of the resistances, the effect of this being to speed up the operation of the regulator. This improves the steadiness of operation, especially on load, and materially reduces the amplitude of the voltage ripple caused by the regulator. The resistance R_1 has a negligible temperature coefficient and acts as a series swamping resistance to the coil L_1 . By this means the effects of temperature changes on the controlled voltage are very greatly reduced.

The "bucking" effect described above is dependent upon the periods of time during which the contacts are opened and closed, which in turn depend upon the mean field current required to meet the generator condition. As this field current depends upon speed and load conditions, the controlled voltage will vary from this cause. This variation is almost entirely eliminated by the addition of the compensating coil L_2 , which carries the generator field current, and which is connected so that it opposes the main winding L_1 . The coil L_2 is a low resistance winding connected in series with the external battery so that it carries only the battery current. The coil is so connected that when charging current is passing it assists the winding L_1 and causes a reduction in the generator voltage, thus tending to limit heavy charging currents into a partly discharged accumulator. When the system is functioning normally, and the battery is floating, no current is passing through coil L_2 , and the voltage is that of the regulator setting. If a heavy external load on the generator tends to cause discharge from the battery, the current through the coil causes the generator voltage to rise until the generator takes over the load and the battery is again floating. The winding thus exerts a stabilizing influence. It is essential to reduce sparking at the contact point to a minimum in order to maintain good voltage regulation and to reduce as far as possible the serious interference which would otherwise be caused to the operation of any nearby wireless installation. A regulator usually requires but little attention, and this would consist of cleaning and burnishing the contact points, and slight adjustment of the spring tension on the armature to compensate for wear at the contact points. When testing or adjusting a regulator the aircraft should be "run up" on the ground, and the following procedure carried out—

- (i) Disconnect the battery.
- (ii) See that all load circuits are switched off.
- (iii) A voltmeter should be connected across the terminals to which the main positive and negative leads from the generator are attached.
- (iv) Run up the engine to start up the electrical generator.
- (v) Gradually increase the engine speed until a steady maximum voltage is obtained. This voltage should be 14 volts.
- (vi) In order to check the operation of the regulator, increase the speed of the engine further and see that the voltage remains constant at 14 volts.
- (vii) Re-connect the battery, and speed up the engine to obtain a steady operating voltage. See that the battery cut-out is closed; this will be indicated by a slight charging current shown on the battery ammeter.
- (viii) Stop the engine, and see that the battery cut-out opens with a discharge current not exceeding 7 amperes.

If the above tests show that the regulator is out of adjustment, the following instructions should be carried out—

- (i) Disconnect the battery leads.
- (ii) Remove the small pivoted armature and the fixed contact screw.
- (iii) Clean and burnish the contact faces, and replace armature and contact screw; see that contact faces are parallel after refitting.
- (iv) Set the contact gap to a maximum opening of .005 in. and tighten lock nut on fixed contact.
- (v) Connect a voltmeter across yellow and blue terminals, run the generator at 4,000–5,000 r.p.m. and set regulator to 14 volts by adjusting knurled screw. Voltage adjustment should always be made with battery disconnected. When the voltage regulator arm has been removed during an overhaul, care must be taken on reassembly to ensure that the bearings are adjusted so that the arm is free to rock with just perceptible side play.

Battery Cut-out

This is a device which is connected between the accumulator and the generator. Its duty is to disconnect the accumulator from the generator at all times when the voltage of the latter is below that of the former, thus preventing the accumulator from discharging itself through the windings of the generator but connecting it to the generator again when this has attained a voltage sufficiently high to ensure the passage of a charging current.

In some electrical installations on aircraft the battery cut-out is installed as an isolated item of equipment, whilst in others it is combined with the voltage regulator. The combination of the two instruments, however, merely consists of mounting them together on a common base, and under a common cover. Electrically, they are quite independent, and the



FIG. 32. "A" TYPE CUT-OUT 12 OR 24 VOLTS

Length $6\frac{1}{2}$ in. Width 4 in.
Projection $2\frac{1}{8}$ in. Weight $2\frac{1}{2}$ lb.
Supplied suitable for use with either 12 or 24 volt equipment, this cut-out is suitable for loads exceeding 150 watts. It is a high-class instrument and thoroughly reliable.

(Rotax Ltd.)

operation of one is not in any way affected by the operation of the other. For purposes of convenience, the cut-out which is normally supplied with the Mark IV voltage controller is here described.

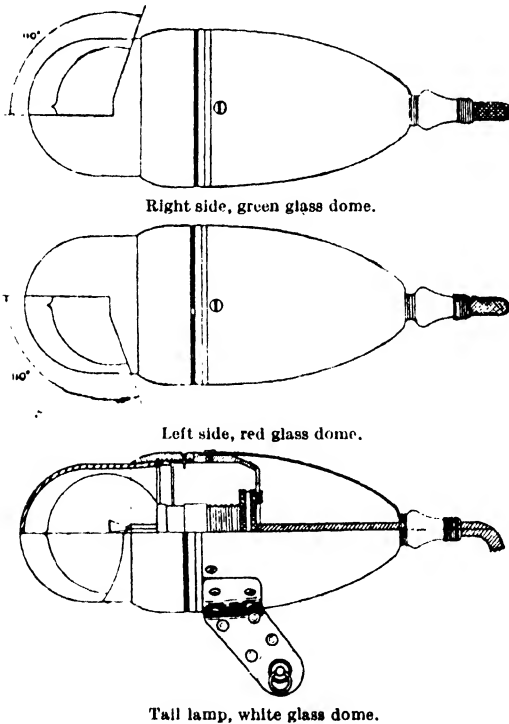


FIG. 33. "F" TYPE CUT-OUT 12 VOLT
 Overall length 3½ in.
 Width 3¼ in.
 Projection 2¼ in.
 Weight 13 oz.
 This automatic cut-out is suitable for use with dynamos up to 150 watt output. (Rotax Ltd.)

Referring to Fig. 31, the cut-out solenoid carries two windings L_4 and L_5 , L_4 being in series with the battery load, while L_5 is a shunt coil connected across the generator armature in series with the resistance R_5 . When the generator is started up the contacts S_2 are open. As soon as the voltage reaches a certain value, the solenoid core attracts a small iron armature and closes S_2 , thus joining the battery positive to generator positive; the battery is then connected across the generator armature through the coil L_3 on the regulator and the series cut-out coil L_4 , which is wound so that it assists the shunt coil L_5 . If, for any reason, a reverse current passes, due to the battery discharging into the generator, the series coil L_4 opposes the shunt

coil and S_2 opens, thus disconnecting the battery.

The swamping resistance R_5 is connected in series with L_5 to reduce



Tail lamp, white glass dome.

FIG. 34

(By courtesy of Vickers (Aviation), Ltd.)

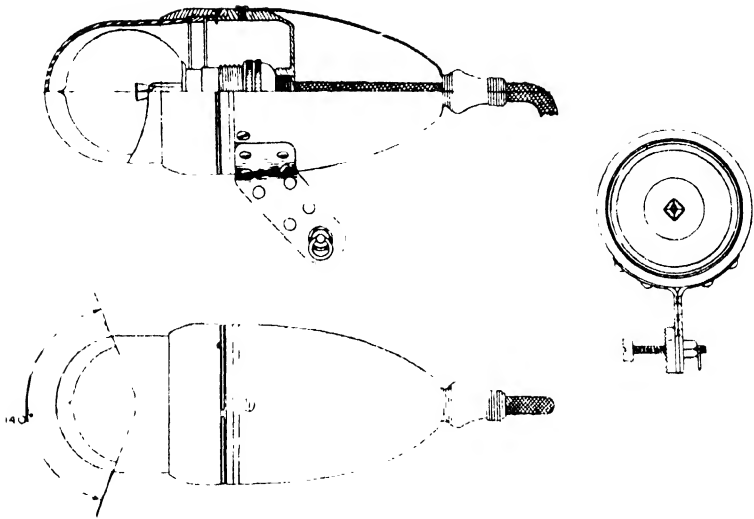


FIG. 35. TAIL LAMP
(By courtesy of Vickers (Aviation), Ltd.)

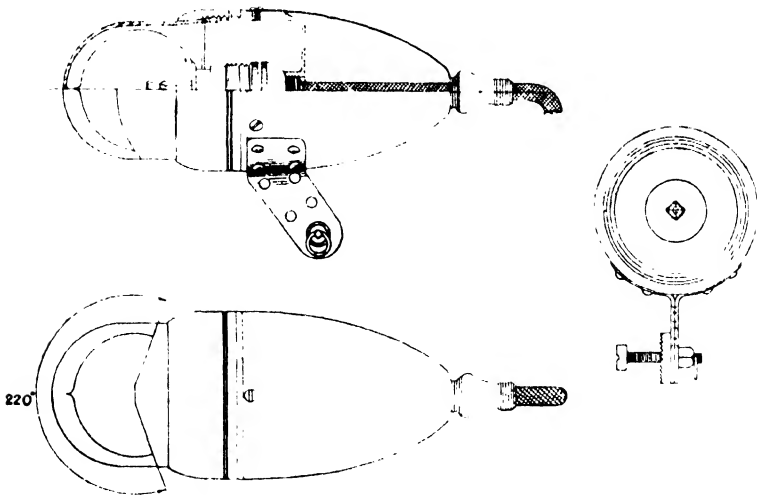


FIG. 36. HEAD LAMP
(By courtesy of Vickers (Aviation), Ltd.)

the effect of temperature variation, and ensures that the cut-out functions within the voltage limits set by the accumulator and voltage regulator. The resistance R_2 in series with L_2 is permanently connected across the generator field, and thus fulfils the purpose of the field shunt, previously employed as a separate component to improve the performance of the generator and to assist regulation.

Adjustment of the battery cut-out is carried out as follows --

- (i) Disconnect accumulator.
- (ii) Examine cut-out contacts, and clean if necessary.
- (iii) Set contact gap to .02 in. maximum.
- (iv) Adjust the regulator to give 12 volts by means of knurled screw.
- (v) Adjust cut-out control spring until contacts just close.
- (vi) Re-set the regulator to 14 volts and connect accumulator.
- (vii) The cut-out contacts should open with a maximum battery discharge of 7 amperes.

Navigation Lights

The International Commission for Air Navigation (October, 1928) lays down the following regulations for the lighting of aircraft at night--

FOR LANDPLANES

(a) *Right Side Lamp.* On the right side a green light dispersed over an angle of 110 degrees and visible at a distance of 8 km. (Fig. 34).

(b) *Left Side Lamp.* On the left side a red light dispersed over an angle of 110 degrees and visible at a distance of 8 km. (Fig. 34).

The lights (a) and (b) above shall be so fitted that the green light shall not be visible from the left side nor the red light from the right side.

(c) *Tail Lamp.* As far aft as possible a white light shining rearwards, dispersed over an angle of 140 degrees and visible at a distance of 5 km. (Fig. 35).

Tail navigation lamps are frequently installed on the trailing edges of rudders, and where this practice is adopted it is important that the effect of installing such a lamp in this position, or of changing the type of this lamp after first installation, is carefully considered in connection with recent Air Ministry requirements regarding the mass balancing of control surfaces.

SEAPLANES AND FLYING BOATS

In addition to the lights used on landplanes, i.e. the right, left, and tail lamps, the following shall be carried--

(d) *Head Lamp.* As far forward as possible a white light dispersed over an angle of 220 degrees and visible at a distance of 8 km. This light is to be used when the aircraft is manoeuvring on the water under its own power, and should be extinguished when the aircraft is in the air (Fig. 36).

(e) *Anchor Lamp.* In a position where its light can be seen in all directions at a distance of 2 km., every flying machine anchored or moored on the water shall carry a white light (Fig. 37).

(f) *Out-of-control Lamps.* In a position where its lights shall be seen in all directions at a distance of 3 km., every flying machine out of control on the water shall carry two red lights 2 metres apart and one over the other (Fig. 38).

SEAPLANES AND FLYING BOATS HAVING A WING SPAN OF OVER 50 METRES

The following regulations as to lighting apply to the above--

- (g) On each lower wing tip, in addition to any other lamps required

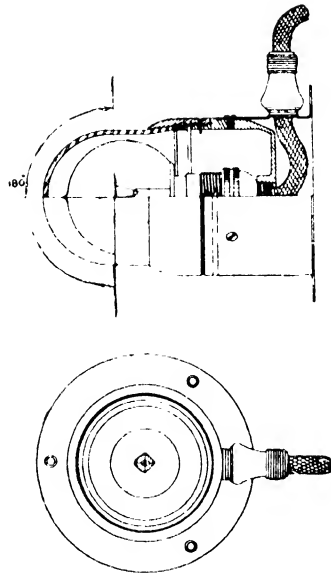
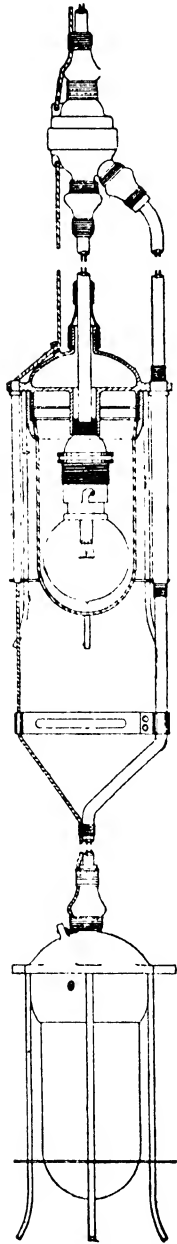


FIG. 37. ANCHOR LAMP
(By courtesy of Vickers (Aviation), Ltd.)

FIG. 38. OUT-OF-CONTROL LAMPS
(By courtesy of Vickers (Aviation), Ltd.)
3-(A.6)

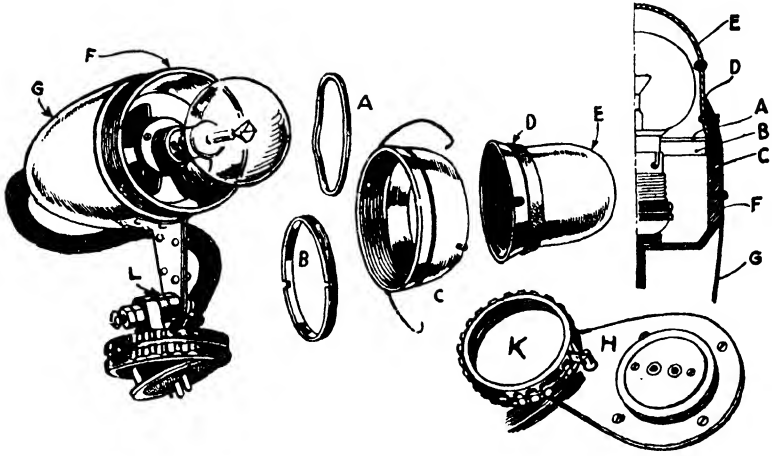


FIG. 39. VICKERS-DAVIS TYPE NAVIGATION LAMP

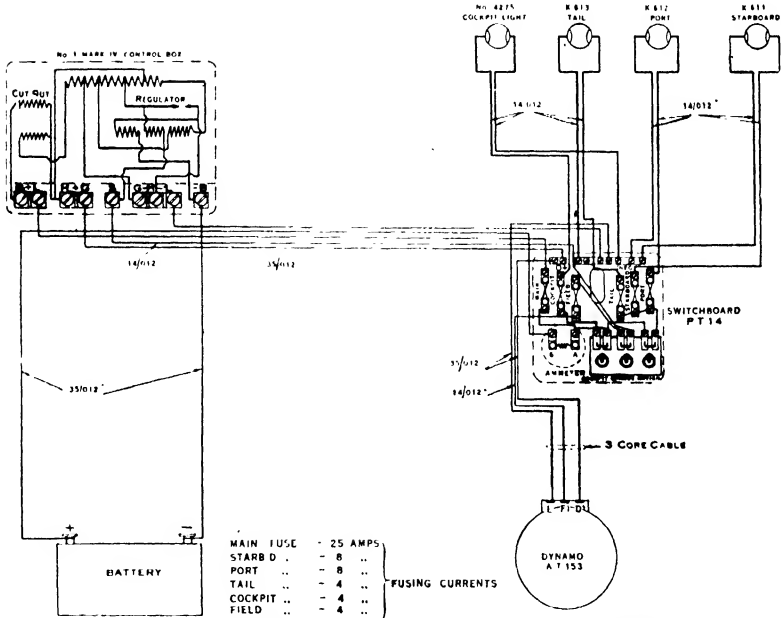


FIG. 40. TYPICAL WIRING DIAGRAM, WITH ROTAX DYNAMO AND SWITCHGEAR AND R.A.F. No. 1, Mk. IV, VOLTAGE REGULATOR AND BATTERY CUT-OUT

by the regulations, a white light showing in all directions shall be carried by aircraft of such wing span when at anchor or moored on the water.

(h) Near the stern of the aircraft and at a height of not less than 5 metres lower than the head lamp a white light visible in all directions shall be carried by aircraft of such wing span when at anchor or moored on the water.

The anchor light illustrated in Fig. 37 conforms with the above regulations.

POSITION OF LAMPS

Right and Left Side Lamps. To be fixed at the extremity of the wing tips so as to denote the complete span. In a biplane the lamps would be fitted to the top plane when this is the larger.

Head and Tail Lamp. To be fixed so as to show the extreme length of the aircraft, or as nearly so as possible.

In certain types, such as central engined seaplane, the head lamp is usually carried on the leading edge of the wing in the central line of the aircraft.

Anchor Lamp. To be fixed to the highest point of the structure of the aircraft so that an unbroken light may be shed. The front main spar in the top centre section main plane and on the centre line of the aircraft is usually found to be the best position.

Out-of-control Lamps. To comply with the regulations, a small mast is necessary so that the lights may be seen in all directions. The lights can be plugged into a socket provided in the wiring system.

Construction and Installation

Figs. 34 to 39 show one series of lamps which has been officially approved as satisfying the regulations of the International Commission.

Head, tail, right and left side lamp bodies are all interchangeable, the only alteration to suit the position in which the lamp is to be employed being the change of the glass dome, and of the metal spinning forming the tail fairing.

The colours are burnt into the glass dome so that damp or heat do not affect them.

Fig. 39 gives the general details of the lamps, which are attached to the aircraft by a metal (aluminium or gunmetal) baseplate *H* by four screws or bolts and wired up to the connections shown thereon. A hinged cap screws over these connections to keep water, dust, etc., from them, and folds back when the lamp is fixed in position.

The body *F* and tail fairing *G* are made of aluminium, the dome housing *G* and locking ring *B* of duralumin.

The glass dome *E* is located and prevented from turning in the housing *C* by a grub screw, the dome being slotted to receive it.

D is a rubber band which protects the dome in its housing, the edge of the dome being further protected by another rubber ring *A* interposed between it and the locking-ring *B*. The glass dome is forced against the sloping face of the housing by screwing up the locking-ring *B*, which then holds it in position.

The housing ring *C* is screwed on the body *F* and locked with a circlip.

The lamps are provided with a considerable angular adjustment in a vertical plane by means of the nuts and interlocking teeth at *L*. No adjustment in a horizontal plane is provided and the position of the lamp in this respect is governed by the position of the baseplate *H*, which therefore has to be carefully regulated during its original installation.

Landing Lights

For the purpose of facilitating the landing of aircraft by night it is usual to provide on the aircraft some source of illumination under the control of the pilot, which will aid him to see whether the ground is free of obstructions and to enable him to judge his approach to the best advantage. Where flying after dark is a matter of routine the terminal aerodromes are normally equipped with adequate facilities on the ground for giving the necessary illumination, and the pilot may or may not decide to use the lights provided on his craft. Such lights on the aircraft, how-

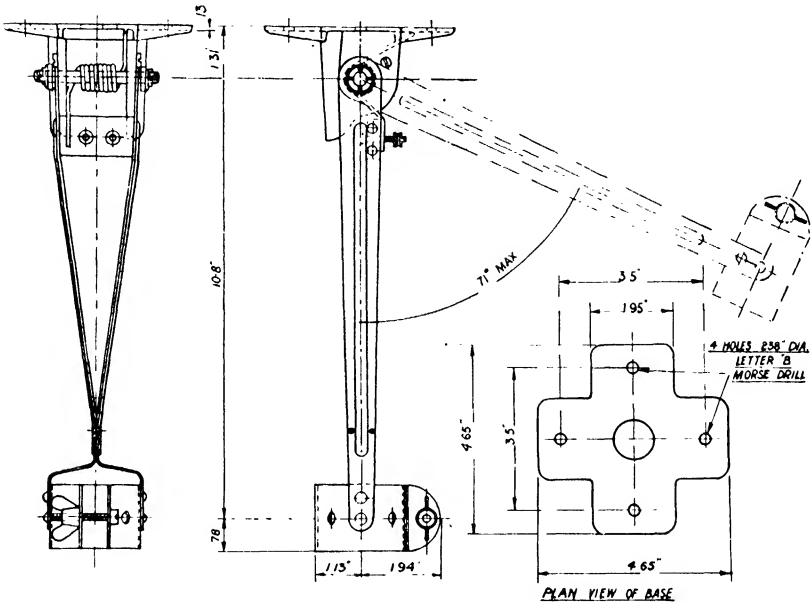


FIG. 41. BRACKET: WING-TIP FLARE, R.A.F. TYPE
(Royal Air Force Official, Crown Copyright Reserved)

ever, should always be carried and maintained in good condition, as they are liable to be required for use at any time in the case of a forced landing.

Lights provided on aircraft to facilitate night landing are of two distinct types, viz. the incandescent electric lamp type, and the pyrotechnic, or flare type. The former have the advantage of being under the control of the pilot at all times, and to be free from dazzling effects. On the other hand, their field of illumination is restricted, they are heavy, and they require a large supply of current. They may be mounted almost anywhere on the aircraft, either externally on brackets, or internally behind a suitably placed "window." They may be fixed to throw a beam in one direction, or they may be mounted on trunnions so that the pilot, by means of suitable remote control gear, may direct the beam at will anywhere within a somewhat restricted field. The lamps require a heavy supply of current, and in order to avoid loss of illumination at a critical moment, such as during a slow glide in to land, it is essential to include an accumulator in the electrical system and not to rely solely on a generator, where output would diminish with loss of speed.

One approved lamp of this type is the Harley (Figs. 42 and 43), which may be obtained with either 6 in., 8 in., or 11 in. diameter reflector. Most types of Harley lamps incorporate a patent spring clip case which can be opened in a few seconds for bulb replacement, etc. The front assembly, containing the front glass, lenses, and rubber cushion is the fixed part of the lamp to which the brackets or fittings for mounting are attached. The

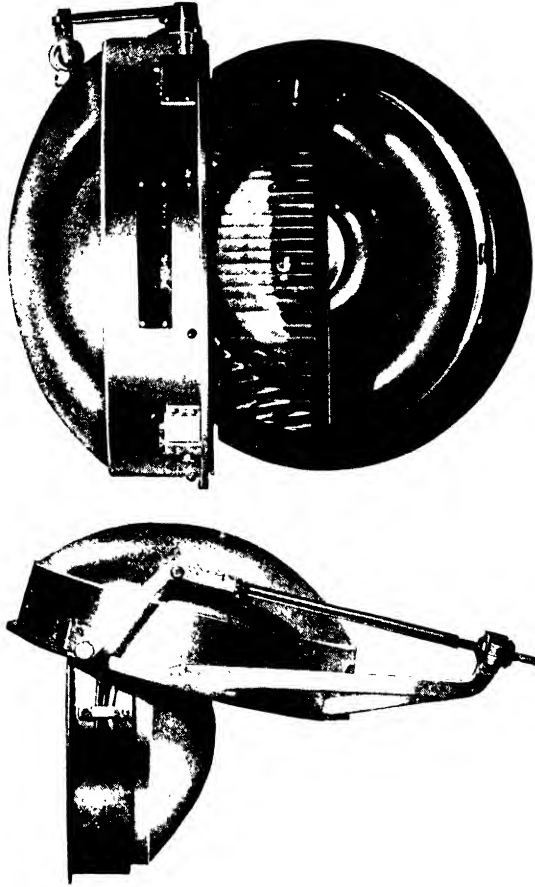


FIG. 42

rear assembly consists of the reflector, bulb, and tension elements for holding the two portions together. In lamps of the vertical dipper type, for the nose fairing of an aircraft, when access to the rear of the lamp is rendered difficult, a casing having a removable front glass is used. The front glass, which is paste sealed, is further secured by a face plate which has a rubber cushion to abut the nose fairing and is positioned by six set screws. The reflector and lenses are set at a number of degrees (6° - 9°) to the face plate and hinge assembly to obtain the correct offset of beam when the said face plate is square with the machine. The lamp is hinged at the bottom and dips in a vertical plane forward.

The wiring lay-out should be the shortest possible to reduce voltage drop. The switch should be placed conveniently near the battery or solenoid switching introduced. Cables should be selected to give a minimum voltage drop for weight, e.g. 110/36 cable to B.S.I. 5002. A fuse of double the bulb amperage should be incorporated in the system.

All lamps of this type normally give a wide spread beam with deep vertical section. The lamp bulbs used may be for 12-volt or 24-volt systems, single or double filament, and vary from 144 watts to 960 watts consumption and a life varying from 30 hours to 100 hours, but replacement should be carried out at approximately half the life.

The battery must be kept in perfect condition, especially if a generator is in circuit, to prevent the possibility of the filament being overloaded and

burnt out. In lamps of the double filament type the main and auxiliary filaments should never be lighted together. The special switch supplied by the makers is designed to prevent this.



FIG. 43

The pyrotechnic, or flare type of landing

light, has the advantage of greatly increased illumination, low weight, simple installation, and negligible current requirements, together with an unrestricted field of illumination. Their disadvantage, however, lies in the fact that, once ignited, they must be allowed to burn themselves out. They are also liable, if not carefully installed and shielded, to dazzle the pilot and thus actually increase the danger of a landing by night. The normal method of installation is to mount the flare in a hinged bracket secured under the lower plane towards the wing tip (Fig. 41). Special attention is directed to the Air Ministry Notice to Aircraft Owners and Ground Engineers No. 30 of 1931.

The Frazer-Nash Wing-tip Flare

Although most modern aerodromes and many emergency landing grounds are now equipped for night landings, there are obviously certain occasions—such as a forced night landing on an aerodrome not so equipped, or on unknown country—when some means of illuminating the ground is desirable. One practical method of achieving this is that which obtains the necessary illumination by the burning of a magnesium flare attached below the wing tips of the aeroplane, ignited at will by the pilot.

Naturally, the problem of designing a suitable method of attaching and operating these high-power flares presents many difficulties, especially that regarding the risk of fire either when the machine is at rest on the ground with the flare still burning, or in the event of a bad landing. In the Frazer-Nash Safety Enclosed Wing-tip Flare device, which is now being supplied to the British Air Ministry by Smith's Aircraft Instruments, special attention has been paid to these difficulties, and as the result of much experimental work a wing tip flare has been produced which is claimed to be as near perfection as possible.

The principal features and advantages of this flare are, briefly, as follows: All working parts are self-contained in a box which is let in flush with the under surface of the wing, and therefore does not offer any wind resistance during ordinary flight, or until the flare is actually in use. The fitting of the flare does not involve any structural alterations to the wings,

and its size is such that it can easily be accommodated between the ribs of the wing. It is operated electrically by two button switches in the cockpit, the contacts being so arranged that it is impossible for the flare to be ignited in the box or until the flare has reached the open position. On pressing one button the box opens and the bracket carrying the flare extends, and when fully extended the flare is ignited.

The device is provided, if required, with a folding glare shield which, together with the bracket, is mounted inside the box and opens out at the same time as the flare ignites. When operated the flare opens against the slip stream, and its operation is not affected by side slipping, climbing, or diving. The second button operates an electro-magnetic gear which enables the pilot to jettison the flare at will should occasion arise—an important

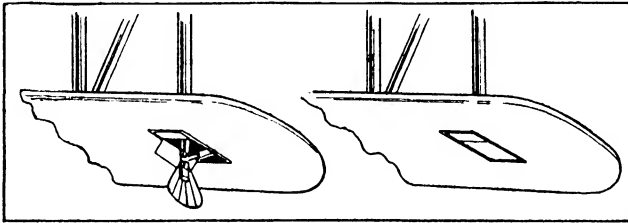


FIG. 43A. THE FRAZER-NASH WING TIP FLARE, OPEN AND CLOSED

feature, as it eliminates risk of fire, always present when landing with a fired flare which has not burnt out. It is impossible for the flare to be jettisoned until the bracket has reached its open position. The Frazer-Nash device is designed to take the ordinary "Holt" type flare, R.A.F. pattern, and this is simply inserted by pushing it into a shoe at the lower end of the bracket arm, no wiring up being necessary in fitting the flare once the device has been installed on the aircraft.

Fuse Boxes

These are safety devices introduced into a wiring system to eliminate risk of fire on an aircraft, and damage to equipment as a result of the occurrence of a short-circuit on the wiring system. It is always desirable to install a main fuse in both poles of the main circuit close to the source of power—the generator, in those cases where no accumulator is carried, and the accumulator, in those cases where only an accumulator or both an accumulator and a generator are carried. In the event of a short-circuit occurring between the main poles of a generator circuit the usual result is a momentary rush of current, followed immediately by loss of excitation of the generator, and consequent decrease or interruption of the generator current. In the case of a short-circuit occurring between the main poles of an accumulator circuit, however, the rush of current is sustained, and the consequent danger of fire is very considerably increased. In addition to the pair of main fuses, it is also desirable to subdivide the whole electrical system on the aircraft into sections, and to fuse each section separately. In the case of sectional fuses, however, it is permissible to provide a fuse in one side of the circuit only. Both main and sectional fuse units must be of the totally enclosed type, that is to say, the length of fuse wire must be totally enclosed in some form of container which will prevent any danger arising from the heating and melting of the wire. Spare fuse units should be carried in some convenient place on the aircraft, and all fuses should be clearly marked with the current at which they are designed to operate. The capacity of a fuse should be from 10 per cent to 50 per cent

in excess of the total current which might be expected to flow through it under normal circumstances, i.e. with all legitimate load switched on, the larger margin of 50 per cent being allowed in the case of lightly loaded

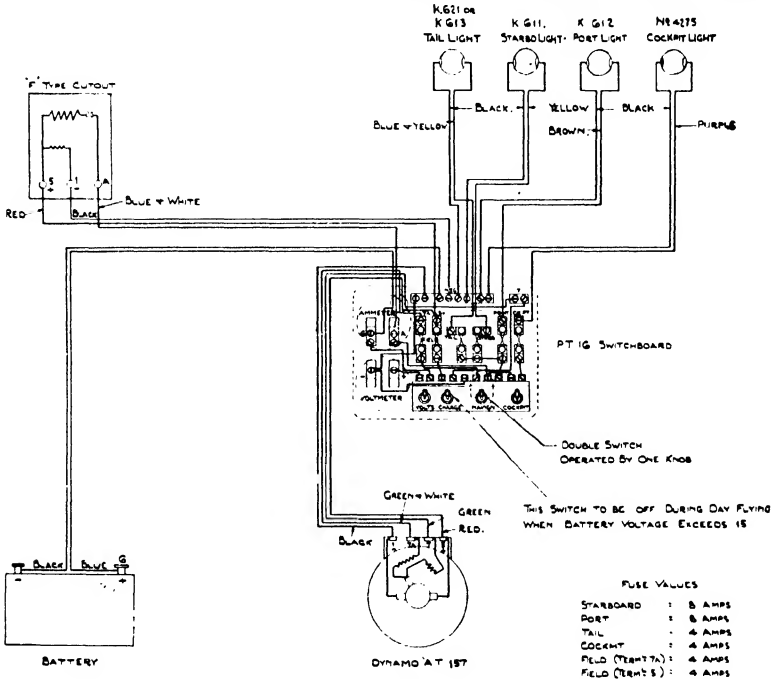


FIG. 44. TYPICAL WIRING DIAGRAM—ROTAX UNITS

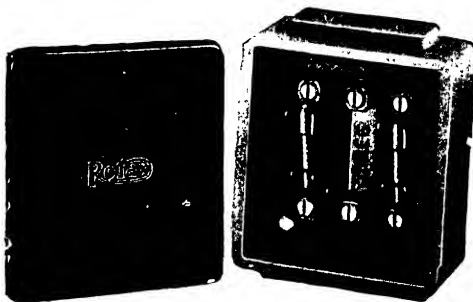


FIG. 45. TYPE G 2-WAY FUSE BOX

Length $3\frac{3}{4}$ in. Width $2\frac{1}{2}$ in. Height $1\frac{1}{2}$ in. Weight 9 oz.

circuits, and the 10 per cent margin in the case of heavily loaded circuits. The relationship of the total possible legitimate load to the safe carrying capacity of the wire concerned should also be taken into account in determining the margin of fuse capacity which should be allowed.

Plug and Socket Connectors (Fig. 50)

A plug and socket connector, manufactured and marketed by Messrs. Vickers, and constructed to Air Ministry design, has been developed to meet the demand for a device to enable electrical connections to be rapidly made or broken, and especially to enable items of electrical equipment to be rapidly removed from, or restored to, aircraft, without the usual laborious manipulation of cable connections to terminals. A particularly useful application is at the wing root joints on aircraft fitted with folding wings, where connections to wing tip flares and navigation lights have to be broken whenever the wings are folded.

Provision can be made for the entry of various types of cables, by using suitable collets. The five-pin and two-pin bases are interchangeable. The plug portion is detached from the socket by a spring con-



FIG. 46. P.T.12 Switch Box

Length 11½ in. Height 6½ in. Depth (overall) 2½ in. Weight 8½ lb.

This is similar in construction to the smaller P.T.14 type, but provides extra controls for the increased number of circuits necessary with large passenger-carrying aircraft. A voltmeter is fitted in addition to the central zero type ammeter, as will be seen from the illustration.

(By courtesy of Rotax Ltd.)

trolled bayonet lock; the socket portion is then made weatherproof by throwing over a spring loaded cap. The plugs are supplied in either duralumin or bronze, the latter being specially suitable for seaplanes and flying boats.

Smith's Petrol-contents Gauge.

Mk. 1. This gauge was developed with a view to meeting the demand for a petrol-contents gauge reading direct on the instrument board, and free from the disadvantages attendant on gauges which depend on air pressure and metal tubing or mechanical transmission mechanism for their operation. Ability to cope with very long transmission distances was also a prime requirement.

The principle is extremely simple. A tank unit comprising a light but rigid structure, made up of an aluminium tube with the requisite end castings, carries at one end a bevel gear (or occasionally a spur gear) which communicates the movement of a float arm to a vertical or occasionally a horizontal spindle. Through a long gland the spindle enters an



FIG. 47. P.T.14 Switch Box
Length 5½ in. Depth 1½ in. Height 5¼ in.
Weight 2 lb.



FIG. 48. P.T.16 Switch Box
Length 7½ in. Depth 1½ in. Height 5¼ in.
Weight 3 lb.

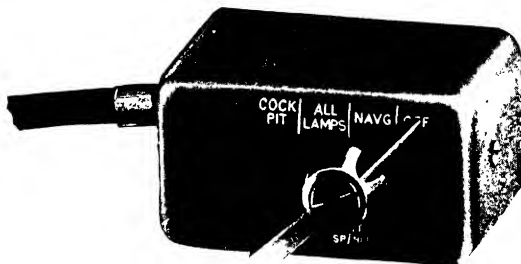


FIG. 49. SP/NI Switch
Length 2½ in. Depth 1½ in. Height 1¾ in. Weight 9 oz.
(By courtesy of Rotax Ltd.)

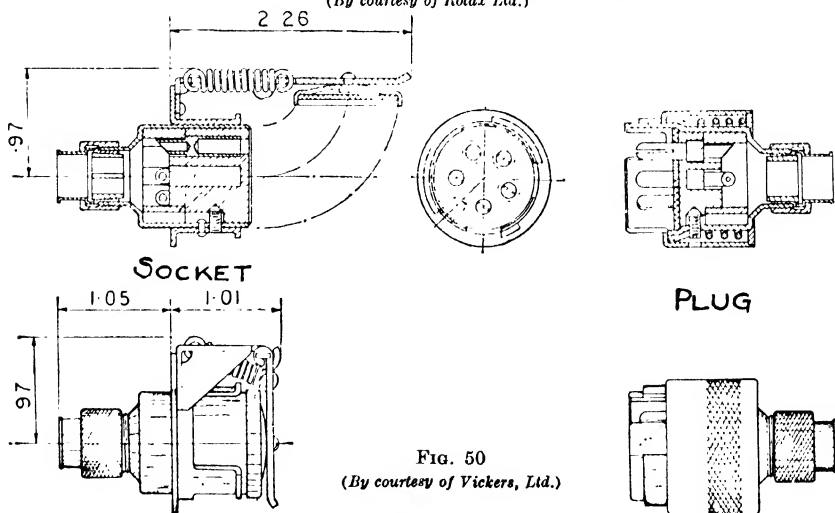


FIG. 50
(By courtesy of Vickers, Ltd.)

enclosed chamber formed of bakelite mouldings, into which are built an electrical resistance and a collector ring. Three terminals emerge from this chamber, connecting respectively with the ends of the resistance and with the collector ring. The distribution of electrical resistance between these terminals depends upon the position of a rheostat brush which forms a bridge between the collector ring and the resistance. The brush is connected to the spindle and, through the medium of the gearing, its position is varied according to the position of the float in the tank. An indicator of special design is so arranged that its pointer takes up a position which depends upon the distribution of resistance between the three terminals emerging from the tank unit. It only remains to connect the system, through a push-button, to a 6-volt or 12-volt circuit to complete the installation. It will be obvious that by the use of multi-way switches several tanks can be brought in turn into electrical connection with the indicator if it is desired to save space on the dashboard.

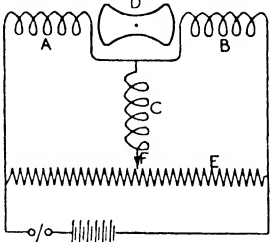


FIG. 51A

It will be obvious that for a fuel-contents gauge to operate over the complete range from completely full to absolutely empty there must be space for the float to move up or down into these positions, with due allowance for the space which the float must occupy. Since the registration

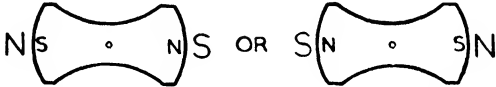
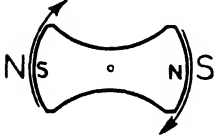


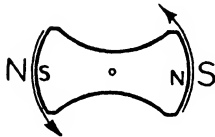
FIG. 51B

of the top few gallons is not of practical importance, there is no need to provide a bump on the top of the tank. At the bottom of the tank, however, where the registration of the last few gallons of fuel can make all the difference between a forced landing and reaching a safer landing-ground, it will be obvious that there will be many occasions when a sump is essential. There are also certain official minimum requirements to be met.

The indicator is an electro-magnetic device which employs a special circuit to move a small soft-iron armature (see Fig. 51A).



S
FIG. 51C



N
FIG. 51D

The two coils A and B are wound on a single special low-hysteresis iron former, and are so arranged that when the contact F is at the mid-point of the potentiometer E, current passes through both coils and maintains the armature D in a horizontal position. When the sliding contact F is moved to either the left or right of the mid-point of the potentiometer E, then current passes through the coil C. By proper arrangement of the polarities of the electro-magnetic coils A, B, and C the armature D can be made to move to the left when the contact F is moved to the left, or vice versa. This is because the sense of the direction of the windings, clockwise or anti-clockwise, for any given sense of the flow of the currents decides the magnetic polarity. Thus, with the

contact F in the mid-position on the potentiometer E , the polarities of the coils may be as shown in Fig. 51B. In this case the resultant force on

D is horizontal, and the indicating pointer attached to D stays in the middle of the calibration scale.

When the contact F is moved to the left, the current through A decreases while that through B increases, and a current passes through C in such a direction that the magnetic polarities of B and C are the same, and the armature will rotate in a clockwise direction (Fig. 51C).

If the contact F is moved to the right, the current through A increases while that through B decreases, and a current passes through C in such a

direction that the magnetic polarity of A and C is the same, and the armature will rotate in an anti-clockwise direction (Fig. 51D).

The extent of rotation depends upon the disposition of the soft-iron cores, the ampere-turns on each coil, and the values of the resistances of the coils, A , B , and C , and the potentiometer E .

The contact F is operated through gears from a movable arm carrying a float in the petrol tank. Owing to the fact that the iron cores in the instrument are not magnetically saturated and that the air gaps are relatively large, the instrument is practically independent of variation in battery voltage.

Coils A and B are together known as the **control coil** and tend to make the pointer stay in the mid-position of the calibration scale. Coil C is known as the **deflecting coil** and tends to make the pointer move away from the mid-position.

The **tank attachment** consists of a doped cork float carried on an arm

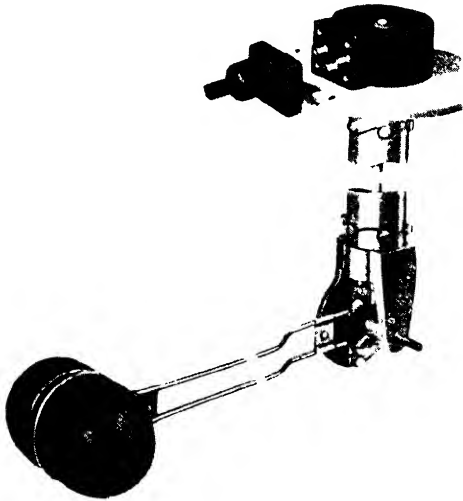


FIG. 51E. TANK ATTACHMENT (Mk. 1)

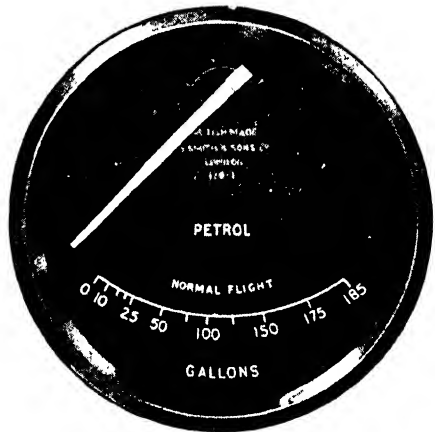


FIG. 51F

which is connected by a pair of bevel or spur gears to a vertical spindle (Fig. 51E). To the top of this spindle is attached the contact arm *F*, travelling over the potentiometer, of which the resistance is about 90-91 ohms. By means of this device varying voltages are applied to the deflecting coil of the instrument, causing the pointer to deflect in accordance with the height of the fuel in the tank.

