FUNDAMENTALS OF MAGNETO IGNITION

FOREWORD

Ignition service within a relatively few years has become a field for specialists. The training, skill and general knowledge of the service technician are the outstanding characteristics of the progressive service business.

As a consequence frequent requests are received at the factory for fundamental information, prepared especially for study and reference in a particular service field. In providing a discussion of the principles of magneto ignition, considerable time has been devoted to the review of magnetism and electricity, after which an analysis of ignition requirements leads to the description of various ignition systems, their development, application and impulse coupling adaptations. The final section deals with magneto service in a general way, no attempt being made to describe specific service operations as applied to individual units, but rather to offer suggestions toward the establishment of efficient service practices.

It has been found impossible to cover the entire field of magneto ignition, or even to deal with individual topics on an exhaustive basis. The range of special applications and installations is so great that many are not even mentioned. Especially is this true of the older ignition systems, which due to changeovers are encountered infrequently in the field.

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SECTION ONE
INTRODUCTION

DEFINITION OF MAGNETO

A dynamo is any machine which transforms mechanical energy into electrical energy. Under this definition there are several distinct classifications, a magneto being the particular type of dynamo which uses permanent magnets to establish its magnetic field.

Strictly used, the term magneto applies only to the current-generating portion of the ignition unit and does not include the transformation of the low voltage primary current to the high voltage secondary ignition spark discharges, nor to the distribution of these spark discharges. As examples of this interpretation, the current-producing unit of the old style crank telephone or of the electric tachometer is also known as a magneto.

In the ignition field the technical definition is not commonly observed and it will be assumed throughout the following discussion that the magneto is the entire self-contained unit as it functions to supply the ignition spark discharges.

GENERAL PURPOSE OF MAGNETOS

Modern magnetos are compact, self-contained units designed and constructed specifically for the production of controlled electric spark discharges of adequate strength to meet the ignition requirements of internal combustion engines or of similar applications.

Entirely independent of any exterior source of electrical or chemical power, a magneto ignition unit depends solely upon mechanical energy, which can be supplied, for example, by hand cranking. This characteristic is of vital importance in remotely located or infrequently operated installations, and of considerable convenience in many others.

Another advantage based directly upon the fact that magnetos operate as a result of mechanical power is the adaptation of the impulse coupling. This simple mechanical device functions at slow speeds in order to produce an automatically retarded ignition spark of greatly increased intensity during the starting period of the engine.

THE MAGNETO ASSEMBLY

A magneto is a precision-built instrument combining painstaking mechanical construction with carefully engineered magnetic and electric circuits. As noted in preceding paragraphs three separate functions occur within the unit (Figure 1):

(a) Current generation, which occurs in the primary circuit when there is relative movement of the primary winding and the interlocking magnetic field.

(b) Voltage transformation, which takes place in the interlocking primary and secondary windings of the coil, the high voltage surge being caused by breaking the primary circuit at the point the primary current reaches its maximum value.

(c) Spark distribution, which consists in conducting the high voltage secondary surge to the desired ignition circuit at the correct intervals. In standard units for single cylinder engine applications, this function is unnecessary.

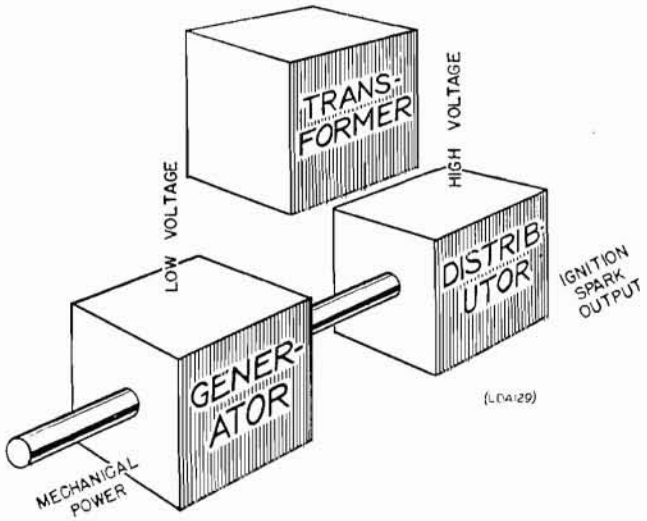


Figure 1—Functions of a Magneto

MAGNETO ENGINEERING

The design of magnetos is influenced by a number of important factors, among which are the requirements of the application, the performance of the magneto, the cost of manufacture and the ease with which the unit may be serviced. The constant research and development work maintained by individual manufacturers has resulted in greatly improved field performance, while both the size and the cost of units have been sharply reduced.

Magneto design over a period of years has been closely linked with the development of magnet steels. The progression from tungsten steels to chromium steels to cobalt steels to Alnico steels has provided the basis for major changes in magneto construction.

MANUFACTURE OF MAGNETOS

In the manufacturing industry a magneto is considered an accessory in relation to an engine, although it is en-

tirely essential to the operation of the unit. Such a classification results from the common practice engine manufacturers have of buying the magneto unit complete from a different manufacturer. Many times the price of an engine is quoted less the magneto as well as other accessories, but it is rarely the case that the individual engine purchaser specifies the make or model of the magneto to be furnished.

Under such circumstances several magneto manufacturers supply the units for original application on many hundreds of kinds of engines. Usually the magneto selected by any one engine builder undergoes a series of exhaustive tests while installed on the actual engine model before it is accepted and designated as standard equipment. The magneto manufacturer then assumes the responsibility for the condition and service of the magneto over a definite period of time, usually 90 days, except under extraordinary conditions.

MAGNETO SERVICE

Service work of all kinds is often divided into the two general classes of maintenance and repair.

Maintenance work is usually considered to include inspection and adjustments made by the operator as well as field service work performed by service technicians. Repair work consists of the replacement of major parts, usually undertaken only in the specially equipped shop, and of the complete overhaul of the unit.

The distinction between the two classes of work is indefinite and varies widely with the field of application. In aircraft engine service practically no work is ever performed on magnetos installed on engines, maintenance consisting of a comprehensive test and inspection routine. After a definite number of hours of service, the aircraft magneto is removed from the engine and completely overhauled. In the tractor and power engine field the opposite is often true, that is, extensive repairs are frequently made on magnetos without removing them from the engine, and magnetos are seldom removed for overhaul until they become inoperative.

THE SKILLED TECHNICIAN

A competent serviceman is expected to be able to diagnose difficulties, make adjustments, install replacement parts and undertake the complete overhaul of many makes and models of magnetos. A thorough understanding of the fundamental design principles, combined with a general knowledge of magneto construction, is the only sound basis on which the skilled technician can apply the special information and equipment at his disposal.

Expert electrical and mechanical service are both required in the maintenance and overhaul of magneto ignition units. The serviceman must be capable of performing precision mechanical work as well as operating electrical test equipment to provide conclusive results.

FUTURE DEVELOPMENTS

The sweeping changes made during the past ten years in magneto design and construction has resulted in the universal acceptance of the rotating magnet principle and the use of Alnico magnets. The trend today is toward further simplification, compactness and reduction in cost.

Introduction of new materials and improvement in old materials will be the most important factors in future magneto development. Continued research in steel alloys promises more powerful Alnico magnets as well as lamination steels of greater efficiency. Metals such as aluminum and magnesium will be developed to a point where they will be used to an advantage for many purposes. Better insulating materials have been developed, making possible the production of an entirely encapsulated molded high tension coil of epoxy compound; another example of improved performance standards. Plastics, ceramics and glass are now developed to a point where they will have far reaching effects on the designs of future ignition units.

