

SECTION 6, CHAPTER 7

IGNITION

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Introduction

1. All internal combustion engines, other than those of compression-ignition (Diesel) type, are dependent on electrical ignition systems. Such engines are widely referred to as spark ignition types, because the charges of fuel vapour/air which are induced into and compressed in the cylinders are ignited through the medium of sparks produced by electric discharges across the gap between

the electrodes of a spark plug fitted in each cylinder. Thus a continuous series of high-voltage electrical impulses, separated by intervals which are related to engine speed, must be made available to each of the spark plugs throughout the period that the engine is running.

2. Ignition systems for spark ignition engines fall into one or the other of two main

categories, viz. coil ignition, and magneto ignition. The former derives its power from an external source, a battery; the magneto, on the other hand, is a self-contained unit in which power is derived from its own built-in generator. Notwithstanding practical differences in construction, etc., both forms of ignition operate on similar basic principles.

Ignition Voltages

3. The voltage required to produce a spark across a plug gap is influenced by the width of the gap and the pressure inside the cylinder towards the end of the compression stroke. Even under the most favourable conditions this voltage must have a peak value of about 4 kV, while voltages of the order of 10 kV may be required in adverse circumstances. The ignition equipment must, therefore, include a device which is capable of converting a low-voltage supply, such as may be obtained from a battery or a generator, into a high-voltage supply. An induction coil is such a device and its basic principles are applicable to both coil ignition systems and magnetos.

The Induction Coil

4. An induction coil, as shown in Fig. 1, is in effect a step-up auto-transformer with self-operated interrupter contacts in series with the primary coil: the low voltage d.c. input is applied to the primary coil through the normally-closed contacts, while the free end of the secondary coil is connected to the centre terminal of the spark plug. On completing the input circuit, the current which flows through the primary coil and the closed contacts magnetizes the soft-iron core; thus the armature is attracted to the core and the contacts are opened, so interrupting the primary circuit. As primary current ceases to flow, the core loses its magnetism and is no longer able to retain the armature against the pull of the contact spring; the contacts close again, and the cycle of operations continues automatically while the supply remains connected to the input terminals.

5. When the core is magnetized, each turn of the winding encircles the magnetic flux present in the core, thus creating "flux linkages", the total number of which is equal to the product of the number of turns in the winding and the number of lines of

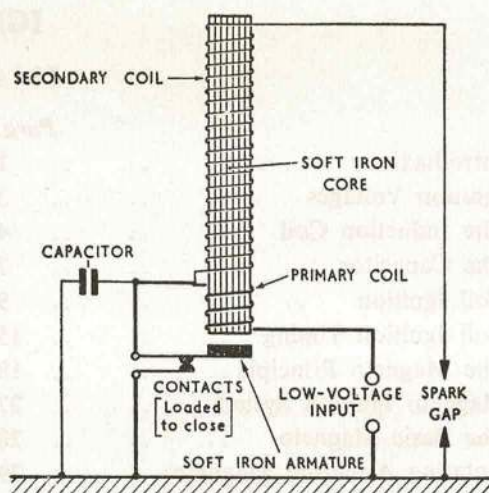


Fig. 1. ELEMENTS OF INDUCTION COIL

force present in the core. According to Faraday's Law, an e.m.f. is induced in a circuit whenever a magnetic flux associated or linked with the circuit undergoes a change, and the magnitude of the induced e.m.f. is proportional to the *rate of change* of the number of flux linkages. Furthermore, the ultimate effect of an induced e.m.f., when associated with current, is to oppose the change of flux that is responsible for its creation (Lenz's Law). Since a change in core magnetization is initiated each time the contacts open or close, it follows that an e.m.f. is induced in the winding during the period immediately following each contact operation. Since the induction coil winding and the input supply source are connected in series to the two sides of the spark gap, the voltage applied to the spark gap is the algebraic sum of input voltage and induced e.m.f.; if the induced e.m.f. is sufficiently high then the voltage applied to the spark gap may well be of the magnitude required to cause arc-discharge across the gap.

6. To appreciate the effectiveness of the induction coil as a means of procuring high-voltage short-duration impulses from a low-voltage constant-current source, let us take a hypothetical but fairly typical example, in which the full winding of the unit consists of 12,000 turns and the current through the primary portion, when this is connected to a 12-volt d.c. supply, attains a maximum value which is sufficient to create a total

flux through the iron core of 6,000 lines. The total number of flux linkages immediately preceding the opening of the contacts is thus $12,000 \times 6,000 = 72,000,000$ or 72×10^9 . If on opening the contacts the flux collapses to zero in 0.0001 second (i.e. 10^{-4} sec.), then the average rate of change in the number of flux linkages during this period is 72×10^{10} linkages per second. A change rate of 10^8 linkages per second gives an induced e.m.f. of one volt; the average e.m.f. induced in the winding during the collapse period (which is, of course, the duration of the output impulse) is thus $72 \times 10^2 = 7,200$ volts—the peak e.m.f. will be considerably higher since the initial rate of field collapse is likely to be considerably greater than the average rate. An e.m.f. will also be induced in the winding during the period of remagnetization that occurs as the contacts close again, but in this case the e.m.f. induced in the primary portion of the winding opposes the build-up of current—remagnetization of the core will probably take about 0.002 sec. (2×10^{-3} sec.), and the average e.m.f. induced in the winding during this period will be of the order of 350 volts.

The Capacitor

7. The very fast rate of flux-collapse that is needed to procure an e.m.f. such as that quoted in para. 6 cannot be achieved simply by opening the contacts in the primary circuit and relying on the natural process of flux "decay" as the magnetizing force (the primary current) is removed: the core must be forcibly demagnetized by passing current through the primary coil in the reverse direction. This is the function of the **capacitor**, often referred to as a condenser, which is shown connected across the contacts in Fig. 1.

8. The capacitor, which is short-circuited and is therefore in an uncharged state when the contacts are closed, acts as a reservoir for the primary current when the contacts open, thus diverting this current from the contacts and so preventing the formation of an arc between the contact faces. The primary current may now be regarded as a capacitor charging current, although it still exerts a magnetizing effect on the iron core. Since a charging current declines as the p.d. between the capacitor plates rises, the opening of the contacts is immediately followed by a reduction in core flux, and an

e.m.f. which is thus induced in the primary portion of the winding is superimposed on the input voltage to continue the charging of the capacitor and increase the capacitor p.d. The induced e.m.f. declines as the rate of charging decreases, and eventually a point is reached where the p.d. of the charged capacitor overpowers the voltage opposing it; the capacitor then discharges itself by sending a current through the primary portion of the winding, thus producing very rapid and complete suppression, or even reversal, of the core flux. From the foregoing explanation of the capacitor's functions it will be appreciated that this component is not in any sense a "frill" which, as is often quoted, merely prevents undue sparking at the contacts; it is an integral part of the ignition device, and it is no exaggeration to say that without it electrical ignition would not be practicable.

Coil Ignition

9. In spark-ignition type engines a spark must be developed across the gap of each plug at the precise instant when the piston associated with that plug reaches the firing point in the operating cycle. Since spark-production coincides with the opening of the primary circuit, the magnetically-operated contacts of the induction coil must be replaced by mechanically-operated contacts which open each time a piston reaches the firing position. Such a switch-unit is termed a **contact-breaker**; it consists in principle of a pair of contacts, spring-loaded to close, and an operating cam which is driven at a speed proportional to that of the engine. Furthermore, the impulses which are developed each time the contact-breaker "points" separate must be applied in the correct sequence to the individual spark plugs of a multi-cylinder engine. This is achieved by connecting each plug in turn to the free end of the secondary through a rotary switch known as a **distributor**; in the four-stroke cycle each cylinder requires one spark in every two complete revolutions of the engine, hence the distributor must be driven at half engine speed.

10. Since both the contact-breaker and the distributor are required to operate at a proportion of engine speed, it is obviously advantageous to utilize the same drive for both components and to employ a contact-breaker cam of suitable contour for the

particular engine—for example, the cam for a six-cylinder engine could be given six lobes and be driven at half engine speed to produce the required three sparks per engine revolution, thus enabling the distributor to be driven from the same shaft. It is usual therefore to manufacture the contact-breaker and distributor in one unit, and to drive this unit from the camshaft which is, of course, driven at half engine speed.

11. An induction coil from which the armature and contacts have been removed is in effect an auto-transformer, but by common usage it is known as an ignition coil. An ignition system comprising an ignition coil, a capacitor, a contact-breaker and distributor, together with the necessary spark plugs, high-tension cables and low-tension wiring, and which obtains its power from a battery, is generally referred to as a coil ignition system—the basic circuit of such a system is shown in Fig. 2.

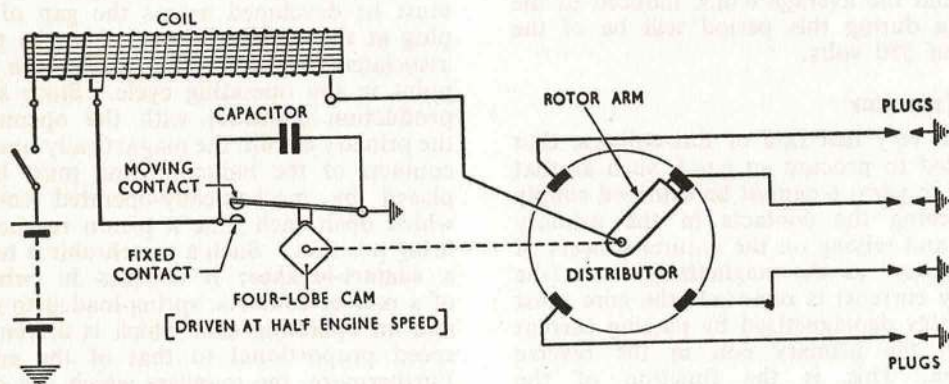


Fig. 2. BASIC CIRCUIT OF COIL IGNITION SYSTEM FOR FOUR CYLINDER ENGINE

12. A coil ignition system possesses the advantages of being fairly cheap in first cost, of requiring relatively little skilled servicing, and of giving a good spark (for easy starting) when the engine is being turned slowly. It has however very definite limitations at the higher end of the speed range, where the primary current has little time during the contacts-closed period in which to build up to the value needed for procuring a high induced e.m.f. in the coil, and its reliability, although generally of a high standard, must inevitably be influenced by the state of the battery. Nevertheless, the balance between these various factors is

such that coil ignition is easily the most widely used system on spark ignition engines.