The **gauge** comprises the coils *A*, *B*, and *C*, and the armature *D* in a circular metal case, with a pointer and dial (Figs. 51F and G). The total angular rotation of the pointer is 75° , or $37\frac{1}{2}^\circ$ on either side of the mid-point. The approximate resistance of coils *A* and *B* is 47 ohms for each half, and of coil *C* 41 ohms.

The **switch** consists of either a push-button switch for single tanks, or a combined multi-way selector switch and push-button for aircraft with more than one tank (Fig. 51H). The selector switch has a snap-over action, and the push-button has a spring return to the off position. The

cable is special petrol-proof three-core cable, one end being sealed in a three-point plug, which is connected to the tank attachment either by four screws, or in certain cases by means of a quickly removable two-prong pin, which can easily be locked in position.

It is necessary to design the tank unit to suit the dimensions of the particular tank in which it is to be installed. The movement of the potentiometer arm *F* has been standardized to approximately 270° ; in order to keep this angle different gear ratios are used, so as to give various angular movements for the float arm. This, together with the fact that the length of the float arm and bracket may be varied, gives the gauge wide adaptability. For the purpose of **calibrating**, the aircraft is set up in the normal flying attitude. The tank attachment is mounted in the tank and connected to the panel meter through the switch and battery. In order that a permanent record of the calibration voltages may be kept, a voltmeter of high internal resistance—1,000 ohms per volt—is connected across B + and P terminals on the

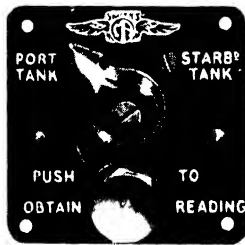


FIG. 51H

back of the meter. Petrol is then poured in the tank in measured quantities and the meter calibrated at convenient points—usually multiples of ten—voltages being taken at each calibration mark. The voltage across meter terminals B + and B - should be taken and recorded (when the instrument is switched on) both at the beginning and at the end of the test. If required, this procedure is repeated with the aircraft in the tail-down position, the marks in this case being made on the upper side of the scale.

During installation it is necessary to bear the following important points in mind. The instrument must be handled carefully at all stages before actual fitting. Any distortion or bending of the arm will cause

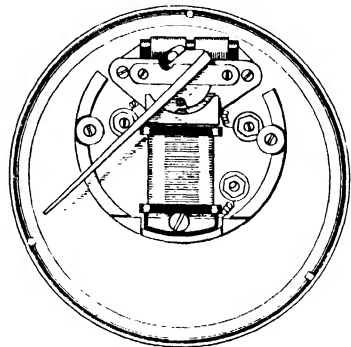
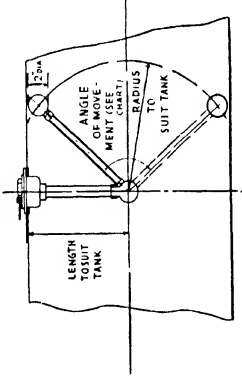
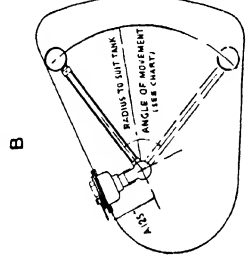
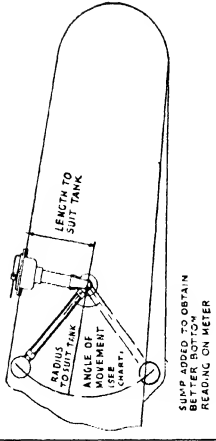


FIG. 51G

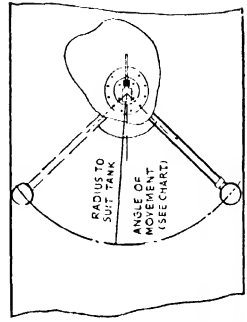
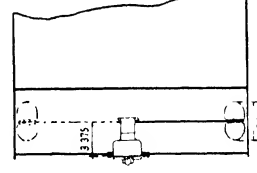
GAUGE: INTERNAL VIEW

METHOD OF FIXING SMITHS FLUSH TYPE
ELECTRIC FUEL GAUGES.

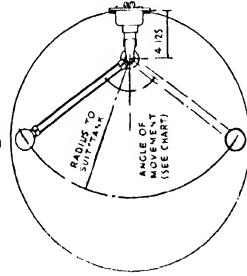
C



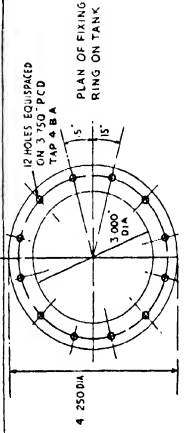
E



D



	A	B	C	D	E
ANGLE OF MOVE	64° 38'	64° 38'	64° 38'	64° 38'	73° 36'
HEIGHT OF FLOAT	186	186	186	186	186
ARM	118	118	118	118	80
POSITION OF CABLE	ANY POSITION				
DISTANCE FROM UNDER	TO MINIMUM				
OF FLOAT	TO SUIT TANK				
HEIGHT OF	TO MINIMUM				
CENTRE OF GEARS	TO SUIT TANK				
	4.125"	4.125"	4.125"	4.125"	3.175"



F. 3.7.1

F. 1

incorrect indication on the meter. If possible, try the movement of the float arm in the tank before actually screwing down the tank attachment, in order to make certain that there is no fouling at either top or bottom, or on any baffle or skin stiffener. The tank attachments must be carefully made with the Langite washer supplied, a suitable jointing compound being used. Sharp bends must be avoided in the cable, particularly where it leaves the tank attachment cable clamp. The cable must be securely supported throughout its length, especially at any point where connections are made to terminal blocks, the switch, or panel meter. If the cable is run in tubes, these must be rigidly held, especially at the ends, as otherwise vibration may cause fracture of the wire. The meter must be set vertically in the dashboard. It is calibrated in the "tail on ground" and "normal flight" attitudes for land machines, and "afloat" and "normal flight" for seaplanes and flying boats. Normal flight corresponds to that attitude of the machine when the fore-and-aft level reads zero. It is useless to read the gauge unless the machine is in this definite position when in the air. The part number of the tank attachment is stamped on the flange, and that of the meter engraved at the extreme top of the dial. It is essential to see that these numbers agree with those shown on the tank drawing or equipment sheet. Wiring diagrams are supplied with every installation, and must be adhered to for the method of wiring. Great care must be taken, when either connecting up or disconnecting the gauge, to see that the terminal P (the white wire) is not short-circuited to either B+ (the red wire) or to B- (the black wire). If the meter pointer reads above the zero mark when the tank is empty or below the maximum reading mark when the tank is full, it indicates that the float arm is not coming up against the stops on the tank attachment, and may be due to the arm fouling on the bottom or top of the tank, or touching a baffle or stringer because the arm has been bent. In an installation having two or more identical tank attachments reading on one meter by means of a selector switch, it is essential to see that the tanks are set up correctly in the aircraft, as otherwise the meter will not give the same reading for all tanks, even though in fact they contain an equal amount of fuel. When attempting to **locate faults** it may be useful to remember that if the electrical lead to the potentiometer arm contact (the white lead) is broken, the meter pointer will read vertically. If the electrical lead to that end of the potentiometer which the contact arm reaches when the tank is full (the blue lead) is broken, the indication on the meter will only be correct when the tank is empty, reading low in all other cases by an amount which increases with the tank contents, the readings actually being confined to the lower half of the scale. If the electrical lead to that end of the potentiometer which the contact arm

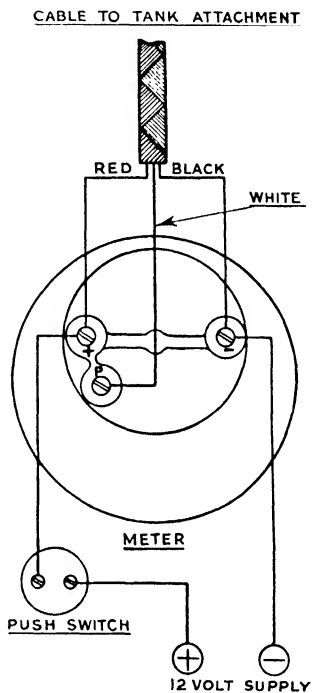
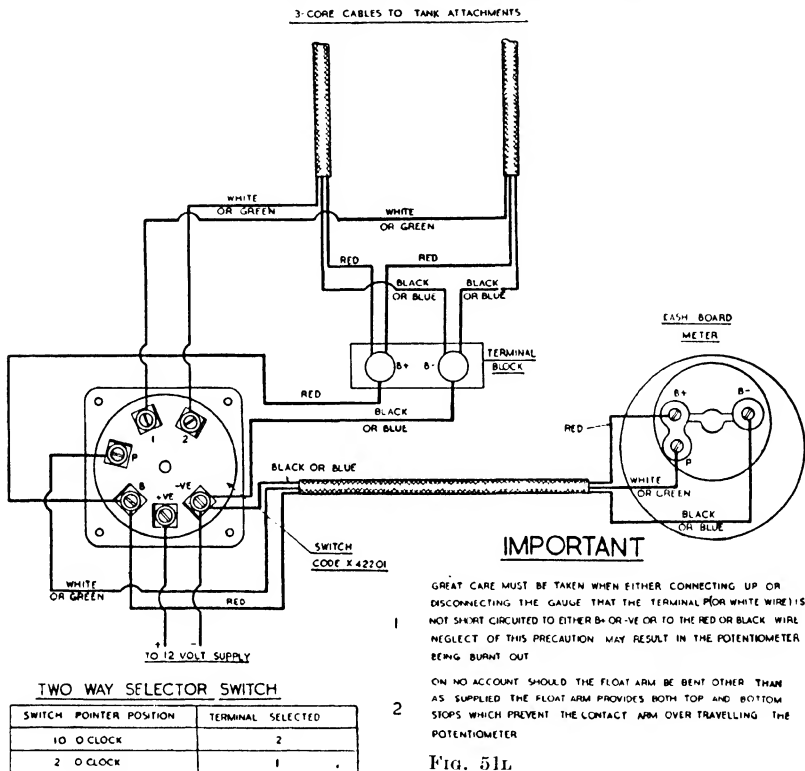


FIG. 51K. WIRING DIAGRAM:
ONE TANK PER GAUGE

reaches when the tank is empty (the red lead) is broken, indication on the meter will only be correct when the tank is full, reading high in all other cases by an amount which increases as the tank contents decrease, the readings actually being confined to the upper half of the scale.

Fig. 51J shows examples of the various ways in which attachments can be mounted in tanks of differing shapes and capacities. Not only are various alternative lay-outs illustrated, but also limiting values for



important dimensions within which, in the interests of standardization, manufacture has been confined.

Mk. IV. Although large numbers of the earlier types of equipment are still giving satisfactory service, Messrs. Smith's have introduced many major modifications into their more recently issued equipments, which are now known as the Mk. IV type. Their sphere of usefulness has also been extended to include dashboard instruments for indicating the position of flaps, retractable undercarriages, and other devices requiring a remote indicator. As compared with previous types, the new equipment can be supplied for operation either by 12 or 24 volts, and the accuracy attained shows a greater independence of voltage and temperature. It is designed to give continuous readings; but although a suitable selector switch can be provided to enable readings (e.g. of the contents of more than one fuel tank) to be obtained on a single indicator, separate indicators for each transmitter unit are preferable, thus eliminating the selector switch.

The shape of the new indicator is more convenient than that of earlier models, and in spite of a reduction in overall size the length of the scale has been increased to $4\frac{1}{2}$ in., owing to the extended arc.

The dial design of the standard indicator is dependent on the function for which it is required. The actual form of the transmitter also depends on its particular application, but the element itself consists of a complete circular resistance on which two brushes make contact at diametrically opposite points. The movement which is to be remotely indicated controls the rotation of the brushgear, the latter being accurately followed by the indicator pointer. Because of the unavoidable friction which occurs between the resistance and the brushes, a certain amount of power is required to operate the system. That this power need only be slight, however, is shown by the fact that the device is successfully applied as a fuel-contents gauge, in which case it is geared to the usual Smith float mechanism. The transmitter is built into a bakelite moulding which can be fitted in several types of housing. It consists primarily of a circular or toroidal resistance tapped at three equidistant points, connections being taken from these points to the indicator. Current is fed into the resistance at two diametrically opposite points by a pair of brushes, mounted together and capable of unlimited rotation, although normally less than 300° is used. This brush assembly is geared to the mechanism, the position of which is to be shown on the indicator. The equipment is of robust construction and has adequate insulation. The terminals are of the approved shrouded type throughout, the binding screws having captive washers. A moulded cover protects the terminals and clamps the cable when in place. The indicator mechanism, which is similar to a small motor, has a slotted stator of normal form, carrying a distributed three-phase Y-connected winding. The rotor is a simple two-pole permanent magnet carried on a spindle turning freely in jewelled bearings, and the assembly is made in a pressed-steel shell forming both a rigid frame and a complete shield to prevent magnetic leakage from affecting other instruments. This complete assembly is housed in a moulded case which has a standard $2\frac{1}{2}$ in. square flange and is closed with a window of non-splinterable glass. A terminal block with cover is provided at the back of the instrument. The three tapplings on the transmitter resistance are joined by cable to the ends of the Y-connected indicator winding, and as the brushes in the resistance are rotated it will be obvious that the current distribution in this, and in the indicator coils, will change both in magnitude and in sign, with the result that the indicator rotor and pointer follow the brush movement through 360° or more if required. Pointer and rotor are accurately balanced, so that if the supply is switched off, the pointer remains in the position to which it was deflected. In fuel gauges particularly this is a disadvantage, and it is overcome by the inclusion of a magnetic pull-off device to bring the pointer to a blank part of the scale when the current supply is interrupted. Unfortunately, this slightly spoils the uniformity of the scale and the otherwise perfect voltage compensation of the equipment. When the apparatus is applied to fuel-contents gauging on a 24-volt electrical supply, two resistances are inserted in the battery leads to limit the current in the case of an accidental short circuit.

The simple electrical circuit is shown in Fig. 52, from which it will be seen that it is the practice to take the battery leads to the indicator, and a five-core cable from the indicator to the transmitter. The equipment is designed for continuous operation, the current consumption being approximately 0.3 ampere at 12 volts, or 0.15 ampere at 24 volts, except when

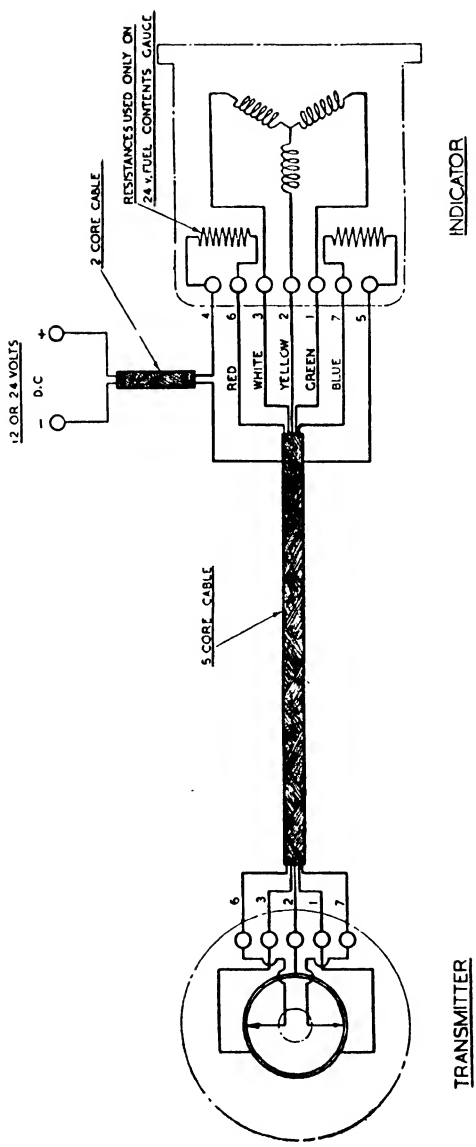


Fig. 52

applied as a 24-volt fuel gauge, when the current is 0.3 ampere. The instrument is voltage-compensated over a wide range, its accuracy remaining unaffected by the length of connecting cable within reasonable limits. It will be noted from the electrical circuit diagram that a five-core cable is needed to connect the indicator to the tank attachment, the terminals of both of these being clearly numbered. When the wiring, with the exception of the battery leads, has been completed, the whole installation should be tested with a Megger to determine the insulation to frame. A value of less than 5 megohms cannot be accepted, and if such a low value is found, it will be necessary to test the wiring in sections to find the fault. It is possible that the connecting cable may be damaged in service, or wrong connections made during installation or repair, and the following notes are intended to assist in the diagnosis of any trouble.

(1) If the pointer remains in the "pull-off" position at 6 o'clock when the current is switched on with the tank empty, this may be due to—

(a) Broken lead in battery circuit, or between the terminals numbered 7 and 6 on indicator and transmitter.

(b) Broken connection between No. 3 terminals.

(c) Broken connection between No. 1 terminals.

To determine the existing fault, fill the tank and note the pointer movements during the process. If pointer remains at 6 o'clock—Fault (a). If pointer moves from 6 o'clock to zero and back—Fault (b). If pointer remains stationary for some time, suddenly moving to half-full and eventually returning to 6 o'clock—Fault (c).

(2) If pointer moves to zero when current is switched on, but rotates in the wrong direction as the tank is filled to the three-quarter point, ultimately coming back to zero, this is caused by a broken lead between terminals 2.

(3) If pointer takes up a position about half-full and rotates in the right direction as the tank is filled, keeping 180° in front of its correct position, the fault is the result of the reversal of the battery leads or crossing of connections between terminals 6 and 7.

(4) The indicator connections and the transmitter can be connected up in six different ways, of which only *one* is correct. The wrong order will result in a changed zero position of 120° in either direction, or in reverse rotation.

(5) If, after many hours' flying, the indicator pointer shows a tendency to oscillate between some reading and the off position, it is an indication that the potentiometer has become dirty or that the brushes are not pressing sufficiently hard upon it. To rectify this defect the resistance can be easily removed, but in no circumstances should the float arm be caused to move whilst the resistance element is dismantled. If this precaution is taken, there will be no difficulty in getting the operating arm to engage with the brushgear, because the resistance unit has a projecting pin which enters the corresponding hole on the flange. Make sure that all the fixing screws are done up tightly again to ensure a petrol-tight joint. To ensure interchangeability in equipment supplied for one type of aircraft, the gauges are inspected to verify that the readings are within 3 per cent of those obtained in the original calibration, no positive error being permitted below 30 per cent of full scale. It should be noted that the standard tank attachment is designed to enter a 3-in. diameter hole and to be secured by twelve equally spaced 2 B.A. holes on a 3.75-in. P.C.D. If it should be necessary, however, the tank attachment flange may be designed to suit a particular hand hole. The angle through which the

float arm moves should be 98° . This angle has been standardized, but in cases of real difficulty the following angles are also suitable—

Mk. IV Tank Attachment: 63.0° , 80.2° , 94.5° , 101.3° , 115.0° . Mk. III and earlier types of tank attachments: 64° , 80° , 90° , 104° , 108° .

Revolution Indicators (Electrical)

A mechanical revolution indicator requires a rotary drive reaching the full distance between the engine and the indicator. When the distance is great, serious difficulties are encountered, and strains are set up in the drive which cause jerky and inaccurate readings. The development of

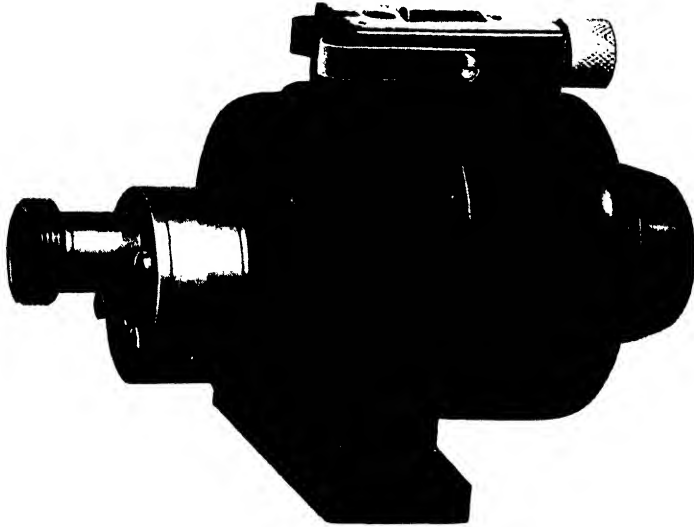


FIG. 53

(By courtesy of the Record Electrical Co., Ltd.)

large aircraft, therefore, renders the use of mechanical indicators impracticable.

The Record Electrical R.P.M. Indicator, which consists of two separate parts, the dynamo or generator, and the voltmeter or indicator, is not subject to these disadvantages and limitations. It has no complicated moving parts, its accuracy is not affected by mechanical wear, and it gives smooth and responsive indications.

The generator is placed near the engine and should be connected to the selected driving shaft by the shortest means of coupling. An electric current is generated proportional to the speed of rotation, and the current is led to the indicator by a pair of insulated wires. The indicator, therefore, can be placed almost any distance away, the resistance of the leads being negligible.

The indicator is a moving coil voltmeter of special construction to meet the exacting requirements of aircraft work. It is calibrated in terms of engine speed.

The Record R.P.M. Indicator is manufactured to Air Ministry specifications for military and civil aircraft.

Every indicator and every generator is standardized for use with any

Record indicator, of whatever type, and thus the stock of spares it is necessary to carry is greatly reduced. For example, a spare triple edgewise indicator would require three generators, one for each dial if individually calibrated, but by standardizing, one spare generator is sufficient. Moreover, the individual units of the edgewise type of indicator are themselves

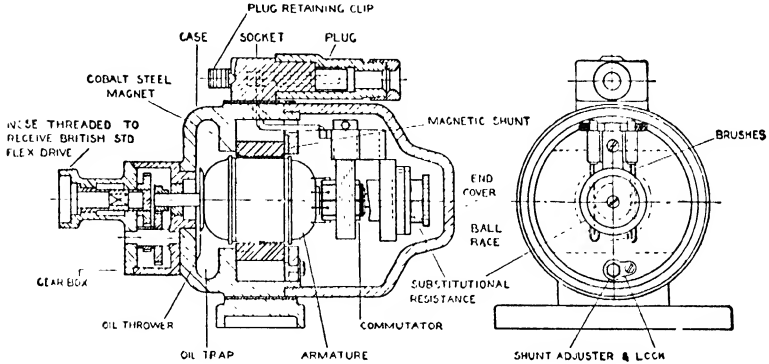


FIG. 54

(By courtesy of the Record Electrical Co., Ltd.)

mechanically and electrically interchangeable, which again reduces the stock of spares. The "Circscale" type is also interchangeable with the edgewise type.

The generator is remarkably small, yet a real power unit (Fig. 53),

BRUSH HOLDER.
(ENLARGED VIEW)

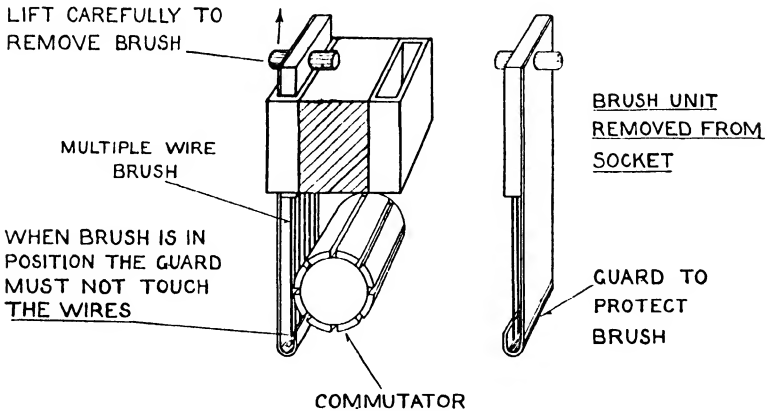


FIG. 55

(By courtesy of the Record Electrical Co., Ltd.)

generating sufficient current at an exceptionally high voltage to operate high torque and high resistance indicators. It employs a cobalt steel magnet, in the field of which revolves a multi-pole armature running on

ball-bearings, and it is enclosed in an aluminium case. A strong nose is fitted on the driving end, threaded to receive a British standard flexible drive, and the armature shaft is connected to the drive by a floating coupling, so that no strains are transmitted to the armature (Fig. 54).

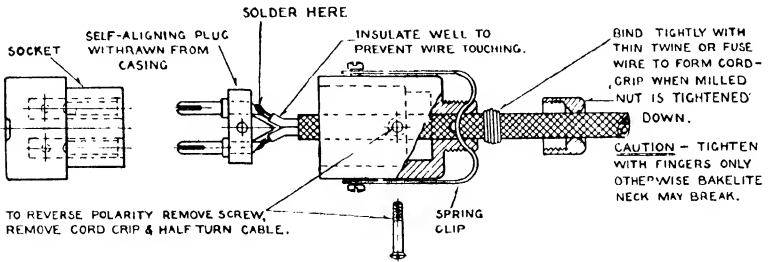


FIG. 56

(By courtesy of the Record Electrical Co., Ltd.)



FIG. 57. CIRCULAR TYPE

Patent

Alternative Ranges: 1,400-2,800 r.p.m.

" 1,600-3,200 r.p.m.

" (or others as required)

Weight 1½ lb. Actual size 3¼ in. × 3¼ in. × 3¼ in. deep

(By courtesy of the Record Electrical Co., Ltd.)

The armature is standardized to give 30 volts at 3,000 r.p.m. If the flexible shaft speed is quarter engine speed, i.e. 750 r.p.m., then four to-one gear wheels are fitted. If the flexible shaft is running at any other speed, appropriate gear wheels are fitted instead. The gear-box is built into the generator and so constructed that the wheels can be changed at any time with very little trouble. So can the form of the nose, should it be desired to adapt the equipment for other than British service engines.

The commutator and brush gear are completely enclosed, but can be inspected by removing the moulded bakelite end cover. The brushes are of gold alloy, protected in a safety holder. Provision has been made for their renewal should occasion arise. To renew a brush all that is necessary is to slide out the old and insert the new (Fig. 55). It is advisable, after the generator has been run for about 500 hours, to remove the brushes and carefully clean away any deposits, particularly from the commutator slots. A toothbrush is very handy for this purpose. If the brushes are worn they should be replaced by spares. No lubrication whatever should be put on the commutator and on no account on the generator bearings and gear-box, which are packed with special grease to withstand extreme hot and cold temperatures.

The electrical connections between the generator and indicator are made by means of specially designed plugs and sockets (Fig. 56). The socket is fixed to the generator, and the plug is held in position by a spring clip, so that it is impossible for it to vibrate loose and become disconnected. Both the socket and plug pins are encased, preventing a short-circuit should they come in contact with any metal parts. The plug is provided with a cord grip. Every plug is interchangeable, both on the generator and indicator ends, the indicators all being fitted with a similar socket. They are also non-reversible, so that when the connections are once correctly made in respect to polarity, the indicator cannot be incorrectly connected. Provision, however, is made for easily correcting any error in polarity which may be made during installation without unsoldering connections; every internal electrical connection is soldered, and the plug connections must also be soldered to ensure reliability.

A desirable form of indicator is the Cirscale pattern, consisting of a patented moving coil voltmeter of unique construction, giving an angular deflection of the pointer of 300 degrees without gearing (Fig. 57). It is fitted in an aluminium case, and efficiently screened to bring compass interference within the prescribed limits.

The Edgewise type of indicator has been designed for compactness, and for readily comparing the speeds of the engines, as similar speeds are in line on the respective dials. It is constructed on the unit principle, each voltmeter being a complete and separate unit, and two or more are screwed side by side on a base to make twin, triple, or other multi-engine indicator (Fig. 58). Each separate unit is complete with its socket and plug as before described, and each is so effectually shielded that the removal of one indicator or any interchange in its position does not affect the readings of the others in the slightest degree. Moreover, a triple edgewise indicator, when placed at a distance of 10 in. from a sensitive compass, will not deflect it more than 2°. This deflection is not varied by engine speed, and can be readily and permanently adjusted on the compass corrector magnets. The dials have a black surface, with engraved scale and figures filled in white, or with scale marks and figures luminized.

The indicators are mounted on the dashboard so that the face is flush with the front of the dashboard. This means that the main body of the indicator projects behind the dashboard, and as the instruments are

somewhat heavy it is very advisable that some means of supporting the rear end of the instrument should be provided. On some aircraft it has been found that the vibration set up by the engine(s) has an effect on the indicators, causing the readings to be unsteady at certain engine speeds. In such cases it is advisable to introduce rubber "buffers" at the points of attachment of the instruments, so that the vibration effects may be damped out.

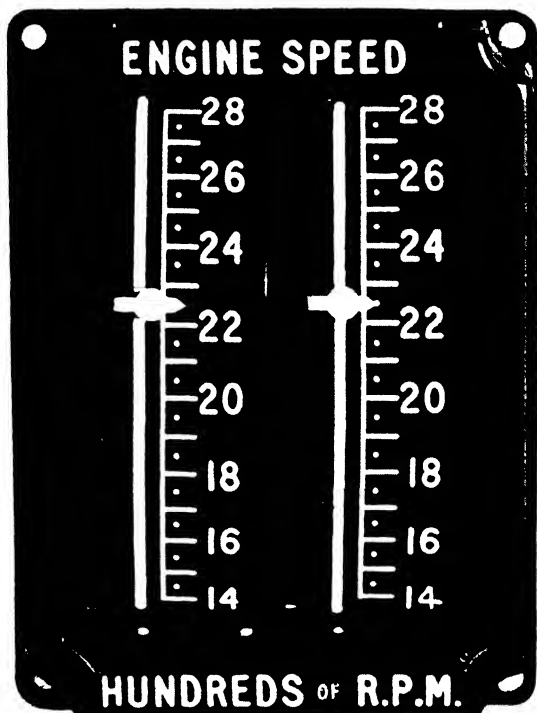


FIG. 58. TWIN EDGEWISE TYPE

Weight 4 lb.

(By courtesy of the Record Electrical Co., Ltd.)

Each generator is standardized to supply current to dual indicators. When one indicator only is employed a resistance must be put in the circuit equal to the load of another indicator; this resistance will be found at the end of the generator (see Fig. 53, "Substitutional Resistance"). To put this resistance in or out of circuit, turn the milled edge right to "I" when using one indicator and left to "II" when using two indicators.

Generators and indicators being screened are not affected by the presence of any mass of iron near them. Aluminium parts used in their construction are anodized and iron parts cadmium-plated, afterwards heavily coated with a cellulose enamel, thus affording protection against climatic conditions.

CHAPTER V

MAGNETOS

A HIGH-TENSION magneto, as used for producing the high-tension current in the ignition circuit of an engine, is really two separate pieces of mechanism in one, viz., a dynamo and a transformer, the latter operating to produce a high-tension current by means of the low-tension current supplied to it by the former.

The dynamo portion of the machine is, in many cases, constructed on quite orthodox lines, and consists simply of a permanent magnet, in the field of which revolves a plain two-pole armature carrying a single winding of relatively heavy gauge wire, called the primary winding.

In magnetos used for ignition purposes on engines with upwards of six cylinders this construction is somewhat modified, as will be explained later, in order to enable the machine to run at a lower speed than would otherwise be necessary, but the principle of operation is the same.

To return to the simple case already referred to, the dynamo is not fitted with a commutator, but with the equivalent of a single slip-ring, and this takes the form of an insulated contact screw which rotates with the armature. One end of the primary winding is permanently connected to "earth," or the metal body of the armature, the other end being connected to the insulated contact screw. This screw is affixed to a plate on the end of the armature, and this plate also carries a pivoted arm provided with another contact screw which is in contact with "earth." The two contact screws are normally kept in close contact by means of a spring. We thus see that under normal circumstances the primary winding of the armature is short-circuited, as one end is permanently attached to "earth," and the other end is connected to earth through the connection at the two contact screws, one of which—the fixed one—is insulated, and the other permanently earthed. If the machine is rotated in this condition, therefore, we shall generate an alternating current in the closed primary winding. As the magnetic field has only one north and one south pole, and as the armature has only a plain winding, each "arm," or "side," of the armature winding cuts the magnetic lines of force at a pole-face twice in each revolution, i.e. once at the north pole and once at the south pole. It therefore follows that the E.M.F. generated in the armature winding reaches a maximum in each direction once per revolution, or, in other words, we obtain a maximum voltage—usually about 10 to 16 volts—twice in each revolution of the armature. A graph of the changes in this E.M.F. would show the voltage commencing from zero, rising by a gentle curve to a maximum, then descending to zero, and rising again to a maximum on the opposite side of the zero line, again to return to the zero position.

So much for the dynamo side of the machine, and now to consider the transformer, or step-up side. A transformer is yet another device which operates by reason of the cutting of lines of force by a conductor. When lines of magnetic force are cut by a conductor an E.M.F. is produced in that conductor. With a magnetic field of given strength, the value of the E.M.F. produced in a conductor depends on the number of lines of force cut in a given time, and if a number of such conductors are connected together in series, then the total resulting E.M.F. is the sum of the E.M.F.'s produced in the separate conductors. Thus a much greater E.M.F. can be

produced from a large number of conductors connected in series than can be produced from a small number of conductors operating under con-

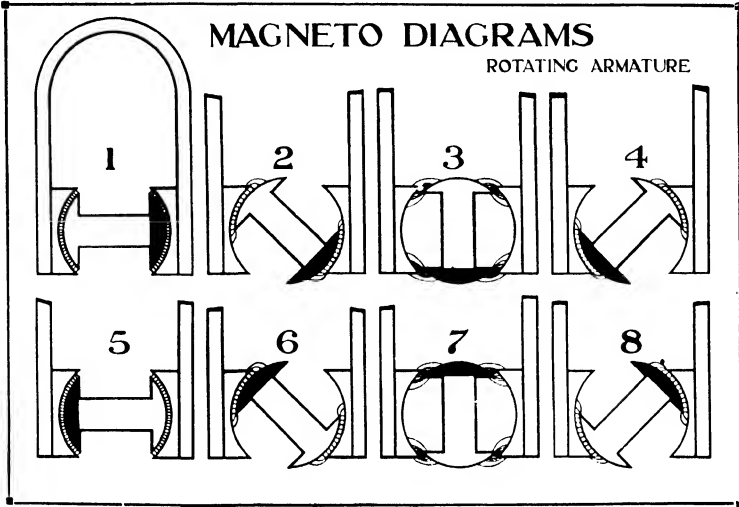


FIG. 59

(Royal Air Force Official—Crown Copyright Reserved)

ditions which are otherwise similar. Again, the important point to remember is that it is the cutting of the lines of force which produces the E.M.F.,

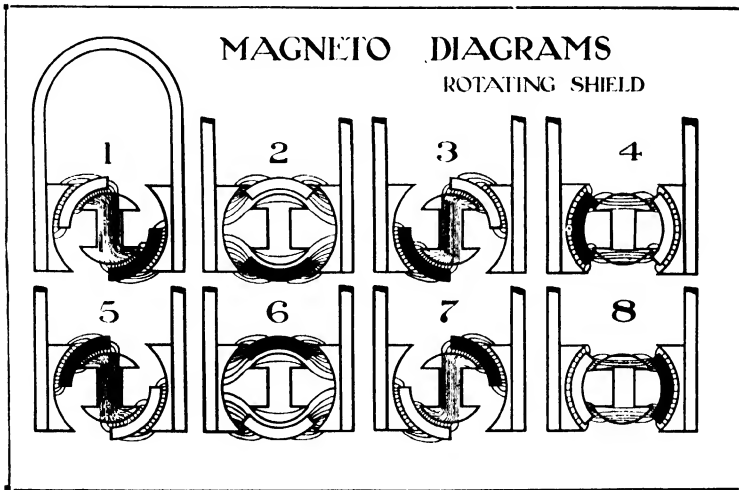


FIG. 60

(Royal Air Force Official—Crown Copyright Reserved)

and provided this can be established, it does not matter which moves—the conductor, or the magnetic field. Precisely the same result can be

obtained without either the conductors or the magnetic field moving, simply by causing the strength of the magnetic field to vary. (Fig. 60.) It is this latter condition which obtains in the transformer contained in a magneto.

It has been shown that by rotating the armature of the dynamo we have produced in its primary winding an alternating E.M.F. This armature winding is therefore in itself an electro-magnet, by reason of the current circulating in the conductors. The strength of this electro-magnet is largely increased by reason of the fact that the conductors are wound upon an iron core. The armature of the magneto, in addition to carrying the primary winding referred to, which consists of relatively few turns, also carries an entirely separate winding, consisting of a very large number of turns of fine gauge wire, which is called the secondary winding. One end of this secondary winding is permanently connected to "earth" and the other end is brought out to a highly insulated slip-ring, mounted on the armature shaft at the end remote from the two contact screws already referred to.

When the armature is revolving there is an alternating E.M.F. produced in the primary winding, and this alternating E.M.F. causes the winding, with its iron core, to produce an alternating magnetic field. The lines of force of this field—not the lines of force of the relatively weak fixed permanent field—are cutting the conductors of the secondary winding already referred to, and producing in it another E.M.F. of higher voltage than that produced in the comparatively small number of turns of the primary winding. But because the E.M.F. in the primary winding is rising and falling at a comparatively slow speed, the resulting lines of force are cutting the conductors of the secondary winding at the same comparatively low speed.

Although the E.M.F. thus produced in the secondary winding is higher than the E.M.F. in the primary winding, yet it is still not high enough to be able to produce a spark at the points of a sparking plug, and it is necessary to raise it considerably before it can be of any use for ignition purposes. This result is attained by causing the conductors of the secondary winding to be cut by the lines of force at a very much greater speed, and this speeding up is attained without increasing the speed of rotation of the armature, simply by breaking the primary circuit at the moment of maximum E.M.F. When the primary circuit is broken at the moment of the maximum E.M.F. there is a sudden collapse of the magnetic field, just at the moment of its maximum intensity. The lines of force, therefore, collapse very suddenly, and in doing so they cut the conductors of the secondary winding at very high speed, and produce in it a momentary E.M.F. of a very high value, and this is used to produce the spark at the sparking plug. The sudden breaking of the primary circuit is accomplished by opening the two contact screws already referred to. These screws, one of which is fixed, and one mounted, on a pivoted arm, are carried by a plate mounted on one end of the armature shaft. This plate revolves within a fixed annular ring, which is provided with two slight excrescences to form cams. As the armature is revolved, the end of the pivoted arm carrying one contact screw is struck by these cams, and the screw at its other end is thereby forced out of contact with the fixed contact screw, and the primary circuit is broken.

In order that the E.M.F. in the primary winding shall reach as high a value as possible, it is essential that no unnecessary resistance be included in the circuit, and the two contact screws are therefore tipped with platinum or a special hard alloy of high conductivity which will withstand the hammering action to which it must be subjected under working conditions.

To avoid the destructive effects of sparking at these contact points, a condenser is incorporated in the magneto and is connected straight across the points.

The sparking at the points is the outward sign of the highly inductive quality of the circuit which is being broken, and it has already been pointed out (page 18) that inductance in a circuit produces an effect analogous to inertia of the current, i.e. the effect is to tend to maintain the flow of the original current after the instant of opening circuit. This effect would tend to slow up the breakdown of the magnetic field and thus reduce the strength of the secondary current, but the presence of a condenser across

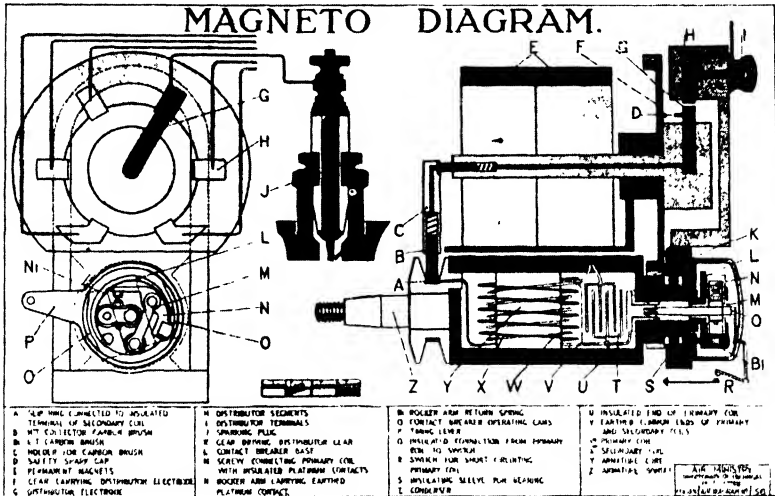


FIG. 61

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the contact points provides a reservoir into which the inductive current can flow quickly, and thereby not only is the destructive effect of sparking at the points avoided but a more rapid breakdown of the magnetic field is achieved.

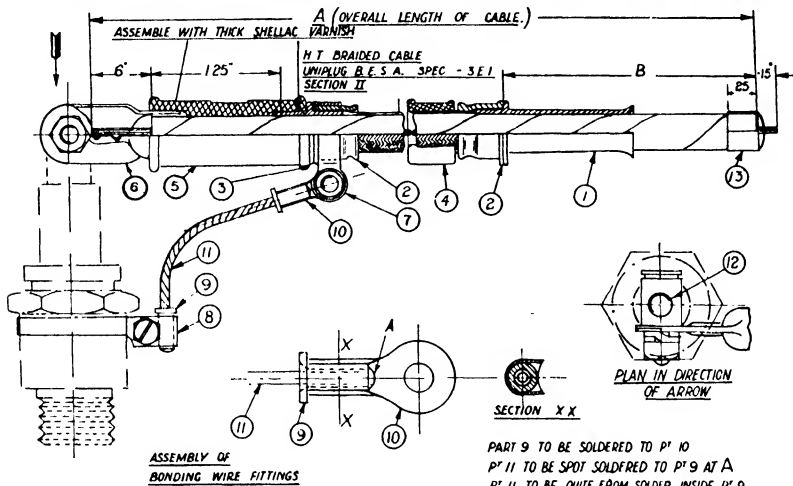
Whilst the foregoing is the basis of design of all magnetos, and is that actually adopted in nearly all magnetos designed for use with engines having up to 4 or 6 cylinders, certain modifications in construction are adopted for magnetos designed for use with engines having a larger number of cylinders.