The trend of the past toward the use of ignition systems completely shielded, so as not to cause radio interference, has been fully accepted and further developed. Today this type magneto is in use on far too many installations to mention here.

The great strides made in the development of the electronic tube may result in the replacement of the mechanically operated breaker mechanism by an electronic controlled switch.

Servicemen everywhere should make every effort to keep up to date on the many new developments in magneto ignition systems. One of the more important phases of the service industry is the complete replacement of obsolete equipment with the new and better units.

SECTION TWO
MAGNETISM & ELECTRICITY

APPLICATION OF FUNDAMENTAL THEORY

A clear and thorough working knowledge of the fundamental principles of magnetism and electricity is essential to service technicians engaged in the analysis, maintenance and repair of magneto ignition units and systems.

A magneto functions as the result of a synchronized combination of magnetic and electric circuits, these circuits being interlocked both mechanically and electrically. In the discussion which follows the theoretical basis for each of the circuits is developed and explained separately, their inter-relation being described in a later section when the operation of the complete magneto is analyzed (See Page 24).

MAGNETISM

A complete, sound explanation of magnetism has not yet been established, although some of the characteristics and effects have been known for centuries. To the average person the invisible forces surrounding magnetic poles are usually somewhat mysterious, possibly because their origin is seldom understood.

Magnetism, however, furnishes the absolute basis for the design of magnetos, as well as for most other electrical machinery. The importance of reviewing and analyzing the known facts and theories cannot be overemphasized.

MOLECULAR THEORY OF MAGNETISM

It has been well established by scientific research and reasoning that all matter is composed of atoms. Atoms are the ultimate division of matter in which the characteristics of the known elements are retained. Most substances, however, are composed of several elements, the atoms of the elements combining to form molecules, the smallest possible division of the substance to retain the physical characteristics of the substance. Conversely, the physical characteristics of a substance are determined by the kinds of atoms in its molecules as well as by their arrangement.

Magnetism is believed to result from the arrangement of the molecules in a particular material. It is assumed that the molecules of any substance are in constant motion, the pattern of such motion being entirely haphazard. When a material is placed in a magnetic field this pattern of molecular motion is subject to change, the extent depending greatly upon the nature of the material. In cases where the change is so great that the molecules line up to form a definite current, magnetic poles appear at the points of greatest concentration of positive or negative charges, and a field of force lines surround the space adjacent to the molecular path.

In certain steels the pattern of molecular motion continues even after the magnetizing force is removed, the steel thereby retaining the properties of a magnet and being classified as a permanent magnet. In other steels and nearly all other materials the pattern of molecular motion breaks up almost immediately when the magnetizing force is removed, the magnetic properties disappearing simultaneously.

TYPES OF MAGNETS

The basic classification of magnets group known types as either permanent or temporary magnets.

Permanent magnets occur in nature in the lodestone (magnetite ore) which was discovered hundreds of years ago, together with its remarkable properties of attracting bits of iron and of assuming a north and south direction when suspended in air. Subsequently it was learned that this magnetism could be transferred, as for example when a steel needle was brushed by a lodestone it acquired to some degree the magnetic properties of the lodestone. The fact that these magnetic properties were retained for an indefinite period by certain materials was the original basis for the definition of a permanent magnet.

Temporary magnets retain their magnetic properties only as long as the original magnetizing force is present.

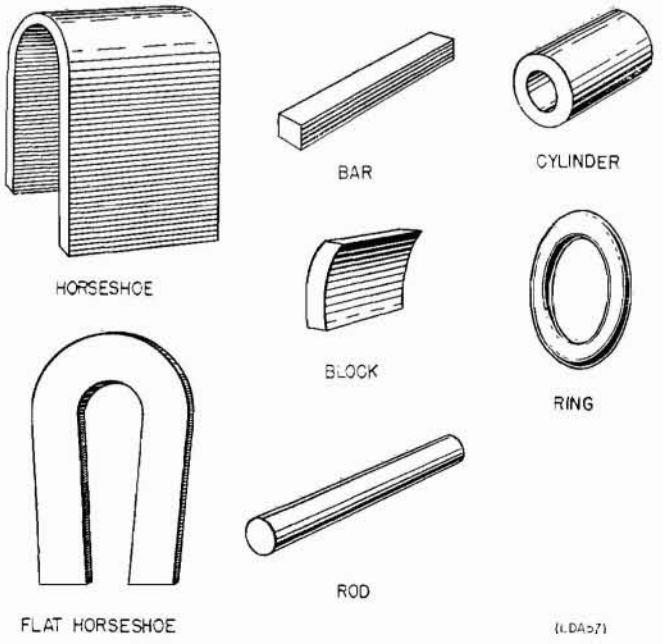


Figure 2—Physical Shapes of Permanent Magnets

Thus a piece of soft iron when placed adjacent to a permanent magnet will exhibit all the properties of the permanent magnet, except that when the permanent magnet is removed, the soft iron immediately loses its magnetic properties. Such a magnet is sometimes called an induced magnet. Another type of temporary magnet is the electromagnet, which is produced by passing an electric current through a coil wound around a soft iron core.

PHYSICAL SHAPES OF PERMANENT MAGNETS

Permanent magnets are available in a great many physical shapes (Figure 2), among the most common being the familiar horseshoe type and the plain bar or rod. The recent development of stronger permanent magnet steels has permitted the use of smaller and more compact magnets in magneto construction, with far-reaching design changes as a result.

Magnet steels such as tungsten, chromium and cobalt can be cast, forged or rolled into the physical shapes desired and can be machined for the final fit. The new Alnico steel can be either cast or "sintered", a process by which the powdered metals of the alloy are formed into the desired shapes by the application of heat and tremendous pressure. Alnico is an extremely hard, crystalline metal and cannot be machined by ordinary methods; it can, however, be cut with a grinder or rubber wheel.

DEMAGNETIZATION

Permanent magnets are permanent only in a relative sense. It is perfectly possible to completely demagnetize the best known permanent magnet steel. This can be accomplished by one or more of three general methods.

(a) Application of a sufficiently strong field of opposite polarity.

(b) Heating to a high temperature.

(c) Subjecting the piece to mechanical vibration.

Deliberate demagnetization is often necessary in machine shops in order to eliminate undesirable magnetism in crankshafts or other metal pieces.

Causes of demagnetization are equally important in the case where it is desired that a piece of steel retain its magnetism. The same three general methods listed above tend toward the demagnetization of steel (stray fields of opposite polarity, high temperatures, mechanical vibration). The ability a steel has to hold its magnetism in spite of these demagnetizing forces is known as its retentivity, and is a highly important factor in the selection of permanent magnet steel to be used in magneto construction.

PERMANENT MAGNET MATERIALS

Pure, soft iron does not retain magnetism, but many steel alloys have been found which do possess this property. Among these alloys are the chromium, tungsten and cobalt steels. Their magnetic retentivity varies, the cobalt steel being somewhat superior, but at the same time several times as expensive. The percentage composition of all of the magnetic alloys is a critical factor in their final characteristics.

The development of an aluminum-nickel-cobalt alloy of steel known as Alnico has during recent years practically obsoleted all other steels as permanent magnet material, at least in the magneto field. Alnico has more available energy for a given volume than any other permanent magnetic material; this greater stored energy being available at a lower cost. Because of its higher coercive force shorter and more compact magnets may be used, permitting considerable improvement in the design and construction of instruments requiring permanent magnetic fields. Alnico also possesses much greater stability than other permanent magnets as explained in the following paragraph.