13. **Operation.** With the ignition switched on and the points of the contact-breaker closed, a complete low tension circuit is made. When the points are opened by the cam, the low tension circuit is broken and a high voltage is induced in the secondary winding which is transmitted from the coil via the rotor arm and distributor cap electrode to a sparking plug. When the contact-breaker points are fully open the rotor arm is opposite a particular electrode. Further rotation of the cam will again close and open the contact-breaker points, and the rotor arm will be opposite the next electrode which is connected to a sparking plug in conformity with the engine firing order. It is important that the gap between the fully opened points of a contact-breaker for a coil ignition system should be 0.012 in. to 0.015 in., or as per the maker's instructions.

14. **Ignition Advance and Retard.** Provision is made to automatically advance and retard the ignition as required while an engine is running, i.e., although an engine is timed at top dead centre with the ignition fully retarded, the ignition timing will be varied according to the engine running conditions. This is necessary because the combustion of the gasoline/air mixture in a cylinder of an internal combustion engine is not instantaneous; therefore, in order to obtain peak pressure (complete combustion) just as the piston is about to descend on the power stroke, the faster an engine runs the earlier will have to be the ignition point.

Automatic advance and retard is effected by one or both of the following methods:—

(a) By centrifugal governor mechanism attached to the distributor shaft. The action is based on the centrifugal effect of two small weights which are flung outwards as the speed of the engine increases. An arrangement of levers transfers this movement to the cam which is also coupled to the rotor arm; this slight movement in the direction of rotation of the shaft, advances the ignition.

(b) By a vacuum control connected to the induction system. This consists of a small circular "metal pressing" in which a flexible diaphragm is contained. One side of the diaphragm is mechanically connected by a short rod to a bracket clamped round the distributor body (Fig. 3). The other side forms a chamber from which runs a narrow bore tube to the induction manifold. When the engine is running the depression in the manifold is felt along the tube and so into the chamber; this distends the diaphragm, causing the control rod to pull the distributor body round to an advanced position. The centrifugal governor adjusts the ignition according to engine speed whereas the vacuum control adjusts the timing according to the engine load, i.e., throttle opening.

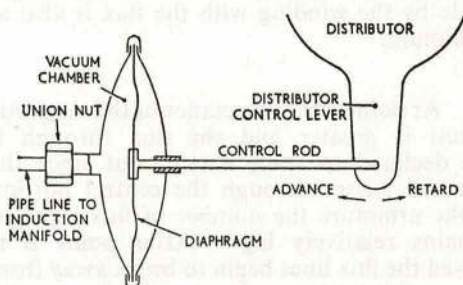


Fig. 3. VACUUM CONTROL

Coil Ignition Timing

15. General. The purpose of timing the ignition is to ensure that the spark for igniting the compressed gasoline/air mixture occurs at the required moment to give maximum power. Definite and precise timing data is peculiar to each type of engine, and it is essential that the manufacturers' instructions are followed. However, as an example, if the firing order of a 4-cylinder

engine is 1,3,4,2, and the timing is at T.D.C. with the ignition fully retarded, the following routine would be carried out.

16. Engine Setting.

(a) Remove the valve cover, turn the engine until the inlet valve of No. 1 cylinder closes and continue turning until the firing mark or T.D.C. is in line with the pointer.

(b) Recheck; piston of No. 1 cylinder is now at T.D.C. compression stroke and about to start the power stroke.

17. Distributor Unit Setting.

(a) Remove the distributor cover and ascertain the direction of shaft rotation.

(b) Check the contact-breaker gap and adjust, when fully open, to the maker's recommendation.

(c) Turn the distributor shaft until the rotor is pointing towards the front of the engine and assemble the distributor unit to the engine, ensuring that the dog or gear is correctly meshed. On some engines it is also very important to note that the distributor drive also meshes correctly with the oil pump.

(d) With the distributor clamping bolt loose, the body can now be turned either way.

(e) Turn the distributor body against the direction of rotation until the contact-breaker points are just about to open; tighten the clamping bolt.

(f) Temporarily fit the distributor cover; remove the cover noting which segment the rotor arm is pointing to; connect this segment to No. 1 spark plug. Connect the remainder of the leads in the firing order in the D.O.R. of the rotor.

(g) Turn the engine and check; start the engine. Slight adjustment may be necessary and this can be obtained by loosening the clamping bolt and moving the distributor body in the D.O.R. of the rotor to retard and vice versa.

The Magneto Principle

18. The two major short-comings of coil ignition, viz. decreasing effectiveness at high speeds and reliance on an external source of electrical energy, are avoided in magneto ignition. The magneto is a self-contained

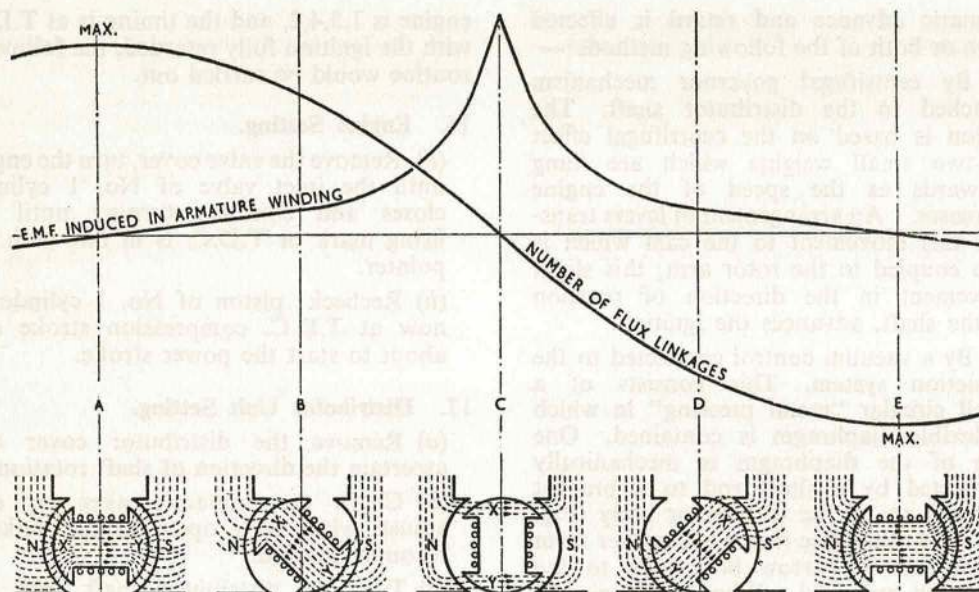


Fig. 4. FLUX- AND E.M.F.-VARIATION IN H-TYPE ROTATING-ARMATURE P-M GENERATOR
(Single-coil Open-current Winding)

unit in which the requisite energy for spark production is derived from an integral permanent-magnet generator; all other operative components such as the transformer system, contact-breaker, capacitor and (in most cases) distributor are incorporated in the one instrument. The general principle of producing a high-voltage electrical impulse by procuring the sudden collapse of a strong magnetic field, which links with the turns of a winding, is utilized in magneto ignition as in coil ignition, but the method by which this is achieved is noticeably different in the two systems.

19. The ideal ignition impulse has a voltage wave-form which consists of a series of sharp peaks of very brief duration and separated by much longer intervals of near-zero voltage. Impulses having a wave-form that is a fair approximation of this requirement can be produced by a rather unconventional form of permanent-magnet generator, in which the rotating armature core is of H-section and the armature winding is disposed round the central portion of the core as shown in Fig. 4.

20. If it is assumed that the winding is on open circuit the magnetic flux due to the permanent magnet field system will be at

a maximum in position A, since in this position of the armature the reluctance of the magnetic circuit is a minimum; moreover, virtually the whole of the flux passes through the central portion of the armature core and is thus encircled by the armature winding, consequently the number of linkages made by the winding with the flux is also at maximum.

21. At point B the reluctance of the magnetic circuit is greater and the flux through it has declined to some extent, but since the flux still passes through the central portion of the armature the number of flux linkages remains relatively high. After point B is passed the flux lines begin to break away from the core at an increasing rate until, at point C, the flux is at a minimum: furthermore, such lines as continue through the core now take the short paths through the end portions—in this position the number of flux linkages made by the winding is virtually zero. At point D the flux has increased and again flows through the central portion of the armature core, giving roughly the same number of flux linkages as at point B, but the flux direction, relative to the armature winding, is reversed: the flux conditions at point E are as at point A, i.e. the total flux

and the number of flux linkages are again at maximum.

22. The variation in the number of flux linkages made with the armature winding, and the resulting e.m.f. induced in the winding during 180° of armature rotation is shown by the two curves of the diagram. At point A the number of linkages is at a maximum and unchanging; there is therefore no e.m.f. induced in the winding at this point. As the armature moves away from position A the number of flux linkages begins to decrease. If the armature is turning at a constant speed the rate of change in the number of linkages will be very small at first, giving rise to a correspondingly small induced e.m.f. in the winding, but it will increase progressively until, at point C, the rate of change is at a maximum as the flux changes direction relative to the armature winding, and the e.m.f. induced in the winding likewise rises sharply to peak value at this point. Beyond this point the change in the number of flux linkages becomes progressively more gradual until, at point E, there is no change when the flux has again reached maximum; the e.m.f. induced during this period thus declines, rapidly at first and then progressively more slowly until it falls to zero at point E. If armature rotation is continued through a further 180° the cycle of induced e.m.f. will naturally be repeated, although the second peak of e.m.f. will be of opposite sign to the first—it will, however, be of comparable magnitude and will therefore be just as efficient as a means of spark production.