It has already been explained that magnetos such as that described above will produce two sparks per revolution of the armature. A single cylinder four-stroke engine requires one spark for each two revolutions of the crankshaft, and a four-cylinder engine will require four sparks for each two revolutions of the crankshaft, or two sparks per revolution. Thus, a magneto such as that described, if connected to a single cylinder engine, would revolve at one-quarter engine speed, and if connected to a four-cylinder engine, at crankshaft speed. When the number of cylinders is increased the number of sparks required per revolution of the engine is also increased, and these could be obtained by increasing the speed of the magneto in relation to that of the engine. But when we get

to a 12-cylinder engine, such a magneto would require to revolve at three times crankshaft speed, and thus might have to revolve at 6,000 to 9,000 r.p.m.

To construct an ordinary magneto to revolve at such high speeds is not a practicable proposition, as the result would be a heavy machine of inferior reliability. The problem is solved by introducing certain modifications into the design of the magneto, which result in obtaining four sparks per revolution of the armature instead of only two. It is

TITLE: BRAIDED H.T. LEADS SCREENED MAGNETO BONDED PLUG. LION II AND I



Nº	PART Nº	Nº OFF	Nº	PART Nº	Nº OFF
1	A. G. S. 1511	1	8	A. G. S. 1534	1
2	A. G. S. 1512	2	9	A. G. S. 1599	2
3	A. G. S. 1513	1	10	A. G. S. 1600	1
4	A. G. S. 1514	1	11	A. G. S. 1598	1
5	A. G. S. 1515	1	12	A. G. S. 1595	1
6	A. G. S. 1516	1	13	A. G. S. 1518	1
7	A. G. S. 1537	1			

FIG. 62

(R.A.F. Official, Crown Copyright Reserved)

not necessary here to enter into details of such modifications, except to say that they consist of the duplication of the magnetic circuit, and this duplication again is achieved in different ways by different magneto manufacturers.

In such machines it is also customary to remove the primary and secondary windings from the revolving armature, and to introduce them into the stationary outer magnetic field. The strength of this field is varied by the revolving plain iron armature, resulting in the production of an alternating E.M.F. in the stationary primary winding, and the rupture of this E.M.F. in exactly the manner already described.

Having seen how the high E.M.F. necessary to effect ignition in an engine is produced, it remains to describe how the current is conveyed to each cylinder in turn. To effect this the magneto is fitted with a piece of mechanism termed a distributor. Although the distributor is normally

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incorporated in the magneto, there is no particular reason why this should be so, except ordinary convenience.

The distributor consists of a revolving brush which rotates within a
SKETCH SHOWING L.T. CABLE CONNECTIONS. MAGNETO CUT-OUT SWITCH FOR
TWIN ENGINE (SCREENED CABLES)

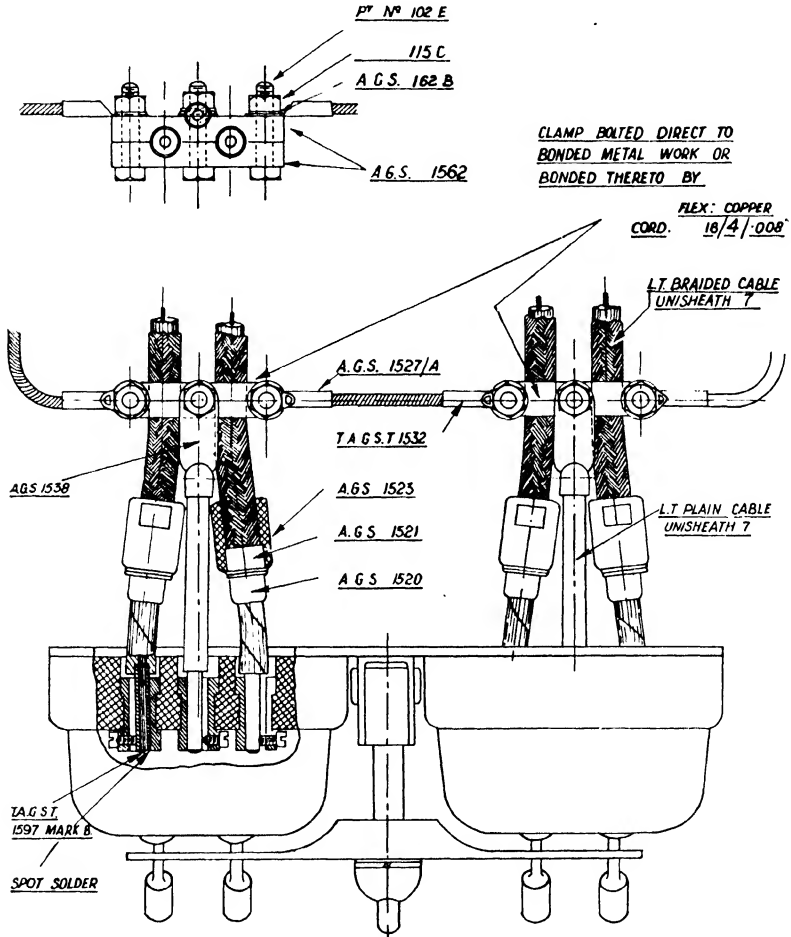


FIG. 63

(R.A.F. Official, Crown Copyright Reserved)

ring of insulating material containing a number of fixed conducting points of metal. These points are equal in number to the number of cylinders in the engine, and are equally spaced around the periphery of the ring of insulating material. The rotating brush is also of insulating material, but has moulded into it a core of conducting material which is in permanent connection with the unearthed, or insulated, end of the secondary winding.

The brush may be provided at its outer extremity with a spring loaded carbon brush, which makes contact as it revolves with each of the fixed metal points in the outer ring in turn. It is more usual, however, in modern magnetos, to dispense with the carbon brush and to leave a small fixed air gap between the fixed contacts and the revolving metallic brush.

Since each cylinder in the engine is required to fire once in two revolutions, it follows that the distributor brush must make one revolution to every two revolutions of the engine. The distributor brush is driven by gearing from the armature shaft, the ratio of the gearing varying with the number of cylinders in the engine, and the ratio of the armature speed to the engine speed. A highly-insulated lead is taken from each of the fixed contact points of the distributor to each of the sparking plugs in the engine. If wireless equipment is installed on the aeroplane it is necessary to **screen the magneto** and ignition leads in order to minimize interference with wireless reception. The sparks produced at the sparking plugs and within the distributor will set up violent oscillations in the aether, and the high-tension leads to the plugs are excellent aerials for propagating the aether disturbances, which will be picked up by the aerial of the wireless receiving installation, and will produce loud crackling noises in the telephones, sufficient to drown all but the very loudest signals. Screening the magneto is accomplished by totally enclosing the whole of it, especially the distributor, in an earthed metal case. The ignition leads are screened by braiding them externally with fine wires, which cover every portion of the insulation of the wire, and are also earthed. The braiding over the leads should go right up to, and be connected with, the metal case over the distributor. At the other end, it should be continued to within $1\frac{1}{2}$ in. of the sparking plug terminal, and also be earthed at that end, and at all intermediate clamping points. (See also pages 176-180.)

There is a special type of shrouded sparking plug on the market which incorporates an insulated external metal shroud over the whole plug. This shroud is in contact with the metal braiding over the cable, and is also in direct contact with "earth." It is also very desirable to use metal-braided cable from the low-tension switch to the terminal connector at the contact-breaker. Where a metal-braided cable is used for this purpose, it is permissible to utilize the external metal braiding as an earth connection between one side of the switch in the cockpit and the metal body of the engine. It must not be overlooked that a length of metal-braided cable is, in effect, an electrical condenser, the external braiding forming one plate, and the internal conductor the other plate. The longer the length of such cable, therefore, the greater is its electrical capacity. When metal-braided high-tension leads were first introduced it was quickly found that they were liable to interfere with the satisfactory functioning of the magneto, and this was immediately traced to the inability of the magneto to supply sufficient energy to charge up the capacity of the leads, and at the same time have sufficient energy in reserve to produce a spark at the sparking plug. The trouble was cured by increasing the electrical output of the magneto, and there is little cause for complaint on this score, so far as modern magnetos are concerned.

Ignition systems utilizing high-tension cables with external metal braiding, however, require special protection and care against the effect of damp weather, if difficulty is to be avoided in connection with engine starting. The faintest trace of dampness on the outside of the cable, between the high-tension terminal of the sparking plug and the nearest point of the external braiding—which, of course, is earthed—is often sufficient to render engine starting extremely difficult, if not impossible. On engines provided with mechanical or some other form of engine starting gear

capable of turning the crankshaft over at a relatively fast speed, the effects will not be so marked, and the use of shrouded plugs will also tend to minimize the trouble which may otherwise be expected from this cause.

Magnetos for aircraft engines are divided into two classes: magnetos for light aircraft—generally of 4 to 7 cylinders and magnetos for heavier aircraft, from 9 to 14 cylinders, and upwards.

(A) Light Aircraft Magnetos

Magnetos for light aero engines are generally of the type where the armature rotates and produces two sparks for every revolution of the armature.

So far as possible, the magneto is built up of easily accessible components, or sub-assemblies—

Housing. This is die-cast aluminium with the armature poles cast integral with it, as is also the distributor endplate, the bearing at the driving end also being located in the same casting.

Armature. This consists of core, winding, condenser, and two endplates, one being integral with the driving spindle and carrying the ball-bearing from the driving end, the other forming a container for the condenser and carrying the bearing at the contact-breaker end of the magneto. The armature is of the standard "II" pattern with malleable cast-iron cheeks on a laminated core. This armature is wound with a primary winding of approximately 200 turns of .7 mm. I.C.C. enamelled wire and has a secondary winding of 8,000 to 9,000 turns of .0032 in. I.C.C. enamelled wire. The end of the primary and the beginning of the secondary are joined together and the two ends of the primary are brought out at the condenser end of the armature and are soldered direct to the condenser. The insulated end of the secondary is brought out at the top of the winding and enters a slip-ring which is pressed on to the driving spindle. The condenser is so fixed in its endplate that one side is earthed and the other end comes out to a boss which is insulated and allows for connection to be made through the endplate to the contact-breaker.

Contact-breaker. The contact-breaker revolves with the armature and is spigotted into the condenser endplate. The screw which fastens the contact-breaker assembly to the endplate also acts as a conductor for the L.T. current and clamps direct on to a brass block which is insulated from the base itself by means of fibre or some insulating material. This block also carries the adjustable contact. The contacts are usually of 25 per cent iridium and 75 per cent platinum. The lever which is controlled by a spring is the standard bell-cranked type and operates on a pivot formed integral with the base but insulated from the lever itself. The reason for this insulation is to prevent any current passing through the pivot and causing pitting and sluggish operation of the lever.

Between the contact-breaker base and the armature when assembled into the housing of the magneto, is an endplate which carries the bearing at the contact-breaker end of the armature and spigots into the housing. On to this endplate spigots a cam which operates the contact-breaker lever. This cam is a steel ring, hardened, and having ground on it two lobes—or, in some cases, these lobes are affixed to the rings and not integral with it. As the contact-breaker operates, these lobes open and close the contacts at predetermined positions.

Distributor Slow-speed Wheel Assembly. For magnetos of more than two cylinders a distributor and distributor gear-wheel are used. The slow-speed wheel assembly is on ball-bearings in a little housing which spigots into the distributor endplate. Through the centre of these bearings passes a brush holder. The brush holder is connected to the slip-ring of the

armature by means of a small "L"-shaped collector moulding, fastened at the driving end of the housing.

Timing of the Magneto. The timing of the magneto is very important and holes are usually provided in the top of the housing to allow for the insertion of a timing gauge. The armature is rotated in the direction in which it is intended to operate and the tip of the pole on the armature is spaced 3 to 4 mm. from the tip of the pole in the housing. With the armature held in this position the cam is rotated in its cover tube until the contacts are just opening on the leading edge of the lobe. The cam when in this position is fitted to the cam-cover tube which itself is fitted into the contact-breaker endplate by means of a screw. For magnetos arranged for variable timing, a slot is provided and for fixed ignition machines a recess large enough for the head of the screw only is provided.

A moulded contact-breaker cover is usually provided which has a terminal and a spring inside which makes contact with the screw fixing the contact-breaker assembly to the armature; thus, the lobe connected to this terminal provides a ready means of earthing the magneto when necessary.

These magnetos being arranged for a varying number of cylinders are run at varying speeds in relation to the engine, viz.—

2-cylinder magnetos run at	$\frac{1}{2}$	engine speed		
4-cylinder	"	"	engine speed	
5-cylinder	"	"	$1\frac{1}{4}$	engine speed
6-cylinder	"	"	$1\frac{1}{2}$	" "
7-cylinder	"	"	$1\frac{3}{4}$	" "

The 7-cylinder magnetos are strictly limited in their application, since it is inadvisable to run them above 5,000 r.p.m. continuously, and are therefore only applicable to relatively low speed 7-cylinder engines.

There is yet another application of the rotating armature magneto and that is where the magneto is used purely as a generator with a separate distributor-head on the engine; in this case, one terminal only is provided for distribution, both sparks passing through this terminal to the centre terminal of the distributor-head, whence, passing through the brush holder, it is distributed in the normal manner to each cylinder. This arrangement provides a very light ignition system and is preferable in some engine installations to a magneto and distributor in one unit.

Magnetos for Gipsy I Engines. One A.G.4-2 left-hand rotation, base-mounted magneto, bare shaft extension; height of armature centre, 38 mm. One A.G.4-2 right-hand rotation, base-mounted magneto, with type A Impulse starter and half Simms coupling; height of armature, 38 mm.

Magnetos for Gipsy II Engines (or as alternative on Gipsy I engines). One A.G.4-4 left-hand rotation, base-mounted magneto, bare shaft extension; height of armature, 38 mm. One A.G.4-4 right-hand rotation, base-mounted magneto, with type L.-2B. impulse starter and half Simms coupling, height of armature, 38 mm.

Magnetos for Gipsy III Engines. One A.G.4-4 left-hand rotation, base-mounted magneto, bare shaft extension; height of armature centre, 38 mm. One A.G.4-4 right-hand rotation, base-mounted magneto, with type L.-2B. impulse starter and half Simms coupling; height of armature centre, 38 mm., arranged for running in an inverted position.

Type A.G.4 Magnetos

These magnetos are of the standard rotating armature type with a strong magnetic field which remains constant over an extended period.

The magnetos are base-mounted and are supplied with height of centres of spindle above the base of 38 mm.

Housing. The housing is die cast, with the distributor endplate and driving endplate integral parts of it, thus making an exceedingly rigid mechanical structure.

Windings. The primary and secondary windings are wound on the usual "H" type armature. The beginning of the primary winding is connected to the core, whilst the end is joined to the insulated side of the condenser and to the beginning of the secondary winding. The other end of the condenser is connected to the core. The insulated side of the condenser is connected to the insulated platinum contact of the contact-breaker, and the insulated end of the secondary is connected to the brass insert in the slip-ring.

Contact-breaker. The contact-breaker is of the usual design, i.e. a brass base on which is mounted an insulated contact block carrying an adjustable contact, the other contact being carried on a bell crank lever. The timing lever, by means of which the moment of ignition is varied, may be moved through an angle of 25 degrees.

Safety Spark Gap. To prevent the armature being damaged in the event of an interruption of the external high-tension circuit, safety gaps are provided, and in each case they are fitted on the brush holder and operate between the distributor brush and the slow-speed wheel.

Current Distribution. The distributor brush connected to the end of the secondary winding is mounted on the gear-wheel and rotates at half armature speed.

The earlier types of A.G.4 magnetos were fitted with a bronze distributor wheel meshing with a Textolite armature wheel. In the later types, the distributor wheel is made of Textolite and meshes with a steel armature wheel. Where replacements are necessary for the older type machine, the armature wheel can be replaced by a steel one and still mesh with the bronze distributor wheel, but the bronze distributor wheel cannot be replaced for a Textolite wheel for meshing with a Textolite full-speed wheel; both must be changed to the later combination.

Type A.G.4-2 magnetos are fitted with a plain journal bearing for the slow-speed wheel, and the oiling instructions given under "Maintenance in Service" should be strictly followed.

Type A.G.4-4 magnetos are fitted with a ball-bearing for the slow-speed wheel and no means of lubrication is provided.

Direction of Rotation and Relative Speed. Each magneto is arranged for one direction of rotation only and bears an arrow stamped in a conspicuous position, which indicates the direction for which the particular machine is designed. The driving speed, for all A.G.4 types, is crankshaft speed.

Installation. Set the engine to the correct firing position of No. 1 cylinder and turn the magneto armature in the direction indicated by the arrow until the distributing brush approaches No. 1 segment of the distributor. The contact-breaker should be in the fully advanced position and the contacts just separating (by not more than .0015 in.). The magneto driving wheel or coupling can then be engaged with the driving wheel or coupling on the engine drive and the magneto fastened in position.

Cutting Out the Magneto. The magneto may either be cut out of action by short-circuiting the primary winding—and this is easily done by connecting the terminal on the contact-breaker cover through a switch to the frame—or earthed. When the switch is closed the magneto will be inoperative.

LUBRICATION

(a) *A.G.A-2 Magneto (Gipsy I)*. The rotating armature of the magneto is fitted with two ball-bearings which are packed with Price's High Melting Point Grease before the magneto leaves the works.

The only part requiring lubrication is the distributor gear-wheel bearing, and eight (8) drops of light oil poured into the oil well at the distributor end of the magneto, every 25 hr. running, is sufficient.

Should the magneto stand for two weeks or more or the oil wick become dry, then the distributor end cup should be filled with oil until the oil overflows through the drain-hole seen on the left when facing the distributor.

(b) *A.G.A-4 Magneto (Gipsy II and III)*—or as alternative on Gipsy I.

All bearings in this magneto, fitted to both armature and slow-speed wheel, are of the ball-bearing type and are packed with Price's High Melting Point Grease before the magneto leaves the works. No provision is made for oiling the magneto at all, and it should not be necessary to disturb the bearings for filling with grease until a general overhaul of the engine, at the end of 450 hr. flying, is made.

NOTE. The platinum points of the contact-breaker must be kept absolutely free from oil. This is of the utmost importance, because any oil on the contacts will become oxidized and prevent good electrical contact between the platinum points when closed. The current from the magneto may be reduced considerably on this account.

Distributor and Brush Holder. Remove the distributor and clean the inside of it with a cloth moistened with petrol. Any dust or foreign matter that may accumulate inside the distributor is liable to cause leakage, the symptoms of which are misfiring or poor starting. In a similar manner wipe the surface of the brush holder.

Slip-ring and Collector Brush Holder. Remove the aluminium dust cover at the driving end of the magneto and take out the collector brush holder, which is secured to the top of the main housing by two screws, and with a cloth moistened with petrol wipe off any dust from the cone. Do not unnecessarily remove the carbon brush from the collector moulding.

Clean the flanges of the slip-ring in a similar manner. This can be done by lightly pressing one corner of the cloth between the slip-ring flanges and slowly turning the engine crankshaft, making sure that the magnetos are switched off.

Contact-breaker. The contact-breaker is readily accessible by removing the cover and can be withdrawn from the magneto after unscrewing the centre fixing screw.

Examine the contacts and if these are dirty the surface of each contact should be cleaned with a piece of very fine emery cloth or paper, care being taken to remove any emery dust which may have accumulated.

Examine the bell-crank lever bearing bush and if dry, smear with a little light oil. After re-fitting the lever on the bush, it is important that any excessive oil should be wiped off.

Refit the contact-breaker, taking care to locate the key on the contact-breaker base in the keyway of the armature spindle. With the feeler gauge on the spanner supplied with the magneto, check the contact gaps when the heel is on the high part of the cam; this gap should be 0.012 in. and if necessary should be carefully adjusted to this dimension by the aid of the feeler gauge and spanner. Do not adjust the contact gaps unnecessarily.

Adjustment and Location of Faults. If the engine is firing irregularly, though some portion of the ignition system is frequently at fault, the

magneto is not always the cause of the trouble. The investigator should, in the first place, satisfy himself that the fault does not lie in the plugs, the sparking gaps of which should be about 0.4 mm. (= .016").

Irregular firing might result from defective operation of the contact-breaker. To determine whether this is the case, the contact-breaker cover should be removed with a view to observing if the contact-breaker fixing screw is securely tightened.

Special attention should also be given to the platinum screws which should be securely locked in position. The platinum points should be carefully examined, and, if necessary, cleaned with very fine emery cloth. When the armature is revolved the maximum contact gap should be set to the feeler gauge provided on the contact-breaker spanner. This gap should, from time to time, be checked and, if necessary, the long contact screw should be adjusted.

Examine and, if necessary, clean the high-tension mouldings as instructed.

If sparking persistently occurs at the safety gap of the magneto, it is an indication that there is a break in the external high-tension circuit. If the engine stops firing altogether, it is probably due to the conductor from the low-tension earthing terminal of the magneto coming in contact with the frame, thus rendering the magneto inoperative.

If the investigation indicated above does not reveal the cause of the faulty ignition, the magneto should be returned to the makers.

Dismantling the Magneto. Total dismantling of the magneto should be rarely necessary, but instructions are given below in case this should be required.

In the ordinary way, the only attention which need be given to the magneto is to examine the contact-breaker, which is readily accessible, and may be removed and replaced without disturbing any other working part of the magneto.

In dismantling the magneto, the following procedure should be observed.

1. Remove the contact-breaker cover, cam ring, and distributor moulding.
2. Remove dust cover at the back of magnet, also the collector moulding underneath.
3. Remove earthing brush on left-hand side of housing, looking at the distributor end.
4. For A.G.4-2 magnetos, remove the slow-speed wheel oil-well and wick on right-hand side of housing, looking at distributor end.
5. Remove the contact-breaker endplate.
6. Remove the slow-speed bearing assembly.

(a) In the case of A.G.4-2 magnetos, this is accomplished by removing the locking ring, at the back of the bearing underneath the magnet, which is sprung into a groove in the spindle. It is possible to get at this locking ring by slightly moving the magnet on the pole shoes after having removed the magnet screws. A soft iron keeper passing under the base of the magneto must be fitted on the poles of the magnet before this is done.

(b) In the case of A.G.4-4 magnetos, the bearing assembly is dismantled by unscrewing the four screws fastening the bearing housing into the distributor endplate, and can be removed through a hole in the slow-speed wheel from the front of the magneto.

7. The armature may now be withdrawn from the housing, but in every case before this is done a keeper must be fitted to the magnet, or else it will be necessary to remagnetize the magnet on reassembly.

NOTE. When reassembling the magneto, great care should be taken

to ensure that the key on the contact-breaker base engages with the slot in the armature spindle.

Watford Types

The principle on which the Watford four-spark magneto is made is that of the pure inductor. The inductor consists of two cheeks which are assemblies of laminae mounted concentrically on a hollow spindle made of high tensile steel, the design of which makes a very light construction. The inductor runs in a tunnel on ball bearings. The bore of this tunnel presents six poles to the inductor, four of which are connected to the extremities of four permanent bar magnets and the other two form part

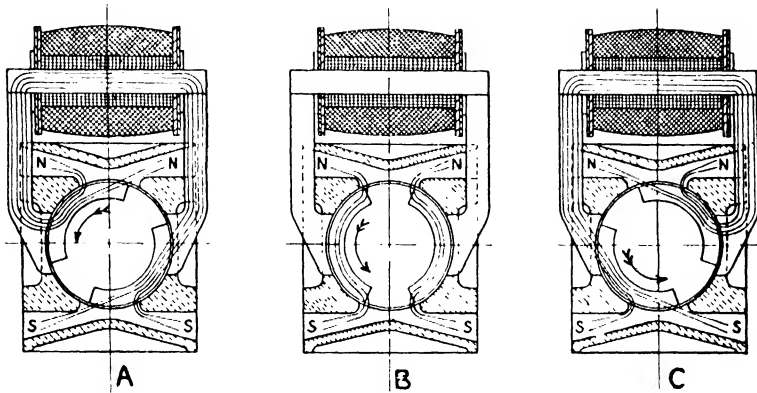


FIG. 64

of the armature core. The whole of the laminated pole shoes, which are made of a special high permeability steel, are cast in a casing of aluminium to ensure a solid construction, the pole shoes representing cylindrical faces to the inductor.

The action of this inductor principle will be easily understood with reference to the three diagrams showing the flux changes for different positions of the inductor through 90° movement.

Fig. 64A shows the flux direction from N. through the armature via the left-hand limb of the armature core.

Fig. 64B shows the rotor in a position giving zero flux, i.e. the flux is passing from one pole of the magnets to the other pole through the rotor.

Fig. 64C shows the flux direction from N. through the armature via the right-hand limb of the armature core.

As will be seen from the illustrations, the armature core is stationary.

The low-tension current can be traced on the diagram (Fig. 65), the lead being enclosed within the magneto and terminating at the insulated platinum screw carrier via the laminated bronze and steel connection *O*. The other end of the primary winding is earthed.

The outside lead of the secondary winding is connected to a fixed insulated terminal on the armature, and is transferred through the centre of the distributor rotor to the distributing electrode, thence jumping to the distributor segments, which are connected to the high-tension terminals in the distributor block. The distributor is fitted with a centre terminal to enable a hand-starter magneto to be used.

The condenser is mounted in a case of insulated material above the

armature. The condenser is connected in the usual manner, i.e. in parallel with the primary winding and the platinum contacts.

The entire magnetic flux system is laminated, and this in conjunction with the design of the tunnel and inductor is designed to give extremely active and intensely powerful magnetic flux alternations through the armature core. The speeds at which the magneto will run efficiently are much in excess of those obtainable by any other system. The magneto will function perfectly at 8,000 r.p.m., the number of sparks being 32,000 sparks per minute.

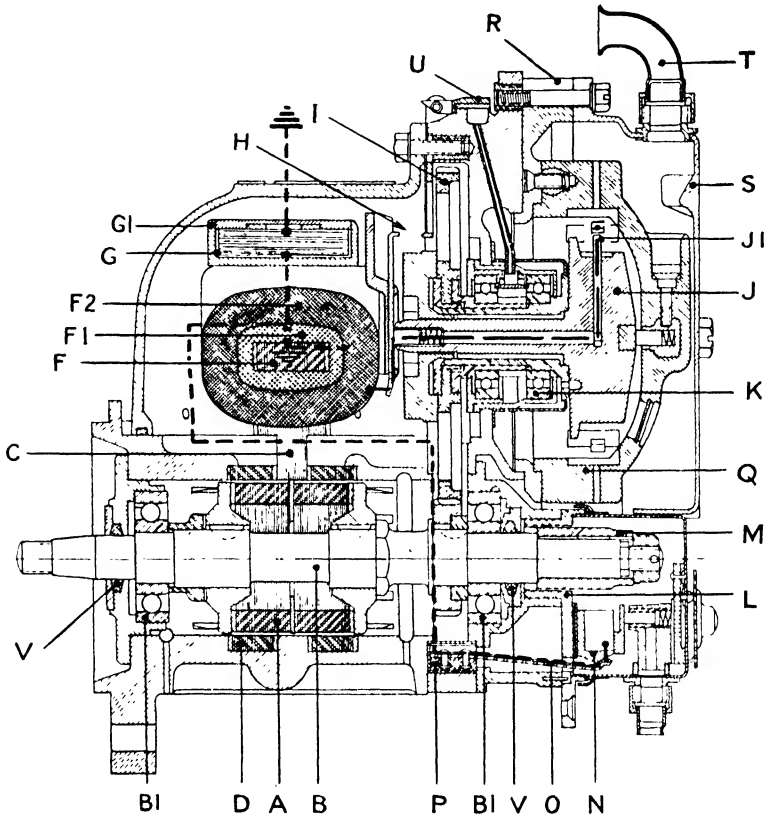


FIG. 65

- A = Laminated inductor.
- B = Hollow driving shaft.
- B1 = Rotor bearings.
- C = Armature pole shoes.
- D = Magnet pole shoes.
- E = Magnets.
- F = Armature.
- F1 = Primary winding.
- F2 = Secondary winding.
- G = Condenser.
- G1 = Case of special insulating material for condenser.
- H = Safety gap.
- I = Distributor gear wheel.
- J = Distributor rotor.
- J1 = Distributor electrode.

- J2 = Distributor terminal.
- K = Distributor spindle ball bearings.
- L = Stationary contact-breaker base.
- M = Rotating cam.
- N = Insulated platinum screw carrier.
- O = Insulated low tension laminated connection to contact-breaker.
- P = Insulated block for earth terminal wire.
- Q = Distributor block.
- R = Aluminium mounting ring for distributor block.
- S = Distributor block screen.
- T = Hand starter terminal.
- U = Common lubrication cap for all bearings.
- V = Felt packing glands.

The magneto is fully screened to prevent interference to wireless apparatus.

The usual voltage under fully screened conditions, that is with 6 ft. of braided cable on each lead, is 10,000 volts.

Scintilla Type

The Scintilla-type magneto employs a rotating permanent magnet, and the delicate parts, such as the coil and the contact-breaker with its contact points, are stationary. The four-pole permanent magnet 1 (Fig. 65B) rotating between the stationary pole shoes 2 produces in the core 3 a

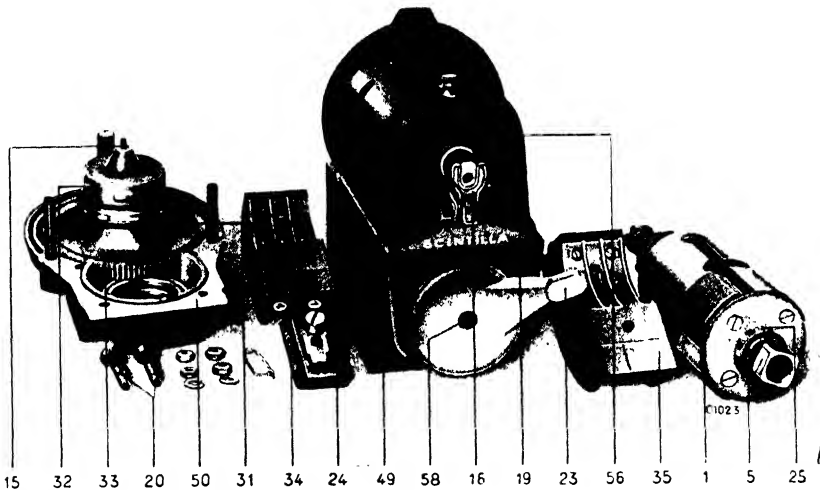


FIG. 65A. MAGNETO TYPE GN 8-D PARTIALLY DISMANTLED

strong alternating magnetic field. This magnetic field generates an alternating low-tension current in the primary winding 4, the latter being composed of a few turns of thick wire. When this current reaches its maximum value, the breaker cam 5 causes the breaker lever 7 to turn on its axle 6, thereby separating the contact points 10, thus leaving a gap between them. The cam is mounted on the back end shaft of the rotating magnet 1, its position being fixed in relation to the magnetic field. The short contact point 8 (Fig. 65C) is connected to the motor frame through the breaker lever 7 and the main spring 9, whereas the long contact point 10 is fixed to the insulated support 11, and is kept in permanent contact with the primary winding 4 by means of brushes fitted to the primary connecting strip 22. Owing to the contact points 8 and 10 separating, the primary current is suddenly interrupted. The normal width of the gap must be 0.3-0.4 mm. In order that there may be four interruptions per revolution, corresponding to the four maximum values of the primary current, the cam is provided with four bosses. For the same reason the cam is provided with two bosses for a permanent magnet having two poles, and with eight for a magnet with eight poles. The advancing and retarding of the ignition are obtained by making the contact-breaker assembly

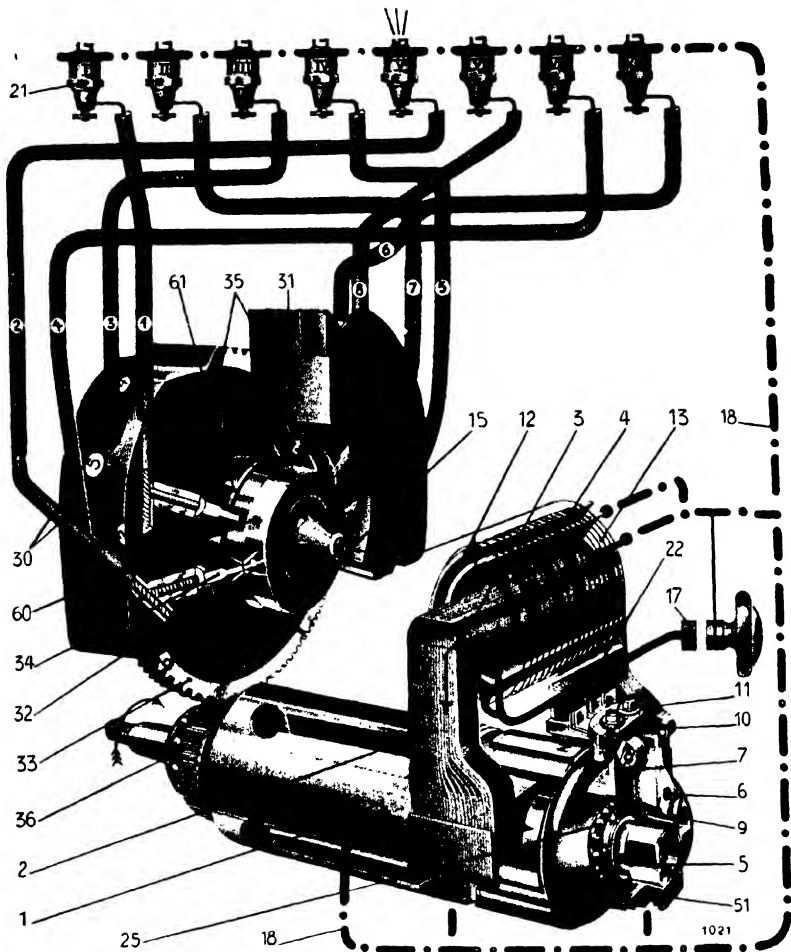


FIG. 65B. WORKING DIAGRAM OF THE MAGNETO FOR 8-CYLINDER ENGINES
 (An anti-clockwise rotating magneto is represented. To determine the direction of rotation the magneto should be viewed from the driving end.) Order of firing: 1, 7, 3, 5, 2, 8, 4, 6.

- | | | |
|--|--|---|
| 1. Rotating permanent magnet with laminated pole-pieces. | 18. Motor frame (ground). | 34. Electrodes in distributor block. |
| 2. Stationary laminated pole shoes. | 19. Breaker cover. | 35. Distributor blocks. |
| 3. Laminated core of coil. | 20. Securing screw for front end plate. | 49. Magneto housing. |
| 4. Primary winding. | 21. Sparking plugs. | 50. Front end plate. |
| 5. Four-boss breaker cam. | 22. Primary connecting strip to fastening screw for ground wire. | 51. Contact-breaker cage. |
| 6. Breaker lever axle. | 23. End cover with advance lever. | 52. Spring for contact-breaker end cover. |
| 7. Breaker lever. | 24. Securing cover for distributor blocks. | 55. Coil. |
| 9. Main spring for breaker lever. | 25. Ball race (front end). | 56. Main cover. |
| 10. Long contact point (insulated). | 30. Ignition cables. | 58. Securing screw for contact breaker end plate. |
| 11. Insulated support. | 31. Distributor cylinder. | 60. Segment in distributor cylinder carrying boost current. |
| 12. Condenser. | 32. Segments in distributor cylinder carrying secondary current. | 61. Collector ring for boost current. |
| 13. Secondary winding. | 33. Large distributor gear. | |
| 15. High-tension carbon brush in distributor cylinder. | | |
| 17. Insulated terminal of magneto switch. | | |

oscillate round the cam 5 by means of the timing lever 23 (Fig. 65A), the interruption of the primary circuit being thus advanced or retarded. The condenser 12, which is in parallel with the contact points 8 and 10, prevents abnormal sparking at these points when the interruption of the primary current takes place, thereby reducing their wear to a minimum and at the same time ensuring regular sparking. The sudden interruption of the primary current generates a high-tension current in the secondary winding 13, the latter being composed of a large number of turns of fine wire. One end of this secondary winding 13 is connected to the motor frame 18 through the primary winding 4, while the other end terminates at the central contact which forms part of the coil. The high-tension carbon brush 15 transmits the current successively to the sparking plugs 21 through the medium of the distributor. The high-tension carbon brush 15 of the distributor cylinder bears on the central contact of the coil, and is electrically connected to the two segments 32, which are simultaneously under pressure at every interruption. The distributor cylinder 31 is fixed on the large distributor gear 33 in a definite position relative to the contact-breaker. The segments 32 successively pass the electrodes 34 on the distributor blocks 35, thus transmitting the current through the ignition cables 30 to the sparking plugs. Referring to the diagram, electrode No. 1 is under pressure and a spark is produced at the plug of the first cylinder viewed from the front end.

The breaker cam has four bosses, consequently the magneto produces four sparks per revolution, and as these must succeed each other at equal intervals the bosses are displaced 90° . The distributor has to supply eight sparks, and must therefore rotate at half the speed of the driving spindle. On the other magnetos this alters according to the number of the cylinders—for example, on the twelve-cylinder magneto it is $\frac{1}{3}$. In order that the ignition may be cut out, the effect of the contact-breaker must be neutralized as follows (See Fig. 65B)—

The end of the primary winding 4 terminates, through the primary connecting strip 22, at the terminal to which is connected the primary cable. The latter is taken to the insulated terminal 17 of the magneto switch, the second terminal of the latter being connected to the motor frame 18. When the switch is closed, the primary winding is short-circuited and ignition ceases, due to the effect of the contact-breaker being neutralized. Aero engines are generally provided with a special ignition system for starting purposes, which is usually a small hand-driven magneto or battery ignition with separate coil and contact-breaker. In order to obtain the spark from the auxiliary starting device for the cylinder which is on the explosion stroke, the service magneto is fitted with a special distributor cylinder having four segments instead of the usual two. The starting segments are arranged to follow the service segments at a pre-determined angle, and are connected electrically to the collector ring.

Scintilla magnetos described "D" (for example GN 12-D) are suitable for use in connection with an auxiliary starting device. The timing of these magnetos should be carried out in the following manner—

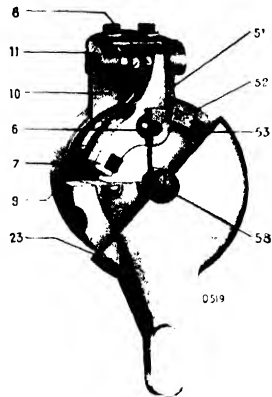


FIG. 65c
SECTION THROUGH THE
CONTACT-BREAKER OF A
CLOCKWISE-ROTATING
MAGNETO

Turn the engine so that the piston of No. 1 cylinder comes towards the end of the compression stroke, and stop as soon as the point of maximum

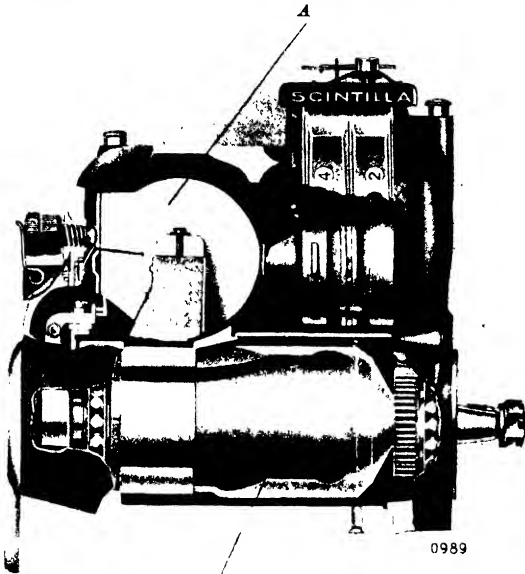


FIG. 65D. ROTATING MAGNET
Magneto type GN 8-D sectionalized

- A, Stationary coil carrying primary and secondary windings and condenser
- B, Rotating Permanent Magnet

advance is reached—this maximum power. Next,



FIG. 65E. MARKS ON FRONT
END PLATE AND LARGE
DISTRIBUTOR WHEEL

is also the point where the engine develops its maximum power. Next, make the mark on the large distributor wheel (visible when taking off left-hand distributor block) correspond to the mark on the front end plate. At this moment the contact points open when the advance lever is in the advanced position. On magnetos with fixed ignition the contact-breaker is always in the advanced position. For the above-mentioned operation it is assumed that the driving couplings are already engaged, but that one of them is still loose on its spindle, unless an adjustable type coupling is fitted. When the timing is completed, the couplings should be firmly secured on their spindles. If the magneto has variable ignition, the advance lever is to be fixed in the most suitable of the eight possible positions. Next, connect up the rods to the advance lever, making sure that the whole range of movement is available after connecting up.