STABILITY OF ALNICO MAGNETS

Possibly the greatest advantage in using Alnico magnets in place of other steels in the construction of magnetos is its extreme stability as a permanent magnet. Tests have shown that stray fields have only a very slight demagnetizing effect until they become very powerful (Figure 3), that temperatures up to 500°C. produce no discernible effect and that resistance to vibration is much greater than that of any other permanent magnet material (Figure 4).

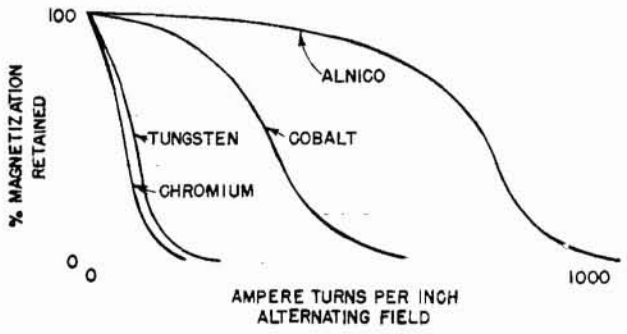


Figure 3—Effect of Stray Fields on Magnet Steels

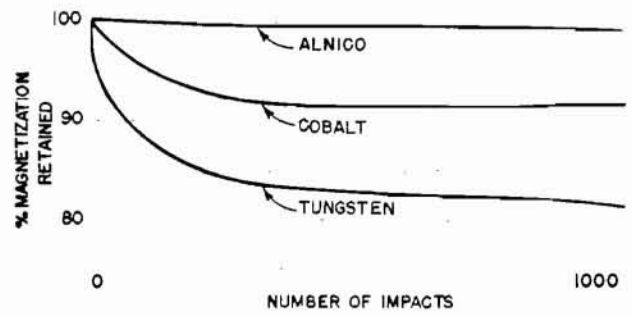


Figure 4—Effect of Vibration on Magnet Steels

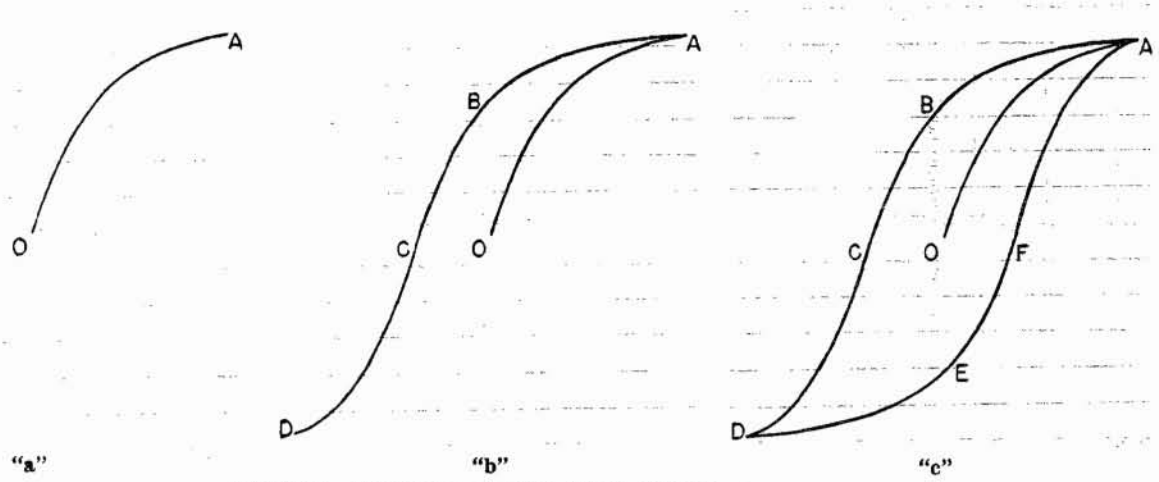


Figure 5—Development of a Hysteresis Loop

MAGNETIC CHARACTERISTICS OF STEELS

The magnetic characteristics of thousands of steels have been determined in extensive laboratory research programs devoted to tests of the retentivity, reluctance and magnetic saturation values of the steels.

Retentivity as explained in a preceding paragraph is the ability of a steel to retain magnetism.

Reluctance of a steel is defined as the resistance offered to the establishment of a magnetic flux path. Permeance is the reciprocal of reluctance and therefore indicates the ease with which a magnetic flux path can be established.

The magnetic saturation point of a steel is reached when further increases in the magnetizing force fail to produce any corresponding increases in the magnetic strength of the steel.

DEVELOPMENT OF THE HYSTERESIS LOOP

The study of the magnetic qualities of various steels is part of a research program concerned with magnetic hysteresis, which is defined as the lag of the magnetic flux in a material behind the magnetizing force. Hysteresis tests indicate graphically the important magnetic properties of a steel in a curve known as the hysteresis loop.

The hysteresis loop is the complete record of results obtained when a piece of steel is subjected to a variable magnetic field of known strength. As the strength of the field is increased from zero the magnetism of the steel increases as shown by the curve (Figure 5 "a") until a point (A) is reached, beyond which any further increase in the strength of the field does not produce any appreciable change in the magnetism of the steel. This point is known as the saturation point and is important because it indicates the maximum limit of magnetic strength which can be absorbed by the particular steel.

After reaching the saturation point, the magnetizing force is decreased until it reaches zero, the decreasing strength of the magnetism in the piece of steel being indicated by curve AB (Figure 5 "b"). It should be noted here that diminishing the magnetizing force to zero does not, however, return the steel to a neutral state, the amount of magnetism which remains in the steel being indicated by OB and known as the residual induction or magnetism.

Proceeding with the next step the polarity of the magnetizing force is reversed and then increased until the piece of steel reaches a neutral state as shown by the portion of the curve BC (Figure 5 "b"). The amount of magnetizing force necessary to bring the steel back to a neutral state is then indicated by OC, which is known as the coercive force for the particular steel.

As soon as the piece of steel has passed through its neutral state, and if subjected to an increasing magnetizing force, it will become magnetized in the opposite direction until it reaches the saturation point D (equal and opposite to A) as indicated by the portion of the curve CD (Figure 5 "b").

After the saturation point D has been attained, the magnetizing force is again diminished to zero (Figure 5 "c"), leaving a residual magnetism of OE (equal and opposite to OB). The magnetizing force is then reversed and increased until the steel again reaches a neutral state, and the coercive force OF (equal and opposite to OC) is indicated. Increasing the magnetizing force will then bring the steel back to its original saturation point.

It should be noted that only during the original magnetization of the piece of steel will the curve OA be secured, all subsequent changes occurring on the hysteresis loop ABCDEFA.

SIGNIFICANCE OF THE HYSTERESIS LOOP

The analysis of the hysteresis loop for a particular steel reveals most of the steel's important characteristics in relation to magnetism. In general there are two basic viewpoints: (a) use of the steel as a permanent magnet and (b) use of the steel as part of a magnetic circuit.