23. Although a very high e.m.f. could be induced in the manner just described, an abnormally large number of turns in the armature winding would be required to give voltage peaks that are capable of producing sparks at fairly low speeds. Also, the rise in voltage is not rapid enough for practical ignition systems, and the instant at which this rise occurs is largely a matter of chance. These defects can be eliminated by modifying the armature winding to include a second (primary) coil of low resistance and relatively few turns, in addition to the original (secondary) high-resistance coil of many turns, so that the complete armature unit becomes, in effect, an auto-transformer. The primary is short-circuited periodically through the points of a contact-

breaker, the operation of which is controlled by the armature shaft, and a capacitor is connected across the contact-breaker points to speed up the reversal of flux through the armature core and to minimize arcing between the contact faces. With this arrangement, the flux through the armature core links with the turns of the primary coil just as it does with the turns of the original (secondary) coil. If the primary circuit is kept continuously on open circuit, then the e.m.f. induced in the secondary by armature rotation will remain as described in para. 22, and an e.m.f. of similar wave-form, but of much lower peak value, will also be induced in the primary.

24. Provision is made for closing the contact-breaker points when the armature reaches a position where open-circuit e.m.f. is zero (A in Fig. 5), and the points remain closed until just after the position of maximum e.m.f. (open-circuit) has been passed, i.e. at C. During the period that the primary is short-circuited through the contact-breaker points, the e.m.f. induced in it gives rise to a primary current which, in accordance with Lenz's Law, has a magnetic effect which opposes the change in flux responsible for the creation of the e.m.f.—in other words, the primary current tends to sustain the flux through the central portion of the armature core while the latter rotates through rather more than 90° , with the result that the number of flux linkages made with the complete armature winding at position C is very little less than at position A. The rate of change over this period is thus very small, and the e.m.f. developed in the winding as a whole is, consequently, almost negligible—even so, the almost minute e.m.f. in the primary is still able to support a fairly substantial primary current because of the extremely low resistance of the short-circuited primary.

25. The distribution of flux at C is completely artificial and is attributable to the effect of the primary current. When this current is interrupted by the opening of the contact-breaker points, flux distribution immediately reverts to that obtaining in corresponding open-circuit conditions, as indicated in the previous diagram; i.e. the flux through the central portion of the armature core immediately collapses and is re-established in the opposite direction

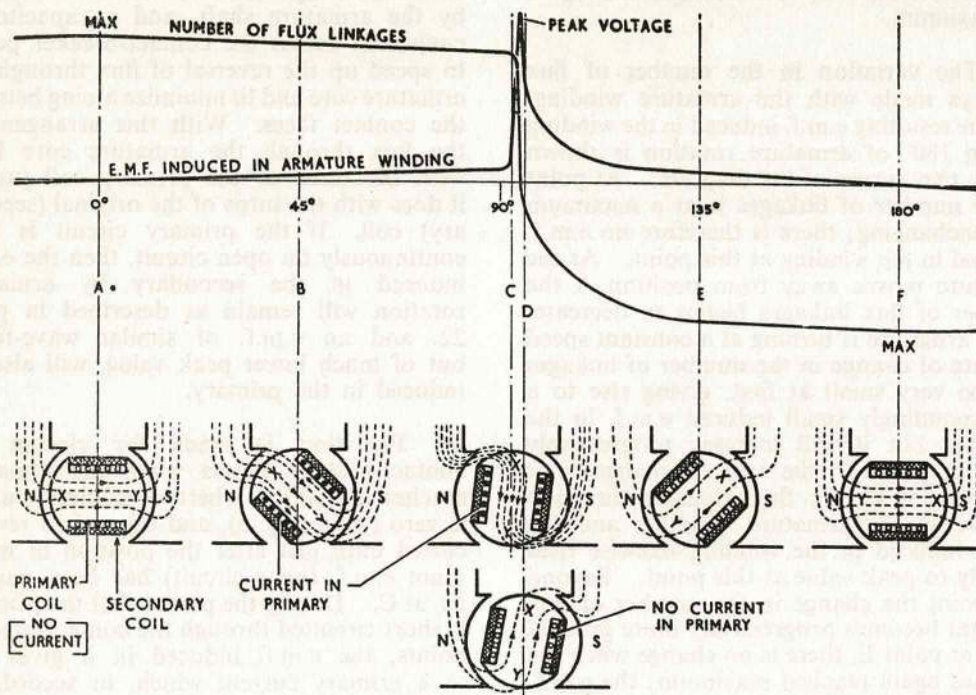


Fig. 5. FLUX- AND E.M.F.-VARIATIONS IN ROTATING-ARMATURE MAGNETO

relative to the armature winding, a process which is speeded up by the discharge of the capacitor (which is charged as the contact-breaker points begin to open) through the primary coil in the reverse direction.

26. This process of flux collapse and re-establishment in the opposite direction is extremely rapid, and the rate of change in the number of flux linkages made with the armature winding is very high indeed. As a result the e.m.f. induced in the winding undergoes a very rapid rise to an extremely high value which, in the case of an armature turning at only some 200 r.p.m. may possibly be in excess of 10,000 volts. After the contact-breaker points open, open-circuit flux conditions again hold good until the armature reaches position F (180°), when a further cycle of primary-controlled flux variation, in every way similar to that already described, begins with the closing of the contact-breaker points for the second time. Two peaks of e.m.f., each capable of producing a spark when applied to a spark plug although they are of opposite sign, are

thus produced for each revolution of the armature.

Magneto Ignition System

27. Fig. 6 shows, in symbolic form, the basic elements of a magneto (rotating-armature) ignition system for a four-cylinder engine—this particular form of magneto has been used as an example because the rotating-armature device has been utilized to describe the basic principles of the magneto. A revolving type of contact-breaker, in which the two-lobe operating cam is stationary and the contacts are carried on a disc mounted on the armature shaft, is used to short-circuit the primary of the magneto. Since this arrangement provides for two voltage-peaks per revolution of the armature, and two sparks are required for each complete revolution of the four-cylinder engine, the armature is driven at engine speed. The output from the armature winding is picked up by the rotor arm of the distributor through a brush and slip-ring connection. This is rendered necessary by the fact that

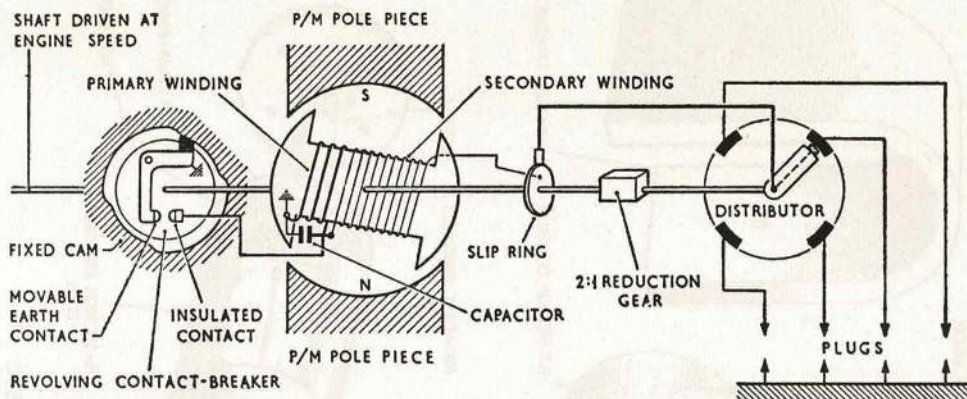


Fig. 6. ELEMENTS OF MAGNETO (ROTATING-ARMATURE) IGNITION SYSTEM

while the armature must run at engine speed to provide four sparks for every two revolutions of the engine, the rotor arm must only make one revolution during this period and must, therefore, be driven at half engine speed.

The Basic Magneto

28. Although there are several different types of magneto the essential components are, in principle, alike in all types. These essential components may be classified as follows:—

(a) **The Magnets.** The permanent magnets which provide the initial flux may be of horse-shoe, bar or tubular type, according to the construction of the magneto.

(b) **The Armature.** This term is applied to the unit consisting of primary and secondary coils together with the soft-iron core on which they are wound, irrespective of whether it rotates or not.

(c) **The Rotor.** In any magneto it is essential to have a rotating member for periodically reversing the magnetic flux through the armature core, thus inducing initial e.m.f. in the armature winding. The form taken by this component determines the type name of the magneto.

(d) **The Contact-Breaker.** This unit may be either of rotating or stationary type: in the former the contacts or "points" are mounted on a base-plate, which in turn is carried on the rotor shaft, and they are operated by a stationary cam; in the stationary type the contact-plate

is a fixture and the operating cam is mounted on the rotor shaft.

(e) **The Distributor.** Although the distributor is electrically part of the magneto system, in some installations it is not actually embodied in the magneto assembly but is a separate unit driven from the engine.

(f) **The Capacitor.**

Rotating Armature Magneto

29. In the rotating-armature magneto the armature, contact-breaker and capacitor revolve; the magnet is stationary. A magneto of this type supplies two sparks per revolution of the rotor; the method of obtaining the periodic flux-reversals that are essential for inducing e.m.f. in the armature winding was discussed earlier in this chapter, where this form of magneto was used to illustrate the basic principles of magneto ignition.