Impulse Starter (see Fig. 66)

This device consists essentially of two members, the driving member,

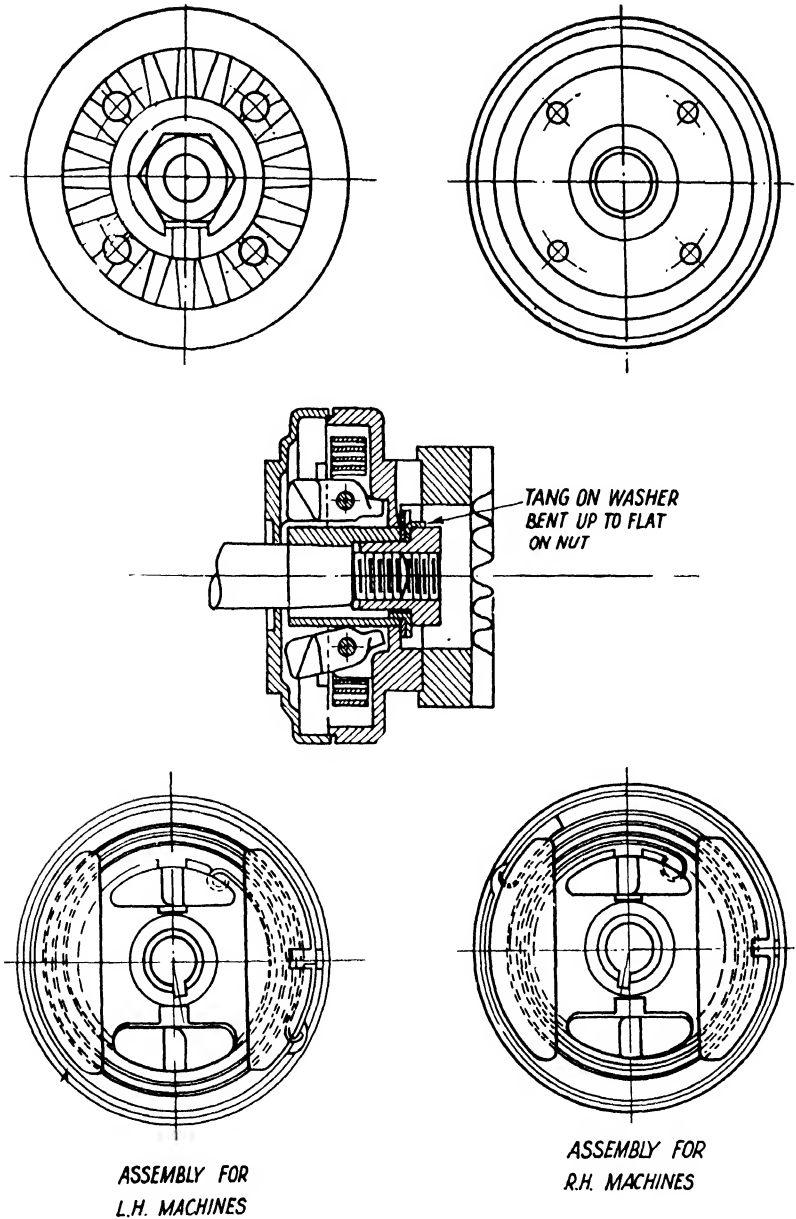


FIG. 66. IMPULSE STARTER. MAIN ASSEMBLY

which is coupled to the magneto driving shaft of the engine, and the hub assembly, which is rigidly secured to the magneto spindle.

The driving member and hub assembly are linked together with a stout helical spring. The hub carries two pawls, one end of which engages with the cam profile machined on the inside face of the driving member.

A special endplate is fitted to the driving end of the magneto and is provided with a stop.

The action of the impulse starter is as follows—

1. When the driving member is rotated, one of the pawls will reach the top position and, being free to drop, engages with the top of the end-plate. The armature and hub assembly are thus locked and held stationary.

2. Further rotation of the driving member will cause the helical spring to be wound up, and an angular displacement will take place between the driving member and hub assembly.

3. At a pre-determined position the cam on the inside face of the driving member engages with the outer end of the pawl and forces it inwards.

4. This disengages the pawl from the stop in the endplate, and, due to the winding up of the spring, the hub assembly, together with the armature, receives a sudden impulse. The magneto is timed so that the contacts separate during this very rapid "flick over" and an intense spark is thus automatically produced.

5. The pawls are so weighted that the heavy ends are thrown out by centrifugal force and automatically clear themselves from a further engagement with the stop on the endplate as soon as the engine accelerates. The speed at which this occurs is about 160 r.p.m. magneto speed.

6. As soon as the pawls cease to engage, the two members, i.e. the driving member and hub assembly, rotate as a single unit.

It should be specially noted that as two pawls are fitted, two impulses are obtained every revolution of the magneto driving shaft.

The A.G.4-2 magneto may be fitted with the Type "A" impulse starter. This starter is susceptible to end-thrust and it is therefore important that a slight amount of endplay (.02 in.) be allowed when fitting the rubber distance-piece in the Simms coupling. If any endthrust is exerted, the hub, after it has been released from the stop, will remain in this position and the impulse starter is then absolutely inoperative.

If it should be found at any time that the impulse starter is sticking and does not operate, the bolts fixing the magneto to the base plate of the engine should be released and the magneto moved slightly outward: there is sufficient clearance between the bolts and the bolt-holes to allow for this. The impulse starter will then immediately be released.

Two other points should be watched with this type of impulse starter, viz.—

(a) See that the driving pin is free in the guide block.

(b) See that the pawl is free on its bearing.

If either of these points is suspected, it will be necessary to dismantle the impulse starter by unscrewing the fixing nut; and to do this it is necessary to insert a locking pin in the hole in the impulse-starter casing.

A.G.4-4 magnetos are fitted with type "L.-2B." impulse starters, which is a smaller and lighter device of the "A" type. Both types are absolutely interchangeable, and therefore this lighter type can be fitted to magnetos already equipped with the "A" type, if necessary.

The "L.-2B." type impulse starter is not so susceptible to endthrust as the type "A," but although it will not adversely affect the functioning of the impulse starter, it is not advisable to exert endthrust.

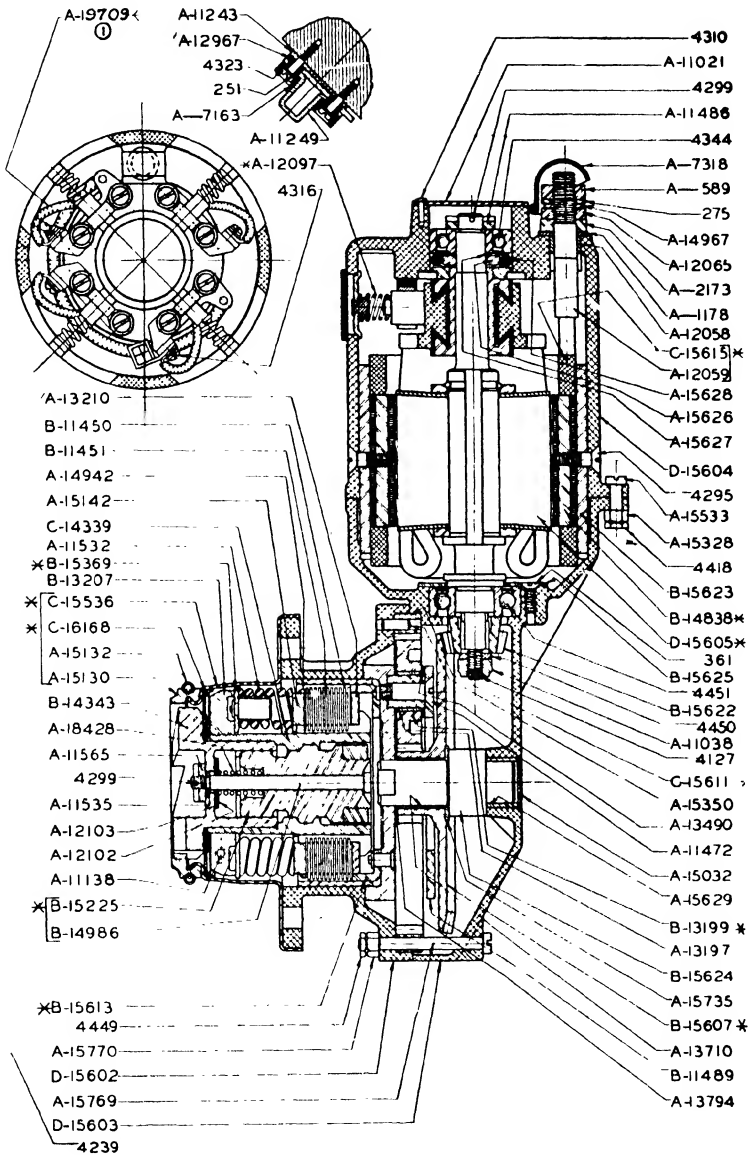


FIG. 67. ECLIPSE ELECTRIC STARTER

102 ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT

A.G.4-4 magnetos, not having any oiling system, can be fitted in an upright or inverted position. If, when this is done, either of the magnetos is fitted with an impulse starter, the stop on the back member must always be on top since the pawls are gravity-operated. Therefore, in order to distinguish which way up the magneto and impulse starter should be fitted, the word "vertical" or "inverted" is engraved on the back member of the impulse starter. The back member engraved with the word "vertical" indicates that the magneto should be fitted to either a Gipsy I or Gipsy II engine, and where the word "inverted" is engraved, it denotes that the magneto should be fitted to the Gipsy III engine.

This engraving on the impulse starter back-plate is applicable to those which have only one stop on this member; where two stops are provided, no special identification will be engraved externally, it being possible to operate these impulse starters either vertically or invertedly.

TIMING OF IMPULSE STARTERS

1. *Impulse Starters for Magnetos Rotating Clockwise.* Rotate the starter in a counter-clockwise direction until the two arrows, which are shown one on the starter endplate and one on the driving member, coincide. At the same time, see that the distributor brush is just overlapping the segment on No. 1 terminal. At this point, the contacts are just open with the timing lever advanced, and the sparking will take place on cylinder No. 1. Crank the engine to the desired firing angle and fix the magneto in this position.

2. *Impulse Starters for Magnetos Rotating Counter-clockwise.* Rotate the starter in a clockwise direction until the two arrows coincide, and proceed as in 1.

The only attention required during running, under normal conditions, is a few drops of machine oil occasionally inserted through the hole in the endplate.

DISMANTLING OF IMPULSE STARTER

The impulse starter is dismantled by unscrewing the one fixing nut which holds it to the spindle of the magneto. To do this it is necessary to insert a locking pin in the hole of the impulse starter casing. This locking pin should be used when assembling the impulse starter to tighten up the fixing nut, but it is vitally important that it should be removed before assembling the magneto on the engine.

EFFECT OF WEAR

Wear of the stops which retain the impulse unit B.T.H. Type L in position during normal running of the engine, i.e. when the unit is inoperative, has the effect of increasing the degree of advance of the ignition timing, and it is important that the advance shall at no time exceed that quoted on the engine data plate or in the instruction book.

The timing should, therefore, be periodically checked, and, if necessary, reset by means of the vernier coupling.

All details of the result of each examination should be entered in the log book, with particular reference to any adjustments made. An indication will thereby be provided of the extent, if any, to which the stops have worn.

Eclipse Electric Starter

The Eclipse Direct Cranking Electric Starter, Type Y-150, is furnished in the following models—

Model
M. 2266
M. 2286

Rotation
Clockwise
Anti-clockwise

The type Y-150 starter is designed to crank an engine continuously with the power available from a standard aircraft storage battery. It

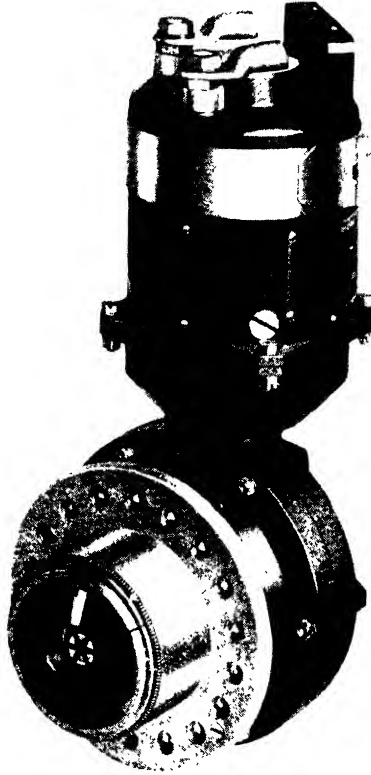


FIG. 68. ECLIPSE ELECTRIC STARTER UNIT

consists of an electric motor which drives reduction gearing operating an automatic meshing and demeshing mechanism through an adjustable torque overload release.

Referring to the cross-section (Fig. 67), it will be seen that a bevel pinion, mounted on the electric motor armature shaft, drives a bevel gear. This is integral with a spur pinion which meshes with three planetary gears. These are mounted on the barrel and run in a stationary gear fastened to the housing. The planetary gears drive the barrel containing the torque overload release, a spring-adjusted, multiple disc clutch. The externally splined clutch discs are driven by the barrel and the internally splined discs drive the spline nut. Threaded within this is the screw shaft which is caused to advance at the first rotation until the stop nut rests against the back end of the threads. The starter jaw advances with the screw shaft and meshes with the engine jaw. A friction brake is used to make the jaw advance into mesh before rotating. This consists of a three-

piece friction ring having tips which fit into corresponding slots in the jaw. It is held in place on the baffle plate by a spring of predetermined tension.

The rear faces of the starter jaw teeth are sloped so that when the engine starts the jaw is pushed out of mesh. The clutch is a safety device to allow only the desired amount of torque to be used for turning the engine over and also to protect the starter from possible damage in case the engine back-fires.

When starters are shipped from the factory a dust cover is sometimes mounted on the forward end over the starter jaw. It should not be removed until mounting the starter.

The Type Y-150 starter is applicable to engines having the standard 5 in. S.A.E. starter mounting flange. Six studs are located in this flange on a 4-in. bolt circle.

There should be approximately $\frac{3}{8}$ in. clearance between the engine jaw and the starter jaw when the latter is out of mesh. This should always be checked when fitting.

The flange on the starter is drilled with eighteen holes providing various positions 20° apart in which the starter can be mounted to give the best clearance. The starter will operate equally well in any position.

The starter may be operated from a 6-volt battery when used on engines up to 250 cub. in. displacement, but for engines from 250 to 450 cub. in. displacement a 12-volt battery must be used. The regular aircraft type non-spillable battery should be used, many makes of which are now available. It is difficult to make any recommendations on the size to be used as this will depend on the current required in addition to the starter, by landing lights, navigation and instrument lights.

The battery carrier should be located as close to the starter as convenient in order to simplify the wiring. It must be adequately vented.

The use of a solenoid switch is recommended where the Y-150 starter is at some distance from the push switch. In this type of installation an ordinary push switch in the cockpit is sufficient for the current which it will be required to carry. The wiring will consist of two circuits, the "battery-starter-solenoid" circuit, and the "solenoid-push-switch-battery" circuit.

If a solenoid switch is not used, a heavy duty push-switch must be installed. The circuit then is a simple series connection.

The engine manufacturer's instruction book should first be followed for preparation of the engine before starting.

Usually, the spark is at full advance and the throttle is slightly open when the starter is operated. If the engine fails to start readily the cause should be ascertained at once in order to avoid running the battery down. If it is required to unload the cylinders of their charge, the propeller should be pulled through one-third or one-half turn in its normal direction (switch off) to disengage the starter jaw. When released, the propeller may be turned in the opposite direction as required and then primed again for a new start.

All starters are sufficiently lubricated prior to shipment and should require no attention for a considerable period of service. Do not put oil on the commutator as it will seriously hinder the operation of, or cause considerable damage to, the motor.

The brushes should be inspected at 150-hour intervals to see that they are bearing on the commutator and that they do not bind in their respective holders. If such periodic examination should disclose worn brushes, they should be replaced immediately. Burning of the commutator and insulation usually results from failure to make such replacement in time.

The brush springs should also be examined and if they have lost their tension they should be replaced. The brushes should be under at least 20 oz. pressure.

Do not use emery cloth or rough sand-paper on the commutator. It can be polished with fine sand-paper. Make sure all sand particles are cleaned out before operating the motor. If the commutator becomes rough or burned, remove the armature and take a light, smooth cut across its face.

If the motor fails to operate, the trouble may be in the solenoid switch or the push switch. A jumper wire connected across the large terminals of the solenoid switch will make a direct circuit between the battery and starter. If the motor operates with this jumper wire, the solenoid or push switch is inoperative.

The bearings are lubricated with a good grade of neutral bearing grease.

The gears and clutch are lubricated with a light covering of No. 32 Gredag. It is highly important that no other lubricant be used.

All starter clutches are carefully set prior to shipping and should not require altering. The setting is determined by the size of the engine on which the starter is to be used and it requires special equipment.

An oil seal is incorporated in all starters to prevent seepage of oil from the engine crankcase into the starter housings. Engine oil will slow up the operation of the starter so that its performance is unsatisfactory.

A baffle plate is provided to cover completely the portion of the starter protruding into the crankcase, to protect the starter from oil splash. A leather seal is also assembled within the baffle plate back of the starter jaw in the event of the oil level, for any reason, approaching the opening in the baffle plate.

(B) Heavy Aircraft Magnetos

As indicated previously, for heavier aircraft engines the design of the magneto is radically modified and four sparks per revolution of the rotor are provided. This type of magneto falls into three sub-divisions—

1. Polar inductor type—where the flux is reversed in the rotor itself.
2. Polar inductor type—where the flux is reversed in the armature poles which carry a stationary coil.
3. Rotating magnet type—where the magnet itself is incorporated in the rotor assembly.

In all three types the general arrangement of components is identical, and they are arranged in easily accessible sub-assemblies.

Housing. This is a die casting and has cast in it the armature poles which protrude above the top face. This housing also contains the end-plate suitable for spigot mounting—or in the case of base-mounted magnetos, inserts in the base for fixing. The poles are laminated and sheet iron material is used so that the losses are reduced to a minimum. On these poles is fastened the armature assembly.

Armature. This is a bobbin having a laminated core with primary and secondary windings similar to the rotating armature type magneto. The primary usually contains about 200 turns of H.C.C. enamelled wire and the secondary approximately 10,000 turns of H.C.C. wire. A condenser is fastened to this bobbin and one side is connected to the insulated side of the primary and the other is connected to earth, the beginning of the primary winding having already been earthed in the bobbin; the secondary is brought out to the coil moulding. The distributor endplate is a separate die casting and spigots into the housing carrying one of the

rotor bearings, the other rotor bearing being integral with the housing. This endplate also carries the slow-speed wheel assembly.

Slow-speed Wheel Assembly. This is very similar to the one described for light aircraft, except that the brush holder makes direct contact with the coil moulding.

Distributor. This is a completely moulded unit and also spigots into the distributor endplate.

Rotor has four poles, which, in the case of the pure inductor magneto is laminated, as the flux has to be reversed in this rotor, and in the case of the other two types of magnetos is made of solid malleable cast iron of low hysteresis loss. In all cases a straight, though non-magnetic, shaft is used with the driving spindle at one end, and the cam operating the contact-breaker mechanism at the other. The rotating magnet rotor is a tubular, or in some cases a bar magnet, spigoted into the inductor fingers, thus providing a magnetic flux directly on those fingers. The inductor fingers are spaced 90 degrees apart, being alternately north and south. In the case of the pure inductor machine, pole inductor magnets are affixed to the housing, one or two on either side, the flux passes through laminated poles to the housing and the rotor. These magnets are usually of straight magnetic cobalt steel.

Contact-breaker. The contact-breaker mechanism is very similar to that used on light-weight magnetos, with a bell cranked lever having platinum iridium contacts affixed to it, and being controlled by a spring. This lever operates on a hardened steel pivot. Also affixed to the base is an insulated block which carries the adjustable contact. The primary from the insulated side of the condenser is taken by means of a lead to this insulated block through the endplate, contact being either permanent or through some sort of spring or plug connection. This contact-breaker lever is operated by a hardened cam which is fitted to the spindle and has four lobes. These lobes are so arranged that the contacts are held open for the correct period and closed for the correct period to allow the flux to build up to its maximum value. The whole of the contact-breaker is shielded by means of a pressed metal C.B. cover, in which is an insulated connection which connects to the block on the C.B. base, and forms a means of affixing the lead for earthing the magneto.

Timing of Magneto. The timing of this magneto is carried out in a similar manner to that described for lightweight magnetos, except that the contact-breaker base itself is moved, and an adjustable strap is provided in the endplate for setting the timing, all the parts, i.e. the cam, contact-breaker, keyways in the rotor, being so arranged that the timing is very nearly correct when the parts are assembled, and therefore this strap has only to be moved a relatively small distance to adjust the timing correctly.

Magnetos Types A.C. and S.C.

Types A.C. and S.C. magnetos belong to that distinctive class of high-tension magnetos known as the "Polar Inductor" type, and are provided with a stationary armature in which the current that produces the spark is generated. This current reaches a maximum four times during each revolution of the rotating member, called the polar inductor, and accordingly four sparks per revolution of the magneto shaft are produced. Types A.C. and S.C. magnetos are supplied in the following forms.

A.C.12. A base-mounted magneto suitable for 12-cylinder aeroplane engines, and provided with a trailing starting-point, the distributor having

protruding segments, and arranged for front fixing. The distributor and contact-breaker are fitted with metal shields arranged to accommodate metal-braided cable to standard specification. The low-tension lead (metal-

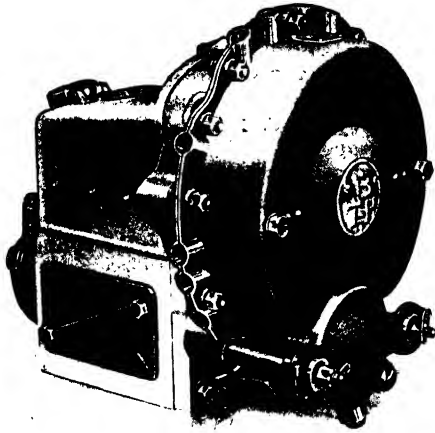


FIG. 69. TYPE A.C.12-1 BASE-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

braided) is connected to the contact-breaker in such a manner as to ensure the whole being effectively shielded. Variable or fixed ignition can be arranged as required.

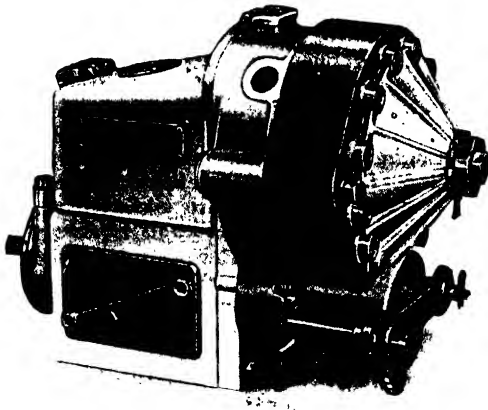


FIG. 70. TYPE A.C.12-9 BASE-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

S.C.12. Similar to A.C.12, but designed for spigot mounting, and having an oil-tight gland in the driving endplate, preventing oil under pressure in the crankcase from being forced into the interior of the magneto.

Shields for contact-breaker and distributor are embodied similar to those on the A.C.12 magneto.

The above two magnetos can be supplied with distributors arranged for the ignition cable to be brought out either in an axial or a radial direction. They can also be supplied unshielded.

S.C.14. Similar to S.C.12 but designed for a 14-cylinder engine. This magneto can only be supplied with high-tension leads of the distributor brought out in an axial direction, but can be supplied unshielded.

S.C.10-1. Similar to type S.C.14, but designed for 10-cylinder engines. The distributors are arranged for the ignition cables to be brought out in an axial direction only. This type of magneto is driven at $1\frac{1}{2}$ times engine speed, and is supplied to operate as right- or left-hand machines.

S.C.9. Similar to S.C.14, but designed for a 9-cylinder engine.

S.C.7. Similar to S.C.14, but designed for a 7-cylinder engine.

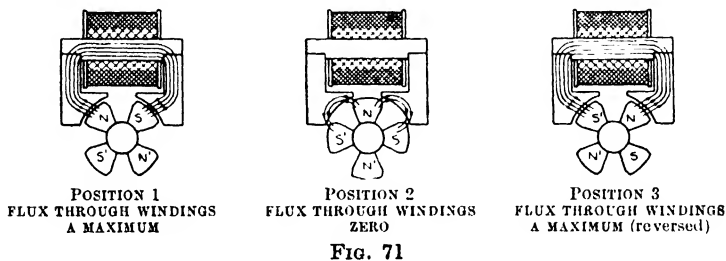


FIG. 71

Each type can be supplied for either right- or left-hand rotation as required. The shaft extension is always provided with a taper of 1 in 10. For standard base-mounted magnetos the distance between the centre line of the shaft and the bottom of the base plate is 45 mm.

Owing to the special arrangement of the Type A.C. and S.C. magnetos, dismantling can be carried out with very great ease. The design is such that the various screws and the different components, which are grouped to form distinctive sub-assemblies, are readily accessible. The magnetos are fitted with "straight through" steel shafts on which the rotating inductors are mounted, forming an excellent mechanical construction specially adapted to withstand the severe vibration met with in service on aeroplane engines. The rotor requires no fixing screws.

Low Speed. As there are four sparks per revolution of the shaft the magneto operates at half the speed at which a rotating armature type of magneto (suitable for a corresponding number of cylinders) is driven. This conduces to long life of the various moving parts.

The low-speed sparking characteristics of the magneto are extraordinarily good, and starting is therefore facilitated.

Rotating Safety Spark Gap. The safety spark gap electrodes are mounted on the half-speed wheel of the magneto, and thus when the machine is in operation these electrodes are constantly sweeping through the air, by which means undue ionization is entirely avoided.

Ample Leakage Surface and No Brushes. Owing to the fact that the windings do not rotate, no slip-ring is required, and the leakage surfaces are appreciably in excess of those provided in rotating armature magnetos. These two features ensure immunity from internal electrical leakage.

Stationary Armature and Laminated Iron Circuit. As previously stated,

the armature of this magneto is stationary. It can be easily removed, and is designed to give unusually large safety factors in the winding.

The entire iron circuit, in which the flux reversal occurs, is laminated,

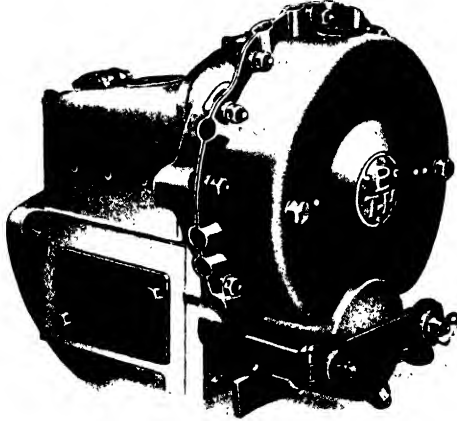


FIG. 72. TYPE S.C.12-7 SPIGOT-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

thus giving a very rapid rise of voltage at "break" and resulting in increased intensity of the spark.

Distributor. A special type of distributor is provided operating with a small spark gap between the rotating metal brush and the segments, the

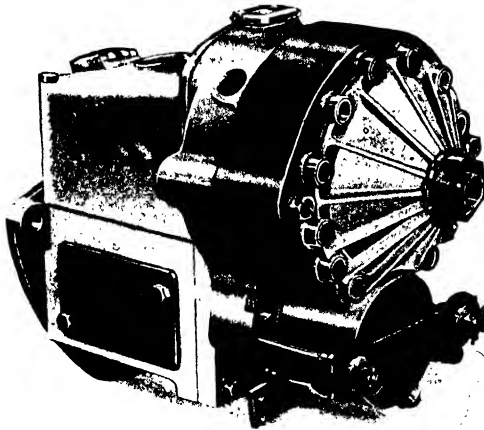


FIG. 73. TYPE S.C.12-10 SPIGOT-MOUNTED MAGNETO
(By courtesy of B.T. H. Co.)

latter being arranged to protrude well beyond the surface of the material. With distributors of this design "tracking" cannot occur.

The distributor used on the Types A.C. and S.C. magnetos is fastened to the magneto by means of two set screws which are screwed into bronze

inserts located in the aluminium end-casting. In addition these machines have a metal shield which completely screens the distributor and contact-breaker to prevent interference with wireless apparatus installed on the aeroplane.

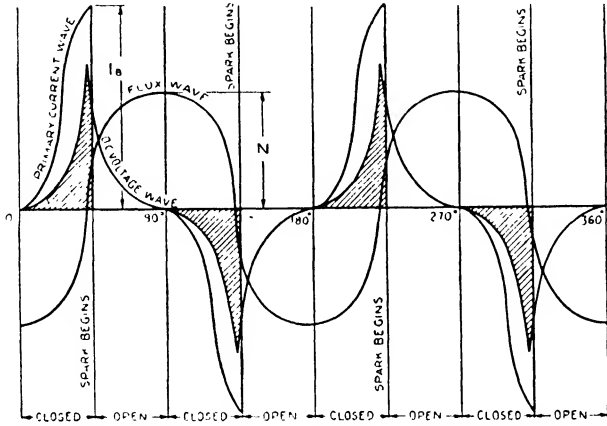


FIG. 74. FLUX AND VOLTAGE WAVES IN ONE REVOLUTION
(By courtesy of B.T.-H. Co)

The whole range of these aircraft magnetos are designed for use with metal-braided cable, but, by the introduction of special cable fittings, plain rubber cable may be used.

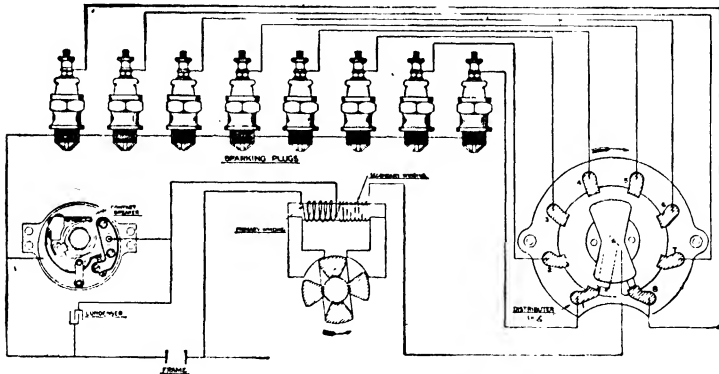


FIG. 75. CONNECTION DIAGRAM FOR SINGLE-POINT IGNITION
NOTE. The order of the plugs does not denote the numbering of the cylinders commonly adopted.

(By courtesy of B.T.-H. Co.)

LIGHT-WEIGHT MAGNETOS

Where magnetos of exceptionally light weight are required, as for racing machine engines, all types of magneto can be supplied with the main castings made of Ultra-light Magnesium Alloy. These magnetos are unshielded and the distributors are suitable for use with plain high-tension leads.

DESCRIPTION AND OPERATION

Magnets and Flux Distribution. Two cobalt steel magnets having phenomenally high magnetic characteristics are fitted on the sides of the main body casting, and make intimate contact with the two laminated annular poles at each end of the body casting. The poles of the magnets are disposed axially so that the two laminated poles at the ends of the body casting are of opposite magnetic polarity. The flux enters the annular end of the rotating inductors via the small air gap, passing through the inductors to the armature core. The reversal of the magnetic flux in the armature core is effected by the rotation of the inductors or fingers in the manner illustrated in Fig. 71, from which it will be seen that there are four complete reversals of flux in the armature core for every revolution of the rotor shaft. Fig. 74 shows flux and voltage waves produced.

Relative Speed and Direction of Rotation. The type S.C.7 magneto is driven at $\frac{1}{2}$ engine speed, the type S.C.9 at $1\frac{1}{2}$ engine speed, the types S.C.12 and A.C.12 at $1\frac{1}{2}$ engine speed, and the type S.C.14 at $1\frac{1}{2}$ engine speed. All these magnetos can be supplied to operate as right- or left-hand machines as conditions demand, and are suitable for operating in pairs on engines arranged for dual ignition.

Primary Winding. The beginning of the primary winding is connected to the armature core or earth, and the end is connected to the beginning of the secondary winding and to the contact-breaker. The cam operates the rocker arm, separating the contacts four times per revolution of the shaft. When the contacts are closed the primary winding is short-circuited, and as the inductor rotates, the current induced in the primary winding builds up until the cam separates the contacts at the instant when this current is at a maximum. The instantaneous collapse and reversal of the flux at the moment of "break" produces the high voltage in the secondary winding which causes the spark.

Secondary Winding. As previously mentioned, the beginning of the secondary winding is connected to the end of the primary winding, and the end of the secondary winding is connected to the small brass insert in the armature coil moulding. This insert makes contact with the collector brush, which is in turn connected to the rotating metal brush. The spark leaps from the rotating brush to the various segments as the brush rotates, and thus the ignition sparks are distributed to the various plugs on the engine. These connections will be clearly understood on reference to Fig. 75. It should be particularly noted, however, that the order of the plugs as shown in the diagram does not necessarily agree with the numbering of the cylinders commonly adopted.

Safety Spark Gap. The safety spark gap is one of the special features in the design of this type of magneto. Should any connecting lead become disconnected from its plug, undue rise of voltage, which might damage the insulation of the magneto, is guarded against by the provision of the safety gap across which the spark may discharge when there is no alternative gap between the spark plug electrodes. A brass point protrudes from the distributing brush box towards the slow-speed gear-wheel, and a serrated stud, screwed into the gear-wheel, constitutes the other pole of the gap. Owing to the fact that this gap is always rotating, the air between the electrodes is in a constant state of commotion, and thus ionization is reduced to a minimum. Furthermore, the machines are provided with suitable means of ventilation so that the air in the machines is constantly being changed. These features ensure that the spark gap will be reliable in practice.

Contact-breaker. It is necessary to close and open the primary circuit four times during each revolution of the rotor shaft, and this is effected by means of a four-point cam which is mounted on the end of the shaft.

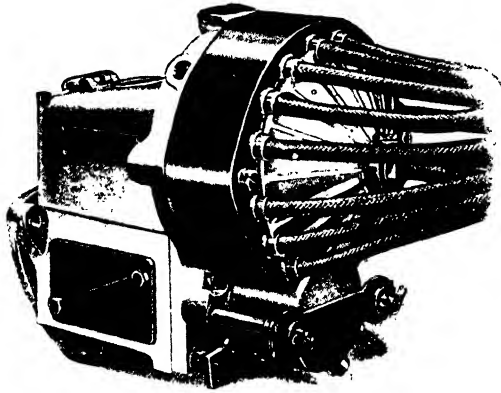


FIG. 76. TYPE S.C.14-1 SPIGOT-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

This cam operates a bell-crank lever, the end of which carries the movable contact. When the lever is deflected by the cam the distance between the platinum points should not be greater than 0.012 in., and this should be checked from time to time, and adjusted, if necessary, as instructed under "Location of Faults."

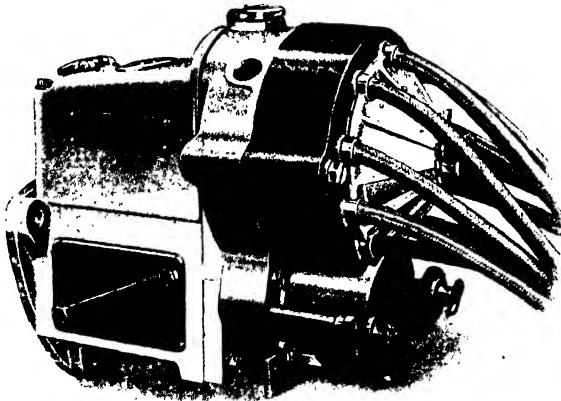


FIG. 77. TYPE S.C.9-1 SPIGOT-MOUNTED MAGNETO
(By courtesy of B.T.-H. Co.)

The usual form of fibre bush is replaced by a bronze bush lubricated by means of a small oil wick fitted inside the bearing pin. There is a radial hole in the pin so that oil from the wick can flow outwards and lubricate the bearing surface.

Installation. Fix the driving gear wheel or coupling to the magneto shaft, set the engine to the correct firing position on No. 1 cylinder, and adjust the coupling or gear wheel of the magneto shaft so that proper engagement occurs. With the contact-breaker lever in the "fully advanced" position the contacts should be just separated (by not more than

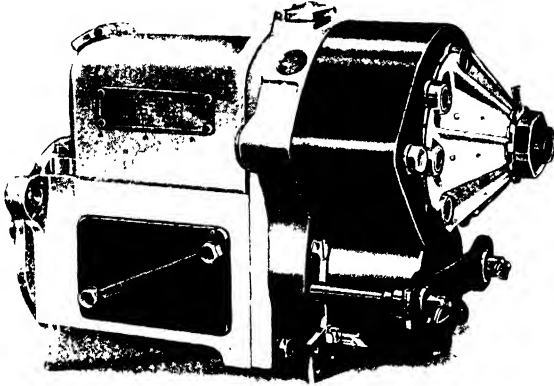


FIG. 78. TYPE S.C.7-1 SPIGOT-MOUNTED MAGNETO

0.0015 in.) and the distributor brush should be just overlapping the segment of the distributor marked No. 1.

Base-mounted machines should be secured to the platform by inserting loosely two of the fixing screws, and the engine then turned several times while the magneto is observed closely, to determine whether any move-

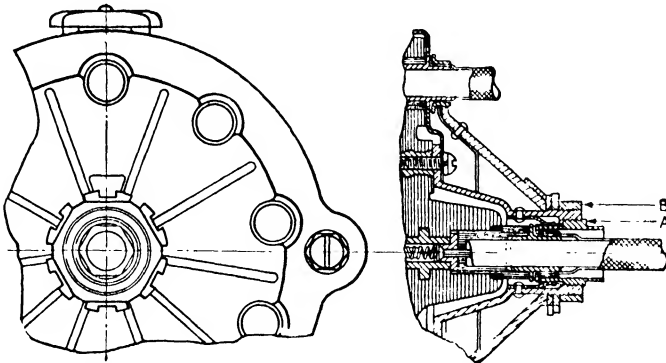


FIG. 79. SECTIONAL VIEW OF DISTRIBUTOR AND CLAMPING PLATE

ment occurs. If any movement is observed, it is an indication that the coupling is not in correct alignment, and this fault must be rectified before anything further is done. It is most important that no stress be thrown on the driving spindle of the magneto due to incorrect alignment of the coupling. When it is established that the magneto and engine shafts are in perfect alignment, the fixing screws should be tightened.

On spigot-mounted magnetos the allowable tolerance on the spigot, and the spacing of the three fixing holes in the flange are in accordance with the limits specified by the B.E.S.A. specification.

Cutting Out the Magneto. The low-tension terminal is connected to the end of the primary winding so that the magneto may be cut out of action by simply connecting this terminal to earth by means of a suitably located

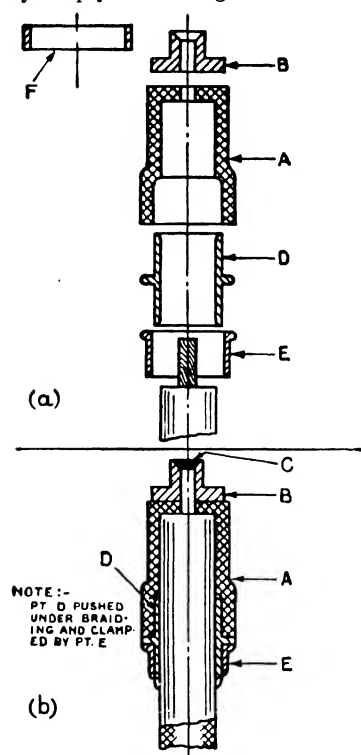


FIG. 80. DIAGRAM SHOWING METHOD OF ASSEMBLING DISTRIBUTOR LEADS

to dust out the distributor when an examination of the magneto is made, say every 25 hr. In the event of any adjustment being made to the metal-distributing electrode it is necessary to ensure that this electrode does not foul the distributing segments. The correct clearance is 0.016 in. to 0.02 in., and the pitch of the screw for adjusting the brush is such that a quarter of a turn moves the brush approximately 0.004 in. In order to check this clearance all the distributor terminals should be short-circuited by means of a wire, and connected in series with a bell and battery to the contact-breaker terminal. The screw securing the brush-holder sparking electrode should then be turned until, on rotating the magneto, the bell rings on say two or three segments. If the screw is now screwed in a minimum of 1 and a maximum of $1\frac{1}{4}$ turns this adjustment will be correctly made.

switch. An insulated insert connected to the outside end of the primary winding is contained in the moulding situated in the contact-breaker cover. A suitable terminal is also provided on the cover for connecting the earthing lead.

Contact-breaker. The magnetos are intended to operate with gaps of approximately 0.012 in. between the contact points, and the permissible tolerance on different points of the cams should not exceed 0.0015 in. This means that the minimum gap between the contacts may be 0.0115 in., and the maximum gap 0.013 in.

It is of the utmost importance that the platinum contacts be kept absolutely free from oil, because if any oil is present it becomes oxidized and prevents the contacts from making good electrical contact when closed.

When necessary the contact points may be cleaned with very fine emery cloth, but under no circumstances should they be filed. They may be taken out and carefully trued up in the lathe, with a hand tool, if they become pitted. Great care must be taken that they make good contact with one another.

Distributor. As no contact with the track of the distributor is made and the high-tension arc is not struck close to the moulded material, cleaning is seldom necessary, but it is advisable

Assembling Distributor Leads. When fitting the high-tension metal-braided leads to the distributor proceed as follows—

1. Remove the clamping plate which secures the leads in position in their respective sockets after first unscrewing the centre nuts *A* and *B*. (See Fig. 79.) *A* is the nut securing the starter lead, and *B* the nut securing the remaining leads in position.

2. Cut cable to length to suit respective cylinders.

3. The cable fittings fit over the ends of the cable (see Fig. 80). Remove metal braiding for 30 mm. and fix standard cable fittings *D* and *E*. Slip distance piece *A* over the cambric covering. Bare cable for distance of

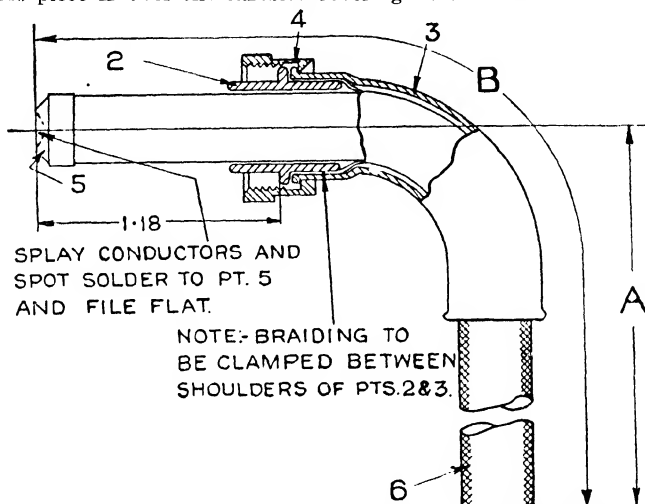


FIG. 81. HIGH-TENSION LEAD ASSEMBLY FOR TYPE S.C.9 AND S.C.10 MAGNETOS

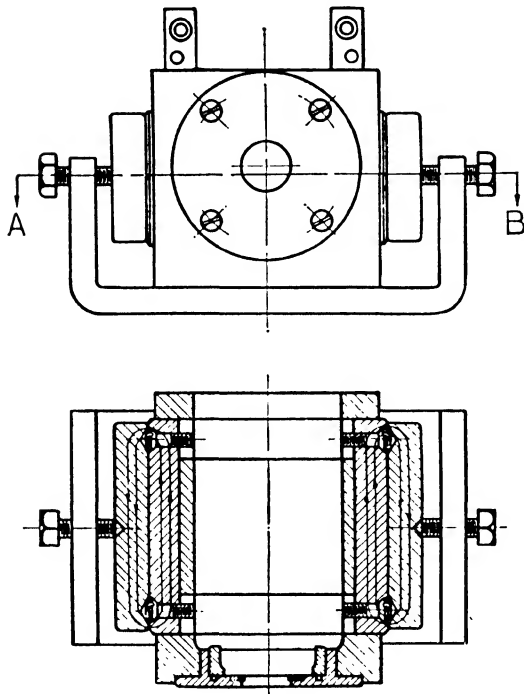
7 mm., slip on nipple *B*, and carefully solder at *C*. All surplus solder to be removed, otherwise a good fit in the socket is not guaranteed.