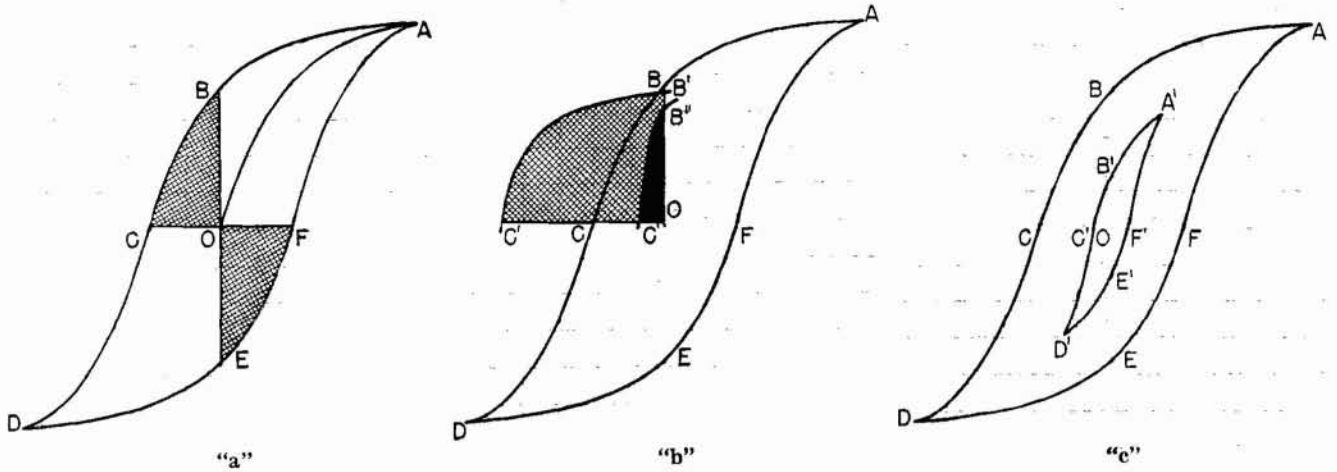


Figure 6—Significance of the Hysteresis Loop

The desired magnetic qualities of the steel are opposite for the two cases.

The area ABCDEFA within the hysteresis loop (Figure 5 "c") is directly proportional to the energy required to pass the steel through a complete magnetic cycle (that is, from the positively magnetized state through neutral to the negatively magnetized state, and back through neutral to the positively magnetized state). In choosing a steel for a permanent magnet this area should be as large as possible, while a steel for laminations should have a loop with as small an area as possible. The area of a hysteresis loop can be measured and by introducing the proper conversion factors the energy used can be given in watts. In the case of transformers this energy is known as the "transformer loss", and is important in computing the temperature rise.

The quality of a permanent magnet is usually judged by its coercive force and by the maximum of the product of its coercive force and its flux density.

The areas OBC and OEF (Figure 6 "a") are the basis for laboratory comparison of permanent magnet steels. For a chrome or tungsten steel the area OB"C" (Figure 6 "b") is very small in comparison with the areas OB'C' indicated for an Alnico steel.

The importance of completely magnetizing a permanent magnet steel is also demonstrated by comparing the hysteresis loops for different amounts of magnetization (Figure 6 "c"). Loop ABCDEA was obtained when the steel tested was magnetized to its saturation point (A), while loop A'B'C'D'E'A' was obtained when the maximum magnetization of the steel amounted to somewhat less than saturation (A'). Note the great differences in residual magnetism (OB/OB'), in the coercive force (OC/OC') and in the area (OBC/OB'C').

MAGNETIC ATTRACTION & REPULSION

When one of the poles of a magnet is held in the vicinity of a compass the compass needle turns and the north-seeking point is either attracted or repelled. Similarly, if one pole of a magnet is held in the vicinity of a pole of another magnet, there is either attraction or repulsion. From such experiments it has been established that like poles (that is, two north poles) repel each other, while unlike poles (that is, a north and a south pole) attract each other. The force exerted between two magnetic poles, either of attraction or repulsion, varies inversely as the square of the distance between them.

Unmagnetized iron is attracted equally by either north or south poles.

The north-seeking pole is often designated as the positive pole of a magnet while the south-seeking pole then becomes the negative pole.

MAGNETIC FIELD

Since the influence of a magnetic pole is apparent when the pole is in the vicinity of some magnetic material, it is reasonable to assume that a field of force surrounds the pole. To demonstrate the presence of this field and for an idea of its shape and extent a simple experiment can be conducted as follows: Lay a magnet, preferably of the bar type, on a flat surface and cover it with a piece of paper. Then shake iron filings on the surface of the paper and observe the pattern which is formed (Figure 7). The concentration of filings at the poles indicates that the strength of the field is greatest at these points, while the fact that some of the filings come to rest between the poles indicates that the field extends from one pole to the other. The experiment can be continued to show that, if two magnets are placed beneath the paper, the magnetic field will, no matter what the position of magnets, extend between unlike poles (Figures 8 & 9).

MAGNETIC FIELD STRENGTH

A convenient conception of the condition existing when unlike magnetic poles are placed a short distance apart is to imagine the two poles connected by lines of force

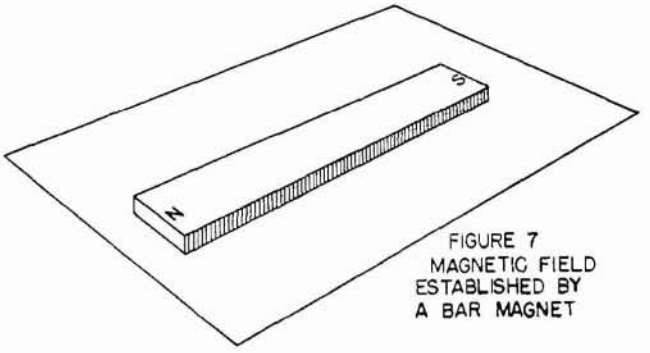


FIGURE 7
MAGNETIC FIELD
ESTABLISHED BY
A BAR MAGNET

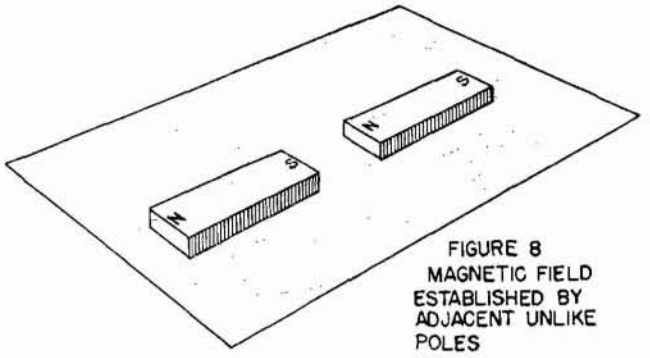


FIGURE 8
MAGNETIC FIELD
ESTABLISHED BY
ADJACENT UNLIKE
POLES

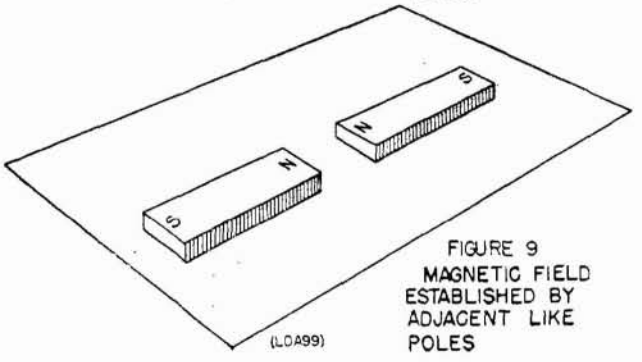


FIGURE 9
MAGNETIC FIELD
ESTABLISHED BY
ADJACENT LIKE
POLES

(Figure 10). Furthermore, these lines of force can be thought of as being elastic, with a tendency to shorten themselves as much as possible. This characteristic accounts for the pull which unlike poles exert upon one another, or upon magnetic substances.