30. The construction of a typical rotating-armature magneto is shown in Fig. 7. The magneto spindle rotates in ball bearings, and carries the H-section laminated soft-iron armature core on which are wound the primary and secondary coils. The armature rotates in a tunnel formed between the pole faces of a horse-shoe permanent magnet. The plate carrying the points of the contact-breaker is keyed to the armature spindle, and the capacitor is enclosed in the contact-breaker end of the armature. At the driving end the armature shaft carries the insulated h.t. slip-ring to which the end

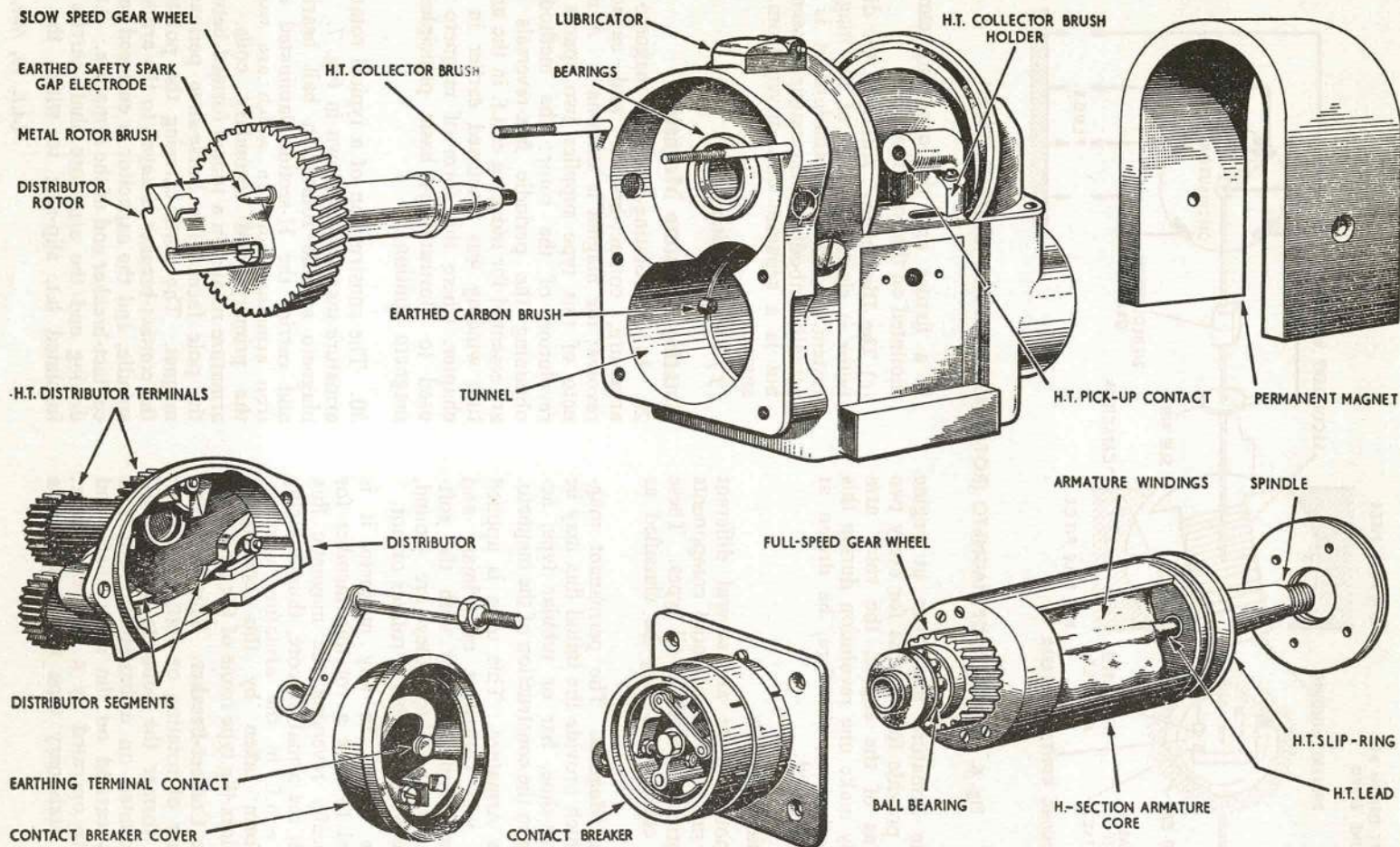


Fig. 7. CONSTRUCTION OF A TYPICAL ROTATING-ARMATURE MAGNETO

of the secondary coil is attached, while the full-speed gear wheel of the distributor reduction gear is carried at the rear end of the shaft. The full-speed gear wheel engages with the slow-speed gear wheel which, running in two ball bearings, carries the distributor rotor arm.

31. One end of the primary coil and one terminal of the capacitor are connected to the metal of the armature frame, while the other end of this coil, together with one end of the secondary coil and the remaining terminal of the capacitor, are taken to the contact-breaker point that is insulated from the contact-breaker base plate. The other point of the contact-breaker is mounted directly on the base plate, and primary current is passed to earth from the earthed terminal via a carbon brush mounted behind the contact-breaker base. A second carbon earthing brush in the magneto carcase makes contact with the armature frame to establish a complete circuit for the primary current when the contact-breaker points are closed, and also connects the capacitor across the contact-breaker points.

32. The free end of the secondary coil is connected to the collector slip-ring on the armature shaft. High-tension current is picked up from the slip-ring by the carbon h.t. collector brush, and is fed to the distributor rotor by the carbon h.t. pick-up brush; it returns to the secondary coil via the distributor, spark plug gaps, engine body, magneto body, earthing brush, armature frame and primary coil. The safety spark-gap (see para. 46) has its points connected to the h.t. pick-up and the magneto body respectively. The earthing switch (see para. 47) is connected to the unearthed end of the primary coil by means of an earthing terminal on the contact-breaker cover which makes internal contact with the insulated contact-point of the contact-breaker.

Note. The ball bearings which support the armature are insulated from the body of the magneto, since the passage of current through them would give rise to pitting and burning of the balls and races: the carbon earthing brushes are consequently an essential part of both the h.t. and l.t. circuits.

33. The rotating armature magneto suffers from the following disadvantages:—

(a) Only two sparks per revolution are obtainable: the magneto must be driven at speeds far in excess of engine speed if it is used on an engine having a fairly large number of cylinders.

(b) The winding, capacitor and contact-breaker are subjected to considerable centrifugal force.

(c) The small space available between the winding and capacitor and the earthed frame of the armature allows only comparatively light insulation to be used for these components.

(d) A large number of rubbing contacts are incorporated in the electrical circuit.

Polar Inductor Magnetos

34. Because of the disadvantages that are inherent in the rotating-armature type of magneto, either polar-inductor or rotating-magnet type magnetos are necessary for certain ignition systems. The rotating member of a polar-inductor magneto consists simply of two or four soft-iron inductor bars mounted on a non-magnetic spindle—the permanent magnets that supply the initial flux, the armature core and winding, the capacitor and the contact-breaker are all stationary. Ample space is thus available for adequate insulation of “live” parts, and centrifugal forces are absent from all components except the very sturdy rotor. The inductor operates in the magnetic circuit in such a way that the magnetic flux through the stationary armature core is reversed four times during each revolution of the rotor. The polar inductor magneto thus gives four sparks per revolution, and it can therefore be run at half the speed of an equivalent rotating-armature magneto.

35. **Two-Bar Polar-Inductor Magneto.** The magnet system components of a typical two-bar polar-inductor magneto are shown in Fig. 8. The initial flux is derived from a pair of permanent magnets of modified horse-shoe type: the like poles of the magnets face each other and are connected together by soft-iron laminations, the recess of each magnet accommodates a non-magnetic “shoe”, and each shoe carries one of the extremities of a laminated U-shaped core on which is mounted the stationary armature winding.

(A.L. 13, Nov. '62)

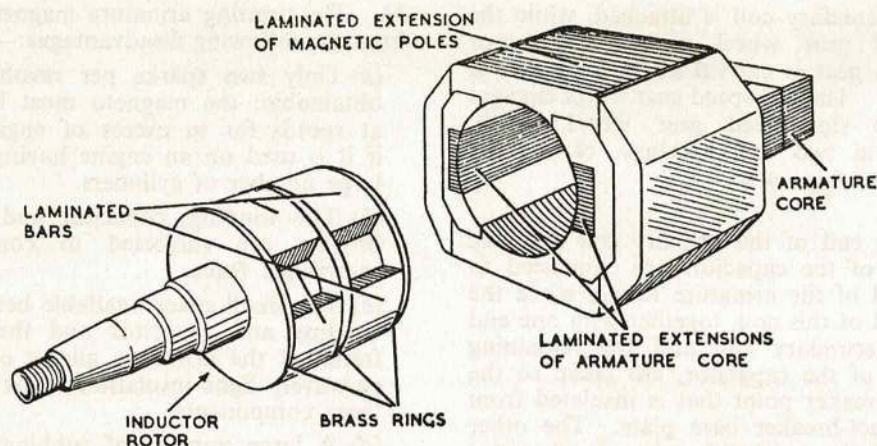


Fig. 8. MAGNET SYSTEM OF TWO-BAR POLAR-INDUCTOR MAGNETO

The rigid structure formed by the magnets, linking laminations, shoes and armature core is shaped internally to form a cylindrical tunnel having, in effect, four separate magnetic faces disposed equally around its circumference. The rotor, which operates in the tunnel just described, consists of two laminated soft-iron bars or inductors secured by means of brass rings to the rotor shaft—the inductors are separated from the shaft and from each other by air gaps. The stationary contact-breaker (not shown in the diagram) is operated by a cam formed on the rotor shaft.

36. Flux Reversal. Fig. 9 shows how the flux through the laminated armature core varies during 180° rotation of the rotor. The upper and lower faces in the tunnel are of opposite and constant polarity, being in constant contact with the N and S poles, respectively, of the magnets. With the rotor in position 1, each inductor bridges the air gap between two adjacent magnetic faces and covers both of these faces completely; the flux passes from the upper (N) pole through the upper inductor to the right-hand end of the armature core, through the core from right to left, through the lower inductor, and thence to the lower (S) pole to complete the magnetic circuit. In this position of the rotor the magnetic flux is at maximum value, since the reluctance between the pole faces and the ends of the armature core is at a minimum, and the whole of the flux links with the turns of the armature winding. In position 2 the rotor

has advanced 45° clockwise, and the edges of each inductor are adjacent to the outer edges of both pole faces; the inductors thus offer a path of low reluctance direct between N and S poles, and no flux passes through the armature core. At position 3 conditions are comparable to those obtaining in position 1, except that the flux now passes from the N pole to the left-hand end of the armature core; it is again at maximum value, but is now flowing through the core in the opposite direction. Conditions at position 4 are comparable to those at position 2 with no flux passing through the core, while at position 5, after 180° of rotor movement, conditions are again as at position 1. There are thus two reversals of flux, each of which is capable of producing a peak of e.m.f. for each half-revolution of the rotor.