Before fixing the above leads it is necessary to place the rubber glands *F* in the sockets of the distributor so that they rest on the ledge. The leads may then be pushed home and clamped, but care must be taken to ensure that the glands are not pushed into the sleeve beyond the ledge. It is important that the clamping plate holds all the distributor leads perfectly rigid.

When assembling the high-tension leads to type S.C.9 or type S.C.10 magnetos, proceed as follows (see Fig. 81). (a) Cut cable to length to suit respective cylinders; (b) remove metal braiding for 32 mm. and bare cable for a distance of 4 mm. Insert part 2 under braiding and clamp with part 3. Slip on part 5, splay conductors and spot solder and file flat. Slip on part 4. The dimension 1.18 in. shown is important, since efficient electrical contact is dependent on it. This only applies in such cases where the above type magnetos have the high-tension metal-braided cables fitted to the distributor independently of each other, and each lead is extracted from the distributor by removing its securing nut.

Cable Specification. Metal-braided high-tension cable, specification E.1, section 2, latest issue (R.A.E. Addendum E/E76), No. of wires 40. Diameter of wires, .010 in. Outside diameter of cable, .355" L to .375" H.

Lubrication. Too frequent lubrication is not desirable in the case of types A.C. and S.C. magnetos. It will be satisfactory if the magneto is lubricated every 200 hr. as follows: six drops of oil to be introduced into the oil cup at the driving end, and six drops in each hole situated under the oil flap above the distributor. One drop each on contact-breaker, bearing, wick, and lubricating pad. Oiling instructions are embossed on the top cover of the magneto.



SECTION A. B.

FIG. 32. DIAGRAM ILLUSTRATING THE METHOD OF SHUNTING THE MAGNETIC FLUX

IMPORTANT. The device for shunting the magnetic flux should not be removed from the magnets until the rotor has been replaced.

Dismantling the Magneto. It should rarely be found necessary to dismantle the magneto entirely, although instructions for doing this are given below. In the ordinary way, apart from occasional lubrication, attention need only be given to the distributor and contact-breaker. Both of these components are readily accessible, and can be quickly removed and replaced without disturbing any of the working parts. In dismantling the magneto the following procedure should be closely adhered to—

1. Disconnect the low-tension lead at the point where it is connected to the low-tension terminal on the contact-breaker cover and then remove the contact-breaker base, timing lever, and cover, as a single unit.
2. Remove the fixing screws holding the distributor to the endplate and remove the distributor and shielding as one unit.
3. Remove the main cover.
4. Disconnect the low-tension lead at the point where it is connected to the condenser, by slackening the two clamping screws.
5. The armature and condenser sub-assembly are the next to be removed.
6. Take out the four fixing screws which secure the distributor gear-wheel assembly to the aluminium distributor endplate, when the complete unit can be withdrawn.

With the magneto in this state it may be again reassembled without the necessity for remagnetizing to ensure satisfactory running, but if it is required to remove the rotor, the machine will require remagnetizing

unless special precautions are taken to retain the flux in the magnets. These precautions consist of shunting the flux through soft iron keepers before actually removing the rotor, and Fig. 82 shows diagrammatically a suitable device for this purpose.

Should it be desired to remove the rotor, proceed as follows—

7. Unscrew the hexagon-headed cam fixing screw and remove the cam with the aid of a special extractor which can be provided for that purpose. The full speed gear-wheel can now be withdrawn by means of an extractor provided for this purpose.

8. Remove the four fixing screws securing the distributor endplate to the housing, and gently tap the rotor spindle at the driving end with a wooden mallet. The distributor endplate will be found to come away from the housing and the rotor can be withdrawn.

Running Overhauls. When the magneto has been dismantled the various parts should be washed in clean petrol. The armature and condenser assembly, being well sheltered from oil and grease, should not require washing, and a wipe over with a clean dry cloth should suffice.

If the rotor has been removed, the ball-bearings should be smeared with good quality lubricating grease before assembling in the housing. Price's H.M.P. grease is recommended for this purpose.

When fitting the distributor gear-wheel sub-assembly great care should be exercised to ensure the correct meshing of the two gear-wheels. The two teeth which are spotted on the larger wheel must embrace the spotted tooth on the smaller wheel.

Great care should be exercised when replacing the armature sub-assembly to see that the small carbon brush is in place in the stem of the distributor brush-holder, and that it is not broken during the operation.

Mouldings which are cracked should be replaced.

Reversing Direction of Rotation. Any magneto can be changed from one direction of rotation to the other by replacing certain components and re-timing the magneto for the opposite hand. As this operation is one of considerable delicacy the magneto should in every case of this kind be returned to the manufacturers, who will make the necessary changes and re-test the magneto before returning it.

Location of Faults

When trouble occurs with the ignition system of the engine it does not necessarily indicate that the magneto is at fault. Incorrect clearance of the valve tappets or incorrect compression of the cylinders may cause irregular firing of the engine. Irregular firing may also result from faulty sparking plugs or from defective operation of the contact-breaker of the magneto.

Ignition troubles fall into two categories: (a) local misfiring, which is generally confined to one cylinder, although it may occur in two; and (b) general misfiring, which may be evidenced by a scattered misfiring or a complete shut-down of the engine.

When looking for local trouble, the cylinder which is misfiring can be found by the well-known method of "shorting out" the plugs, one at a time, until the faulty cylinder is found. The short-circuiting of a defective plug will not further affect the running of the engine, but if the plug is performing its duty properly, then an immediate reduction of engine revolutions will be noticed when it is short-circuited. Having located the cylinder which is misfiring, remove the high-tension wire from the sparking plug and hold its end within $\frac{1}{8}$ in. of the wall of the cylinder and observe whether a spark jumps the gap with the engine running. If a strong spark

passes, remove the sparking plug and replace it with a plug known to be in good condition. If this does not cure the trouble it is not due to the ignition system. If no spark, or only a weak spark, is observed, disconnect the wire from the distributor block, and see if the magneto is delivering a good spark to the lead. If it does not give a good spark, then the trouble is in the distributor block, and this may be due to dirt or oil. Clean the distributor, and if there is still no spark, then the distributor is faulty. If a good spark is delivered to the lead, then the lead is faulty.

Faulty sparking plugs are usually either the result of sooting up, or are caused by the electrodes burning away, thus causing the length of arc (and, correspondingly, the voltage necessary to produce a spark) to be too great. It is even possible, in the case of a leaky plug, for so much heat to be generated by the escaping gases as to cause burning of the insulation and melting of the electrodes.

The most common reason for local misfiring on two cylinders is due to the high-tension wires being attached in an incorrect order.

Spark plugs can sometimes cause local misfiring which is hard to locate, especially when it does not occur regularly. If the spark plug points are set too far apart, the engine will be difficult to start and will misfire at high speeds; if set too closely, the engine will start easily but will throttle very poorly. The gap should be set to 0.4 mm. approximately (= .016").

When general misfiring is experienced, remove the magneto from the engine and test it on spark gaps, and if the spark is weak or absent, then there is an internal fault in the magneto. If there is a good spark, then the magneto is in good condition so far as the general trouble is concerned.

If sparking persistently occurs at the safety gap of the magneto, it is an indication that there is a break in the external high-tension circuit.

If the engine stops firing altogether, it is probably due to the conductor from the low-tension earthing terminal of the magneto coming into contact with the frame.

The low-tension lead connection must be rigidly clamped under the insulated terminal nut fixed to the contact-breaker cover, and also at the point where it is connected to the condenser. This lead serves to connect the primary winding of the armature to the contact-breaker, and, therefore, any faulty connection will interfere with the satisfactory operation of the magneto.

If the engine is running at a normal speed under load, the timing lever should be in the "fully advanced" position. The position of the lever should, therefore, be examined to see that it is correct, for if the lever be inadvertently pushed to the "fully retarded" position the sparking characteristics of the magneto will not be so good.

The cable for each high-tension connection should be pushed right home into the hole in the distributor, and firmly secured by means of the clamping plate and fixing nuts. It is advisable to examine these high-tension connections from time to time.

It is most important to check the gap between the contacts when the fibre heel on the contact-breaker lever is resting on a cam point. The gap should be nominally .012 in., and the actual gap should not exceed .013 in. maximum or .0115 in. minimum. The gauge provided is exactly .012 in. thick, so that by introducing this between the contact faces it is an easy matter to determine whether the gap is correct. If the gap is appreciably in error it will seriously interfere with the functioning of the magneto, and any discrepancy of this kind should be most carefully put

Defect	Possible Causes	Effect
(1) Small contact gaps.	(a) Bad adjustment. (b) Wear of fibre heel. (c) Wear of cam. (d) Pitting of contact faces.	Retarding effect on magneto timing. Poor low speed results. Arcing at contacts.
(2) Large contact gaps.	(a) Bad adjustment. (b) Contacts worn. Sometimes due to excess in spring pressure. (c) Insulated block not secure.	Advancing effect upon magneto timing. If excessively large will tend to cause firing to cut out in fully advanced position.
(3) Contacts pitted or blackened.	(a) Oil or foreign matter on contact faces: (1) through use of dirty feelers; (2) excess of oil on contact-breaker generally. (b) Rocker-arm movement sluggish. (c) Weak control spring. (d) Rocker arm too loose or too tight a fit on the bearing bush. (e) Rough contact faces. (f) Contact loose in either rocker arm or insulated block. (g) Timing out—too far retarded. (h) Magneto being run continually in retarded position. (i) Contact-breaker making bad contact inside top of condenser endplate. (j) Primary connection to condenser not good. (k) Condenser earth connection loose. (l) Condenser loose in clips. (m) Condenser defective. (n) Contacts badly out of line or not parallel. (o) Bad metal in contacts.	Excessive arcing at contacts. Poor low speed results. If very bad, causes misfiring at high speeds. Erratic firing.
(4) Broken spring.	(a) Kinked, badly shaped, or brittle springs. (b) Rusting of spring.	Usually cuts sparking out altogether.
(5) Fibre bush of insulated block cracked.	(a) Faulty bush. (b) Excessive force used in tightening of screw.	May cut out sparking altogether.
(6) Seizure of rocker arm.	Lack of lubrication.	No spark.

right by adjusting the contact screw carried by the insulated brass block on the contact-breaker base until the desired gap, as measured by means of the feeler gauge, is obtained.

Before condemning the magneto as being responsible for lack of ignition, always check the ignition switch and make sure that it, or some of its wiring, is not at fault.

As previously mentioned, irregular firing might result from defective operation of the contact-breaker, and the following table gives contact-breaker defects, how caused, and their effect upon the functioning of the magneto.

A classification of ignition troubles is as follows—

FAULTY SPARKING

1. Contact point clearance incorrect.
2. Breaker points burned or dirty.
3. Distributor brush burnt away.
4. Distributor segments burnt away.
5. Distributor block dirty.
6. Distributor out of time with armature.
7. Safety gap clearance insufficient.
8. Condenser short-circuited or punctured.
9. Magnets weak.
10. Loose or corroded connections inside the magneto.
11. Faulty earthing switch.
12. Moisture inside the magneto.

MAGNETO FAILS TO DELIVER SPARK

1. Primary open-circuited or earthed.
2. Secondary open-circuited or earthed.
3. Earthing switch closed.
4. Distributor block short-circuited.
5. Brush-holder short-circuited.

Complete Overhaul and Repair of Magnetos

When dismantling the magneto for overhaul or repair, it should be first dismantled into its sub-assemblies, and generally in this condition most of the parts can be inspected for flaws and wear. Mouldings which are cracked should be replaced.

After a magneto has completed 500 hr. running it is generally necessary to repack the slow-speed bearing with grease, but this should be the only time when it is necessary to dismantle this bearing assembly.

Magnetos on reassembly should of course be remagnetized, unless the magnets have been shorted by a soft iron keeper prior to dismantling the machine—this practice should be carried out where no magnetizing facilities are available.

After reassembly, the magnetos should be run for 4 hr. or 8 hr. sparking across standard approved gaps—described later. The magneto should be run for 8 hr. when any important insulated part such as the distributor, brush-holder, slip-ring, or high-tension collector moulding has been replaced; replacement of armatures, condensers, and contact-breaker levers also necessitates 8 hr. endurance run.

The normal test speeds for these magnetos are—

Sparks per Revolution	No. of H.T. Terminals	Speed
2	1- 6	3,500 r.p.m.
2	7- 9	4,000 "
4	6- 8	2,500 "
4	9-12	3,500 "
4	14-18	4,000 "
6	8-12	2,500 "
6	14-18	3,500 "
8	16-24	3,500 "

Immediately after the endurance run the magneto will run at normal test speed with all distributor leads disconnected and must spark over

the safety gap only. This test is carried out with the magneto still hot. The maximum temperature during the endurance run should not exceed 40° rise in temperate climates.

After the above tests the magneto should be examined to see that no faults have developed. The magneto should then be tested to see that at a speed of 350 r.p.m., with each lead connected to a standard approved gap, the magneto sparks regularly, and over a period of 1 min., the percentage of misses should not exceed 1 per cent of the total number of sparks produced in that time. This condition applies to both advance and retard for magnetos having a 15 degrees timing range, and where a 30 degrees timing range is employed, a speed of 600 r.p.m. in the full retard is permitted.

Spark Gaps for Testing Magnetos (see Fig. 83). Spark gaps used in the testing of magnetos are of two kinds—annular and ball gaps. The annular gap is more suitable for endurance tests, whilst the ball gap is very satisfactory for low-speed tests.

In order to ensure that the low-speed performance of the magneto is correctly determined, it is important that the insulated third point be always maintained sharp and correctly set.

Hand Starter Magnetos. These magnetos are of the rotating armature type and are operated by hand through a 5 : 1 gear reduction. The armature and contact-breaker mechanism is exactly the same as for the standard type of magneto, and the high-tension current is collected direct from the slip-ring through collector mouldings fitted to the side of the housing—one on either side. The gear on the armature is cut integral with the spindle, to obtain the smallest possible diameter. The slow-speed wheel, to which is fastened the handle, is of Textolite and is housed in an endplate at the opposite end to the contact-breaker mechanism.

Automatic Timing Device (see Fig. 84)

Certain magnetos are fixed so far as the contact-breaker mechanism is concerned and an A.T.D. is used to advance the magneto timing relative to the engine crankshaft. These A.T.D.'s are usually of the centrifugally operated type.

The device consists of two members—the driving member, on which is fitted the weights carrying hardened steel rollers, which rollers engage the surfaces of the cam fitted on the other member, called the magneto member, which part fits directly to the spindle of the magneto.

The driving member works on a bearing formed by the spindle of the magneto member, the whole device being locked to the magneto spindle by means of a nut. Bosses on both magneto and driving members are drilled to hold the coil springs. These springs, together with the cams, determine the characteristics of the device. As the speed increases the weights tend to move outwards by centrifugal force, and as they move on the cam from the magneto plate, they displace this plate in relation to the driving member, thus automatically advancing the magneto timing relative to the engine timing.

The degrees range of the device is determined by the distance between the spring bosses in the free position. As soon as the bosses come together, the spark ceases to advance and the device then operates for any higher speeds as a solid coupling.

Sparking Plugs and Resistors

Normally the gas between the points of a sparking plug is an almost perfect insulator, and a very high voltage is required to break down this

resistance. Moreover, the gases in the engine cylinder are considerably compressed at the moment of firing, due to the motion of the piston, and this results in an even higher voltage being required to break down the

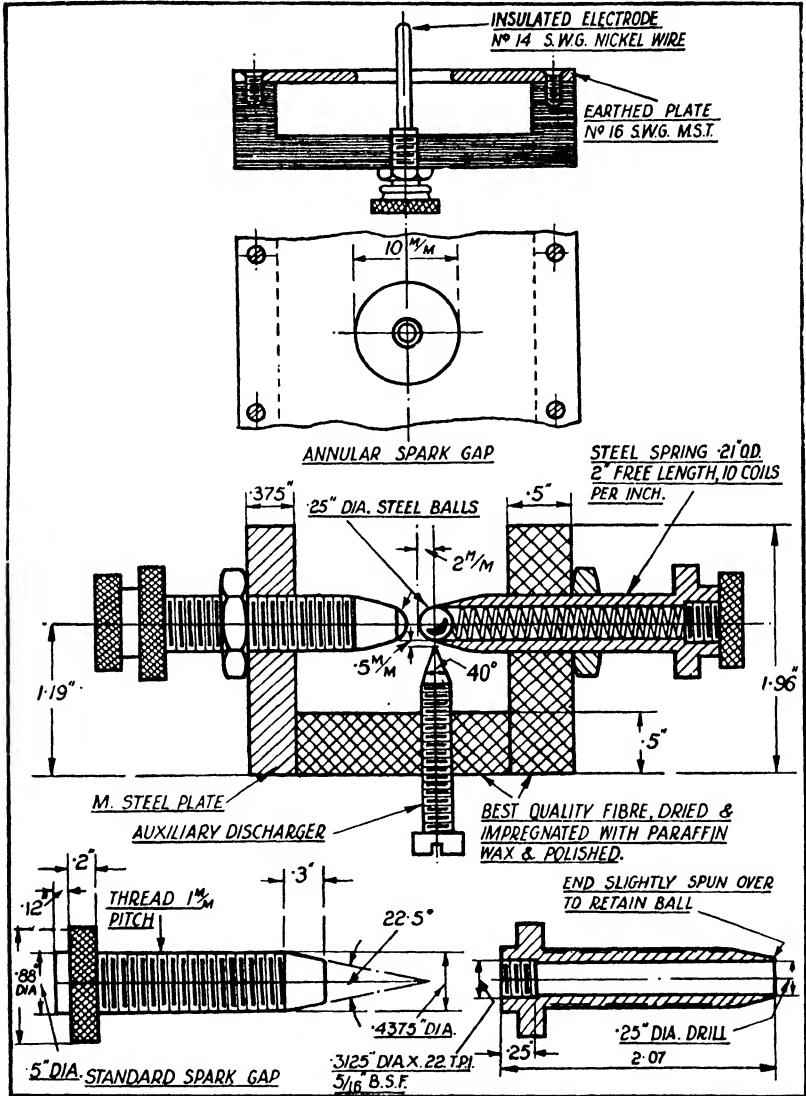


FIG. 83

increased resistance of the compressed gases. When the voltage has risen to a sufficiently high value—some thousands of volts—the first effect is to produce ionization of the gases between the plug points, and in this condition the resistance of the gases is reduced and a current passes. The

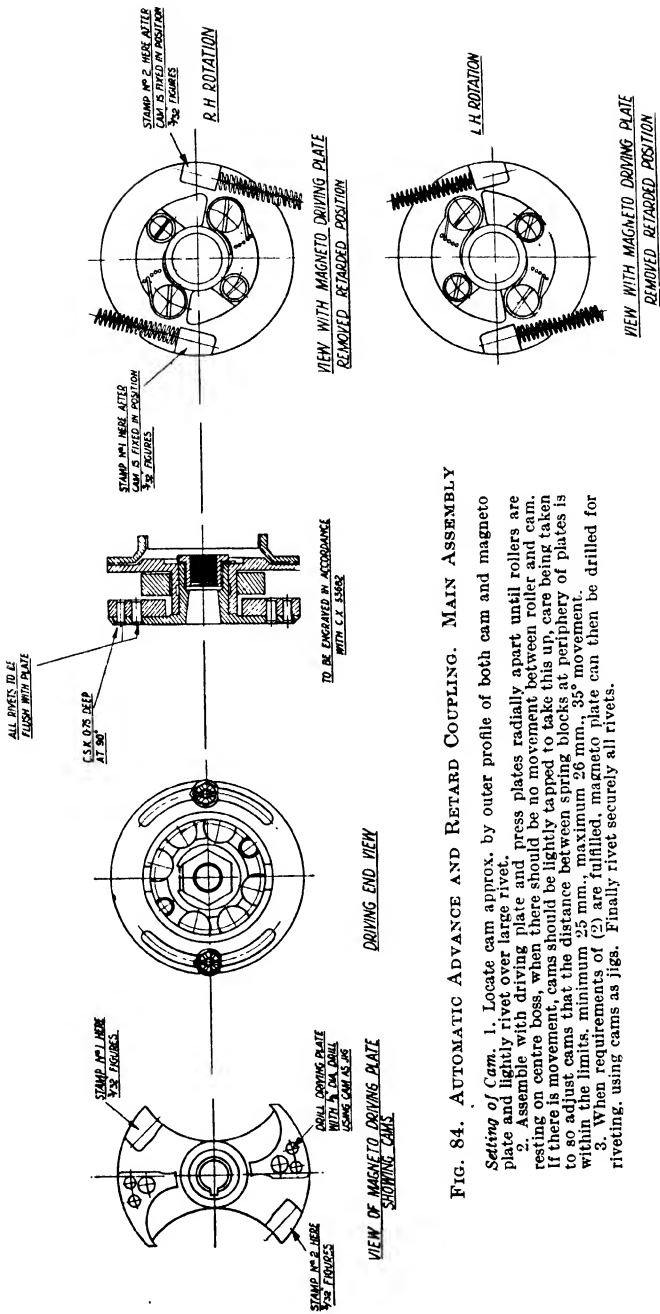


FIG. 84. AUTOMATIC ADVANCE AND RETARD COUPLING. MAIN ASSEMBLY

Setting of Cam. 1. Locate cam approx. by outer profile of both cam and magneto plate and lightly rivet over large rivet.

2. Assemble with driving plate and press plates radially apart until rollers are resting on centre boss, when there should be no movement between roller and cam. If there is movement, cams should be lightly tapped to take this up, care being taken to so adjust cams that the distance between spring blocks at periphery of plates is within the limits, minimum 25 mm., maximum 26 mm., 35° movement.

3. When requirements of (2) are fulfilled magneto plate can then be drilled for riveting, using cams as jigs. Finally rivet securely all rivets.

passage of the current enormously increases the ionization of the gases and the resistance of the gap is thereby further reduced very considerably to something of the order of 100 ohms or less. While, therefore, the initial discharge consists of a relatively enormous, but only instantaneous, surge of energy, due to the very high initial voltage, the tail of the discharge is weak but relatively sustained, but may actually contain as much or more total energy than the initial large surge. These characteristics of the discharge, especially the large initial surge, are greatly amplified by the use of screened cables, since without screening the rate of discharge is limited by the resistance of the magneto winding, which forms part of the circuit. With screened cables, however, the current is stored—before ionization occurs at the spark gap—in the capacity in parallel with the plug, and when the discharge occurs the energy is released from this capacity and is not restricted by the resistance of the magneto winding. The amount of energy which can be stored in this capacity is proportional to the size of the capacity and the square of the voltage required to break down the resistance of the gap. Thus the use of screened high tension leads, or screening harness, has the effect of very largely increasing the capacity connected in parallel across the points of the sparking plugs, and this results in a much stronger and hotter spark, and, incidentally, to more speedy deterioration of the plugs due to erosion of the points. This erosion occurs because of the largely increased concentration of energy on a very small area of the surface of the metal, resulting in melting and vaporization of the metal at that point at the instant that the spark passes. Erosion of the points of the plug can be reduced to normal limits by employing a “resistor” of about a thousand ohms between the cable end and the plug terminal. A resistor of this value has the effect of producing a considerable reduction in the rate of discharge without reducing the energy of the spark, and the rate of erosion is reduced to that obtained with unscreened cables. Resistors of higher value have been tried but discarded since, although they further reduce the rate of discharge and the total amount of energy dissipated, they also reduce the rate of erosion to a point which is undesirable with plugs in an engine using “doped” fuel.

Bonding

On aircraft of wooden or composite construction and, to a less degree, on aircraft of all metal construction, it is necessary to ensure that all metal parts, components, equipment, etc., are electrically connected together. This may be accomplished by the installation of a special system of bare copper wires, or by other approved means. Vibratory contact between adjacent masses of metal must be specially guarded against. The object of bonding is twofold, viz.: (a) as a precaution against fire, by avoiding the possibility of sparking between adjacent metallic masses, due to electrical discharge caused by flying through clouds or electrified atmosphere, and (b) as a means of maintaining the electrical capacity of the aircraft constant, and so avoiding the fading of wireless signals, as any variation in the natural capacity of the aircraft will affect the tuning of the wireless apparatus on board.

The full official requirements in regard to bonding are published in Air Ministry Specification G.E.125, which has been reproduced in full in the *Handbook of Aeronautics*,* and to which further reference should be made. but some notes on this subject appear on page 174 *et seq.*

* Published by Pitman

CHAPTER VI
WIRELESS EQUIPMENT*

WIRELESS signalling is carried out by means of aether waves radiated from a transmitting station, and the form of wave may be divided into two fundamental types, viz.—

(a) The wave radiated from a “spark” transmitter, and known as a spark or damped wave.

(b) The wave radiated from a continuous wave transmitter, and known as a continuous or undamped wave.

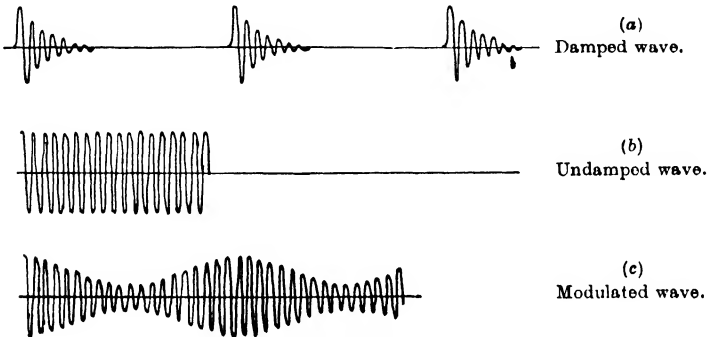


FIG. 85

Damped waves consist of successive wave trains in which the amplitude of the oscillations, after reaching a maximum, decline gradually to a minimum.

Signalling by means of damped waves can only be carried out by the use of the Morse or similar code, where letters and figures are represented by various combinations of long and short emissions of energy. Even the dot signal in this case will consist of a large series of separate damped oscillations. If the transmitting key is held down by the operator, a continuous noise will be heard in the telephones at the receiving end. Damped wave transmission is entirely unsuitable for telephonic communications, and its use on aircraft has now been abandoned.

Continuous waves are those which, after reaching the steady state, are periodic, i.e. the successive oscillations are identical. In the absence of some modifying influence, a transmitting station cannot communicate by Morse code on continuous waves, since no dots and dashes can be produced at the receiving end. The depression of the transmitting key will produce a simple click in the telephone receivers, and another click will be produced when the key is lifted, but there will be silence between the clicks, however long the key is held depressed, since the diaphragm of the telephone receiver cannot respond to the high frequency of oscillations of the continuous wave transmitter. In order that continuous waves

* Extracts from A.P. 1903, published by H.M.S.O., have been made with the kind permission of the Controller.

may be usefully employed they must be modulated in one of the following ways—

(a) By varying the amplitude, or frequency, by the keying operation, in telegraphic transmission. (Usually known as C.W.)

(b) By varying the amplitude, or frequency, in a periodic manner, at an audible frequency, and key controlled for the purpose of telegraphic transmission. (Usually known as I.C.W. or Tonic Train.)

(c) By varying the amplitude, or frequency, according to the characteristic vibrations of speech. (Usually known as Radio Telephony or R/T.)

The variation of frequency of C.W. transmissions may be accomplished at the sending station, by interrupting the aerial current at intervals corresponding to an audible frequency. A device for obtaining this is called a "tone sender." Another method of obtaining the desired result, is by interrupting the current in the detector circuit at the receiving station at audible frequency. An arrangement for doing this is called a "ticker," and is generally either an arrangement for breaking and making the circuit, or altering the capacity, inductance, or coupling, by breaking or making an additional circuit, or rotating a closed coil near one of the coils in circuit.

The normal method now adopted, however, is by loosely coupling to the detector circuit of the receiver a separate circuit known as the heterodyne circuit. This consists of an inductance and capacity in parallel, in which a continuous high frequency oscillation of very low amplitude is maintained by some suitable device—usually a valve. The frequency of the heterodyne circuit is made variable, between very wide limits, by adjustment of the condenser. When there is no incoming signal, the frequency of the heterodyne circuit is so high as to be inaudible, and no sound is heard in the telephones. When a continuous wave strikes the aerial, two voltages will be acting on the detector, one at the frequency of the incoming wave, to which the aerial and secondary circuits are tuned, and one at the frequency of the heterodyne circuit, which is coupled to the detector circuit. Unless these two waves are of exactly the same frequency they will not rise and fall in time with one another, but will get into step and out of step alternately. When they are in step there will be a maximum of voltage, since the two voltages are acting in the same direction. When they are out of step there will be a minimum of voltage, since the two voltages are acting in opposition to each other.

Thus, the interaction of the two waves gives rise to a "beat" voltage being applied to the detector, and the frequency of these beats of voltage is equal to the difference of the frequencies of the two component waves, and the rectified current through the telephones will rise and fall at this beat frequency, giving a corresponding note. The great advantage of the heterodyne system of reception is that the note is absolutely under the control of the receiving operator. By a slight variation of the heterodyne condenser he can adjust the note in his telephone to any pitch that suits his hearing, and it is thus very easy to get over interference by over-reading. When working on short waves very great accuracy in operation is required, but on long waves very great latitude in operation is possible.

The variation of amplitude of a continuous wave transmission may be accomplished at the sending station, and enables communication to be carried on with a receiving station which is not equipped with a heterodyne receiver. A continuous wave transmission which is broken up or varied in this manner is known as a tonic train, or interrupted continuous wave. When a steady voltage, as from a battery, is applied to the anode of a transmitting valve, a high frequency oscillation of constant amplitude is

generated in the aerial. If, then, an alternating voltage is applied to the transmitting valve, a high frequency oscillation will be generated whose amplitude will vary at alternating frequency.

The resulting condition of affairs is illustrated below. Whenever the anode is positive to the filament, an oscillation is set up in the aerial, which rises quickly from zero to a maximum, and dies away again as the anode voltage falls. During the negative half cycles of applied voltage, the valve ceases to maintain the aerial oscillation, which consequently dies away. We thus get a succession of tonic trains, one for each cycle of the A.C. supply, and these, when applied to the detector of the receiver, will give rise to a note in the telephones, without requiring a heterodyne. The note given is a pure one, whose pitch corresponds with that of the frequency of the alternating supply.

We have dealt with the telegraphic methods of communication by means of continuous waves, and there remains only the telephonic method.

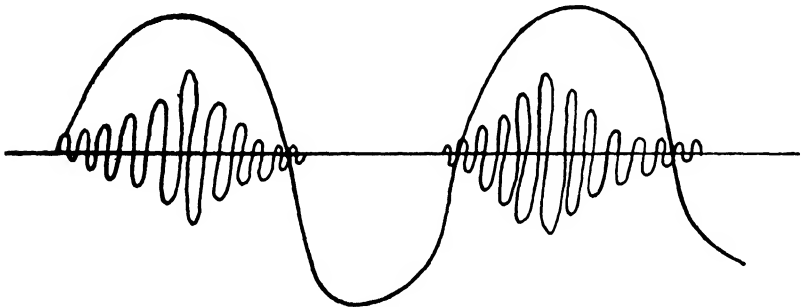


FIG. 86

In this system, also, the sending station generates and radiates a continuous wave emission which, as we have already explained, has a natural frequency much too high to be received by telephones in conjunction with an ordinary receiver. For the purposes of telegraphic communication we have shown how this emission of energy may be modulated, at either the sending or receiving end, to render the signals audible. For telephonic communication the continuous wave emission (carrier wave) is modulated at the sending end, by having impressed upon it audio frequency waves, produced by the effects of speech, music, etc., on a microphone, included in the transmitter circuit. For the reception of such transmissions a plain rectifying receiver only is permissible. The use of a heterodyne receiver of the type used for C.W. telegraphy would result only in the production of the note of the carrier wave over the speech. The range of communication by radio telephony is considerably less than with radio telegraphy, assuming transmitters, receivers, and other conditions to be otherwise equal.

Continuous wave communication is much more efficient than spark, or damped, wave communication, and much greater selectivity is obtainable, but on the other hand more apparatus, and of a more delicate nature, is required for its reception than is necessary for the reception of "spark waves."

No definite range can be laid down for any wireless transmitter. Generally, the range is governed by—

- (a) Type of aerial used.
- (b) Amount of power used in transmitting.
- (c) The aerial of the receiving station.

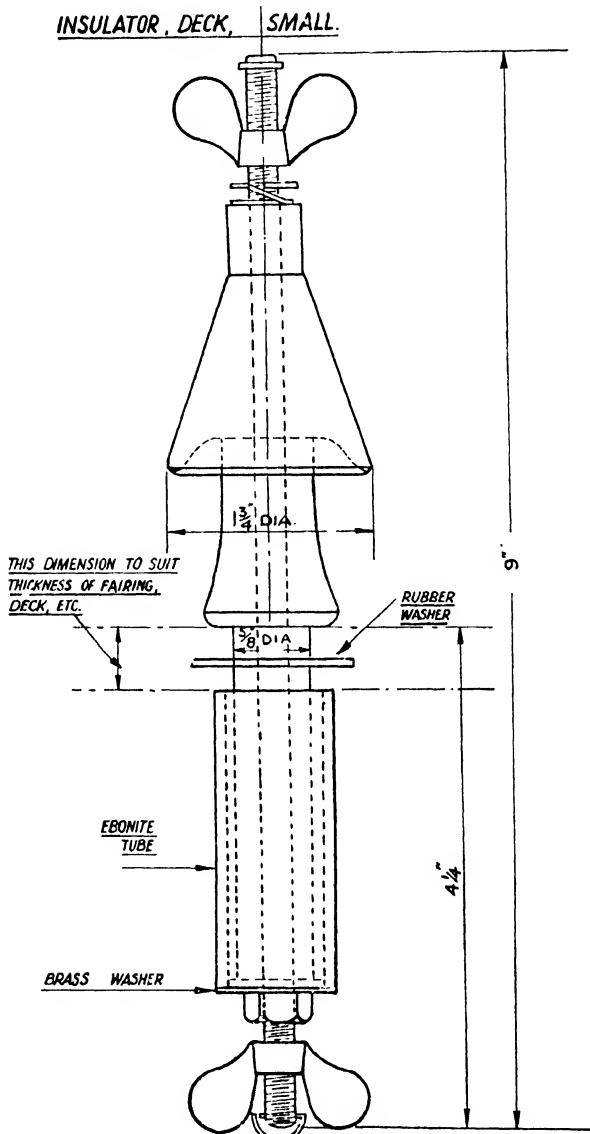


FIG. 87

(R.A.F. Official, Crown Copyright Reserved)

(d) The skill of the receiving operator.

(e) The efficiency of the receiving set.

The range of a transmitter used in the air is greater than that of the same transmitter used on the ground, but will vary with the type of aircraft and aircraft aerial, the receiver being the same in each case. Generally, the range of a transmitter is increased when working over water or very flat country, and decreased when working over hilly or heavily wooded country. In certain areas the absorption of aether waves is very marked, and causes a decrease in the strength of the signals received in these areas. There are also occasions when there is a marked decrease of signal strength due to "fading" effect, and although the causes of this "fading" effect are not fully understood, it may occur in any locality when working over long ranges.

An *aerial*, in one form or another, is an essential part of a wireless installation, both for transmission and for reception, and the aerial used on an aircraft may be of either the fixed or trailing variety. An aerial is a conductor, or system of conductors, usually open at one end and connected to a wireless transmitting or receiving instrument at the other end. The conductor used may be either covered or uncovered wire, but should not be made of magnetic materials (i.e. iron and steel). Copper or bronze wire is the most suitable. The conductors of the aerial must be very effectively insulated from the aircraft structure, and from any bulkhead or partition through or near which they may pass, before reaching the wireless set (Fig. 87). Porcelain is the most suitable material for insulation.

The normal aircraft type of aerial consists of a single wire varying in length from 150 ft. to 350 ft. This aerial consists of a number of strands to give it flexibility and strength, and is wound on a small winch or reel fitted into the aircraft, so that a part or the whole of the wire may be let out into the air through an insulated fairlead. When communication is carried out on one definite frequency (wave-length) it is desirable that when the whole of the wire is let out, the length of aerial shall be suitable for that frequency (wave-length). The end of the aerial wire is weighted to ensure that the wire is carried clear of the aircraft and to enable it to take up a suitable position in the air. The weight used for this purpose may be in one piece, weighing approximately 1 lb., or may be in the form of a number of smaller weights, weighing approximately 2 oz. or 3 oz. each, and spaced a few inches apart at the end of the aerial wire. Under normal conditions of flight the aerial takes up a position in the air as shown in Fig. 88.

This shape of aerial is directive, that is, it does not radiate equally in all directions. The only parts of the aerial which may be said to be good non-directive radiators are those parts which take up a vertical position in the air, i.e. the "weight" end and the aircraft end, but these represent a comparatively small part of the total aerial. The aerial shown in the above figure is directive fore and aft, that is, the signals will be strongest within its range in front or behind the aircraft; directly on each side the signals will be weakest.

In measuring the wire for a new trailing aerial, allowance must be made for the stretch of the aerial in the air, or the wire must be thoroughly stretched before measurement. The amount of stretch will vary with the type of wire used and the length of the aerial. A 200 ft. aerial of 7/25 gauge wire will stretch as much as 3 ft. to 5 ft.

An aerial should occasionally be run out from an aircraft on the ground, and the full length of wire inspected. If it is badly kinked, or shows signs of fraying, a new aerial should be substituted immediately. It is particularly necessary to examine the wire at the point where the weight is joined

to it. It is a good plan to fix the weight or weights on to a short section, say 2 ft. or 3 ft., of flexible steel wire, which in its turn is securely fixed to the end of the aerial wire.

A *fixed aircraft aerial*, that is, an aerial or aerial system which does not trail from the aircraft in flight, consists of a system of aerial wires fixed to the aircraft and insulated from it. This form of aerial is at present generally used in connection with short-wave telephony. Speech is possible between aircraft in any direction over a range of at least 2 miles,

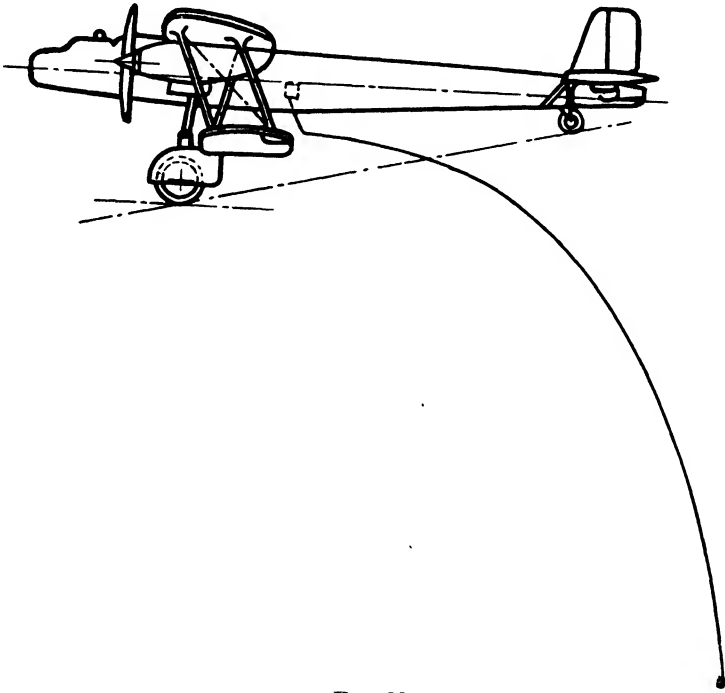


FIG. 88

and from the air to the ground up to 10 miles, but these are very arbitrary figures, and depend largely on the type of wireless set and the power used.

These aerials usually consist of wires stretched, one on each side of the aircraft, between wing tip and rudder post, with lead-in wires from the centre of each to a suitably placed deck insulator on the aircraft, and thus form a double T aerial. At wing tips and rudder post the aerial wires terminate in insulators, which are connected to the fixed attachments on the aircraft by means of a short length—twelve to fifteen inches—of rubber shock absorber cord, which keep the aerial wires taut whilst insulating them, both electrically from "earth," and mechanically from vibration, etc. The construction of a typical form of insulator is shown in Fig. 89.

The aerial wire, at its point of entry into the insulator, should be frequently inspected, as it is here that it is most likely to fray or break. Special precautions are necessary at the points of attachment to the tail to ensure that, should an aerial wire break in flight, and be blown back into the tail

structure, there will be no danger of it interfering with the free movement of rudder(s) and elevator(s).

A wireless transmitting set intended for use in aircraft requires official approval, both in respect of design and construction, before it is installed in the aircraft. Similar approval is also required in respect of the method of installation in the aircraft of the various components of the set, such as generator, batteries, aerial winch, transmitting unit, etc. In each case the main essentials necessary to obtain such approval are freedom from fire risks and freedom from weakening the structure of the aircraft, i.e. the object in view is to ensure that the airworthiness of the aeroplane is

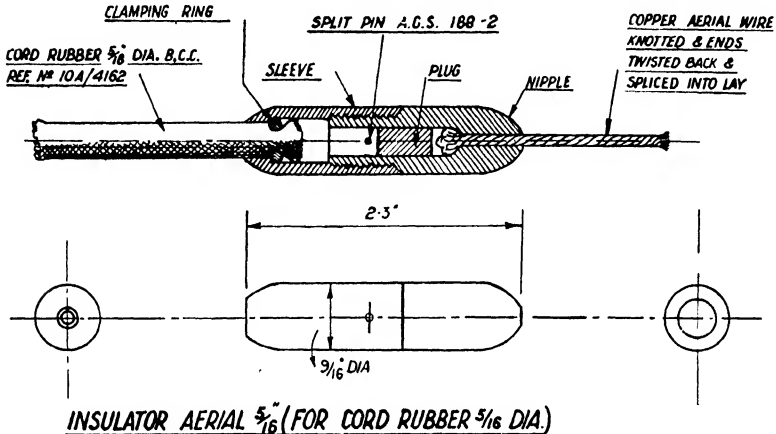


FIG. 89

(R.A.F. Official, Crown Copyright Reserved)

in no way impaired by the proposed installation. Some leading particulars of the principal sets manufactured for aircraft use are appended.