There must be noted in connection with the conception of a magnetic field that there is a dispersal effect as the distance from the pole increases; if the field is thought of as being made up of lines of force, it follows that these lines of force can be considered to repel one another (Figure 11).

By establishing as a standard the strength of a magnetic field assumed to have only one line of force per unit area, the strength of other magnetic fields can be determined by comparison.

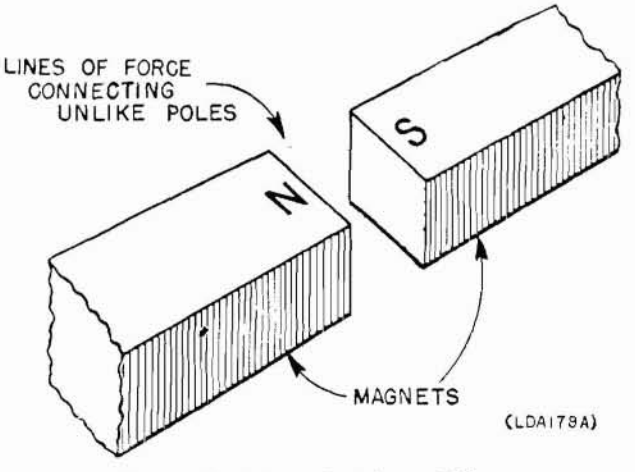


Figure 10—Magnetic Lines of Force

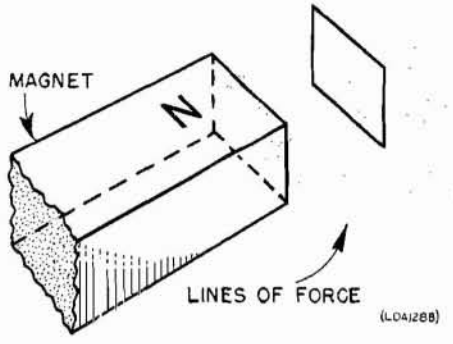


Figure 11—Dispersal Effect of a Magnetic Field

MAGNETIC CIRCUITS

There is no insulator for magnetism known; a magnetic field extends itself readily through glass, rubber or other materials. It is possible, however, to confine the magnetic field within predetermined limits by establishing a closed magnetic circuit.

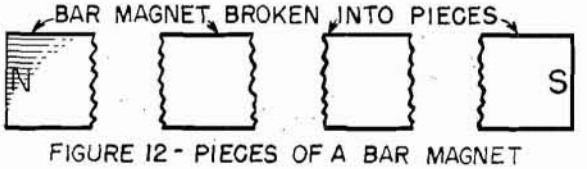


FIGURE 12 - PIECES OF A BAR MAGNET

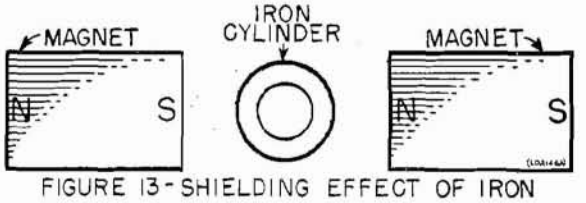


FIGURE 13 - SHIELDING EFFECT OF IRON

When a bar magnet is broken into pieces at right angles to its axis (Figure 12), each piece becomes a separate magnet, one edge of each break becoming a north pole while the opposite edge becomes a south pole. If the pieces are placed in line in the order in which the bar was broken, the original bar magnet is reconstituted, even though the individual pieces are slightly separated, the magnetic flux passing from the end of one piece across an air gap to the end of the adjacent piece. The magnetic circuit formed is not considered a closed circuit, however, since the two end poles have no adjacent, opposite poles. The field established must therefore be

somewhat on the order of the original field established by an unbroken bar magnet (Figure 7).

In explaining the basis of magnetic circuits another important point must be noted. If two magnets are placed some distance apart with opposite poles adjacent and a piece of iron placed in the space between them, it will be found that practically all the magnetic flux linking the two poles passes through the iron rather than the air. If the piece of iron is in the form of a cylinder (Figure 13), no magnetic flux will be found inside the cylinder. This shielding effect of iron is of great importance in confining magnetic fields within desired limits.

A closed magnetic circuit is established when a piece of iron is placed across the poles of a horseshoe magnet (Figure 14 "a"). The magnetic flux in such a case will be found to be confined to the steel of the magnet and the iron bar. Identical results are obtained with two bar magnets and two pieces of iron (Figure 14 "b").

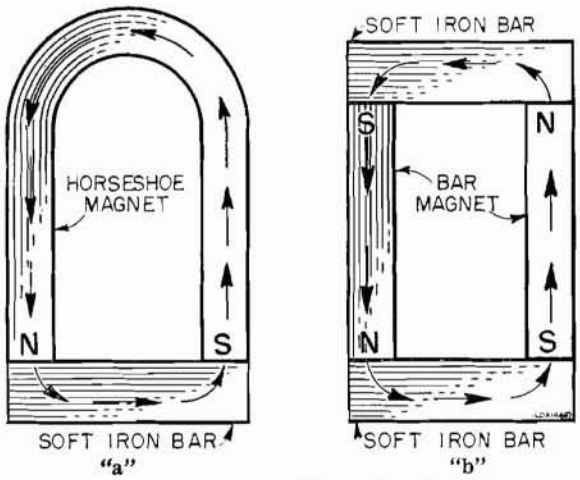


Figure 14—Closed Magnetic Circuits

The principle of a closed magnetic circuit is the basis for the design of electric generators and motors. The closed magnetic circuit mentioned above is so arranged that a part of the circuit can be rotated (Figure 15 "a"); this part may be either the magnet or the iron connecting the poles. Assuming the rotating piece to be the magnet, a small amount of turning will still leave the magnetic circuit intact although the flux lines become quite crowded (Figure 15 "b"). A further turning, however, breaks the circuit (Figure 15 "c"), but a new and opposite circuit is established when the magnet approaches a position exactly opposite its original position (Figure 15 "d"). Rotation of the magnet therefore establishes an alternating flux (complete reversals) in the magnetic circuit; if the rotating member were a piece of iron forming part of the magnetic circuit, an intermittent flux (no reversals) would be established.

ELECTRICITY

Some consideration must be given to the basic theory of electricity before examining the interlocking effects of magnetism.

In developing an explanation of magnetism (Page 5) the statement was made that the smallest possible division of an element is the atom. The atom in turn is an assembly of an equal number of positive charges known as protons and negative charges known as electrons. the total number of protons and electrons being determined by the particular element. It is believed that such a division results in uniform factors for all matter; that is, that all protons, as well as electrons, are identical regardless of the elements which they constitute.

The accepted conception of the structure of the atom groups all of the protons and about half of the electrons in a compact nucleous which serves as the center for an orbitary system in which the remainder of the electrons are in constant, rapid motion. Some of these electrons can be detached by various methods, especially in the case of metals, and a transfer of electrons from one atom to another established. Substances in which the electrons can be moved on application of an electric force are known as conductors, while other bodies in which no movement of electrons is discernible are classed as insulators.

The electron is the smallest definite quantity of electricity known, the value of its charge being 4.774×10^{-10} electrostatic units. An electrostatic unit is that quantity of electricity which, when concentrated at a point unit distance from an equal and similar quantity, and surrounded by air, will be repelled by a force of one dyne.