37. Four-Bar Polar-Inductor Magneto. In this form of polar-inductor magneto the initial magnetic flux is derived from two bar magnets, which are arranged with laminated soft-iron end plates and the extremities of the armature core to form the rotor tunnel—the arrangement is shown in Fig. 10, which also shows the construction of the four-inductor rotor unit. The ends of the tunnel have constant and opposite polarity, hence constant polarity is induced in each of the two pairs of inductor bars: the pair whose junction is adjacent to the N pole of the permanent magnets have N polarity; the other pair have S polarity. The rotor is therefore equivalent to a four-pole permanent magnet, and maximum flux

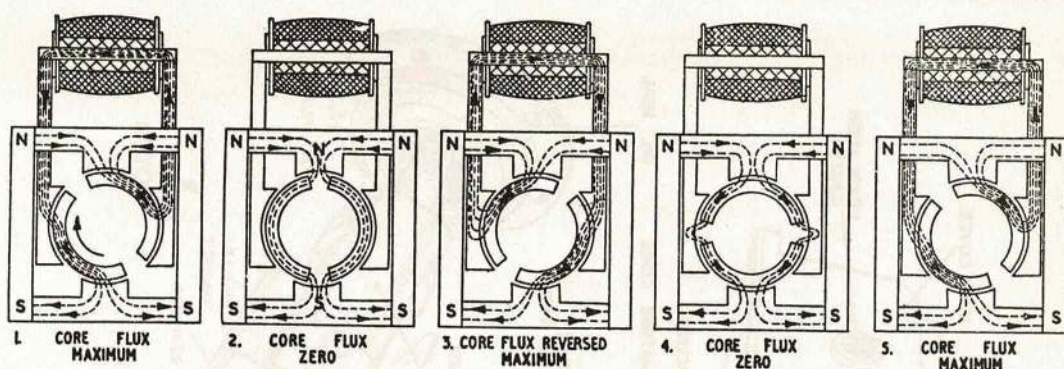


Fig. 9. TWO-BAR POLAR-INDUCTOR MAGNETO (FLUX CHANGES DURING 180° ROTATION)

through the armature core occurs when adjacent inductor bars are immediately opposite the extremities of the core (position 1). When the rotor is displaced 45° (position 2), the extremities of the armature core offer a path of low reluctance between adjacent inductor bars of opposite polarity, and there is no flux through the central portion of the armature core. At position 3 the conditions are similar to those at position 1, except that the flux through the core is

now in the opposite direction. There are thus four reversals of the flux through the central portion of the armature core during each complete revolution of the rotor, hence the magneto provides four sparks per revolution as does the two-bar inductor magneto. There are however, no reversals of the flux through the actual inductor bars in this type of magneto; the hysteresis losses in the machine are, therefore, lower than in the two-bar polar-inductor type.

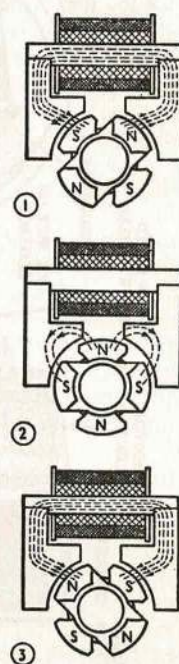
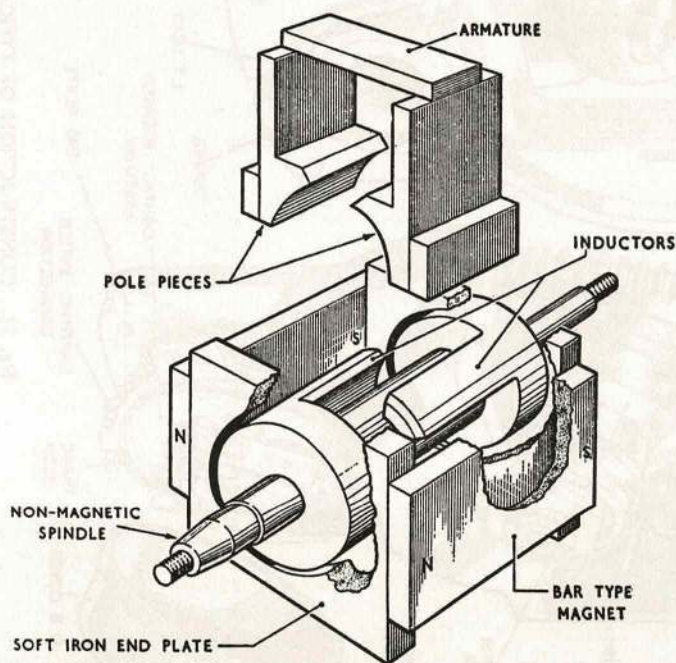


Fig. 10. FOUR-BAR POLAR-INDUCTOR MAGNETO, MAGNET SYSTEM AND FLUX-CHANGES (Magnetic circuit and flux changes)

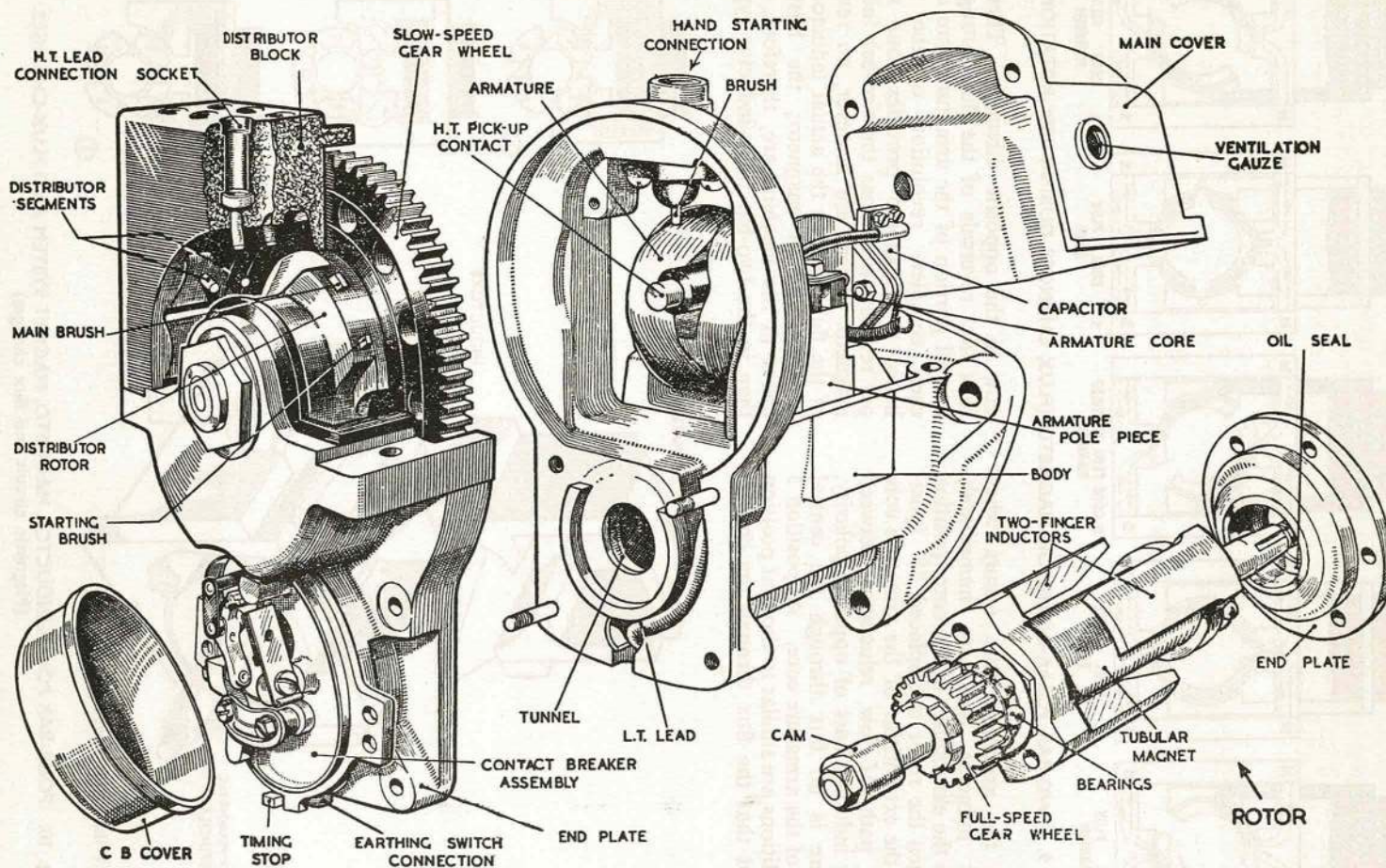


Fig. 11. CONSTRUCTION OF TYPICAL ROTATING-MAGNET MAGNETO

Rotating Magnet Magnetos

38. The development of specialized magnetic alloys such as Alnico, has made possible the production of small but extremely effective permanent magnets which, when used as the rotors of magnetos give all the advantages of the polar-inductor types and at the same time enable considerable savings in weight and bulk to be effected. Fig. 11 shows the constructional details of a typical rotating-magnet magneto.

39. In the example illustrated, the rotor consists of a non-magnetic shaft on which a tubular magnet is clamped between two two-fingered soft-iron inductors set 90° apart; the four inductor bars form alternate N and S poles. The laminated core which carries the stationary armature winding is extended into two pole-pieces, also laminated, which form part of the upper surface of the rotor tunnel; the contact breaker is, of course, stationary, and is operated by the cam on the rotor shaft. The flux changes

through the armature core are identical with those of the four-bar polar-inductor magneto, and four sparks are produced for each complete revolution of the rotor.

Flywheel Magneto

40. This method of obtaining a.c. for ignition purposes is used extensively on small two-stroke engines where one spark per engine revolution is required; Fig. 12 shows a typical flywheel magneto layout. This type is so named because the magnet rotor is combined with, and the magnets constitute most of the mass of, the flywheel. Advantages are that the coil, contact-breaker and capacitor are stationary, and there is no need for a slip-ring and pick-up brush.