1. Marconi Type A.D. 41/42 Medium Wave Aircraft Telegraph-Telephone Set (Fig. 90)

The type A.D. 41/42 equipment in its full power edition has been specially designed for use on the larger types of civil, military, and naval aircraft where it is possible to carry a transmitter of adequate power to give the extended working ranges required by reason of the increased operational ranges of these aircraft, and when a supply of electrical energy is required for lighting and other services in addition to wireless. A reduced power edition is available for medium size civil and military aircraft.

The use of medium waves renders it particularly suitable for use on commercial aircraft which, by international regulations, are bound to use wave-lengths between 826 and 923 metres.

The most important features of the set may be briefly summarized as follows—

(1) The independent "drive" system has been incorporated in the transmitter, thus ensuring constancy of wave-length within narrow limits.

(2) The dial of the variable condenser controlling the drive circuit is calibrated in metres, which permits the rapid adjustment of the transmitter to any desired wave-length within the limits of the set without the use of a wave-meter.

(3) The use of the direct current grid control method of modulation by means of which the modulator valve acts as a variable grid leak in the grid circuit of the magnifier valve, ensuring full deep modulation.

(4) Provision can be made for quick wave selection.

(5) Telegraphy by *continuous* and *interrupted continuous waves* and *telephony*.

Both the transmitter and receiver are designed to cover a wave range of 500–1,000 metres (600–300 kcs.).

Quick wave selection of five pre-determined wave-lengths within a 120-metre band located between the limits of 800 to 1,000 metres can be provided.

The ranges obtainable with the type A.D. 41/42 equipment depend to a certain extent upon the type of aircraft in which it is fitted and on the characteristics of the ground station with which it has to work. Assuming satisfactory installation of the equipment in the aircraft and an efficient ground station of modern design, the maximum range obtainable will be—

	<i>Full Power Transmitter</i>	<i>Reduced Power Transmitter</i>
Air to ground Telephony	400 km. (250 miles)	320 km. (200 miles)
Air to ground I.C.W. Tele- graphy	480 km. (300 miles)	400 km. (250 miles)
Air to ground C.W. Tele- graphy	800 km. (500 miles)	600 km. (375 miles)

The above ranges are obtainable with a “trailing” aerial of the usual type fitted to the aircraft.

Alternative power supply equipments can be supplied to operate the transmitter at either full or reduced power; when operated at full power, the power to the anodes of the magnifier valves is approximately 170 watts, while, at reduced power, it is approximately 100 watts.

The power for the transmitter and receiver together with additional low-tension output is normally derived from a wind-driven generator fitted with a constant speed windmill. The generator provides high-tension for the anode circuits of the transmitting and receiving valves and an adequate low-tension output which charges a 12-volt accumulator. This accumulator forms the main battery of the aircraft which provides current for wireless, lighting, heating, and other purposes. This system has the advantage of avoiding the carriage of two generators, thus effecting a considerable overall reduction in the weight of the equipment necessary to provide the required services. Alternative power supplies are available to suit cases where the aircraft is already equipped with an electrical installation of sufficient capacity to deal with the wireless equipment or where the provision of lighting, etc., is not required.

The transmitter and receiver form two separate units which can either be mounted together or suspended separately to suit the particular aircraft in which the set is to be installed. Each unit can be provided with remote control apparatus.

The operation of changing from “send” to “receive,” also tuning adjustment of the receiver and wave selection in the transmitter can be performed by remote control. Selection of continuous wave, interrupted continuous wave or telephone transmission by remote control can also be provided if required.

Intercommunication apparatus can be supplied enabling either the operator/observer or the pilot to use the set and also affording a means of communication between them.



FIG. 90. MARCONI TYPE A.D. 67A/84/5062D AIRCRAFT WIRELESS EQUIPMENT INSTALLED IN A BRITISH AIRWAYS LOCKHEED "14" AIRCRAFT

Left: Type A.D.84 Receiver. *Right:* Two Type A.D.5062D D.F. Receivers and below Type A.D.67a Transmitter. *Inset:* Fixed aerial support and streamlined casing for D.F. loop

The type A.D. 41/42 equipment, being designed for operation on medium wave-lengths, necessitates the use of a "trailing" type of aerial for all normal purposes. Where desired, a fixed aerial can also be fitted which enables short range communications to be obtained and permits, for example, of "close formation" flying to be carried out in military service.

Where required for emergency working of the wireless equipment, a light 1 h.p. petrol engine can be provided for driving the wind-driven generator when the aircraft is at rest. The generator can either be dismantled from its normal mounting and direct coupled to the engine, or it may be left in its normal position and coupled to the engine by means of a flexible shaft. This arrangement provides communication in the event of a forced landing and also can be used for testing the equipment on the ground. Emergency working for short periods can also be carried out by motoring the wind-driven generator from the accumulator, after removing the windmill.

Direction-finding facilities on the Marconi-Robinson principle can be provided for by the addition of a fixed or rotatable frame aerial and a small light attachment to the aircraft receiver.

A 12-volt accumulator of the unspillable type is normally supplied, the capacity of which is varied to suit the electrical requirements of the aircraft to be equipped.

The switchboard, supplied for combined wireless and lighting, comprises the necessary regulators, switches, fuses, meter, and cut-outs for controlling the low-tension charging.

The following table indicates the types, number, and electrical characteristics of the valves used in the set—

Type	No.	Used for	Filament		Approximate Anode Volts
			Supply Volts	Amperes (Total)	
Det. 1	3	Transmitter	} 12·0	4·0	1,000/1,200 Nil
*M.L. 4	1	Transmitter			
S. 410	1	Receiver	} 12·0	1·9	120
H.L. 410	1	Receiver			
*M.P.T. 4	1	Receiver			

* These two valves are indirectly heated, and to avoid time-lag when changing over from Transmit to Receive and *vice versa*, the modulator and all the receiving valve filaments are kept heated on both transmit and receive while being extinguished on the *off* position. The total filament current consumption on Transmit is, therefore, 5·9 amperes and on Receive is 3·9 amperes at 12 volts.

The weight of the complete transmitting and receiving equipment depends to a certain extent upon lengths of inter-connecting cables. Without any of the optional items, such as intercommunication apparatus, emergency power supplies, etc., the weights of the equipment are approximately as follows—

Equipment	Combined Wireless and Electrical Services	Wireless Equipment only for Use with Existing Electrical Equipment	Wireless Equipment and Rotary Transformers
Full power transmitter	145 lb. (66 kg.)	—	—
Reduced power transmitter	120 lb. (54.5 kg.)	75 lb. (34 kg.)	97 lb. (44 kg.)
Additional weight for—			
Intercommunication gear		8 lb. (3.65 kg.)	
Fixed aerial supplies		7.5 lb. (3.4 kg.)	
Emergency equipment		57 lb. (26 kg.)	
Remote control		5 lb. (2.3 kg.)	
Remote control for wave selector		2 lb. (0.9 kg.)	

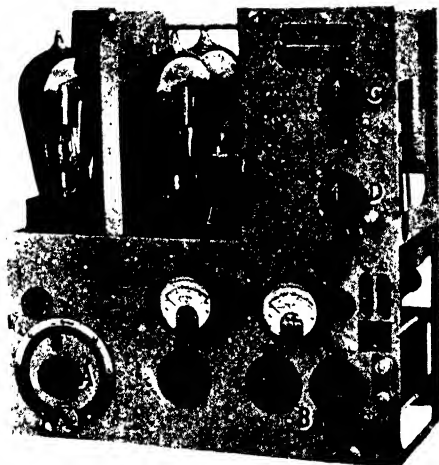


FIG. 92. TRANSMITTER, TYPE A.D.41

A = Drive tuning condenser. C = Telegraph-telephone change-over switch.
 B = Aerial tuning controls. D = Send-receive change-over switch.

Note. If the aircraft is already fitted with a 12-volt heating, lighting, and charging equipment, which will also provide the extra wireless load (i.e. approximately 250 watts) rotary transformers can be supplied instead of the wind-driven generator.

The above schedule is then modified as follows—

- | | |
|-------------------------------------|--|
| One Rotary Transformer | For transmitter: 12 volts 18 amperes input; 1,000 volts 150 milliamperes output. |
| One anode converter* | For receiver: 12 volts 2 amperes input; 120 volts 30 milliamperes output. |
| One generator with constant speed | |
| Windmill | Deleted. |
| One switchboard | Deleted. |
| One accumulator (12 volt) | Deleted. |
| Code word | IGUFZ. |

* A 120-volt H.T. dry battery can be supplied instead of the anode converter if desired.

2. Marconi Medium Wave Aircraft Wireless Equipment, Type A.D. 49/50

The type A.D. 49/50 equipment has been specially designed for use on the smaller types of civil, military and naval aircraft where restricted space or service requirements preclude the use of a higher power equipment.

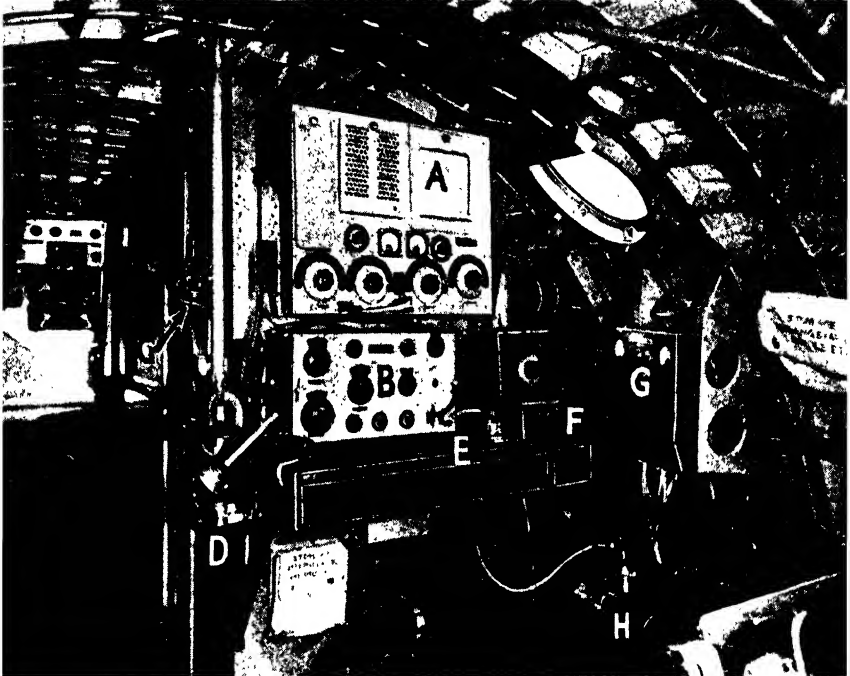


FIG. 93. MARCONI TYPE A.D. 67/6872 TRANSMITTING-RECEIVING AND DIRECTION-FINDING EQUIPMENT INSTALLED IN AN IMPERIAL AIRWAYS FLYING BOAT

- | | |
|---|--|
| A = Type A.D.67 Transmitter. | E = Manipulating key. |
| B = Type A.D.6872 Receiver. | F = Hand reversing switch for "D.F." and "Homing." |
| C = Rotatable frame aerial for direction finding. | G = Main power control unit. |
| D = Microphone and telephones. | H = H.T. power supply unit. |

The use of medium waves renders it particularly suitable for use on commercial aircraft which, by international regulations, are bound to use wave-lengths between 826 and 923 metres.

The most important features of the set may be briefly summarized as follows—

(1) Both the transmitter and receiver are fitted with quick release shock-absorbers. After unplugging the connecting leads from a junction box, the transmitter and receiver can be easily removed for inspection purposes.

(2) The transmitter incorporates a special circuit with two multi-electrode valves connected in parallel which perform the functions of "drive" or master oscillator, power magnifier and modulator.

(3) The dial of the drive tuning condenser is calibrated in metres which

permits of rapid adjustment to any desired wave-length within the limits of the transmitter without the use of a wave-meter.

(4) Provision can be made for quick wave selection within the wave-range of the transmitter by either direct or remote control.

(5) Telegraphy by *continuous* and *interrupted continuous waves* and *telephony*.

The transmitter is designed to cover a continuous wave-band of 600 to 1,000 metres (500-300 kcs.).

The receiver is designed to cover a continuous wave band of 600 to 1,550 metres (500-196 kcs.).

The ranges obtainable with the type A.D. 49/50 equipment depend to a certain extent upon the type of aircraft in which it is fitted and on the characteristics of the ground station with which it has to work. Assuming satisfactory installation of the equipment in the aircraft and an efficient ground station of modern design, the following ranges should be obtainable :

Air to ground	240-290 km. (150-180 miles)
Air to ground I.C.W. Telegraphy	290-350 km. (180-220 miles)
Air to ground C.W. Telegraphy	400-480 km. (250-300 miles)

The maximum power rating of the transmitter is approximately 65 watts to the anode of the magnifier valve on C.W. and I.C.W. Telegraphy and approximately 45 watts on Telephony.

Power for the transmitter and receiver can be derived from a double output wind-driven generator fitted with a constant speed windmill. The generator provides high-tension for the anodes and low-tension for the filaments of the transmitting and receiving valves. If combined wireless and electrical services are to be provided, a generator with a larger L.T. output for charging a 12-volt accumulator is supplied.

An alternative power supply in the form of a rotary transformer is available for use in aircraft already equipped with a 12-volt battery of sufficient capacity to deal with the wireless equipment.

The receiver is designed for installing near to and for direct operation by the pilot. The transmitter, when fitted with remote control, can be installed in any convenient position in the aircraft. Quick release shock-absorber fastenings can be fitted to the top, back or bottom of the instrument boxes, thereby considerably facilitating installation work.

The operation of the "send-receive" switch and of quick wave selection in the transmitter can be performed by remote control if desired. Selection of continuous wave, interrupted continuous wave or telephone transmission by remote control can be provided if required.

When remote control wave selection is fitted a pilot lamp at the pilot's

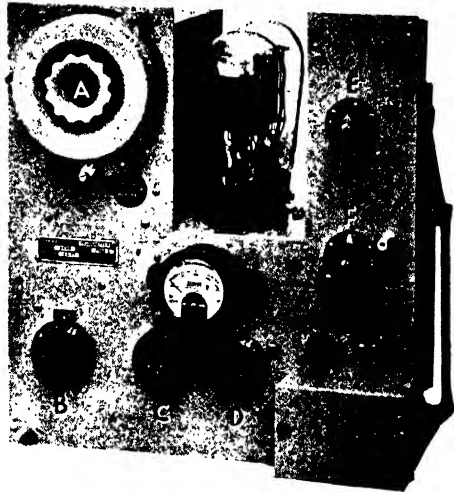


FIG. 94

end of the control unit indicates the correct setting of the tuning condenser for the required wave-length.

The type A.D. 49/50 equipment being designed for operation on medium wave-lengths necessitates the use of a "trailing" type of aerial for all

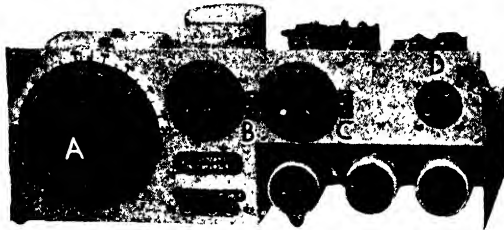


FIG. 95

normal purposes. Where desired, a fixed aerial can also be fitted which enables short range communications to be obtained and permits, for example, of "close formation" flying to be carried out in military services.

Facilities for direction finding by either the "homing" system or by taking D.F. bearings on ground transmitters can be provided by means of the addition of a frame aerial and a small amplifying attachment to the normal receiver.

The switchboard, supplied for combined wireless and lighting, comprises the necessary regulators, switches, fuses, meter and cut-outs for controlling the low-tension charging.

The following table indicates the types, number and electrical characteristics of the valves used in the set—

Type	No.	Used for	Filament		Approx. H.T. Volts
			Supply Volts	Amperes (Total)	
D.E.T. 8	2	Transmitter	12	2	800
*M.S. 4 B	2	Receiver	} 12	1.0	200
*M.H. 4	1	Receiver			

* These two valves are indirectly heated and in order to avoid time lag on changing from "Transmit" to "Receive" are kept heated during transmission and reception. The total filament current is 3 amperes on "Transmit" or "Receive."

The weight of the complete wireless equipment depends to a certain extent upon the length of the connecting cables, and the accessories provided. Without any optional items, the weight of the equipments are approximately as follows—

Power Supply	Wireless Equipment for Use where Lighting, etc., is not required	Combined Wireless and Electrical Services
Wind-driven generator	62 lb. (28 kg.)	*80 lb. (36.5 kg.)
Rotary transformer	*62 lb. (28 kg.)	

* Excluding 12-volt battery.

Additional weight for remote control (wave selector), 2 lb. (0.9 kg.)

3. The Plessey, Type A.C.44

This is a medium power equipment intended for use where telegraph or telephone communication is required on medium waves from 600 to 1,000 metres, and where remote operation and remotely operated wave-length changing is required. Normally four pre-set wave-lengths (600, 862, 900, and 930 metres) are provided on the transmitter, but these may be adjusted to suit requirements, and in special cases wavebands other than 600–1,000 can be provided. Receiver tuning is continuously variable

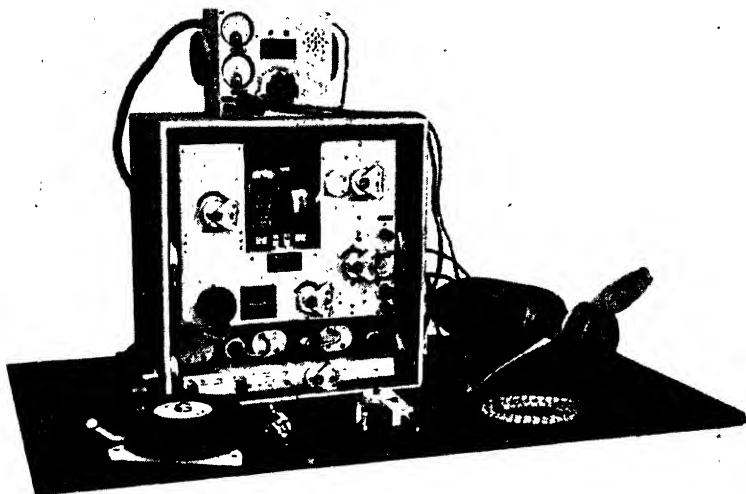


FIG. 96. THE PLESSEY TYPE A.C.44 MEDIUM RANGE EQUIPMENT

550–1,000 metres, but if required the receiver can be provided with a second waveband above or below the normal or on short waves.

The transmitter input is 160 watts H.T. at 600 volts, and 60 watts L.T. at 9 volts. The output power (aerial) is 36 watts (C.W. telegraphy), 18 watts (telephony), or 18 watts (I.C.W. telegraphy).

The transmitter employs a master oscillator for frequency control. This master oscillator drives two amplifier valves in parallel, the anodes of which are connected to the aerial circuit through a special coupling circuit which prevents overloading of the amplifiers should the aerial be lost or the aerial circuit detuned.

At the same time, a pre-set adjustment on the aerial loading coil enables the equipment to be readily adjusted in the case of aircraft having different aerial capacities, and this equipment can be used in aircraft having aerial capacities from 200–350 mmf. without any difficulty and without the need of tapped loading coils.

It should be noted that in the operation of this transmitter, when the aerial circuit is detuned, the D.C. to the anodes of the amplifier valves falls instead of rising, and that in tuning the transmitter the aerial tuning should be varied until the maximum plate current is obtained, and not the minimum.

Telephony and I.C.W. are obtained by means of a low-power modulation system giving approximately 70 per cent modulation.

RANGE

Telephony and I.C.W. Telegraphy . . .	180 miles
C.W. Telegraphy	500 miles

These ranges are those which will be obtained under general conditions when working from aircraft to a modern airport. In particular parts of the world, ranges considerably in excess of these will be obtainable in some cases.

All the transmitter units are carried on a light weight aluminium framework, the master oscillator being entirely screened from the remainder of the circuit. All valves are mounted on a panel in the centre of the unit. The aerial tuning and coupling units are carried on the right-hand side of the valve panel, while the modulation and control circuits are contained at the bottom of the framework.

A main plug on the front of the transmitter carries the cables connecting the transmitter and receiver to the generator and other units. On removing this plug and releasing the rubber ring supports, the transmitter can instantly be withdrawn from the crate.

VALVES

Master Oscillator	Mullard T25 D
Amplifier	Mullard T25 D (two in parallel)
Modulator	Mullard 104V

The receiver is of the superheterodyne type, and is provided with automatic volume control and special circuits for the reception of C.W. telegraph signals. A total of four valves is employed, giving a maximum sensitivity of 35 microvolts with an output power sufficient for loud reception in two pairs of low-resistance telephones.

With an input of approximately 50 microvolts, the receiver will produce 0.75 watts of speech across the telephones.

The receiver tuning is performed electrically. No mechanical controls are employed, and hence all backlash and difficulty in tuning is obviated. No reaction control is provided and only one main control on the receiver is required, the automatic volume control keeping the level of received signals correct.

For the reception of C.W. telegraphy, a switch on the receiver brings into operation a local oscillator which provides the required beat note, and this beat note is maintained constant in amplitude by the automatic volume control, with the result that the aircraft may fly directly over a station transmitting C.W. telegraphy without loss of beat note and without interference due to key clicks.

The construction of the receiver is similar to that of the transmitter, and the rubber suspension system is also similar. The receiver is mounted in the crate below the transmitter so that the circuits are not affected by heat from the transmitter valves.

VALVES

Mullard FC 4	Mazda AC/HL/DD
Mazda AC/VP 1	Mazda AC/2PEN/DD

The transmitter and receiver are provided with metal bosses carrying flexible rubber rings which are held in special supports in a welded tubular steel crate. This crate is enclosed with detachable sides, provided with ventilation, and both the transmitter and receiver are therefore contained

in one unit floating on rubber and the crate can be bolted direct into the aircraft without further preparation.

The transmitter and receiver can be supplied in separate crates for installation in small aircraft.

The control unit is designed to be fitted near the pilot in the case of

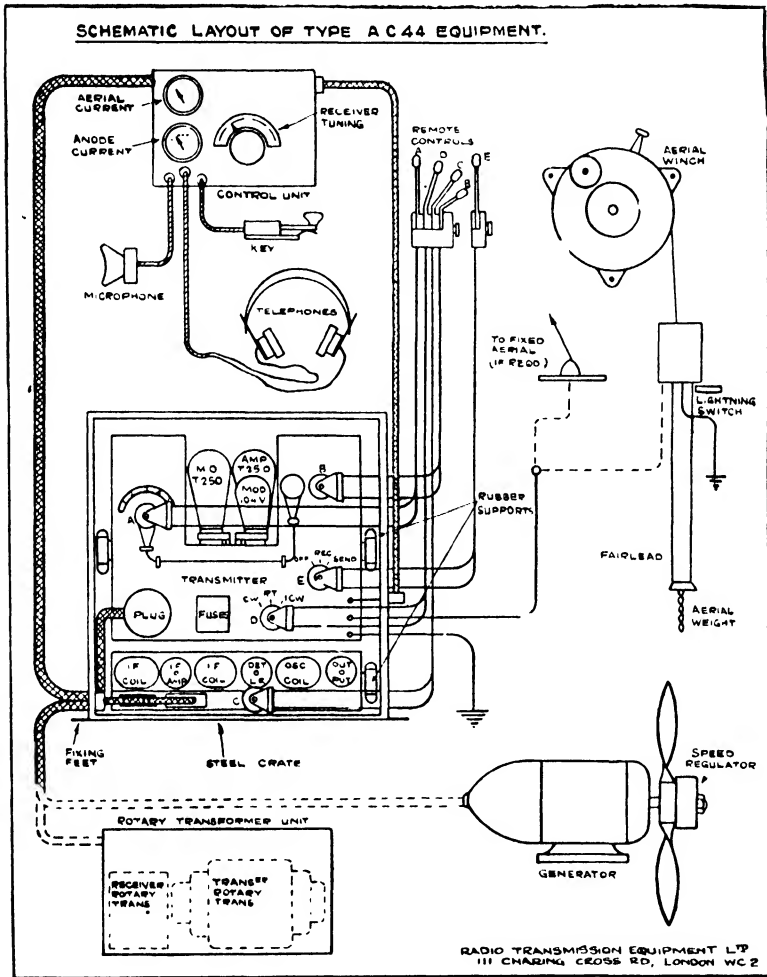


Fig. 97

the remotely operated installation, or near the operator where the apparatus is not remotely operated.

The unit contains—

One D.C. feed meter indicating the total current consumption of the equipment.

One aerial ammeter indicating the aerial current.

Three jacks for microphone, telephones, and key.

A special receiver tuning control with wave-length change switch where the receiver employs two wavebands.

As already stated, this receiver tuning control is performed electrically and is entirely free from backlash or other difficulties usually connected with the mechanical system of tuning. The control unit is connected to the transmitter unit by a cable carried in a braided sleeving provided with a metallic shield to prevent interference from external sources being picked up on the receiver.

The construction is similar to that of the other units. A light metal framework carries all the components and circuit and this is fitted with a removable front cover.

The control unit is supported on rubber rings in a similar manner to the transmitter and receiver, but it is not contained in a crate, the supports for the rubber rings in this case being fitted direct to the structure of the aircraft.

Two aerial systems may be used—

- (1) Trailing aerial.
- (2) Fixed aerial.

Communication on trailing aerial will usually be much better than on fixed aerial and much longer ranges will be obtained.

In very large aircraft good results may be obtained from the fixed aerial system, which is usually fitted between wing tips and tail of the machine.

Type A.C. 44B

This equipment is exactly similar to the type A.C.44, but, instead of the master oscillator being adjusted in steps, a continuously variable wave-length range between 550 and 1,000 metres is provided. It is primarily intended for installations not employing remote control.

A complete equipment comprises the following—

	Dimensions	Weight
Transmitter	14 in. × 7 in. × 11 in.	15 lb.
Receiver	14 in. × 7 in. × 3½ in.	4 lb.
Control unit	8½ in. × 6½ in. × 2½ in.	4 lb. 2 oz.
Remote controls	—	1 lb. 8 oz.
Winch with aerial }	6 in. dia.	6 lb. 12 oz.
Wire and weight }		
Fairlead	according to installation	2 lb.
Microphone Telephones (1 pair and telegraph key)	—	1 lb. 8 oz.
Generator windmill and speed regulator	12 in. × 4½ in.	16 lb.
Cables	according to installation	2 lb.
Steel crate and cover	9 in. × 16½ in. × 17 in.	7 lb. 6 oz.

Approx. total weight, Type A.C. 44 60 lb. 4 oz.

Approx. total weight, Type A.C. 44B 54 lb.

4. Marconi Combined Medium Wave and Short Wave Aircraft Telegraph-Telephone Set—Type A.D.37a Transmitter, A.D.38a Receiver (Fig. 98)

The type A.D.37a/38a equipment has been approved by the British Air Ministry for fitting in British commercial aircraft, and is installed on the Imperial Airways aeroplanes flying on the England-South Africa air route.

The most important features of the set may be briefly summarized as follows—

(1) Separate high-frequency circuits are employed for the two transmitting wave-ranges, but by utilizing the same valves, modulator system, and other component parts in common, it has been possible to produce an extremely compact design.

(2) The independent "drive" system has been incorporated in both the medium and short-wave circuits, thus ensuring constancy of wave-length within narrow limits.

(3) The dials of the variable condensers controlling the two drive circuits are calibrated in metres, which permits the rapid adjustment of the transmitter to any desired wave-length, within the limits of the set, without the use of a wave-meter.

(4) The use of the direct current grid control method of modulation, by means of which the modulator valve acts as a variable leak across the grid circuit of the magnifier valve.

(5) Separate high-frequency circuits and a high-frequency amplifying valve are employed for the two receiving wave-ranges. The detector valve and the low-frequency magnifier valve are common to both wave-ranges.

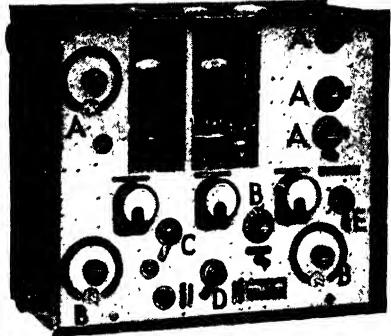
The combined medium and short-wave transmitter forms a



TYPE A.D.38A RECEIVER

Transmitter

- A = Medium wave controls.
- B = Short wave controls.
- C = Medium/short wave C.O. switch.



TYPE A.D.37A TRANSMITTER

Receiver

- A = Medium wave controls.
- B = Short wave controls.
- C = Medium/short wave C.O. switch.
- D = C.W.-I.C.W.-telephone switch.
- E = Send-receive switch.

FIG. 98

single unit in one box, and the receiver constitutes a second unit in a separate box of identical width and depth. The two instrument boxes can, therefore, be installed either separately or as one unit, according to the space available in the aircraft.

Direction finding facilities can be provided for by the addition of a small light attachment to the aircraft receiver.

The set provides for the transmission and reception of continuous wave, interrupted continuous wave, and telephone signals. The transmitter is provided with the independent drive method of frequency control.

The transmitter and receiver are continuously adjustable between the following limits—

Medium-wave range.	.	.	.	.	500-1,000 metres
Short-wave range	.	.	.	.	40-80 metres

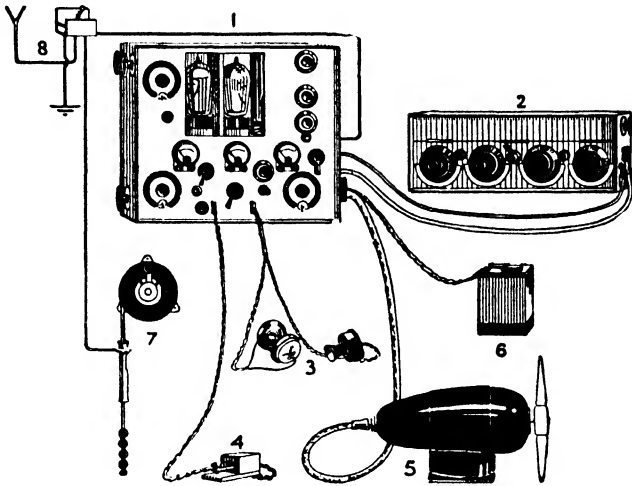


FIG. 99. KEY PLAN OF STANDARD EQUIPMENT FOR TYPE A.D.37A/A.D.38A AIRCRAFT SET

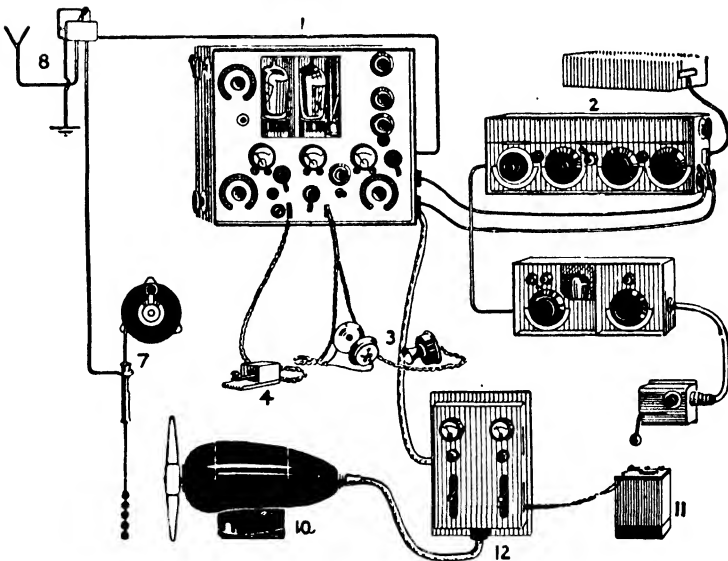


FIG. 100. KEY PLAN OF EQUIPMENT FOR TYPE A.D.37A/A.D.38A AIRCRAFT SET WITH LIGHTING SWITCHBOARD AND TYPE A.D.32A DIRECTION-FINDING ATTACHMENTS

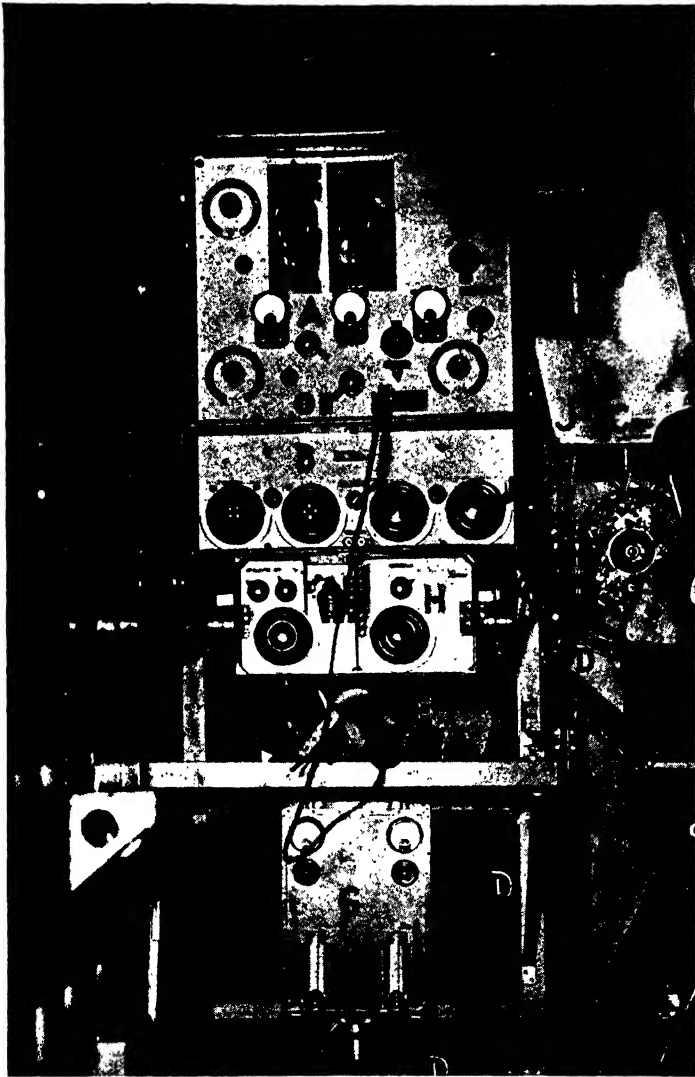


FIG. 101. MARCONI TYPE A.D.37A/A.D.38A AIRCRAFT SET AND THE TYPE A.D.32A DIRECTION-FINDER INSTALLED IN AN IMPERIAL AIRWAYS PASSENGER-CARRYING AEROPLANE

- | | |
|---------------------------------------|--|
| <i>A</i> - Transmitter. | <i>F</i> - Manipulating key. |
| <i>B</i> - Receiver. | <i>G</i> - Combined wireless and lighting switchboard. |
| <i>C</i> - Aerial winch. | <i>H</i> - D.F. attachment. |
| <i>D</i> - Fairlead. | <i>J</i> - Aerial change-over switch. |
| <i>E</i> - Microphone and telephones. | |

Additional plug-in-coils can be provided to extend the wave-range of the receiver from 40 to 150 metres.

Alternative power generators can be provided to operate the transmitter at either full or reduced power. When operated at full power, the input to the anodes of the magnifiers is approximately 170 watts on the medium wave-lengths and approximately 120 watts on the short wave-lengths. At reduced power the figures are approximately 100 watts and 70 watts respectively.

Assuming normal conditions and the use of a modern receiver at the aerodrome, the maximum ranges from aircraft to ground are approximately—

	<i>Full Power</i>	<i>Reduced Power</i>
C.W. Telegraphy . . .	500 miles (800 km.)	380 miles (600 km.)
I.C.W. Telegraphy . . .	300 miles (480 km.)	250 miles (400 km.)
Telephony	250 miles (400 km.)	200 miles (320 km.)

On the short waveband the ranges obtained depend upon the factors which govern the propagation of these waves, i.e. the actual wave-length used, the time of day and night, the season of the year, etc. Provided the correct conditions are selected, ranges varying from several hundred to several thousands of miles can be obtained.

The standard type A.D.37A/38A transmitting and receiving set comprises the following main items—

- (1) Transmitter, complete with four valves.
- (2) Receiver, complete with four valves.
- (3) Microphone and telephone head-set, mounted in adjustable flying helmet.
- (4) Manipulating key.
- (5) Wind-driven generator, fitted with constant speed windmill.
- (6) Accumulator battery, 6-volt 22.5 ampere-hour capacity.
- (7) Trailing aerial supplies (aerial winch with aerial wire and bead-type weight and fairlead).
- (8) Fixed aerial supplies (insulators, aerial wire, aerial-change-over switch, etc.).
- (9) Set of suspension brackets and sundry cables, etc., for wiring up.

5. Marconi Type A.D. 57/5872, Telephone Telegraph Transmitter and Receiver, with Visual and Aural Direction Finding and Homing Equipment

The Marconi medium and short wave transmitting and receiving equipment, type A.D. 57/5872 is particularly suitable for large commercial, naval, and military aircraft operating over long routes and in which the conditions of service require a wide choice of operating wave-lengths.

THE TRANSMITTER TYPE A.D. 57 consists of two separate transmitter panels mounted in one box (Fig. 102). One panel carries the medium wave equipment, and the other the short wave equipment. Each panel is complete with its own valves, master oscillators, power amplifiers, feed meters, switching arrangements, etc.

The box is constructed of duralumin sheet, riveted, and sprayed in non-inflammable Marconi aircraft grey paint. The chassis is of aluminium, riveted and sprayed in non-inflammable Marconi light grey paint. The components are of high grade insulating material, aluminium and copper, with maconite wiring, and full tropical finish. All screws and nuts are fitted with locking devices.

The instrument boxes are of rigid construction and are fitted with a special quick release anti-vibration suspension, to protect them from shock.

The medium waveband for transmitting is 600–1100 metres (500–272.7 kcs.) covered in one range.

Transmission can be effected on continuous waves, interrupted continuous waves or telephony.

The power in the aerial circuit is approximately 66 watts on C.W., I.C.W., and telephony.

Assuming communication with a modern airport receiver, reasonable freedom from interference and transmission over agricultural country, the

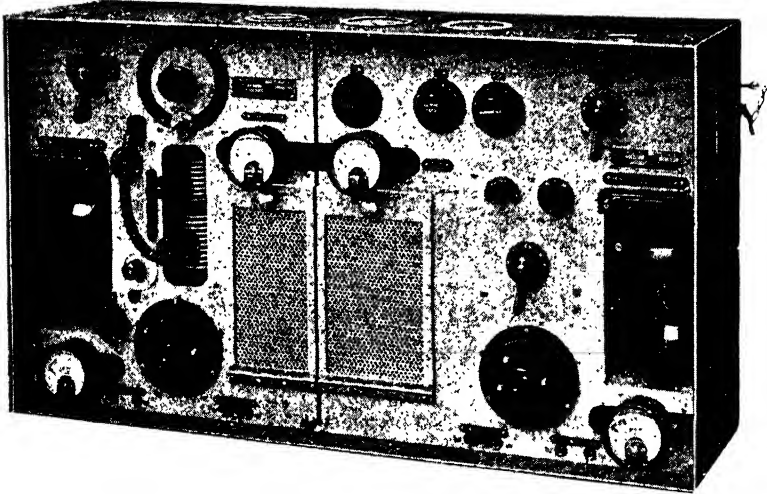


FIG. 102. MARCONI AIRCRAFT MEDIUM/SHORT-WAVE TRANSMITTER, TYPE A.D.57/A

following approximate ranges will be obtained when using a trailing aerial—

Air to ground C.W.	400 miles (640 km.)
Air to ground I.C.W.	300 miles (480 km.)
Air to ground Telephony	200 miles (320 km.)

The medium-wave transmitter circuits consist of a valve master oscillator circuit driving an air-cooled anode power amplifying valve.

The master oscillator tuning condenser is calibrated directly in metres, and by means of a click stop arrangement 4–5 pre-determined spot wavelengths can be rapidly and accurately selected.

Special easily detachable feed meters are provided in the master oscillator and power amplifier anode circuits.

Telephony modulation is effected by the use of a modulator valve operating as a variable grid leak in the grid of the power amplifier valve. The depth of modulation is approximately 60 per cent.

Telegraphy is effected by keying across a resistance in the high-tension negative supply. With the manipulating key open, a heavy negative bias is put upon the grids of the master oscillator and power amplifier valve and clear crisp cut-off results.

For interrupted continuous waves, an interrupter disc mounted on the

high-tension generator and connected in series with the manipulating key produces an audible note of approximately 1000 cycles per second.

The high-tension input to the power amplifier valve is approximately 132 watts.

The total high-tension input to the medium wave transmitter is 1,200 volts at 144 milliamperes.

The total low-tension input is approximately 42 watts at 12 volts 3.5 amperes.

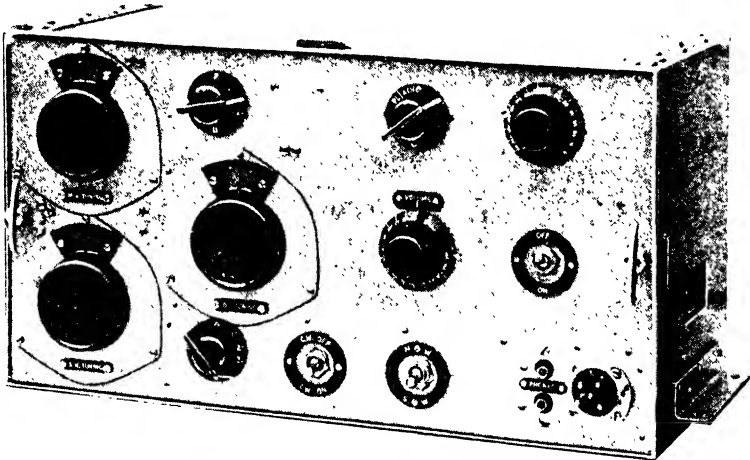


FIG. 103. MARCONI AIRCRAFT MEDIUM/SHORT WAVE AND D.F. RECEIVER
TYPE A.D. 5872A

The medium-wave transmitter has the following controls—

- (1) M.W. transmit/off stand-by switch (or receive).
- (2) C.W./I.C.W./Tel. switch.
- (3) Master oscillator tuning condenser.
- (4) Anode tap selector.
- (5) Aerial tap selector.
- (6) Aerial variometer.
- (7) Neutrodyne switch and neutrodyne condenser.