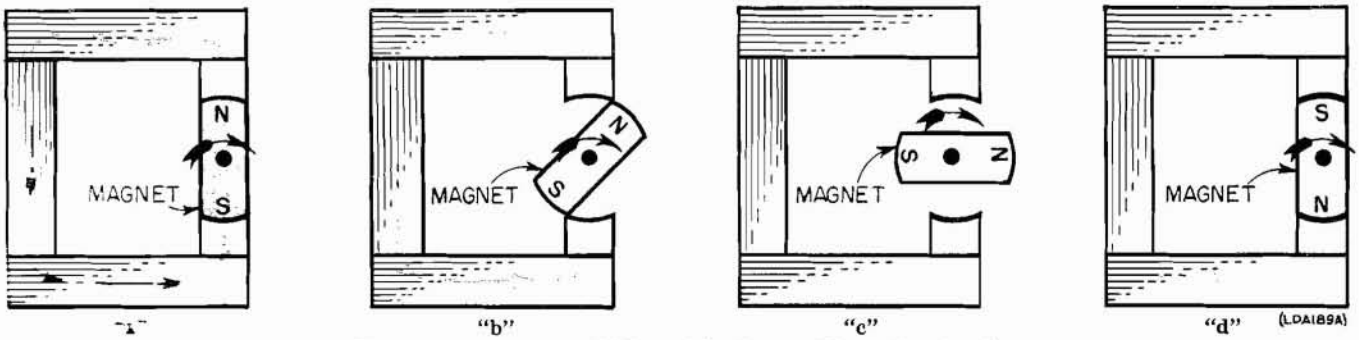


Figure 15—Rotation of Magnet in Closed Magnetic Circuit

ELECTRIC CURRENT

The fact that electrons can be detached from the outer orbitary paths of one atom and transferred to the orbitary system of another atom provides the basis for the accepted definition of an electric current. Any inter-atomic movement of electrons can, by this reasoning, be considered an electric current, but more practically a current is defined as the orderly movement of electrons along a conductor. In many respects the passage of electrons along a conductor can be compared with the flow of water through a pipe.

A direct current is a current in which the electronic movement is unidirectional, although the value of the current may vary or pulsate. An alternating current is a current in which the direction of movement of the electrons reverses periodically, first being positive then negative—alternating between maximum positive and negative values.

The path of an electric current is known as a circuit, the electrons moving from a point of excess electrons (negative) to a point of electron deficiency (positive).

The unit of measurement of electric current is the ampere.

ELECTRIC POTENTIAL (VOLTAGE)

To make water flow through a pipe, there must be a difference of pressure between the inlet and the outlet. To make electric current flow along a conductor there must be a difference in potential between the two ends of the conductor. Electric potential (commonly known as voltage) is the excess of electrons which exist at one point in comparison with some other point.

The practical unit of electric potential is the volt.

Electric potential is established by electro-magnetic induction, chemical reactions and other less used methods.

RESISTANCE

When water flows through a pipe, the quantity which actually passes a certain point is limited by the friction of the walls of the pipe. A similar condition exists in the flow of an electric current in a conductor, where the opposition to the passage of electric current is termed the resistance. Both the water friction in the pipe and the electric resistance in the conductor result in a heat loss which can be computed.

Resistance to electric current varies widely with different materials. Silver has the lowest known resistance, but most other metals, especially copper, also have comparatively low resistance. Materials with a low resistance are known as conductors, while those with a very high resistance, such as mica, rubber, glass and air are known as insulators.

The practical unit of measurement of resistance is the ohm.

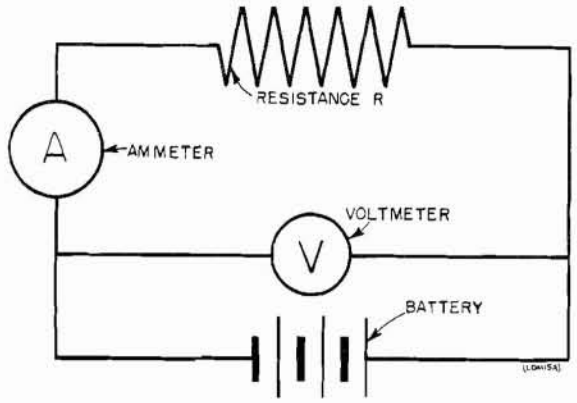


Figure 16—Simple Electric Circuit

OHM'S LAW

An electric circuit (Figure 16) always involves factors of potential (volts), current (amperes) and resistance (ohms). The relationship of these factors is expressed by Ohm's law: when a steady direct current flows in a circuit the current is directly proportional to the voltage and inversely proportional to the resistance. When the current is expressed in amperes, the voltage in volts and the resistance in ohms, the law takes the form of the following important equations:

$$I = \frac{E}{R} \quad (1) \qquad E = IR \quad (2) \qquad R = \frac{E}{I} \quad (3)$$

The equation (2) should be especially noted since it is the basis of voltage drop calculations. The voltage drop E, across a known resistance R, through which a known current I, is flowing is by definition IR.

RESISTANCE IN SERIES

When two or more resistances are placed in a series circuit (Figure 17) the total resistance is the sum of the individual resistances.

$$R = R_1 + R_2, \text{ etc.}$$

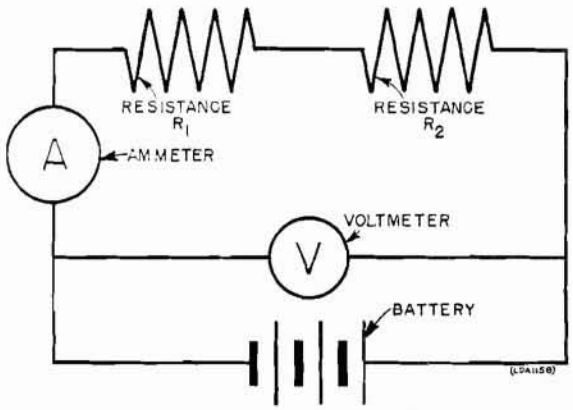


Figure 17—Resistances in Series

RESISTANCES IN PARALLEL

When two or more resistances are placed in a parallel circuit (Figure 18) the total resistance is the reciprocal

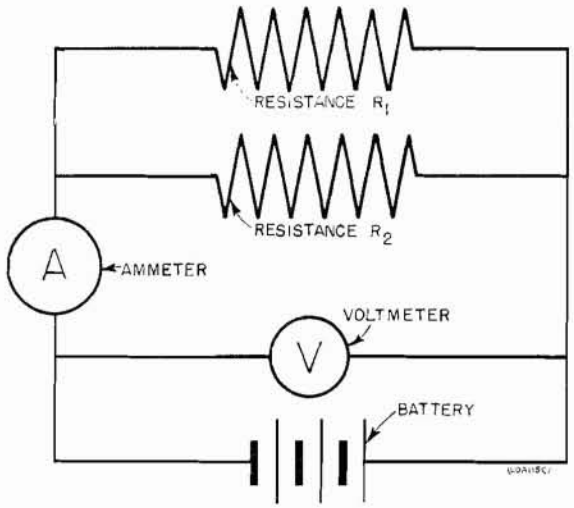


Figure 18—Resistances in Parallel

of the sum of the reciprocals of the individual resistances.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \text{ etc.}$$

The reciprocal of resistance is called the conductance and is often used as such in solving for values in parallel circuits.