41. The ignition coil (l.t. and h.t. windings), laminated armature, contact-breaker mechanism and capacitor are normally assembled on the stator or armature back-plate which is secured to the crankcase, although there

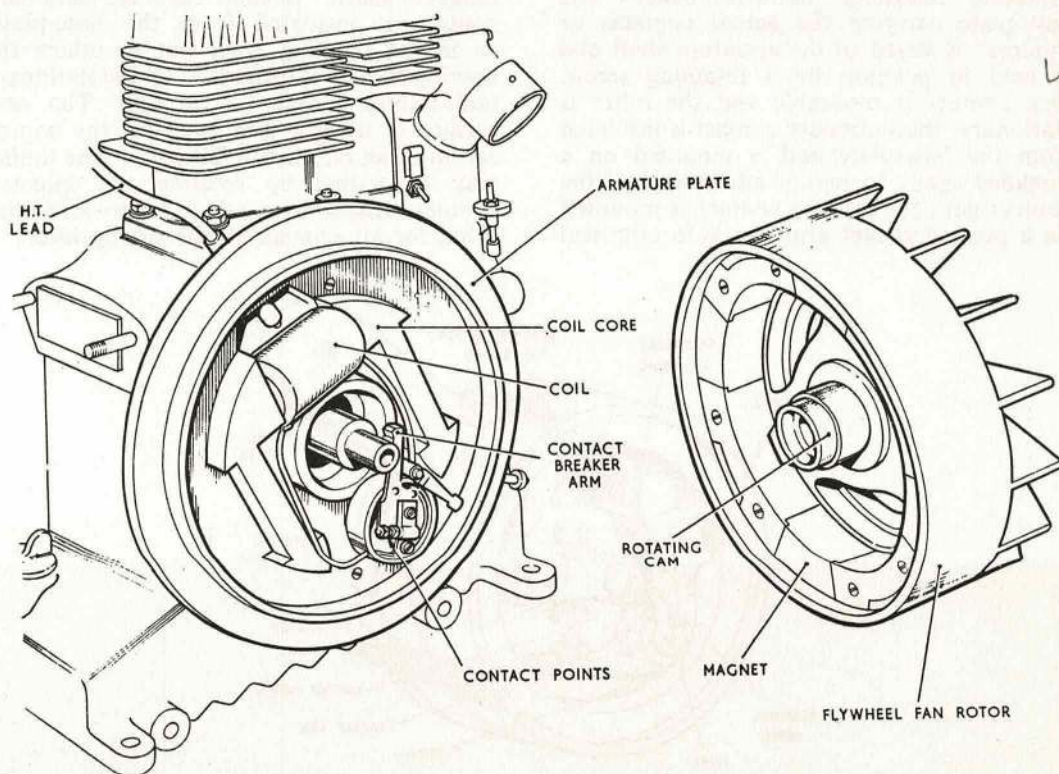


Fig. 12. TYPICAL FLYWHEEL MAGNETO LAYOUT

are examples having the l.t. coil only on the stator, the h.t. winding being located elsewhere.

42. Powerful magnets, generally built up in laminated form, are secured evenly around the inner circumference of the flywheel. These magnets are alternately N- and S-pole and, as the flywheel revolves, they register with the ends of the laminated armature upon which the coil is wound. The contact-breaker is usually operated either by means of a cam lobe on the flywheel boss or by a cam keyed to an extension of the mainshaft, and alternately completes and interrupts the path to earth of the primary l.t. voltage generated. During the latter phase, h.t. voltage is induced in the secondary coil and transmitted via the h.t. lead to the sparking plug.

Contact-Breakers

43. **Rotating Type.** Fig. 13 shows the details of construction of a typical rotating-armature magneto contact-breaker. The base-plate carrying the actual contacts or "points" is keyed to the armature shaft and is held in position by a retaining screw. One contact is moveable and the other is stationary: the stationary contact is insulated from the base-plate and is mounted on a threaded shank to permit adjustment of the contact gap; the moving contact is mounted on a pivoted rocker arm and is in electrical

contact with the base-plate, which in turn is earthed through a carbon brush at the back. The pivoted rocker arm, which is spring-loaded to close the contacts, is provided with a fibre heel that bears on the inner surface of a stationary cam ring. The inner surface of this cam ring is shaped to form two lobes with corresponding points 180° apart; these lobes lift the rocker arm, against the thrust of the spring, to open the contacts twice in each revolution of the armature shaft. The timing of the spark is varied by moving the cam ring by means of a timing lever—movement of the ring against the direction of armature rotation advances the spark so that it occurs earlier in the compression stroke of the operating cycle of the engine.

44. **Stationary Type.** In polar-inductor and rotating-magnet magnetos the contact-breaker base-plate is stationary (Fig. 14). The rocker arm that carries the moving contact is operated by a rotating cam, which in most cases is keyed or verniered to the magneto shaft. In some cases the stationary contact is insulated from the base-plate, as in the rotating type, but in others the moving contact is insulated and the stationary (adjustable) contact is earthed. The cam surface is usually lubricated by the wiping action of an oil-soaked felt pad. The timing may be varied by rotating the spigoted contact-breaker base, which is provided with a lug for attachment to the timing lever.

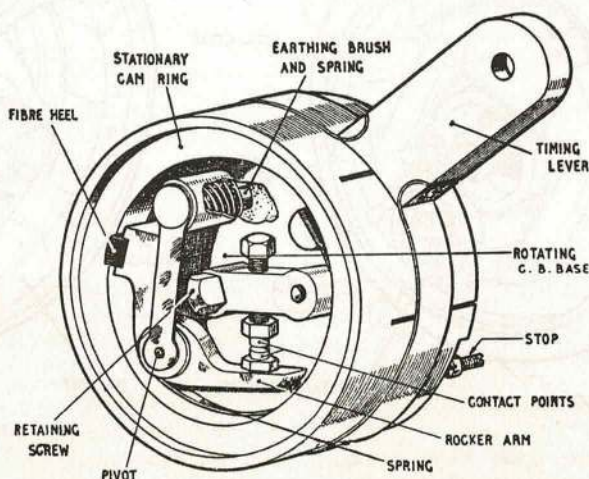


Fig. 13. ROTATING CONTACT-BREAKER

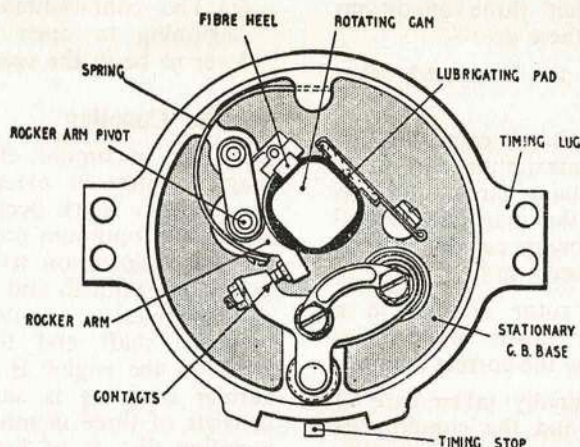


Fig. 14. STATIONARY CONTACT-BREAKER

45. Contact-breaker points are made either of an alloy of platinum and iridium, or of pure tungsten: the former type has excellent non-arcing and non-oxidizing qualities, but is liable to wear rather rapidly and is also expensive; tungsten points, on the other hand, are wear-resistant and are also less costly, but their current-handling ability is inferior to that of the alloy type. In most magnetos the gap between the contact points, when fully open, should be $0.012 \text{ in.} \pm 0.001 \text{ in.}$

Safety Spark Gap

46. In some earlier types of magnetos a spark gap of 8-9 millimetres, between the h.t. lead to the distributor and earth, was incorporated as a safeguard against breakdown of secondary insulation by excessive voltage, such as might occur if the h.t. circuit were to become open-circuited. The gap is sufficiently large to avoid interference with normal operation, but passes a spark at a voltage which is rather less than the safe maximum voltage of the secondary insulation. In later types of magneto the safety factor in insulation has been greatly improved and so the safety spark gap is omitted in these types.

Magneto Switches

47. To retain complete control of engines particularly during starting and stopping operations, the operator must have some means of rendering the magnetos electrically inoperative as and when required. This

need is met by the provision of magneto switches, one of which is fitted in parallel with the contact-breaker points of each magneto. In the OFF position the switch is closed and the primary coil of the magneto is continuously short-circuited; in these conditions the rate of change in the primary current is much too small to produce the sudden collapse of the flux through the armature core that is essential for inducing a very high e.m.f. in the armature winding, and the output voltage from the magneto, even when the latter is being driven at high speed, is consequently of such low magnitude that no sparking occurs at the spark plugs. In the ON position the switch contacts are open and the contact-breaker resumes its normal function.

48. **Important.** In many of the older rotating armature magnetos, one side of the magneto switch is connected to the insulated contact of the contact-breaker through a carbon-brush pick-up in the contact-breaker cover; the other side of the switch is connected to earth. In such cases it must be remembered that removal of the contact-breaker cover automatically leaves the magneto operative, even if the magneto switch is at OFF.

Magneto Timing

49. To obtain maximum h.t. output voltage and effective distribution of the resulting current to the spark plugs, the internal mechanism of a magneto must be assembled

in such a manner that three conditions occur simultaneously; these are:—

- (a) The points of the contact-breaker begin to open.
- (b) The rotating member is occupying the position in which maximum current is flowing in the primary circuit—this is a few degrees past the magnetic neutral by reason of the primary current lagging on the primary induced e.m.f.
- (c) The distributor rotor arm is in a position where its brush overlaps a distributor segment by the correct amount.

These factors are originally taken care of by the manufacturer, and the components concerned are suitably marked to simplify re-assembly of the magneto after any subsequent dismantling.

50. To ensure that each spark-plug sparks at the correct instant in the engine operating cycle, the magneto shaft must be engaged with the magneto drive from the engine in such a manner that the following conditions are fulfilled:—

- (a) The piston in a selected cylinder (usually No. 1) is in the correct firing position specified for the engine.
- (b) The brush of the distributor rotor arm overlaps the distributor segment connected to the spark plug of the selected cylinder.

(c) The contact-breaker points are just beginning to open (the timing control lever to be in the specified position).