The valves are arranged to be heated from the 12-volt supply, the correct operating voltage being maintained on the valves by series and parallel resistances.

(1) The master oscillator valve is a triode, Marconi type DET. 5. An oxide coated filament is used operating at 4 volts 2 amperes. The maximum anode voltage is 400 volts.

(2) The power amplifier valve is an air-cooled-anode triode, Marconi type ACT. 6. An oxide coated filament is used operating at 10 volts, 1.5 amperes. The maximum anode voltage is 1,200 volts.

(3) The modulator valve is a triode, Marconi type MHL. 4. An indirectly heated filament is used operating at 4 volts 2 amperes.

The waveband of the short wave transmitter is 16.9–75 metres (17,750–4,000 kcs.) covered in three ranges of approximately 16.9–27.3 metres (17,750–10,990 kcs.), 32–56 metres (9,380–5,337 kcs.), and 50–75 metres (6,000–4,000 kcs.). The transmitter is designed for continuous wave transmission only, and the power in the aerial circuit is approximately 60 watts.

On the short waveband the ranges obtainable depend upon the factors governing the propagation of these waves, i.e. wave-length, diurnal and seasonal variations, etc.

Provided the correct wave-lengths are chosen, ranges varying from several hundreds to several thousands of miles can be obtained.

The short-wave transmitter circuits consist of a valve master oscillator circuit driving an air-cooled anode triode power amplifier valve.

The master oscillator tuning condenser is calibrated directly in metres. A click-stop arrangement on the master oscillator control permits of the rapid and accurate setting of 4-5 predetermined spot wave-lengths.

Special easily detachable feed meters are provided in the master oscillator and power amplifier anode circuits.

Telegraphy is carried out by the same method as that used on the medium-wave panel.

The high-tension input to the power amplifier valve is approximately 120 watts.

The total high-tension input is 1,200 volts at 130 to 145 milliamperes.

The total low-tension input is approximately 42 watts at 12 volts 3.5 amperes.

The short-wave transmitter has the following controls—

(1) Main master switch, M.W. Transmit and S.W./M.W./Receive/Off short-wave transmit.

(2) Master oscillator tuning condenser.

(3) Master oscillator wave-range selector switch.

(4) Aerial circuit tuning condenser.

(5) Aerial circuit wave-range selector switch.

(6) Aerial tap.

(7) Neutrodyne switch and neutrodyne condenser.

The master oscillator valve is a Marconi triode, type DET. 5, and the power amplifier valve is a Marconi triode, with air-cooled anode, type ACT. 6.

The Receiver Type A.D. 5872

The direction finding receiver type A.D. 5872 employs a high efficiency superheterodyne circuit using multi-electrode valves. (Fig. 103.)

Reception can be effected on C.W., I.C.W., and telephony.

On the medium waveband, the circuit arrangement allows of the receiver being used for direction finding and "homing" with the addition of a rotatable screened frame aerial and a D.F. reversing switch.

By the addition of a visual indicator and a rotary reversing switch, visual course indication can be provided.

The receiver is continuously adjustable between the following limits—

Medium wave-range: 600-2,000 metres (500-150 kcs.) in two ranges of 600-1,050 metres (500-285.7 kcs.) and 1,050-2,000 metres (285.7-150 kcs.).

Short wave-range: 15-75 metres (20,000-4,000 kcs.) in four ranges, 15-22 metres (20,000-13,740 kcs.), 21-33 metres (14,290-9,090 kcs.), 33-51 metres (9,090-5,828 kcs.), and 50-75 metres (6,000-4,000 kcs.).

The receiver is a superheterodyne of modern design, employing six indirectly heated valves with filaments operating at 12 volts. The valves perform the following functions.

(1) Two triode-hexode frequency changers, or "mixers" are used; one for the medium waveband, and the other for the short waveband, with the object of avoiding switching at high frequencies. This valve operates as

an H.F. amplifier, first detector, oscillator, and mixer valve. These valves are Marconi type X. 31.

(2) A variable amplification factor H.F. pentode acts as an intermediate frequency amplifier, working at an intermediate frequency of 465 kcs. The valve is a Marconi type W. 30.

(3) A double diode H.F. pentode acts as a further intermediate frequency amplifier, as second detector and as first stage L.F. amplifier. The valve is a Marconi type WD. 30.

(4) A triode valve Marconi type H. 30 acts as a second audio frequency magnifier.

(5) A separate triode valve Marconi type H. 30 acts as a heterodyne on the intermediate frequency for the reception of C.W. signals.

There are therefore four valves in circuit when receiving telephony or I.C.W. telegraphy, and five valves in circuit when receiving C.W., on either the short or medium wave-range.

Two independent tuning dials are provided, one for each waveband. They are directly calibrated in metres and are illuminated when in use.

The receiver has the following controls—

- (1) Medium wave ganged tuning condensers.
- (2) Short wave ganged tuning condenser.
- (3) Medium wave/short wave selector switch.
- (4) Medium wave range switch.
- (5) Short wave range switch.
- (6) Manual volume control.
- (7) C.W. reception switch.
- (8) Main receiver on/off switch.

Additional direction finding controls incorporated in the receiver are—

- (1) D.F. frame tuning condenser.
- (2) D.F./Plain aerial selector switch.
- (3) Zero clearing control.

The total high-tension input to the receiver is approximately 30 milliamperes at 180–200 volts.

The total low-tension input to the receiver is approximately 2.4 amperes at 12 volts, each valve filament taking 0.3 ampere.

On medium wave-lengths the average selectivity is such that a given signal is reduced by 30 db. if the receiver is adjusted to 10 kcs. off tune.

From 600–1,000 metres a 12-microvolt signal input gives an output of 10 milliwatts. From 1,000–2,000 metres a 16-millivolt signal input gives an output of 10 milliwatts. The maximum undistorted power output, approximately 150 milliwatts.

If specially required, "listening through" can be provided at a small extra cost. This enables the operator to listen for interruptions from the ground station in the intervals between keying, during telegraphy operation. A special small dipole aerial is provided, and is connected to the receiver during telegraph transmission, the receiver being kept in operation all the time. When the key is pressed, this dipole aerial is shorted to earth, so that the receiver does not get overloaded, but receives only enough to act as "sidetone." When the key is open, the dipole is unshorted and the receiver can pick up any interruption message sent out by the ground station. This arrangement saves much time in service, especially when approaching an aerodrome as the ground control station can break in and stop the aircraft transmitting at any moment, instead of having to wait until the aircraft operator completes his message and changes over to receive.

If "listening-through" is provided, the sidetone circuits in the S.W. and M.W. transmitter panels are not used. If "listening-through" is not provided, the usual sidetone circuits operate, and the operator hears his own C.W., I.C.W., or telephony transmission. C.W. sidetone is made



FIG. 104. MARCONI 19' D.F. ROTATABLE LOOP AERIAL, WITH
RETRACTABLE MOUNTING

View showing aerial fitted to Imperial Airways Flying Boat "Canopus."

audible by means of a special interrupter circuit, which makes the C.W. sidetone sound like I.C.W., although only pure C.W. is actually transmitted.

For *direction finding* and "*homing*" with the A.D. 5872 receiver, the following items of equipment are required—

Rotatable Frame Aerial (Fig. 104)

This is a rigid circular screened frame 19 in. (48 cms.) outside diameter, mounted outside the aircraft fuselage, and operated from inside by means of a hand wheel. A circular engraved scale and pointer indicate the angle at which the frame aerial is set in relation to the nose of the aircraft. Bearings can therefore be taken on stations in the usual manner, or the frame can be set at right angles to the line of flight for "homing." By the addition of a visual indicator the facilities of a radio compass are provided.

An automatic clutch in the frame mechanism locks the frame in any desired position as soon as rotation by hand is stopped.

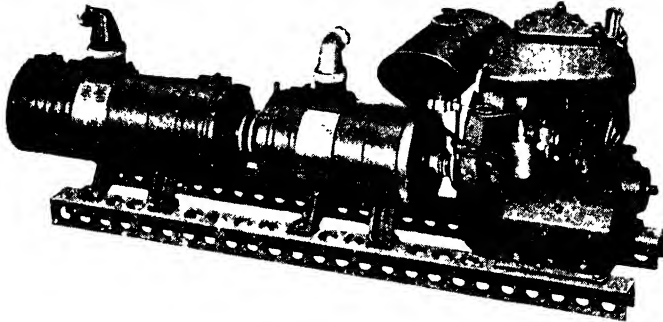


FIG. 105. POWER PLANT FOR MARCONI AIRCRAFT EQUIPMENT TYPE A.D. 57A/5872A MOTOR GENERATOR SET AND EMERGENCY PETROL ENGINE

The frame can be made retractable if desired.

When using D.F. the output from the frame together with that from the open aerial is coupled via a suitable transformer in the A.D. 5872 receiver.

The *hand reversing switch* provides aural "homing." It reverses the phase of the open aerial coupling to the frame aerial, thus producing louder or weaker signals if the aircraft is off course. It is thus possible to steer the aircraft on to its true course, when the signals will become equal, regardless of the phase of the open aerial coupling. An adjustable open aerial phasing resistance is also mounted in the switchbox. This is used to equalize the input from the open aerial with that from the frame aerial.

For visual operation the hand switch is set in its middle position.

The *visual indicator* consists of a centre-reading dashboard instrument, together with a rotating commutator reversing switch, which is driven by a separate 12-volt motor (or by the anode converter). This switch reverses the trailing aerial coupling and also the input to the indicator so that a visual indication of the side off course is given on the indicator. It is thus possible to use the equipment either for visual or aural methods of "homing" at will.

ACCURACY FOR "HOMING." When using "homing" with the open aerial in conjunction with the frame, off-course indications are easily detectable aurally with an accuracy of $\pm 2^\circ$ and with an accuracy of $\pm 3^\circ$ for visual indication.

When using the frame aerial alone, on minimum signal, accuracies within $\pm 2^\circ$ are audible, or visible, at ranges up to 150-200 miles (240-320 km.) depending upon the power of the transmitter, and assuming good reception conditions.

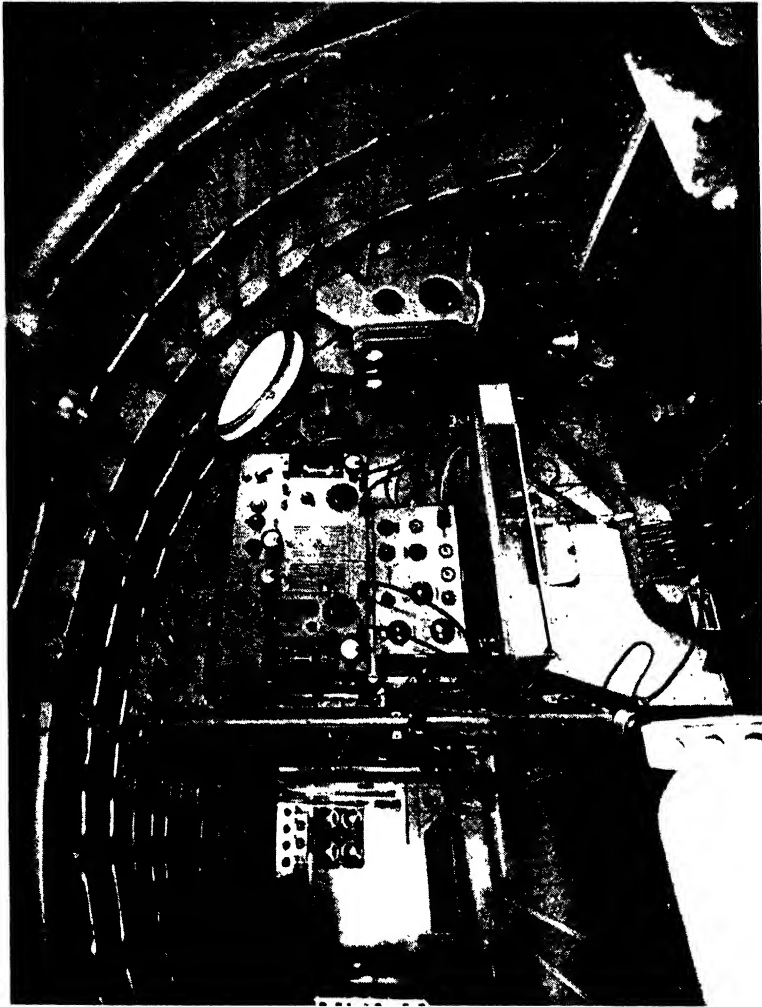


FIG. 106. MARCONI AIRCRAFT EQUIPMENT TYPE A.D. 574/5872
View showing equipment installed in Imperial Airways Flying Boat "Canopus."

For short and medium wave transmission and non-directional reception, trailing aerial and fixed aerial are provided.

A special dipole aerial is supplied in addition if listening through is required.

For directional reception a rotatable screened frame aerial is used, working in conjunction with either the trailing or fixed aerial for "homing" or direction finding.

The transmitter power equipment when used on large flying boats usually consists of a motor generator set in which the motor runs off the 24-volt aircraft low-tension supply, and the double output generator supplies 12-volt low-tension and 1,200-volt high-tension to the transmitter.

The motor takes an input of 898 watts at 24 volts 27 amperes.

The double output generator delivers a high-tension supply of 1,200 volts at 200 milliamperes and a low-tension supply of 12·5 volts 6 amperes.

For emergency working or for charging the aircraft 24-volt batteries when the main engine driven generators are not in use, a 1 h.p. Marconi Stanley two-stroke petrol engine is coupled by means of a quick release coupling to the motor generator set contained in the same bedplate. The 24 volt motor is then used as a generator and delivers 390 watts at 26 volts 15 amperes (Fig. 105).

The Marconi Stanley engine can be started up by motoring the 24-volt generator from the aircraft batteries.

The receiver high-tension is derived from an anode converter running off the aircraft 12- or 24-volt low-tension supply and delivering a high-tension supply of 180 volts 30 milliamperes.

If the motor-generator-petrol engine set is not required, the usual wind-driven generator equipment, either for wireless supplies only, or for charging and lighting services in conjunction with a special charging switchboard, can be supplied. With these wind-driven generators, the receiver high-tension supply is derived from the main generator, no separate anode converter being required. Alternatively, the equipment can be run (at low power) from a rotary transformer fed from the aircraft accumulators. This rotary transformer has an output of 1,000 volts 150 milliamperes and provides the transmitter with approximately 90 watts on the anodes, or 45 watts in the aerial circuit.

Below are given approximate weights and dimensions of the equipment (Fig. 106)—

		<i>Weight</i>		
		lb.	oz.	kg.
Transmitter, Type A.D.57	{ Width . 25½ in. (64·7 cms.) }	43	0	(19·5)
	{ Depth . 8½ in. (21·5 cms.) }			
	{ Height . 14½ in. (36·8 cms.) }			
Receiver, Type A.D.5872	{ Width . 16½ in. (41·2 cms.) }	16	2	(7·3)
	{ Depth . 8¾ in. (22·2 cms.) }			
	{ Height . 9 in. (22·8 cms.) }			
Visual indicator rotary switch.	{ Width . 12 in. (30·5 cms.) }	7	3	(3·25)
	{ Depth . 4 in. (10·2 cms.) }			
	{ Height . 6 in. (15·24 cms.) }			
Aerial change-over switch.	{ Width . 5½ in. (14·6 cms.) }	1	4	(0·56)
	{ Depth . 5 in. (12·7 cms.) }			
	{ Height . 3 in. (7·6 cms.) }			
Visual indicator meter	Overall diameter 3½ in. (8·85 cms.)	8		(0·22)
Carried forward		68	1	(30·83)

ELECTRICAL AND WIRELESS EQUIPMENT OF AIRCRAFT 155

	Brought forward	lb. oz.	kg.
Screened rotatable frame aerial Max. dia. 19 in. (48.3 cms.)		68 1	(30.83)
Trailing aerial supplies		13 8	(6.1)
Fixed aerial supplies		7 11	(3.5)
Dipole aerial supplies		4 0	(1.85)
Engine generator set with emergency petrol engine		4 0	(1.85)
Switchboard		111 8	(50.5)
Headset, complete		11 3	(5.1)
Operating key		1 6	(0.62)
Cables (average)		8	(0.22)
		10 0	(4.5)
Total approximate weight of equipment		<u>244 lb.</u>	<u>(110) kg.</u>

The table below gives particulars of Marconi-Newton type generators and the type of set with which they are designed to work. The windmills designed to drive these generators are of the automatically variable pitch

Type of Generator	High Tension		Low Tension		R.P.M.	Weight		Type of Transmitter
	Volts	Amps.	Volts	Amps.		lb.	oz.	
A.D./Q1	1,200	0.2	16	16	3,500	35	11	For A.D. 41/42 and A.D. 37/38
A.D./Q2	1,200	0.2	16	16	3,500	35	11	
A.D./R1	1,200	0.2	7	10	3,500	24	6	
A.D./R2	1,200	0.2	7.5	10	3,500	25	0	
*A.D./U1	1,000	0.15	16.5	14	3,500	26	12	
†A.D./U2	1,000	0.15	16.5	14	3,500	29	0	
*A.D./U5	1,000	0.15	16.5	14	3,500	27	0	
†A.D./U6	1,000	0.15	16.5	14	3,500	29	4	
*A.D./U9	1,000	0.15	16.5	14	3,500	27	0	
A.D./H14	1,000	0.15	—	—	3,500	12	0	
*A.D./U10	800	0.13	16.5	14	3,500	26	12		For A.D. 49/50
A.D./H12	800	0.13	12.5	3.25	3,500	14	0	
*A.D./H15	800	0.13	12.5	3.25	3,500	14	12	

* For tunnel mounting in the leading edge of the wing.
 † For cradle mounting.

type, which ensure constant voltage almost irrespective of load and air-speed. There is a range of these windmills, and reference should be made to the maker as to the most suitable one to use with a given generator and

aircraft, but the following table gives some particulars of the different types—

Type	Drq. No.	Range of Total Airspeeds over Windmills*	Corresponding Range of r.p.m.	Generator for which approved
<i>Marconi Newton,</i>				
Type 110	18267	70-170 m.p.h.	Approx. 3,500 r.p.m.	Any approved type of electrical generator
" 112 and 112 S.	18645	70-300 "		
" 140	18267	70-170 "		
" 142 and 142 S.	18645	70-300 "		
" 160	18267	70-170 "		
" 180	18267	70-170 "		
" 182 and 182 S.	18645	70-300 "		

* Including slipstream if any.

When Marconi-Newton Constant Speed Windmills, types 110, 140, 160 and 180, are used, it is essential that the following instructions be observed to ensure the correct functioning of their regulating mechanism.

(1) The windmills are to be tested before each flight for freedom of the blades. For this purpose the blades are to be turned against the force of the internal springs in the direction to coarsen their pitch, care being taken that the blades are gripped as near as possible to the centre to avoid damaging or distorting the blades.

(2) The windmills are to be lubricated after approximately every 20-hours' flying by means of a few drops only of very light machine oil introduced into the hole provided.

THE WESTINGHOUSE G.D. TRANSMITTER, with a power output of 15 watts, is designed primarily for the private owner. The unit operates from the standard 12-volt aircraft battery and incorporates a self-contained dynamotor. This feature reduces the amount of fitting necessary to the single unit and the remote control since only one battery cable and the remote control cable need be installed and the transmitter takes up very little space. It is recommended that a quarter wave trailing wire aerial be used, but the transmitter will operate satisfactorily with any type of fixed aerial. It is designed to operate at either 3,105 or 3,120 kilocycles, but can be supplied for operation on any two frequencies relatively close together between 2,000 and 6,600 kilocycles. Transmitting frequency is maintained by low temperature coefficient plug-in type quartz crystals. The maximum output is 15 watts with 100 per cent modulation. The remote control incorporates one single toggle switch to control the filament current, another to select the desired transmitting frequency, and a microphone jack. The controls are supplied either in a standard aircraft instrument case or for separate mounting with individual nameplates. An aerial meter with a luminous dial fitted in a standard case as is used for aircraft instruments is also supplied. The dynamotor and its filter are mounted on the transmitter chassis and enclosed by the cover of the transmitter unit. Adequate overload protection is provided by fuses located both in the 12-volt supply line and in the high voltage anode circuit. A spare high voltage fuse is supplied with the unit and clipped on to the cover. The transmitter itself incorporates an amplifier stage, with two screen grid valves.

DIMENSIONS

Transmitter case: $12\frac{1}{2}$ in. \times $8\frac{1}{2}$ in. \times $7\frac{1}{2}$ in. (32.5 \times 21.5 \times 19.5 cm.).
 Overall dimensions including Lord shock-absorber mountings and cable plugs: $15\frac{3}{8}$ in. \times $8\frac{1}{2}$ in. \times $8\frac{3}{8}$ in. (39 \times 21.5 \times 22 cm.).
 Remote control cable length: 20 ft. (6.16 metres).
 Battery control cable length: 4 ft. (1.22 metres).
 Remote control metre case: 2 in. diameter (7 cm.).
 Weight of complete transmitter: 25 lb. 14 oz. (11.8 kg.).

GENERAL MAINTENANCE OF W/T EQUIPMENT

All wireless equipment requires particular care, both in use and in store. If proper care is not exercised failure in communication is likely to result, and the faults which develop will be found difficult to locate.



FIG. 107. M.L. AIR-DRIVEN GENERATOR: TYPE "K"

The M.L. Air-driven Generator is the latest machine to be added to the range of M.L. machines for aircraft.
(By courtesy of Rotax Ltd.)

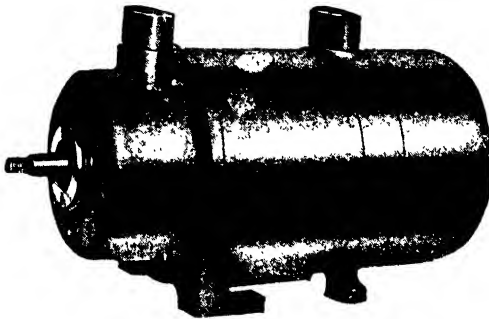


FIG. 108. M.L. ROTARY TRANSFORMER: TYPE "G"

The M.L. Rotary Transformer type "G" has been specially designed for radio transmission work on aircraft. Its chief features are extremely light weight, compact design.
(By courtesy of Rotax Ltd.)

Sand, dust, and other grit particularly must be guarded against. Instruments in use must be cleaned and dusted daily, or more often if required. Where dust storms are prevalent, dustproof covers should be made for instruments, and the latter should be removed from aircraft when not in use. All contacts must be kept clean. Files, or anything rougher than the finest grade emery cloth, should never be used on contacts, and fine contacts should be cleaned with tissue paper or a dry cloth.

Oil or grease on contacts must be guarded against, key contacts requiring particular attention in this respect.

Instruments should never be left in full sunshine, particularly in the East. This applies especially to instruments constructed of ebonite, which will soften and warp in the sun.

Dry cells (primary batteries) should not be stored in a hot place, as the heat will cause evaporation of the moisture in the cell. They should be stored vertically to allow any gas generated to escape uniformly. The terminals must be kept clean and free from sulphate, and every care must be taken to prevent short-circuiting. No short lengths of lead should be left lying about.

Dry (inert) cells should never be moistened until actually required.

In hot climates the deterioration of dry cells is very great; arrangements should be made for periodical turnover.

All equipment must be kept as dry as possible, and sea water particularly should not be allowed to reach any instrument. Damp enormously reduces the insulating properties of ebonite, woodwork, and insulation or wiring. Its effects are deceptive, and it is in the internal fittings, windings, and wirings that the danger of dampness particularly lies.

Insulators of an aerial system and of instruments must be carefully examined from time to time.

Ordinary clear dope is a plain solution of celluloid, and is a reasonably good insulator. Aluminium dope, however, may be quite a good conductor, especially where high voltages or radio frequency oscillations are concerned. It should not, therefore, be applied to any surface in contact with an aerial insulator or similar fitting within two or three inches of such fittings.

Head telephones should be examined daily to ensure that the telephone leads are not wearing, and that the small nuts are tight. Faults in head telephones are a very frequent source of failure.

Valves should not be handled more than necessary, and when not in use should always be kept in the boxes provided. The habit of shaking or tapping a valve is to be discouraged. Valves must not be forced into sockets; if properly handled, they will go in quite easily.

High-tension generators must be kept dry and free from dust. The clearance between the casing and the armature is small, and care must be taken to prevent the outer case (streamline cover) becoming dented or bent. Sparking is generally an indication of dirt and damp, and it is particularly likely to occur if a generator has not been used for some time.

Rotary Machinery—General. (a) Absolute cleanliness of all parts must be observed, and all machinery must be examined in detail periodically. Any heating above the normal must be carefully noted, as this is a certain indication of fault. (b) Commutators require particular attention. They must be kept absolutely clean, and it is essential that they should be "true" and that there should be a minimum of sparking at the brushes. A commutator should generally be cleaned when the machine is moving (to prevent "flats") with a rag, not cotton waste, damped with methylated spirit. Where possible, the brushes should be shifted occasionally along the rocker. Experience will teach how to avoid ordinary sparking, which is generally due to a loose or worn-out brush, or to a dirty commutator. Abnormal sparking often indicates a serious overload, or even a broken coil. Careful attention must be given to the lubrication of all bearings, and for this purpose anti-freezing grease is usually specified by the makers.

As a means of protection to aircraft whilst replenishing the fuel tanks, the structure of the aircraft should always be "earthed" whilst stationary

on the ground to prevent the building up of large static charges of electricity. This is usually accomplished through the tail skid or by means of a trailing conductor.

APPROVED RADIO APPARATUS

The undermentioned types of radio apparatus are at present approved officially for use on civil aircraft—

<i>Type</i> R.X.25 Receiver	<i>Range</i> 600–5,000 metres (provisional)
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TELEGRAPH-TELEPHONE SETS

Set	Type	Wavelengths in Metres
Marconi's Wireless Telegraph Co. Ltd.		
A.D.6	Transmitter	400–1,200
"	Receiver	300–1,500
A.D.6A	Transmitter	400–1,200
"	Receiver	850–950
A.D.6C	Transmitter	500–1,500
"	Receiver	500–3,500
A.D.6H	Transmitter	300–1,500
"	Receiver	200–1,800
A.D.6M	Transmitter	550–1,550
"	Receiver	550–1,550
A.D.6N	Transmitter	550–1,150
"	Receiver	500–1,300
A.D.8	Transmitter	600–1,500
"	Receiver	600–4,000
A.D.18A	Transmitter	300–1,600
"	Receiver	300–1,800
A.D.19	Transmitter	40–60
A.D.20	Receiver	15–150 (in four ranges)
A.D.20A	Receiver	80–180
A.D.22B	Transmitter	600 and 850–900
"	Receiver	600–900
A.D.22C	Transmitter	600 and 850–900
"	Receiver	600–900
A.D.22D	Transmitter	600 and 800–950
"	Receiver	600–950
A.D.24A	Transmitter	30–60
A.D.37A/38A	Transmitter	40–80 and 500–1,000
"	Receiver	40–1,000
A.D.37C/38B	Transmitter	40–80 and 500–1,600
"	Receiver	40–80 and 500–1,600
A.D.37D/38C	Transmitter	35–70 and 500–1,000
"	Receiver	35–70 and 500–1,000
A.D.37E and Rotary transformer	Transmitter	40–80 and 500–1,000
"	Receiver	500–1,000
A.D.37F/38D	Transmitter	150–200 and 500–1,000
"	Receiver	150–200 and 500–1,000
A.D.37H/38F	Transmitter	40–80 and 500–1,000
"	Receiver	40–80 and 500–1,000
A.D.41A/42A	Transmitter	500–1,000
"	Receiver	500–1,000
A.D.41B/42B	Transmitter	500–1,000 (in two ranges)

TELEGRAPH-TELEPHONE SETS—*Continued*

Set	Type	Wavelengths in Metres
A.D.41c/42c	Transmitter	500-1,000 (in two ranges)
"	Receiver	500-1,000
A.D.41c/5062B	Transmitter	500-1,000 (in two ranges)
"	Receiver	600-1,550 (in two ranges)
A.D.43A/44A	Transmitter	50-100
"	Receiver	50-100
A.D.43C/44B	Transmitter	50-130
"	Receiver	50-130
A.D.49A/50A	Transmitter	600-1,000
"	Receiver	600-1,200
A.D.49A/5062A	Transmitter	600-1,000
"	Receiver	600-1,200
A.D.49A/50B	Transmitter	600-1,000
"	Receiver	600-1,550 (in two ranges)
A.D.49A/5062B	Transmitter	600-1,000
"	Receiver	600-1,550 (in two ranges)
A.D.51A	Transmitter	147.8-144.9
"	Receiver	147.8-144.9
A.D.57A/5872A	Transmitter	16.9-75 (in three ranges)
"	Receiver	600-1,100 16-75 (in four ranges) and 600-2,000 (in two ranges)
A.D.73A/37K/5872B	Transmitter	16.9-75 (in three ranges) 90-190 and 500-1,000
"	Receiver	15-100 (in five ranges), 183, 300-450 and 600-2,000 (in two ranges)
Plessey Co. Ltd.		
A.C.44	Transmitter	600-930
"	Receiver	600-930
A.C.57	Transmitter	40-80
"	Receiver	550-1,350
Standard Telephone and Cables Ltd.		
A.T.R.4	Transmitter	500-1,100
"	Receiver	500-1,100
A.T.R.6	Transmitter	30-80
"	Receiver	500-1,000
A.T.R.7	Transmitter	500-1,100
"	Receiver	500-1,100
A.T.R.8	Transmitter	30-120
"	Receiver	30-120
A.T.R.4002 S/N.1	Transmitter	30-60 and 600-1,200
"	Receiver	30-1,200

CHAPTER VII

DIRECTIONAL WIRELESS

DIRECTIONAL wireless, as applied to position finding and the navigation of aircraft, has now reached such a stage of reliability that it has made the navigation of aircraft, particularly in fog and over clouds, very much more certain than have any other methods that have so far been used. Various systems have been developed, but so far as the navigation of civil aircraft is concerned, the choice of at least four methods is now available.

1st Method. The object is attained by the transmission of a wireless signal from the aircraft, and the reception of this signal by a particular ground station fitted with special apparatus which enables the operator to ascertain the direction, or bearing from true north, of the aircraft when the signal was received. The bearing is then transmitted by wireless from the ground station to the aircraft.

The apparatus required in the aircraft consists of the ordinary wireless transmitter and receiver, capable of sending and receiving signals over the distance at which the aircraft is operating from the special ground station.

By arranging a second direction-finding receiving station on the ground at the other end of a suitable base line, both stations can take a bearing simultaneously on the aircraft. The second station notifies to the first, or control station, its result, the control station plots this bearing and its own on a map, and obtains an intersection which gives the actual position of the aircraft. The control station can then signal to the aircraft, e.g. 5 miles S.S.E. of Calais. With skilled operators at the ground stations, the position thus found should be accurate to within 3 miles at a range of 150 miles. The aircraft personnel require some training to be able to make the best use of their transmitters and receivers, as speed is essential to accuracy.

The advantages of this system are the simplicity of operation in the aircraft, no apparatus other than that ordinarily required for communication with the ground being necessary, and the use that can be made on the ground of complicated instruments to give great accuracy and reliability.

2nd and 3rd Methods. The Marconi type A.D. 52 direction-finding attachment (Fig. 104) is designed for use in conjunction with Marconi aircraft receivers. Although designed primarily for use with the types A.D. 38 and A.D. 42 receivers, it is also suitable for use with the majority of Marconi medium wave aircraft receivers. The D.F. attachment eliminates the necessity of providing a complete direction-finding receiver in addition to the normal receiver, thus effecting a saving in cost, weight, and space.

The type A.D. 52 attachment is designed for operating on either of two systems of direction finding, namely—

(1) The Fixed Aerial "Homing" System, in which use is made of a single fixed loop aerial in conjunction with a trailing aerial and a loop reversing switch.

(2) The Rotatable Loop Aerial System, which enables bearings of a transmitter to be taken in the usual way, but also retains the special features of the "Homing" system.

The provision of direction-finding facilities in no way interferes with

the normal reception carried out on the trailing aerial, change from normal reception to direction finding being instantaneously effected by means of a small change-over switch mounted in the D.F. attachment.

The attachment is designed to cover a wave-range of 500 to 1,550 metres (600-193.5 kcs.) in two ranges of approximately 500 to 1,100 and 900 to 1,550 metres.

It should be noted that this wave-range will be curtailed when the attachment is used with a receiver having a wave-range less than 500 to 1,550 metres.

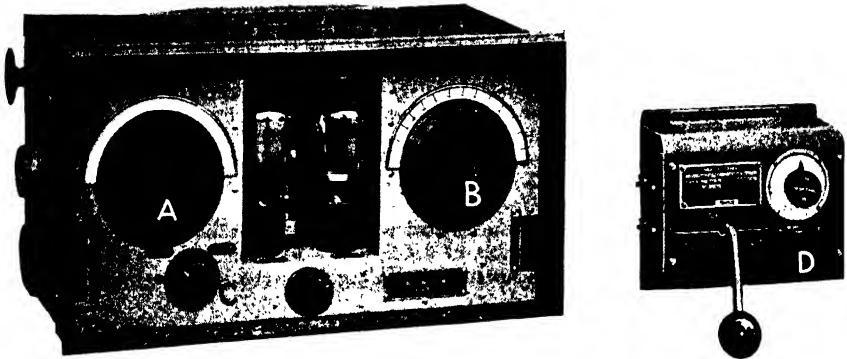


FIG. 109

A = Loop tuning condenser.
B = H.F. tuning condenser.

C = "D.F."-plain aerial change-over switch.
D = Loop reversing switch.

THE HOMING SYSTEM. This is essentially a simple method which enables a pilot to set the course of his aircraft directly towards a known wireless transmitter on the ground. It is particularly suitable for use on aircraft where no special wireless operator and/or navigator is carried, and where the aircraft flies mainly on routes possessing no direction-finding stations on the ground, but where ground communication or beacon transmitters are situated along the route, e.g. at the various aerodromes.

In this system use is made of a single loop aerial installed so that its plane lies at right angles to the fore and aft line of the aircraft, and a loop reversing switch in addition to the normal receiver and trailing aerial.

The loop reversing switch incorporates a three-position switch, and adjustable resistance.

In the *central* position of the switch the loop aerial alone is connected to the receiver; in the *left-hand* position both the loop aerial and the trailing aerial are connected to the receiver, while in the *right-hand* position both the loop aerial and the trailing aerial are connected to the receiver, but the connections of the loop aerial are reversed.

If the aircraft is flying head-on towards the transmitting station, no E.M.F. is induced in the loop aerial and only the signal due to the trailing aerial will be heard when both trailing aerial and loop aerial are connected. Further, under these conditions no difference will be observed whether the switch is moved to either the left or the right.

If, however, the aircraft is not flying head-on towards the transmitting station an E.M.F., depending on the angle of divergence, will be induced in the loop aerial. Now, on moving the switch from side to side the resul-

tant signal strength will be greater if the loop aerial is connected to the receiving apparatus in one direction and less if the loop aerial connections are reversed. From these indications it can be determined whether the transmitting station lies to port or starboard of the fore and aft axis of the aircraft. By suitably correcting the course until no difference in signal strength can be observed, whichever way the loop is connected, the aircraft will be automatically "headed" towards the transmitting station. The accuracy of the course can be checked by putting the switch in the central position (connecting only the loop aerial) when, if the course is correct, no signals at all will be heard.

The adjustable resistance enables the strength of the signal due to the trailing aerial to be made approximately equal to the strength of signal due to the loop aerial and provides a useful indication of the deviation off course. A characteristic of this system is that, in the case of a strong cross wind, the path followed by the aircraft will not be a straight line but will be a curved line, somewhat of parabolic shape depending on the strength of the cross wind. The nose of the aircraft will always point towards its objective, but as the aircraft is blown off its straight-line course its compass bearing will be progressively changing and the machine will eventually arrive more or less "nose into wind," at the desired aerodrome.

THE ROTATING LOOP SYSTEM. This system provides a full direction-finding service in cases where an operator and/or navigator is carried on large civil, military, or naval aircraft, and which fly over territory where no direction-finding stations are available, or over sea. The system enables the aircraft to be headed towards a transmitting station as previously described under "Homing" system, and, in addition, provides a convenient means whereby bearings may be taken on stations which lie off the normal course of the aircraft, and from which the position of the aircraft may be determined by plotting, in the usual way, the bearings of two or more such stations on a chart.

In this system use is made of a small screened loop aerial mounted externally on the aircraft and provided with a hand-wheel and mechanism for rotating the loop from inside the aircraft. The mechanism incorporates a clutch, so arranged that the loop is automatically locked in the desired position when the hand-wheel is released.

The method of taking bearings is similar to that already described under the "Homing" system, so that if "homing" only is required it is only necessary to set the loop at right angles to the fore and aft axis of the aircraft, to operate the loop reversing switch, and to correct the course accordingly. In the case of bearings taken on stations lying off the line of flight, however, the reversing switch is set in the central position and no signal is heard from the transmitting station. The reversing switch is operated and no difference in signal strength can then be observed whichever way the loop is connected, the signal heard being due to that received on the trailing aerial only. When this condition is obtained, the bearing of the desired station relative to the "head" of the aircraft may be read from a scale attached to the mechanism.

The equipment required in addition to the normal receiver for operating on the two methods of direction finding comprises the following—

- (1) *Fixed Loop "Homing" System.*
 - (a) A two-stage tuned H.F. amplifier and a loop tuning circuit.
 - (b) A loop reversing switch unit.
 - (c) A fixed loop aerial.
 - (d) Interconnecting leads.

(2) *Rotatable Loop System.*

As for (1), but employing a rotatable screened loop in place of the fixed loop (Item (c) above).

The type of loop aerial used depends upon the size and type of aircraft. In the case of a biplane of *wooden* construction it is usually possible to mount the fixed loop aerial round the wings and struts or alternatively round the fuselage itself. In the case of an *all-metal* aircraft, however, the foregoing arrangements are not possible and in such circumstances a *small rotatable screened loop aerial* is mounted externally on the aircraft.

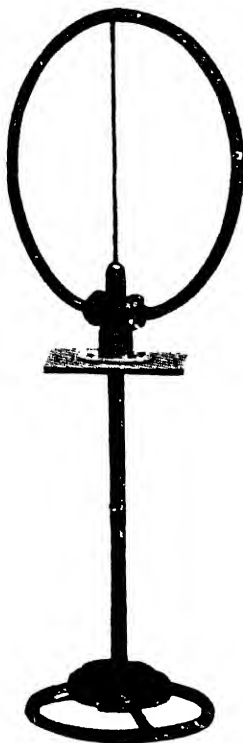


FIG. 110
ROTATABLE SCREENED
LOOP AERIAL

The screened loop aerial can be of the retractable type if required, whereby the loop can be drawn into the body of the aircraft when D.F. observations are not required.

THE HIGH-FREQUENCY AMPLIFIER unit consists of a panel on which are mounted a circuit for tuning the loop aerial to the required wavelength: a two-stage screen-grid high-frequency amplifier and a "D.F.-Plain Aerial" change-over switch.

The tuning control of the loop tuning circuit is calibrated in metres at the time of installing, as the calibration depends upon the electrical characteristics of the loop aerial when fitted.

The tuning condensers of the two high-frequency amplifying stages are simultaneously adjusted by a single dial calibrated directly in metres.

The valves used in each of the high-frequency stages are type S 610 or S 410, according to the type of receiver with which the attachment is used.

The "D.F. Aerial" switch performs the following operations—

(1) When at "Plain aerial" it causes the loop aerial to be earthed, disconnects the two-stage amplifier and connects the trailing aerial direct to the receiver for ordinary reception.

(2) When at "D.F." it connects the loop aerial and the H.F. amplifier into circuit for direction-finding purposes.

The complete panel is contained in a light metal case and can be either bolted directly to the main wireless receiver or mounted separately according to requirements.

The type A.D. 52/42 forms a complete direction finding and receiving equipment which can be used with either the fixed or rotatable aerial system previously referred to in the description of the type A.D. 52 direction-finding attachment.

The equipment is particularly suitable for use in cases where transmission is not required, or where a separate transmitter is installed in the aircraft.

The direction-finding unit (type A.D. 52) and the receiver (type A.D. 42) are mounted together to form a composite unit. The type A.D. 42 receiver incorporates a screen-grid high-frequency amplifying valve, a detector valve with reaction coupling and a pentode output valve.

The type A.D. 52/42 direction-finding receiver is designed to cover a wave-range of 500 to 1,000 metres (600–300 kcs.).

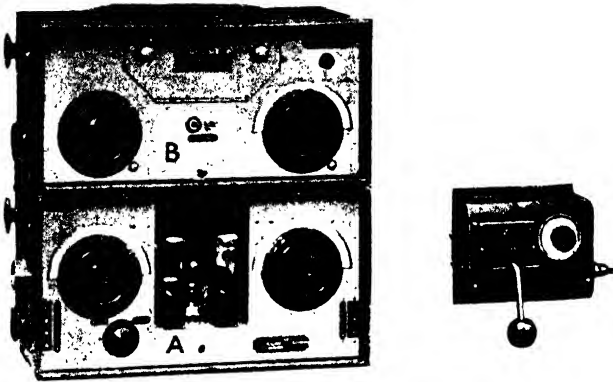


FIG. 111. MARCONI D.F. RECEIVER, TYPE A.D. 52/42

Marconi Aircraft D.F. Receiver Type A.D. 5062B, with Visual Indicator Type 626

The type A.D. 5062B direction-finding receiver is designed for use either as a separate receiving station in aircraft, or in conjunction with the medium wave Marconi aircraft transmitters, e.g. types A.D. 41, A.D. 49, in which cases it replaces the receivers type A.D. 42 and type 50 receivers normally used with those equipments.