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

THE WHEATSTONE BRIDGE

The Wheatstone bridge is a simple electric circuit (Figure 19) set up primarily for the comparison of resistance values. In establishing a comparison circuit of this type at least one known resistance of suitable size is required, while the resistances in the other two legs of the bridge need give only a proportional value.

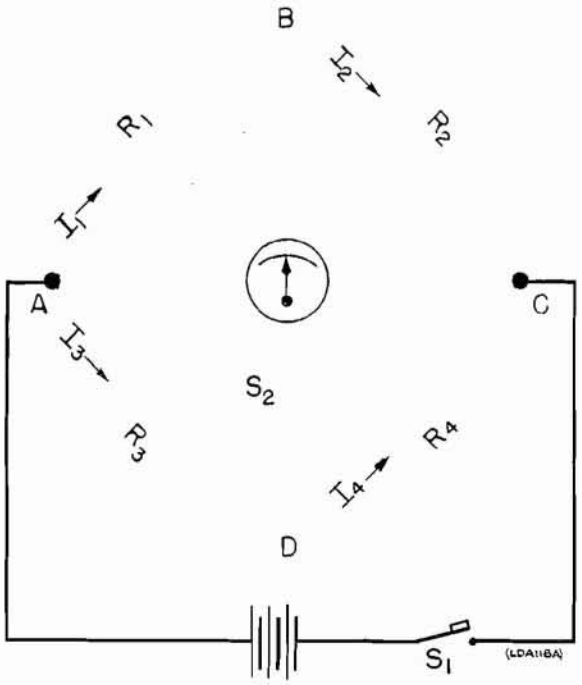


Figure 19—Circuit Diagram of the Wheatstone Bridge

In practice the Wheatstone bridge often consists of a board on which a long, straight resistance wire is mounted adjacent to an evenly divided rule (Figure 20). Connections are provided for the known and unknown resistances and for a battery and indicating instrument. By moving the sliding contact along the resistance wire the proportionate value of two of the legs of the circuit can be determined, and the value of the unknown resistance solved by a simple calculation.

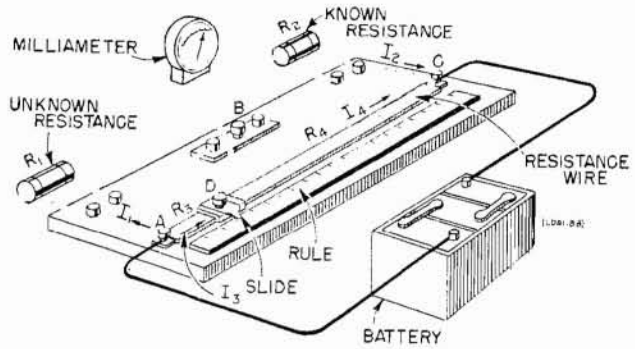


Figure 20—Simple Layout of the Wheatstone Bridge

To determine a resistance value with the bridge circuit a state of balance must first be obtained. With switch S_1 closed so that current flows through the circuit, the resistances R_3 and R_4 must be so adjusted that when switch S_2 is closed no current flows through the center connection BD. Consequently points B and D must be at the same potential and the voltage drop from A to B (R_1I_1) equal to that of A to D (R_3I_3). Similar reasoning establishes the voltage drop from B to C (R_2I_2) equal to that of D to C (R_4I_4). Since no current flows through the center connection, the current in branch AB (I_1) is equal to that of BC (I_2), while the current in branch AD (I_3) is equal to that of DC (I_4). Substituting these current values and dividing:

$$\frac{R_1I_1}{R_2I_2} = \frac{R_3I_3}{R_4I_4} \text{ and } \frac{R_1I_1}{R_2I_1} = \frac{R_3I_3}{R_4I_3}$$

which gives:

$$R_1 = \frac{R_2R_3}{R_4}$$

ELECTRIC CIRCUITS

Electric circuits consist of series circuits, parallel circuits or combinations of both (Figure 21). In a series circuit the entire current flows successively through each section of the circuit. In a parallel circuit the current divides and flows through the various sections.

Kirchhoff's laws of circuits are especially helpful in solving for the various values in a direct current circuit. The first law states that the algebraic sum of all the currents flowing through a point in an electric circuit equals zero. An equation which expresses this law is:

$$I_1 = I_2 + I_3 \quad \text{or} \quad I_1 - I_2 - I_3 = 0$$

The second law of Kirchhoff can be stated as the algebraic sum of all the voltage drops in a series circuit equals zero. In equation form an example of this law is:

$$E = I_1R_1 + I_5R_5 \quad \text{or} \quad E - I_1R_1 - I_5R_5 = O$$

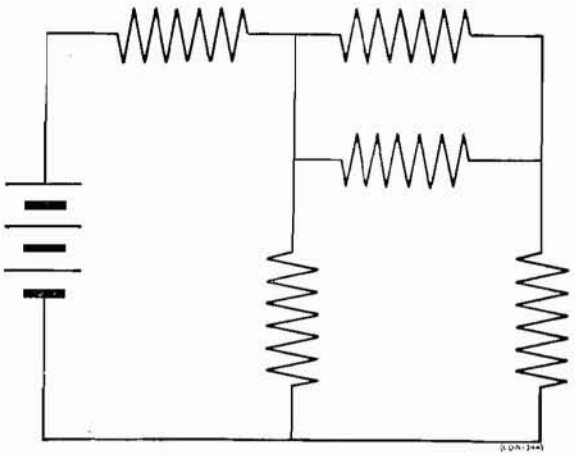


Figure 21—Electric Circuit

ELECTRO-MAGNETIC FIELD

When a compass is placed near a wire carrying an electric current, it will be noted immediately that the compass needle moves to establish a definite relation to the direction of the current in the wire. This action indicates the presence of a magnetic field around the wire and the compass can be used to determine the extent and direction of the flux lines composing the field. As shown in Figure 22 the flux lines surrounding a straight wire have been found to be concentric with the wire, their direction being indicated by the "right hand rule".

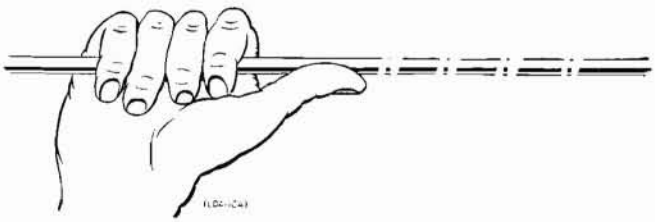


Figure 22—Field Surrounding a Straight Wire

According to this rule, if a wire carrying a current is grasped in the right hand with the thumb pointing in the direction the current is flowing, the curved fingers will point the direction the flux lines encircle the wire.

FIELD SURROUNDING A HELIX

When the straight wire of Figure 22 is bent into a loop as shown in Figure 23, the electro-magnetic field surrounding it is concentrated through the center of the loop. The direction of the flux lines around the wire will retain the same relation to the direction of the current.