Vernier Coupling

51. For maximum engine efficiency, the magneto must be externally timed so that the ignition spark occurs when the piston reaches an optimum position in the cylinder on the compression stroke. This optimum position is critical, and fine-limit adjustment of the relative angular positions of the magneto shaft and the magneto driving shaft on the engine is essential. A Simms vernier coupling is shown at Fig. 15; it consists of three members, and because the coupling disc is of flexible construction it relieves the magneto shaft of any mechanical stresses. It will be seen that the magneto drive member has 19 teeth, while the magneto member has 20 teeth; the latter member is keyed to the tapered magneto shaft and is secured by a castellated nut and split-pin. The composition flexible coupling disc has 19 teeth on one side and 20 teeth on the other—approximately 0.020 in. play is allowed between members as the composition disc tends to swell under running conditions.

52. **Vernier Action.** If the magneto coupling and coupling disc are disengaged from the magneto drive, and both are turned in the direction of magneto rotation by the equivalent of one tooth on the magneto drive coupling, the

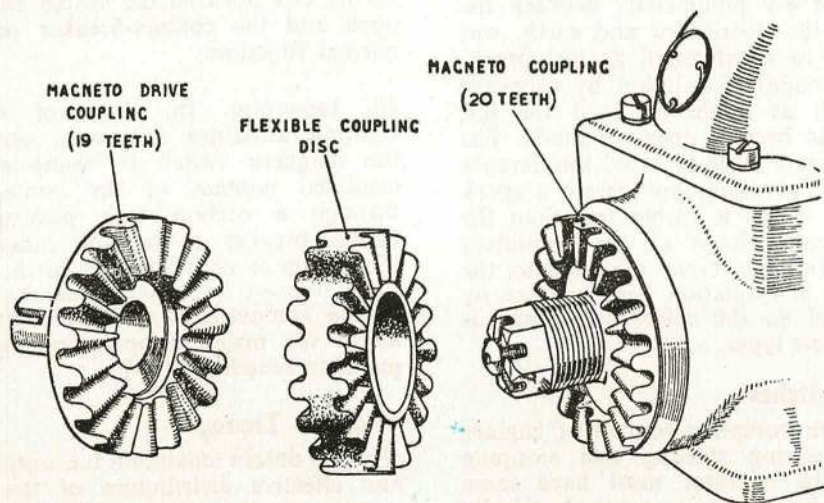


Fig. 15. SIMMS VERNIER MAGNETO COUPLING

magneto timing is advanced $\frac{1}{10}$ of a magneto revolution. If the magneto drive coupling and the coupling disc are held in engagement and the magneto coupling is turned, against the direction of rotation, the equivalent of one tooth on the magneto side of the coupling disc, then the timing is retarded by $\frac{1}{20}$ of a magneto revolution. By performing these two operations in succession, the spark is first advanced by $\frac{1}{10}$ of a revolution and is then retarded from this setting by $\frac{1}{20}$ of a revolution, the overall result being an advance of $\frac{1}{10} - \frac{1}{20} = \frac{1}{20}$ of a magneto revolution, i.e. just under 1° .

Impulse Starters

53. Some rotating-armature magnetos are equipped with impulse starters (Fig. 16). This device is incorporated in the magneto coupling, and it provides, by means of a spring interposed between the magneto drive and the magneto spindle, acceleration of the magneto rotor during the critical period immediately preceding the opening of the contact-breaker points. In this way an intense retarded spark is available for starting and slow running; above a certain speed however, the drive becomes direct and and the ignition timing reverts to normal.

54. The starter has three main components: the body, which is driven by the engine magneto drive through a vernier coupling; the hub, which is keyed to the magneto shaft; and the cover, which is bolted to the magneto end-plate. The body and hub are

connected by a clock-type spring, and two pivoted pawls are mounted on the hub.

55. As the engine crankshaft turns on starting, the drive is transmitted to the body of the impulse starter and through the spring to the starter hub. This condition continues until, slightly before the contact-breaker points are due to open, gravity causes one pawl to fall and engage with the stop on the stationary cover, thus preventing further rotation of the hub and armature. Continued rotation of the starter body winds up the spring until the cam on the body disengages the pawl from the stop; when this occurs the spring unwinds, turning the hub and armature rapidly over the flux-reversal point so that the opening of the contact-breaker points produces an intense spark, which is retarded to an extent that is determined by the angular travel of the crankshaft between engagement and disengagement of the pawl. Under normal running conditions the pawls are thrown outwards by centrifugal force and do not engage with the stop; the hub is thus driven directly and continuously through the spring to give normal timing.

56. **Servicing.** Failure may be caused by sticky lubricant or excessive end-thrust; in such circumstances the unit should be flushed with kerosine and the play between the vernier coupling members should be checked—about 0.020 in. play is necessary. When dismantling or fitting the starter a

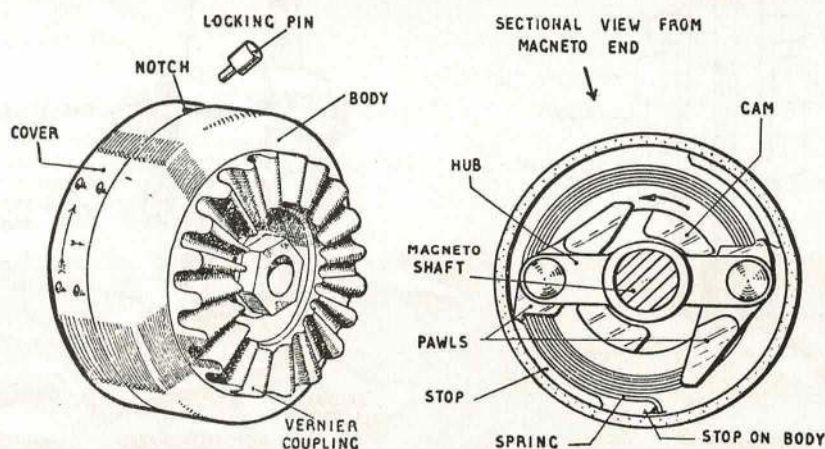


Fig. 16. B.T.H. IMPULSE STARTER

locking pin must be inserted in the notches provided in the rim of the cover and the spigot on the body. The direction of rotation is indicated by an arrow engraved on the cover—the small arrow is for locating the cover and body when assembling the starter.

Sparking Plugs

57. General. The sparking plug is a specially constructed metal plug which is screwed into the combustion chamber of a gasoline engine for ignition purposes, a spark gap being provided between an insulated central electrode, connected to the h.t. distributor, and one or more earthed points on the body of the plug.

58. Construction. The plug consists of three main parts, viz. the central electrode, the insulator and the body (Fig. 17). The high tension current from the coil or magneto is delivered to the central electrode at the correct time, and the circuit is completed by a spark jumping from the electrode to the body of the plug; this spark ignites the gasoline/air mixture. The body is made of

steel formed hexagonally on the outside for the use of a spanner; the lower end is threaded for screwing into the cylinder, and has welded to it the earth electrode(s). The central electrode is made of special alloy steel to withstand great heat, and is provided with a threaded extension for the attachment of the terminal nut. Separating the earth electrode on the body and the central electrode is the insulator which is frequently made of porcelain. A copper washer is fitted between the body and the insulator to ensure gas tightness; another copper or copper and asbestos washer is fitted between the sparking plug and the cylinder head for the same reason. Some plugs can be dismantled for cleaning purposes while others cannot; both types are illustrated (Fig. 17).

59. Classification. A sparking plug is classified by the diameter and length of its threaded portion; the diameter is stated in millimetres (e.g. 10 mm., 14 mm., 18 mm.) and the length in inches (e.g. $\frac{3}{8}$ ", $\frac{9}{16}$ ", or $\frac{13}{16}$ "). This length is termed the reach (i.e. short, medium or long), the reach varying with the

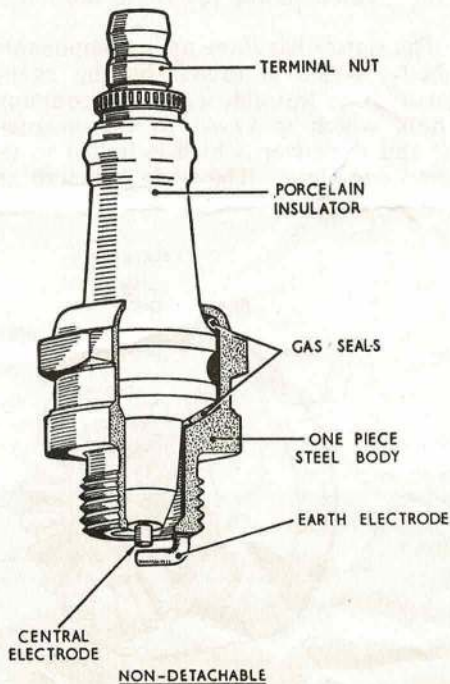
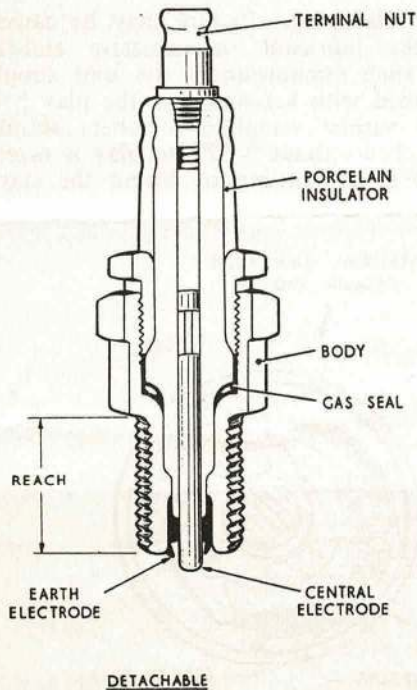
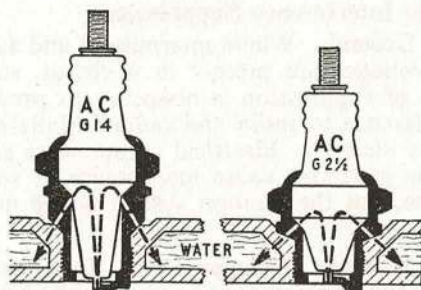


Fig. 17. SPARKING PLUGS

design of the engine. It is important that plugs of the correct reach are fitted at all times: if a shorter reach plug is fitted the spark will occur in a pocket, so slowing combustion and causing the uncovered threads to become burnt; if a plug having too long a reach is fitted, there is always the possibility that damage will be caused to the piston and valves.