The direction-finding receiver consists of the A.D. 50B receiver panel together with an A.D. 62B D.F. panel, mounted in one box as a complete unit, and used in conjunction with either a fixed or rotatable screened frame aerial and, if desired, the visual indicator type 626. The D.F. receiver can, therefore, be used either for aural working or for visual indicator working, in which latter case it becomes what is usually known as "a radio compass."

The provision of direction-finding facilities in no way interferes with the normal reception carried out on the trailing or fixed aerial, a change-over switch being provided for instantaneous switching to ordinary reception or to direction finding as required.

The wave-range covered by the receiver is 600–1,550 metres (500–193.5 kcs.) in two ranges of approximately 600–1,200 metres and 1,100–1,550 metres.

Two systems of direction-finding are available, namely—

(a) The fixed aerial "homing" system in which use is made of a single fixed screened frame aerial in conjunction with an open aerial (fixed or trailing as convenient), the open aerial coupling to the fixed frame aerial being reversed by a hand-operated switch mounted in the A.D. 62 panel.

(b) The rotatable frame aerial system, which enables bearings of a transmitter to be taken in the usual way, but which also retains the special features of the "homing" system.

Under normal conditions "off-course" indications can easily be detected at 3 degrees either side of true course. When using the frame aerial alone, on minimum signal, accuracies within ± 2 degrees are obtainable up to

150–200 miles (240–320 km.), depending upon the power of the transmitter and the absence of radio or other interference.

The approximate sensitivity of the whole receiver is such that an input of approximately 6 microvolts will give an output of 10 milliwatts. The receiver will give an output up to approximately 150 milliwatts without distortion.

The selectivity varies somewhat with the reaction adjustment, but when normally adjusted for telephony reception is such that the output is reduced by 35 db. when the receiver is 10 kcs. off tune.

The fixed aerial homing system is essentially a simple method which enables the pilot to set the course of his aircraft directly towards a known wireless transmitter on the ground. It is particularly suitable for use on aircraft where no special wireless operator and/or navigator is carried and where the aircraft flies mainly on routes possessing no direction-finding station on the ground, but where ground communication or beacon transmitters are situated along the route, e.g. at the various aerodromes.

In this system use is made of a single-screened frame aerial, installed on the fuselage of the aircraft so that its plane lies at right angles to the line of flight of the aircraft, in addition to the normal fixed or trailing aerial used for ordinary reception. The coupling between the frame and open aerial is reversed by means of a three-position switch and is adjusted by means of a variable resistance, both of which are mounted in the D.F. panel.

In the central position of the reversing switch the frame aerial alone is connected to the receiver. In the left-hand position both the frame aerial and the open aerial are in use, while in the right-hand position both the frame aerial and the open aerial are in use, but with the phase of the coupling of the open aerial reversed.

If the aircraft is flying head on towards the transmitting station, no E.M.F. is induced in the frame aerial, and only the signal due to the open aerial will be heard when both open aerial and frame aerial are connected. Further, under these conditions, no difference will be observed whether the switch is moved either to the left or right.

If, however, the aircraft is not flying head on towards the transmitting station, an E.M.F. depending on the angle of divergence will be induced in the frame aerial. Now, on moving the switch from side to side the resultant signal strength will be greater if the open aerial coupling is coupled one way than it will be if it is reversed. From these indications it can be determined whether the transmitting station lies to port or starboard of the line of flight of the aircraft. By suitably correcting the course until no difference of signal can be detected, whichever way the open aerial is connected, the aircraft will be automatically "homed" towards the transmitting station. The accuracy of the course can be checked by putting the switch in the central position (connecting only the frame aerial) when, if the course is correct, no signals at all will be heard.

The adjustable resistance enables the signal strength due to the open aerial to be made approximately equal to the signal strength due to the frame aerial, thus enabling the greatest accuracy to be obtained during operation.

The rotatable frame aerial system provides full direction-finding service in cases where an operator and/or navigator is carried on large civil, military, or naval aircraft, and is particularly useful when flying over territory where no direction-finding stations are available, or over sea. The system enables the aircraft to "home" on a transmitting station as described above, and in addition, provides convenient means whereby

bearings may be taken on stations which lie off the normal course of the aircraft and from which the position of the aircraft may be determined by plotting, in the usual way, the bearings of two or more stations on a chart.

In this system a small rotatable screened frame aerial (Fig. 110) is used instead of the fixed frame aerial. The frame aerial is mounted externally on the aircraft fuselage and is rotatable from inside the aircraft by means of a hand wheel. The rotating mechanism incorporates a clutch so arranged that the frame is automatically locked in the desired position when the hand wheel is released.

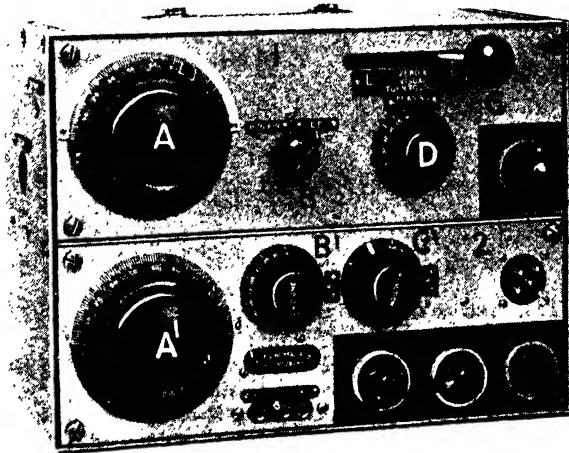


FIG. 112. MARCONI AIRCRAFT D.F. RECEIVER, TYPE A.D. 5062B

The method of taking bearings is similar to that already described under the "homing" system, so that if "homing" only is required it is only necessary to set the frame aerial at right angles to the line of flight of the aircraft, and to operate the reversing switch in the usual manner. In the case of bearings being taken on stations lying off the line of flight, the reversing switch is set in the central position and the frame rotated until no signal is heard from the transmitting station. The bearing of the desired station can then be read from a scale attached to the mechanism.

The indications for "homing" or for D.F. can be observed either aurally or, by the addition of an extra attachment, visually by means of a dashboard instrument (Fig. 113) which indicates by means of a needle the side off-course and also the true course to be flown. It is, therefore, possible once the aircraft has been set accurately on its course, for the pilot to fly to his destination using the dashboard instrument as a radio compass. When using the visual indicator, the hand-reversing switch is set in the middle position and a motor-driven reversing switch is used in its place.

THE FIXED FRAME AERIAL is a rigid screened frame which is mounted on the top of the fuselage or wherever convenient, at right angles to the line of flight of the aircraft.

THE ROTATABLE FRAME AERIAL is a rigid circular frame which is mounted outside the fuselage of the aircraft and operated from inside by means of a hand wheel. A drum and pointer indicates the angle at which the frame aerial is set in relation to the line of flight, and it is thus possible

to use the frame aerial for direction-finding purposes as well as for "homing." An automatic clutch in the frame mechanism locks the frame aerial in position as soon as rotation by hand is stopped.

The D.F. Receiver Type A.D. 5062B (Fig. 112)

This consists of a receiver panel and a D.F. panel in one box, the D.F. panel being in the upper compartment. The output from the frame aerial (fixed or rotatable), together with that from the open aerial (fixed or trailing), passes through a suitable transformer in the D.F. panel. The output side of this transformer is tuned and calibrated directly in metres, and forms the grid circuit of a H.F. pentode valve also carried on the panel.

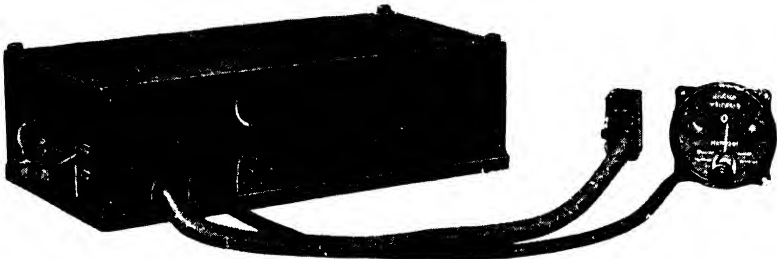


FIG. 113. ANODE CONVERTER VISUAL D.F. ATTACHMENT FOR USE WITH D.F. RECEIVER, TYPE A.D. 5062

On the panel are also mounted (a) a switch for reversing the phase of the coupling of the open aerial to the frame aerial, for giving off-course "homing" indications or for disconnecting it altogether if it is desired to use frame aerial D.F. reception or "homing" on the zero method, (b) an adjustable phasing resistance for adjusting the input from the open aerial, (c) a second switch which enables the operator to switch over from direction finding to normal reception on the open aerial. The D.F. panel also carries the waveband switch (2-way) and plugs and sockets for connecting to the frame aerial, to the open aerial, and to the receiver panel. The reversing switch is an integral part of the D.F. panel, and therefore no external hand-operated reversing switch is required.

The output of the D.F. panel passes to the receiver panel. This is a three-valve receiver using (a) a screened grid H.F. amplifier with tuned grid, (b) a detector with tuned grid and reaction, and (c) a three-electrode L.F. magnifier. The two tuned circuits are ganged to one dial which is calibrated directly in metres. C.W., I.C.W., or telephony can be received at will. A separate volume control is provided, and a two-way waveband switch is provided for selecting the waveband required.

THE VISUAL INDICATOR consists of a centre reading dashboard instrument, together with a rotating commutator reversing switch, which is driven either by a separate 12-volt motor or by the small anode converter which provides high-tension for reception. This switch reverses the open aerial coupling and also the input to the indicator, both reversals being in synchronism. If the visual indicator is in use, the hand-reversing switch on the D.F. panel should be set in the middle position, but if desired aural indications can be checked from time to time by operating the hand reversing switch without stopping the commutator switch. The addition of the visual indicator attachment turns the D.F. equipment into what is often known as a "radio compass."

The power supply is from the 12-volt accumulator belonging to the

aircraft. The low-tension filament supply is approximately 1.3 amperes at 12 volts and the high-tension supply is approximately 20 milliamperes at 200 volts. The high-tension is derived from an anode converter driven from the 12-volt accumulator and taking an input of approximately 2 amperes. The total load on the accumulator during reception is therefore

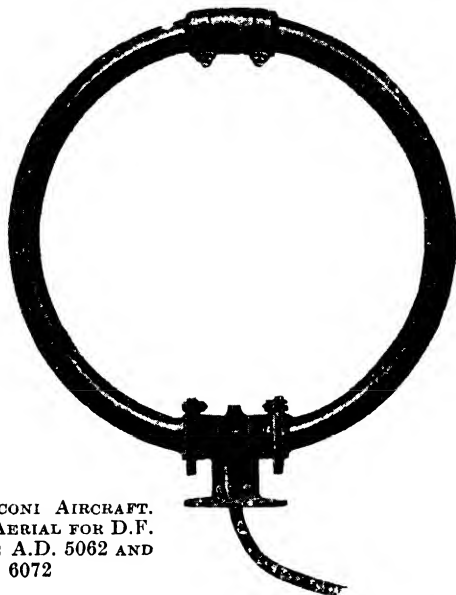


FIG. 114. MARCONI AIRCRAFT.
13" D.F. LOOP AERIAL FOR D.F.
RECEIVER TYPE A.D. 5062 AND
A.D. 6072

3.3 amperes. If the D.F. receiver is used in conjunction with a wind-driven generator powered transmitting equipment, the high-tension will of course be derived from the wind-driven generator instead of from the anode converter, and a separate 12-volt motor will be used for driving the visual indicator.

The approximate overall dimensions and weights of the various items of the equipment are as follows—

Receiver Type A.D. 5062B—

Height, 8½ in. (21.6 cm.)
Width, 11½ in. (29.2 cm.)
Depth, 6 in. (15.2 cm.)
Weight, 14 lb. (6.35 kg.)

Fixed Frame Aerial—

Overall diameter, 13 in. (33 cm.)
Overall height above fuselage, 14½ in. (37 cm.)
Weight, 3 lb. 4 oz. (1.46 kg.)

Rotatable Frame Aerial—

Overall diameter, 13 in. (33 cm.)
Overall height above fuselage, 16 in. (40.64 cm.)
Weight, 11 lb. (5 kg.)

Visual Indicator (Dashboard)—

Overall diameter, 3½ in. (9 cm.)
Weight, 1 lb. 1 oz. (0.45 kg.)
Depth of case behind panel, 1⅞ in. (3.65 cm.)
Overall depth behind panel including studs, 2½ in. (6.35 cm.)

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Visual D.F. Motor Switch Unit Type 626A—

Height, $4\frac{5}{8}$ in. (11.74 cm.)
 Width, 6 in. (15.2 cm.)
 Length, $12\frac{1}{4}$ in. (30.6 cm.)
 Weight, 10 lb. 10 oz. (4.75 kg.)

Visual D.F. Anode Convertor Switch Unit Type 626B—

Height, $4\frac{5}{8}$ in. (11.74 cm.)
 Width, 7 in. (17.78 cm.)
 Length, 15 in. (38.0 cm.)
 Weight, 16 lb. 14 oz. (7.64 kg.)

Trailing Aerial Equipment (Complete)—

Weight, 11 lb. (5 kg.)

Fixed Aerial Equipment (Complete)—

Weight, 4 lb. (1.8 kg.)

The total weight of the D.F. receiver complete is therefore approximately—

(a) with	{ rotatable frame aerial trailing aerial visual indicator type 626B }	. 57 lb. (26 kg.)
(b) with	{ rotatable frame aerial fixed aerial visual indicator type 626B }	. 50 lb. (22.7 kg.)
(c) with	{ fixed frame aerial instead of rotatable frame aerial these weights will be }	. 48 lb. (21.8 kg.) or 41 lb. (18.6 kg.) respectively.

The above weights do not include the weight of the 12-volt aircraft accumulator.

If this D.F. equipment is used in conjunction with a normal Marconi type A.D. 49/50 medium wave transmitting and receiving equipment, the A.D. 5062B D.F. receiver would replace the A.D. 50 receiver, and the power supply and open aerial would already be available in the aircraft. The addition of full D.F. with visual indication could therefore be made to the A.D. 49/50 equipment for an additional weight of approximately 30 lb. (13.6 kg.). If homing only is required, the additional weight is approximately 21 lb. (9.5 kg.).

4th Method. A new system of directional wireless communication with aircraft in flight, originally developed in Germany and now in the experimental stage in this country, appears to have achieved highly satisfactory results and to promise interesting and useful developments. This system, of which the pioneers are Lorenz and Telefunken, is in no sense a navigational system, but is one designed entirely with the object of enabling aircraft to make safe landings on aerodromes enveloped in more or less local fog. Two special extra short-wave receivers are required in the aircraft, in addition to one arranged to work on the ordinary wave-length. Three special extra short-wave ground transmitters complete the equipment. All tuning arrangements are fixed, and the sets are relatively simple and cheap.

The operation of the system is based on the phenomenon associated with ultra short waves of following a straight line, so that two stations which are not in sight of each other cannot communicate or interfere with each other. This fact, of course, permits stations separated by quite short distances—25 to 30 miles or so—to use identical equipment. At present a waveband of 7 to 20 metres is utilized for the new system, and when it is remembered that there is a difference of $4\frac{1}{2}$ million cycles between wave-lengths of 8 and 9 metres it will be appreciated that the risk of interference

is very small. The fact that these ultra short waves are reflected by the Heaviside Layer, and come down again to earth at great distances from the transmitter has no significance as far as the choice of these waves for the particular purpose in mind is concerned. The operation of the Lorenz and Telefunken systems in Germany, however, is accompanied by the formation of two approach paths to the aerodrome, one at 180° to the other, whilst the efforts of the Marconi Co., in this country, are directed towards the development of a similar system in general, but characterized by an elimination of back radiation and therefore the production of only a single path of approach to the aerodrome.

A fact which is vitally important to the successful operation of the system is the ease with which the "fields of strength" set up by the ultra short-wave transmitting aerial can be deformed to an accurate and controlled extent, by means of earthed reflectors, or by the earth itself.

In practice the three ground transmitters are located (a) at the far end of the best landing run for the particular aerodrome. This is the main transmitter and operates on 9 metres. It controls both vertical and horizontal navigation in approach and landing, (b) at the boundary of the aerodrome, on the line of approach. This transmitter operates on 7.9 metres and throws a vertical fan of signals upwards, designed to warn the pilot that he is crossing the boundary of the aerodrome, and (c) approximately two to three miles away from the boundary of the aerodrome, and on the line of approach.

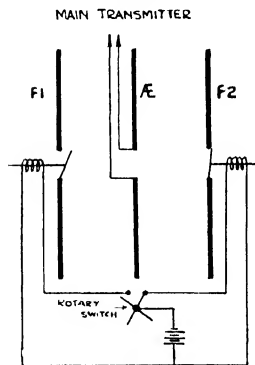


FIG. 115

These dummy aerials are also divided at their middles, but can be made electrically continuous by means of mechanically operated switches which short circuit the gap at the middle. With the switches closed, the dummy aerials act as "reflectors" or "field deformers," but with the switches open they have no effect (Fig. 115).

The purpose of the "field deformers" is so to distort the field as to produce in the aircraft a series of signals which indicate to the pilot his correct flight path.

The normal field of stress surrounding an aerial system consists of a series of concentric hemispheres having the ground line as a common diameter.

In Fig. 116 the dotted circle is the plan view of the field spreading out with equal strength from all round the aerial at *A*. The full line oval is the deformed field produced by the influence of the "field deformer" *F*.

In Fig. 117 the two ovals show the alternative positions taken up by the deformed field by using the "field deformers" at *F* 1 and *F* 2 alternatively. It will

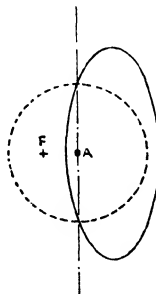


FIG. 116

be noted that the two deformations have certain common points at the

intersections of the loops. An observer stationed anywhere along the line joining these two points of intersection of the loops will receive signals with equal strength from either loop, but if he is placed to one side of the line he will receive signals from one loop with greater strength than he will receive those from the other loop. If the rotary time switch operating the switches at the mid points of the field deformers is so arranged that one deformer is in operation for an appreciably longer period than the other, an indication can be conveyed to the observer to tell him whether he is to the right or the left of the line. On the one side of it he will receive signals which are a series of dashes, whilst to the other side he will hear a series of dots. If placed on the line he will hear a continuous and uniform note, since the dots and dashes will merge to produce that result. (See Fig. 118.)

It should be noted that the loops are not true ovals, but are considerably flattened on their inner sides. This phenomenon ensures that the position of the path of equal strength—the landing path—is very clearly and accurately defined.

Having considered the deformed field in plan, it is necessary to consider it also in section.

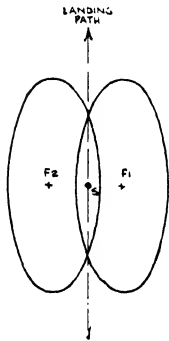


FIG. 117

Fig. 119 shows the shape of a vertical section of the deformed field as seen from one side of the path of approach.

It will be noted that whereas the field produced by medium wave-length emanations is roughly hemispherical, that produced by the ultra short waves chosen is repelled by the earth and results in the shape shown, which is a section in the plane of the landing path. The lower portion of this diagram is reproduced in Fig. 120, and the two subsidiary transmitters have been indicated. The aerials of these transmitters are arranged horizontally so that a broad flat fan of signals is thrown vertically into the air.

An aircraft approaching in fog at, say, 1,200 ft., picks up the first signals at about fifteen miles from the aerodrome, or at nearly forty miles if it is flying at 3,000 ft. The first signals are probably a series of

dots or a series of dashes and the pilot must turn to right or left until the signal note becomes continuous.

A dashboard instrument is provided, the needle of which deflects to right or left in response to the dots or dashes.

The pilot then turns in on the line of approach, keeps his craft on its course by maintaining a continuous signal note, or a steady needle in its vertical position, and maintains a steady height of approximately 1,500ft. This manoeuvre will settle him on his true approach course. As he passes through the field of the most distant ground transmitter a neon bulb in the cockpit is illuminated

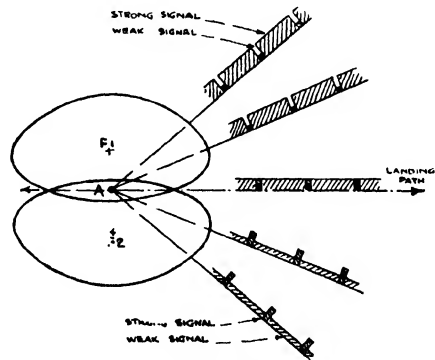


FIG. 118

for a second or two and indicates the exact distance of the aircraft from the boundary of the aerodrome, and that it is time to throttle back.

The aircraft is then put into a natural glide, and direction is maintained by the continuous signal from the main transmitter. At a later stage a

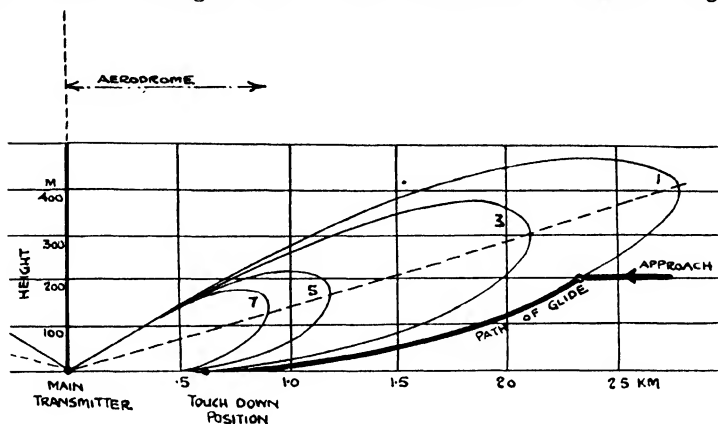


FIG. 119

second neon light is illuminated for a second or two and indicates that the aircraft is passing over the boundary of the aerodrome. The main transmitter provides for control of the glide in, including the holding off stage and the final touch down.

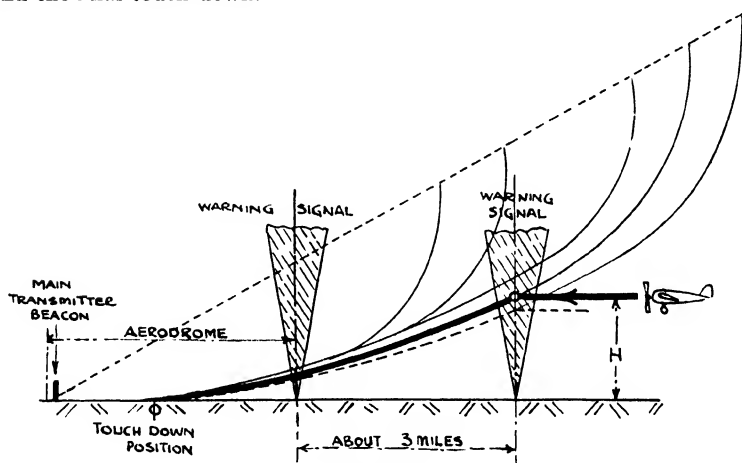


FIG. 120

It will be noted from Fig. 120 that the lines of equal field intensity are crowded close together at the aerial and gradually separate as they travel outwards. The pilot is also provided with a dashboard instrument which indicates the intensity of the field. During the time of approach this instrument will indicate a rapidly strengthening field, since the aircraft is cutting the lines of equal intensity and is approaching the centre

of disturbance. The moment the pilot sees the second neon lamp go out, however, he knows that he has arrived over the boundary of the aerodrome and by minor movements of the elevator he endeavours to keep the reading of this instrument at a constant value. In doing this he causes the aircraft to travel down the particular curved path which the machine picked up at the moment of final reading.

The shape of the distorted field is very similar to the ideal landing path of an aircraft and provides for the glide, holding off, and touch down. It also provides a wide range of paths to choose from, so that the characteristics of any particular machine can be easily catered for. Whilst all lines converge on the aerial, two lines which are only six inches apart over the aerodrome may be two to three thousand feet apart over the first approach beacon. An error of a few inches in height at the hold-off stage will show a violent deviation on the instrument.

The undermentioned types of direction-finding equipment are at present officially approved for use on civil aircraft.

DIRECTION-FINDING EQUIPMENT

Set	Type	D.F. Range in Metres
Marconi's Wireless Telegraph Co. Ltd.		
A.D.16	D.F. receiver	600-1,600
A.D.32A	D.F. attachment	500-1,000
A.D.32B	D.F. attachment	500-1,600
A.D.35A	D.F. receiver	550-1,550
A.D.52A	D.F. attachment	500-1,000
A.D.52B	D.F. attachment	500-1,600 (in two ranges)
A.D.52C	D.F. attachment	500-1,550
A.D.52D	D.F. attachment	500-1,550 (in two ranges)
A.D.5062A	D.F. receiver	600-1,200
A.D.5062B	D.F. receiver	600-1,550 (in two ranges)
A.D.5872A	D.F. receiver	600-2,000 (in two ranges)
A.D.5872B	D.F. receiver	600-2,000 (in two ranges)

BONDING

The close proximity to the radio installation of a high-tension ignition system results in severe electrical disturbances which must be eliminated before the operation of a sensitive receiving system can be made feasible. Furthermore, the vibration of various parts of the machine may be responsible for very troublesome electrical noises in the receiver unless proper precautions are taken. In order to avoid these difficulties it is necessary to resort to electrical bonding of the aeroplane and the complete electrical shielding of the wiring systems and electrical equipment.

Bonding designates the interconnection of all metal parts of the aeroplane in such a manner as to afford between such parts paths of small resistance to the flow of high frequency currents. Charges of atmospheric electricity tend to accumulate on metal parts which are separated from the frame of the machine by high resistance paths. If these paths vary in resistance due to vibration, rubbing, etc., the charges will flow off in an irregular manner, thereby setting up electrical disturbances. If the resistance of the paths is quite high, charges may accumulate until the potential of the isolated part becomes so high that a spark will jump to an adjacent conductor. This not only results in severe radio noise but

constitutes a serious fire hazard. Another point which must be taken into account is the fact that the metal framework of the machine is used as the "Ground" or counterpoise for the radio equipment. For this reason it is important to have this framework interconnected with all other parts of the plane so as to make this counterpoise as extensive as possible. Because of this feature it is necessary to furnish wooden planes with a metal network running through all parts of the machine. Wooden struts, long-erons, etc., are metallized by the use of metal strips fastened longitudinally along such parts and connected together to form a continuous network.

Wooden wings are metallized and bonded in the following manner. A metal strip $\frac{1}{4}$ in. \times $\frac{1}{64}$ in. or larger shall be fastened along the front and rear spars from fuselage to wing tips. These strips shall be interconnected to the "Earth," to the internal brace wires at each drag brace, to the external brace wires and fittings wherever these wires and fittings come into the wing, and to each other by similar strips which run from front to rear spars along each drag brace. The front and rear strips shall also be connected together at the wing tip. If the wing carries a metal leading edge the front metallized strips may be dispensed with and connection made to the edge. The same is true of any metal wires or sheets, in the trailing edge or other parts of the wing, which are of sufficient size to be used in place of the metallized strip. The metal shielding which covers any electrical wires in the wings such as landing light leads, etc., shall be earthed at least every 14 in. to 20 in. to the metallizing strips and at each drag brace.

Wherever control or brace wires, or other movable or semi-movable parts come into casual contact with each other, or with other metal parts of the plane, it is necessary either to furnish insulation at the point of uncertain contact or else to bond the parts together. Crossed wires may be insulated from each other by passing one wire through a hole at one side of a flat insulating washer and the other through a similar hole in the opposite side of the same washer. Small button or egg type insulators (such as micarta spacer wrapped with tape) may be used to hold the wires apart instead of the washer. This method of insulating the wires where they cross is to be preferred to bonding by means of a soldered lead as the flux used in soldering has a corrosive action.

It has been found that turnbuckles and tie rod terminals sometimes offer considerable resistance to the flow of high frequency currents. Such equipment should therefore be tested with the circuit tester described below and wherever a high resistance is found it should be by-passed by a copper bond.

A wooden fuselage is to be bonded and metallized as follows: A metal strip equivalent to that used in the wings is to be fastened along each longeron. This strip shall extend from the engine to the tail surface making good electrical contact with the engine base and with each metal part and fitting along its length, branch strips being used if necessary. These longeron strips must also be connected to the wing strips. All water, gasoline and oil lines should be earthed to the frame at frequent intervals. Rubber hose joints should be by-passed by copper braid bonds.

The metal hinges of rudder, elevators, ailerons, etc., must be bonded across and the control wires attached to such parts must be bonded to the hinges. The whole is to be connected to "Earth," which means making one electrical circuit of all metal parts.

The method generally used is to place braid about 2 in. wide on the control wires near the thimble and wrap with waxed and shellaced cord, then pigtail length of braid to an effective "earth" contact. If soldering

is attempted, it must be done with due care on account of possibility of weakening control wires.

In metal aeroplane metallizing strips are, of course, unnecessary, but it is quite essential that the various parts of the aeroplane be connected by low resistance paths and a certain amount of bonding will sometimes be required in order to achieve this. The resistance between metal parts which are in contact may be rendered high by a protective shellac or other coating or by oxide films. Contact surfaces between each of the parts should be scraped bright and clean and after having been forced into tight contact a new protective coating applied along the outside of the joint. Wherever there is any uncertainty as to a satisfactory connection at a contact it should be by-passed by a copper bond. Parts that are welded together need no attention as welded joints are of low resistance. Lighting wires which are shielded should be bonded every 14 in. to 20 in.

The final test of the efficacy of bonding and shielding together can be made only by noting in the receiver the degree of electrical noise with the machine in actual flight. However, for purposes of maintenance, inspection, and fault finding, it will be quite helpful to employ tests as follows: A circuit tester consisting of a battery, ammeter and series resistance, adjusted to carry 2 amperes at least, is used to determine whether there is a low direct current resistance between adjacent parts. Contact is conveniently made to the parts by the use of stout, sharp pointed electrodes. When one electrode is placed on either side of a joint, the ammeter should read at least 2 amperes. If the reading is irregular or absent it is a sure indication that the resistance of a joint is too high. Head telephones are not to be used in making tests of this type. All bonding and joints throughout the metal framework of the plane should be tested in this way.

Shielding

Whenever a spark discharge occurs in an electrical circuit, high frequency oscillations are set up and create an electro-magnetic effect which is appreciable at some distance from the circuit. If the discharge is highly damped as in the case of spark ignition circuits, the oscillations involve a very wide range of frequencies and a tuned radio receiving set will pick out and amplify those frequencies to which it is resonant. Consequently the ignition circuit can be responsible for a prohibitive amount of noise in the receivers. In order to eliminate this it is necessary to completely enclose the high-tension circuit in a continuous metal sheath, or shielding, which makes good contact with the aeroplane frame at points 14 in. to 20 in. apart. When such a shield is properly installed, the electro-magnetic effect of the oscillations is practically eliminated from the space outside of the sheath.

The low-tension wire systems on the plane may also be responsible for radio noise. Radio frequency interference from sparks at the commutator of the generator may be transmitted along the low-tension systems and unless the wires of this system are effectively shielded, this interference will be audible in the receiver. Furthermore, unshielded lighting and instrument wires may pick up high frequency energy from the ignition or generator circuit due to the fact that the shielding of these circuits is never perfect. This energy is then distributed over the whole low-tension wiring system and may cause serious trouble. Consequently, the only satisfactory practice is to completely shield *all* wires on the machine. In addition a 4 mf. condenser across the regulator and also a tin cover for the generator field lead on the voltage regulator will eliminate noise from these sources.

The high-tension system is shielded as follows—

The magnetos are to be completely enclosed in metal housings. The majority of magnetos on the market have metal housings with openings in them which may or may not be covered by insulating material such as bakelite plugs. In such cases it is necessary, and usually sufficient, to cover the openings with sheet metal so formed as to make firm contact with the housing at several points. One company has developed a completely shielded magneto especially designed to eliminate the disturbances arising inside the magneto housing and to facilitate the earthing to this housing of the shielding on the leads. These magnetos are now available

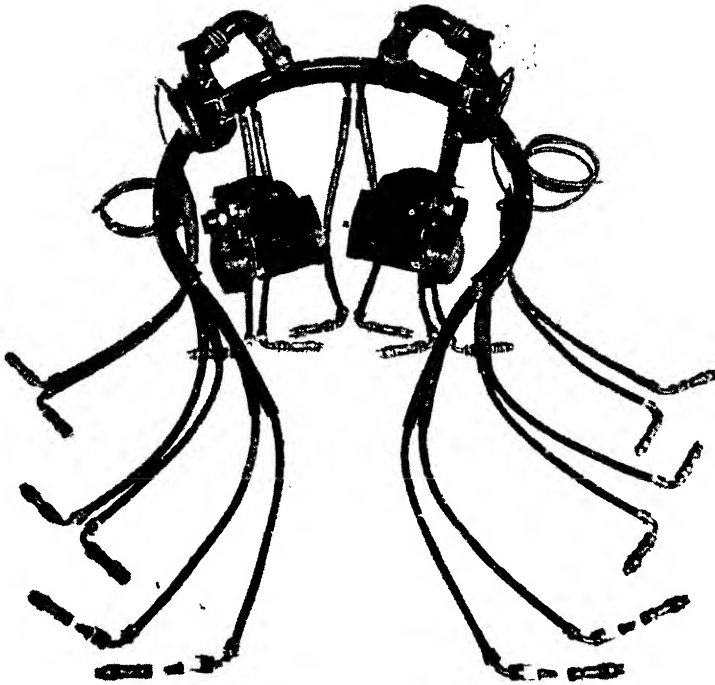


FIG. 121. SHIELDED MAGNETOS AND IGNITION LEAD HARNESS

to the public. This company also furnishes tins to be used with the semi-shielded magnetos.

The leads from the magnetos are to be enclosed in a continuous metal sheath. These are now made available by manufacturers in the form of ignition harnesses, provided with woven shielded auxiliary leads which may be used on various types of motors. (Fig. 121.)

There are available complete ignition harnesses which are encased in flexible braid. If such a harness is employed, it is advisable to run it through a pipe manifold because of the increased mechanical protection. In such a case it is not necessary to solder the braid to the pipe since the braid sheath is continuous. There has recently been placed on the market

a shielded high-tension cable which enables those familiar with the requirements of adequate ignition shielding to construct their own ignition harness.

Where the wires emerge from the magneto housings the braid shielding is to be fastened to the housings at the point of entrance. Frequently such leads emerge through an insulating block and, as mentioned above, this block should be covered with a sheet metal cover. It is advisable to solder the braid to this cover all round the hole through which the wires emerge.

The braiding or pipe should make contact with the engine metal at as many points as may be convenient. Contact is to be made by short pigtailed wires which are bolted or soldered to the framework of the engine. Unless such pigtailed wires have been woven as an integral part of the braid, they must be soldered to the shielding. Great care should be taken not to injure the insulation of the wiring either by heat or by the corrosive action of soldering flux. An alternative to soldering a connection to the shielding is to lay the pigtail or wire along the shield and wrap tightly with No. 20 bare soft copper wire.

The origin of the most severe disturbances due to the ignition circuits is at the spark plug itself, and it is quite essential that this plug be shielded completely. Make-shift attempts at shielding of this part may result in incomplete elimination of interference, in overheating of the plugs, short-circuiting the ignition system and general unsatisfactory operation. Shielded plugs have been designed especially for use on radio equipped aircraft and these have proved satisfactory through an extended period of operation on many leading airlines. For those operators who prefer to use a standard unshielded plug, there are available many styles of shielded covers for plugs which have been designed to effectively suppress interferences arising from the plugs.

As has been stated above, it is quite essential to enclose all low-tension wires in braided cable. The battery itself must be enclosed in a metal box, if required by the regulations, this box being earthed by short leads to the frame of the aircraft. All braiding should be run as close to the terminals of the wires as is possible without creating the danger of a short-circuit. Earth connections should be made as near to all terminals as may be consistent with minimum length of ground leads. It is also necessary to earth the shielding to metallizing strips or to the "Earth" at intervals of 14 in. to 20 in.

A bonding strip must be installed along the back of the instrument board. This strip is to be connected to each longeron, in a metal plane, or to the longeron bonding strips in a wooden plane. The metal cases of all instruments on the board are to be connected to the bonding strip. The metallic lines, tubes and wire shielding shall also be connected to this strip and such lines, etc., shall be earthed at intervals of 14 in. to 20 in. It is also desirable that metal covers be provided for all switches and instruments connected in the low voltage circuits.

If a metal instrument board is used, the bonding strip may be dispensed with. The board is connected to the longeron bonding system and the various connections mentioned above are made to the board. Care must be taken to see that all contacts at the connections are clean and firm.

The majority of engines used at present are fired by magneto ignition systems to which the above directions specifically apply. With installations employing coil ignition it is advisable to follow the same general principles and shield *all* wiring present. It is sometimes believed that this is not necessary, but unless complete shielding is used it will often be found impossible to obtain satisfactory reception with a high gain receiver.

The efficacy of shielding can be determined only by operating the radio

receiver with the aeroplane in flight. In many cases proper shielding will completely eliminate electrical noise from the receiving set, but in no case should there be a residual noise greater than a very faint hum in the telephones. The test should be made under the following conditions.

(1) Both the receiver and the transmitter of the radio set shall be completely installed and connected up.

(2) The aeroplane shall be in flight, the engine running at cruising speed.

(3) The receiver shall be adjusted for maximum gain and tuned for maximum response to a weak incoming signal.

(4) The main L.T. switch to the wireless shall be in the "On" position.

(5) Both ignition switches shall be on.

(6) All other electrical equipment of the aeroplane shall be operating.

There have been no methods devised for predetermining the efficiency of the shielding. Preliminary checks may be made while the engine is running on the ground. It will be noted in many cases that the disturbance is very loud on the ground, due to the vibration of the aeroplane, but becomes negligible in actual flight. The best assurance that the shielding will function properly is obtained by meeting the following three requirements—

(1) All electrical apparatus and conductors must be shielded.

(2) All shielding must be earthed at frequent intervals.

(3) All contacts between metal parts of the machine must be extremely low in resistance.

The bonding and shielding require frequent inspection in order to ensure that the numerous contacts and connections are in good condition. Because of the constant vibration, broken leads and open earth connections are likely to be of common occurrence. It often happens that a single open circuit or high resistance may be responsible for loud noises in the radio receiver. The tracing down of such trouble usually requires a considerable amount of care and patience and involves systematic checking of the bonding and shielding throughout the machine. The details of this check will, of course, vary somewhat with the aeroplanes and installations under consideration, but the procedure should be such as to ascertain whether the fundamental requirements outlined in the foregoing specifications have been fulfilled.

A regularly made inspection of the electric cables, bonding and earth connections in the aeroplane will minimize the possibility of circuit trouble due to loose contacts or broken leads. Poor earth connections reduce the effectiveness of shielding and are the cause of the greatest part of noise interference. Both the ignition system and lighting circuits in the aeroplane as well as all circuits associated with the radio equipment should receive careful attention in this respect. A gradual increase of noise level from day to day can be almost always attributed directly or indirectly to some defect of this nature in the shielding system.

Frequently the source of this noise can be located by means of a small antenna used in conjunction with one of the radio receivers. Such an antenna consists of a length of flexible wire shielded its entire length except for a distance of approximately a foot at one end. The opposite end is connected to the input of the radio receiver and the shield at this end earthed to the receiver mounting. By probing with the unshielded portion of the wire the source of disturbance can frequently be localized.

It should be made certain that the following conditions are fulfilled—

(1) The bonding must be adequate.

(a) The resistance of all joints between metal parts and across bonds should be checked with a circuit tester.

(b) See that all hinges, brace wire and control wire terminals, turn-buckles, etc., are properly by-passed by bonds.

(c) The leads which bond isolated parts to the frame must be as short as possible.

(d) All pipe lines, instrument cases, shielding, oil and petrol tanks, conduit, etc., must be earthed by leads which are as short as possible and extended conductors, such as shields, etc., must be earthed at intervals of not more than 14 in. to 20 in. If there is any possibility of trouble due to inadequate earthing, add additional bonding and see if improvement results.

(2) The shielding must be complete.

(a) See that all wiring is shielded and that the shielding is free from high resistance joints. At the terminals of wires the shielding is to be brought as close to the end of the conductors as is consistent with safety. Where a wire passes through a metal surface the shield must be bonded to that surface all around the hole through which the wire passes, or be thoroughly insulated from this surface.

(b) See that adequately shielded spark plugs are used and that the braid covering the high-tension leads makes good contact with the metal shield on the plug.

(3) There must be no accidental contacts between sliding or vibrating parts. See that all such parts are either insulated at point of contact or are properly bonded.

CONCLUSIONS

In conclusion, it is desirable to utter a word of warning in connection with the installation of electrical and/or wireless installations in aircraft, or the incorporation of modifications of these systems, since such action might invalidate the aircraft's Certificate of Airworthiness. The following official requirements must be borne in mind—

1. All wireless apparatus and accessories used on aircraft must be approved as regards design.

2. All wireless apparatus and accessories installed in aircraft must be certified (release note) as being constructed and tested in accordance with approved designs.

3. The installation drawings, showing the position and methods of installation of each piece of apparatus and of the wiring in the aircraft, must be similarly approved.

4. Installation work, or work in connection with the modification of an installation, and the inspection and testing thereof, must be carried out by, or under the direct supervision of, a duly qualified ground engineer, or contractor officially approved for such work.

5. The necessary log book entries are made and certified, and any necessary action taken to obtain an official amendment of the aircraft's current Certificate of Airworthiness.

In connection with the above, it may be of interest to note that direct application to the Air Ministry for approval of electrical and wireless apparatus and accessories, or of proposed installations, or modification of existing installations, is not always necessary before proceeding with the work, since the Ministry is prepared to accept certificates by duly authorized representatives of certain firms who have been officially approved for the design of apparatus, design of installation, work of installation, or the inspection and test of installation.

Finally, special attention is directed to the requirements of the following Air Ministry Notices to Aircraft Owners and Ground Engineers—

No. 35 of 1936: “Airworthiness Approval Procedure for Instruments and Equipment.”

No. 9 of 1937: “Civil Specification Memorandum No. 4—Lists of Approved Firms.”

No. 6 of 1939: “Approval of Radio Communication Apparatus and its Installation in Aircraft.”

No. 7 of 1939: “Ground Engineers Licensed in Category ‘A’—Duties as Regards Compasses, Turn Indicators, and Electrical Services.”

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