60. Pre-Ignition. Pre-ignition can be caused by the electrodes becoming hot enough to fire the charge before the timed ignition spark occurs, and it is usually due to the use of an incorrect type of sparking plug—one which does not dissipate the heat of combustion rapidly enough (Fig. 18). Pre-ignition may also be caused when a plug of the correct type has become defective under unusually severe working conditions. Persistent pre-ignition causes the electrodes to burn away very rapidly; the engine symptoms are poor performance at high speeds or when pulling hard, usually accompanied by an audible knock because pre-ignition frequently results in detonation.



LEFT-HAND INSULATOR IS LONGER, THEREFORE HEAT TRAVELS A LONGER DISTANCE TO REACH WATER; CONSEQUENTLY THIS PLUG WILL RUN HOTTER.

Fig. 18. HEAT FLOW

61. Heat Range. A sparking plug must dissipate enough heat so that the electrodes do not overheat and glow, thereby causing pre-ignition; it must also retain sufficient heat to burn off any oil adhering to the electrodes before it can bridge the air gap. Because different engines have different operating temperatures the plug manufacturers have made a heat range of plugs to cope with the varied conditions:—

(a) **Hot or Soft Plug.** These are plugs which because of their internal construction tend to retain their heat; they

are used on low speed cold running engines where oil fouling is most likely to be prevalent.

(b) **Medium.** These plugs are used on normal operating temperature engines.

(c) **Cold or Hard Plug.** These are plugs which can dissipate their heat very quickly, thus preventing overheating of the electrodes; used on fast high compression engines.

Note. The manufacturers code stamped on the plug when used in conjunction with the relevant A.P. will ensure that the correct plugs are being used in any particular engine.

62. Plug Testing. A faulty plug in a multi-cylinder engine can usually be located by shorting each plug in turn, using the steel blade of a wooden handled screwdriver to make connection between the plug terminal and the cylinder head, when the engine is running slowly; a plug that does not alter the engine note when shorted, is faulty. Sometimes however, a plug may break down at high speeds only and is difficult to detect. When this happens the plugs should be removed from the engine, cleaned thoroughly, and tested under air pressure on a plug testing machine. When removing or fitting sparking plugs always use the correct sized spanner, which, if possible, should be of the box type; a badly fitting spanner may slip and break the porcelain insulator, thus rendering the plug unserviceable.

63. Cleaning. Sparking plugs when in use gradually become fouled by deposits of oil and carbon which tend to impair their efficiency; regular routine inspection and cleaning reduces this to a minimum. A detachable plug can be dismantled and the electrodes and body interior cleaned with fine emery cloth and a wire brush. When the plug cannot be dismantled the only efficient means of cleaning is by some form of sand-blasting, but if that is not possible a wire brush and a scraping implement should be used.

64. Champion Spark Plug Cleaner and Tester (Fig. 19).

- (a) Clean all oily plugs in white spirits.
- (b) Dry thoroughly in air blast.

(A.L. 13, Nov. '62)

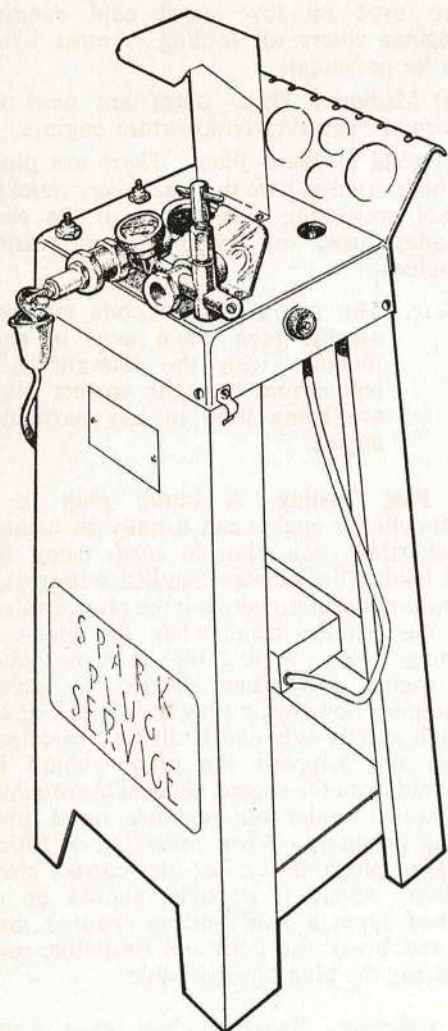


Fig. 19. SPARKING PLUG MACHINE

(c) Place plug in correct sized rubber washer.

(d) Rotate slowly as abrasive blast is turned on for approximately 10 seconds.

(e) Turn on the air blast to dislodge all abrasive particles before removing the plug from the machine.

(f) When thoroughly clean, adjust to the makers' specification with feeler gauges and by bending the earth electrode only to obtain the correct air gap.

Note. Discard any plugs at this stage which show cracked porcelain, badly burnt electrodes or other defects.

65. **Testing.** Screw the plug to be tested into the appropriate part of the machine (Fig. 19), connect the lead and turn on the air until the gauge shows a maximum of 110 lbs./sq. in. Press the button; the spark should be regular, light blue to white in colour, and jumping between the electrodes only.

Note. Discard any plugs which do not attain these standards.

Radio Interference Suppression

66. **General.** Where intermittent and surging voltages are present in a circuit, some form of suppression is necessary to prevent interference to radio and radar installations in the vicinity. Electrical components such as the generator cause interference to some degree, but the ignition system is the main cause.

67. **Methods of Suppression.** Interference from the generator, etc., can be eliminated by fitting capacitors to the electrical terminals. Two methods are in use for the

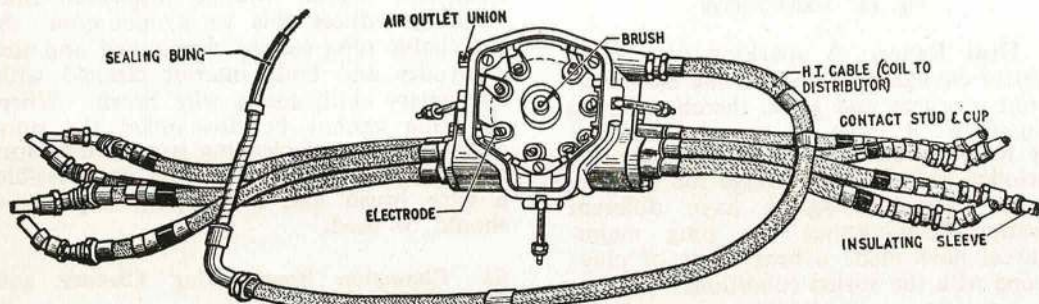


Fig. 20. SCREENED HARNESS ASSEMBLY

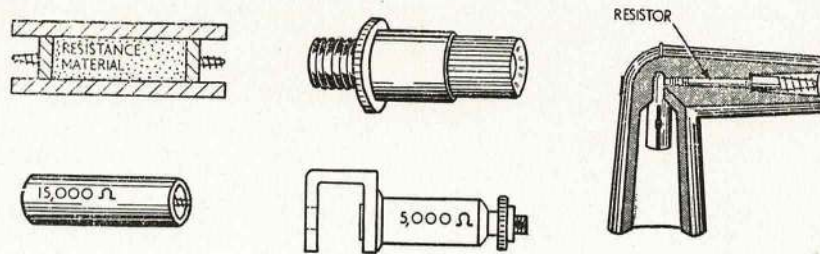


Fig. 21. TYPES OF RESISTOR

suppression of interference from the ignition system; by using special sparking plugs and screening the leads and by the use of resistors:—

(a) **Screening.** This method consists of enclosing the ignition components in earthed metal cases, and of covering the leads with a flexible metallic sheath which is also earthed (Fig. 20).

(b) **Resistors or Suppressors.** The fitting of resistors to the high tension leads is a very widely used method of suppressing interference. The resistors damp down the high frequency component of the current and reduce the radiation to a level which is too low to be picked up by aërials.

68. **Types of Resistor.** Several types of resistor are available as shown in the

illustration (Fig. 21), some being connected into the h.t. lead and others fitting on to the plug tops or screwing into the coil connection. In all cases some high resistance material is incorporated which damps down the oscillations given out by the current.

69. **Location of Resistors.** The two sizes of resistor used in the Service are 5,000 ohm and 15,000 ohm. As the total resistance between the coil and any plug should be at least 20,000 ohms, a 5,000 ohm resistor is fitted to each sparking plug and a 15,000 ohm resistor in the coil lead, as close to the distributor as possible (Fig. 22). Some distributors are now fitted with a resistor forming part of the carbon brush in the centre of the distributor cap, so that some measure of suppression is built into the ignition system.

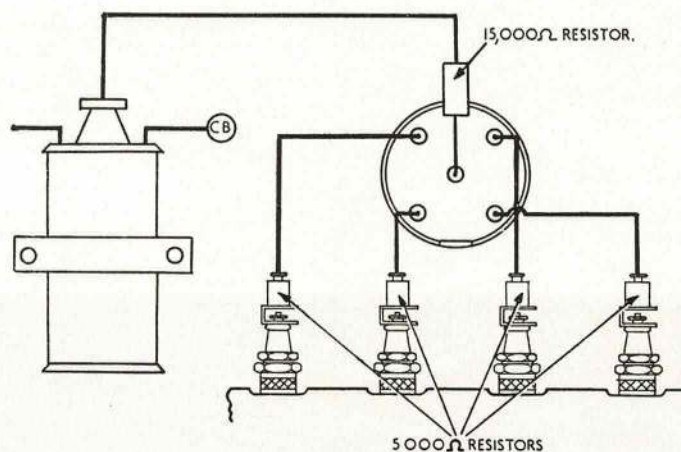


Fig. 22. LOCATION OF STANDARD RESISTORS

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