If additional loops are added in the wire until a helix

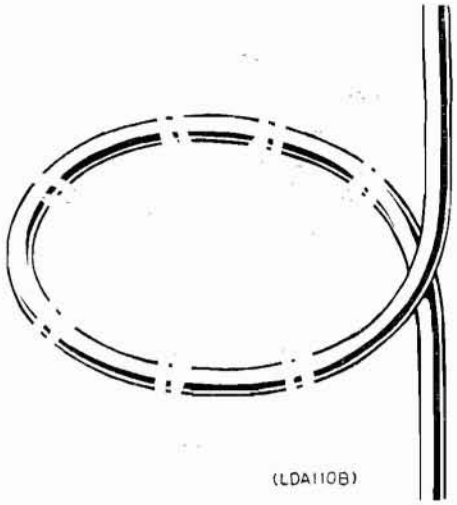


Figure 23—Field Surrounding a Wire Loop

is formed, each loop will establish a field similar to that shown in Figure 23, but as the proximity of the loops increases it has been found that flux lines extending in the same direction form a continuous field through the center of the helix and around its ends (Figure 24). Some of the lines surrounding each of the individual loops still remain, the number of such lines decreasing as the loops are wound closer together.

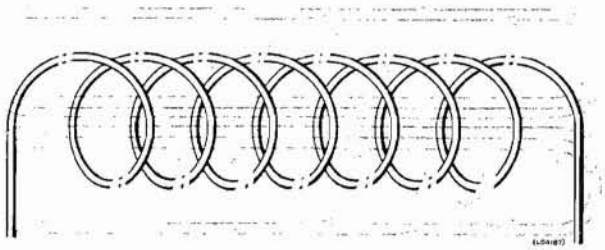


Figure 24—Field Surrounding a Helix

If the ends of a helix carrying a current are tested with a compass, it will be found that each end has the definite characteristics of a magnetic pole, and that the opposite ends of the helix have opposite poles.

INDUCTANCE

It has been shown (Figure 24) that when a current passes through a helix, a magnetic field surrounding the helix is established. When the current stops, this magnetic field collapses. Since the field established by each individual loop of the helix interlocks adjacent loops, any change in the field means that adjacent loops must cut lines of the field (Figure 25) with the result that a current is induced. The direction of this current is such as to oppose any change in the field surrounding the helix. The effect is termed self-inductance and has often been used in connection with low tension ignition circuits (See Page 23).

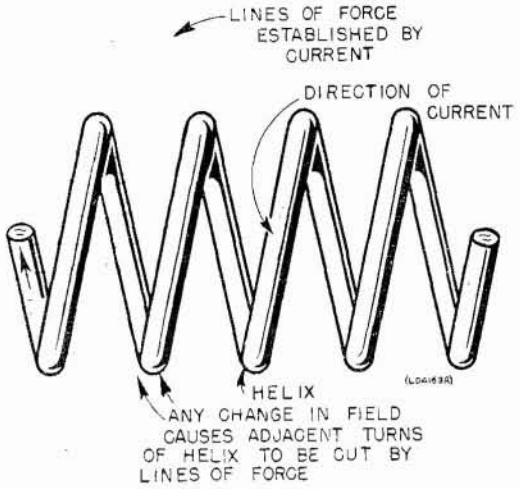


Figure 25—Self-Inductance

When a current flows in a straight conductor, a magnetic field is established surrounding the conductor (Figure 22) in what may be thought of as concentric circles. Any increase or decrease in the current produces corresponding changes in the field so that, if a second conductor is placed parallel to the first, the field will be cut by the conductor each time it rises and falls (Figure 26). If the conductor is part of a complete circuit, an induced current will flow in proportion to the current in the original circuit. The direction of the induced current is such as to oppose any change in the magnetic field of the original current. The effect is called mutual inductance and is the basis of all transformer design.

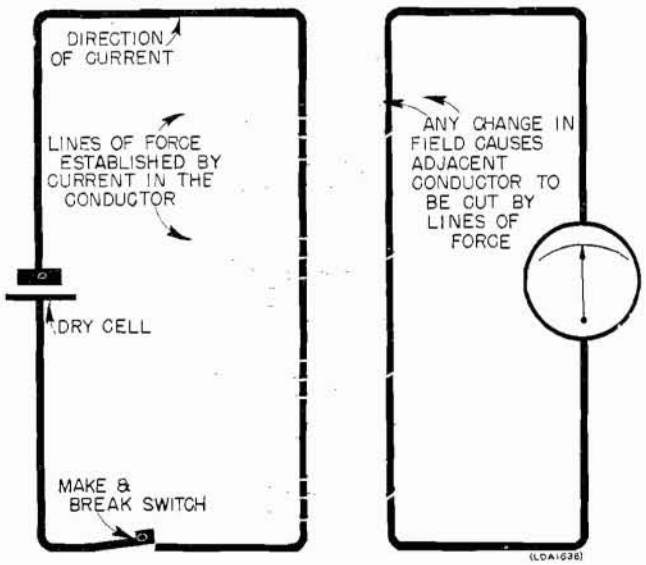


Figure 26—Mutual Inductance

TRANSFORMERS

The transformer is a practical application of the principle of mutual inductance. The assembly consists essentially of a primary winding, a secondary winding and a laminated iron core. When current flows in the primary winding, a magnetic field is established, the iron core concentrating this field so that it interlocks the secondary winding with minimum loss.

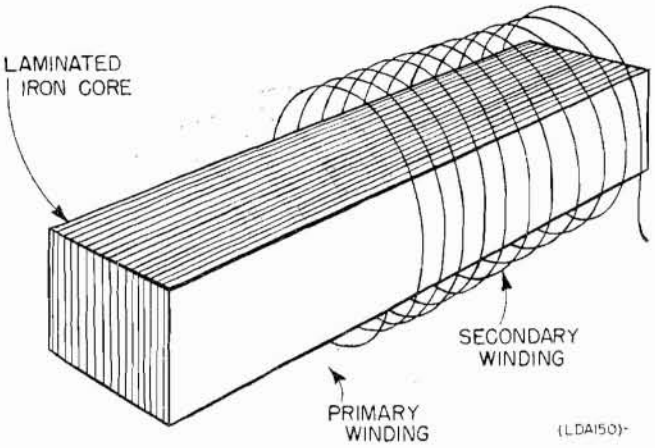


Figure 27—Simple Transformer

There are many forms of transformers, the different types usually being based on the design of the lamination assembly. In Figure 27 the simplest type is shown, where both primary and secondary windings are mounted on a straight core, while in Figure 28 a closed type core is used in order to increase the efficiency.

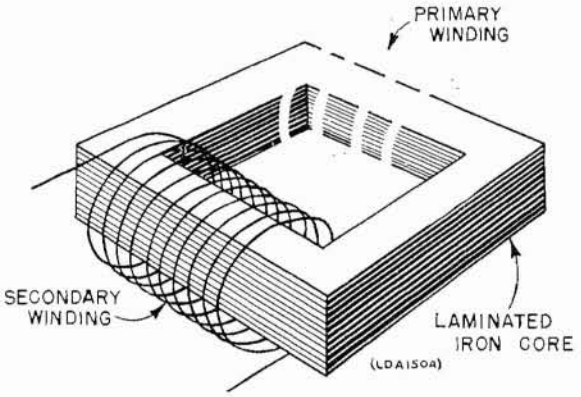


Figure 28—Closed-Core Transformer

The principal purpose of the transformer is to step voltage up or down. The ratio of the turns of the primary winding to those of the secondary winding determines the ratio of the primary voltage to the secondary voltage.

SPARK OR INDUCTION COIL

Transformer action to secure high voltage current from a low voltage supply is well illustrated in the spark or induction coil (Figure 29). Tracing the circuit shown in Figure 30, low voltage current is supplied by the battery to the contact post, across the breaker points to the primary terminal of the coil, through the primary winding

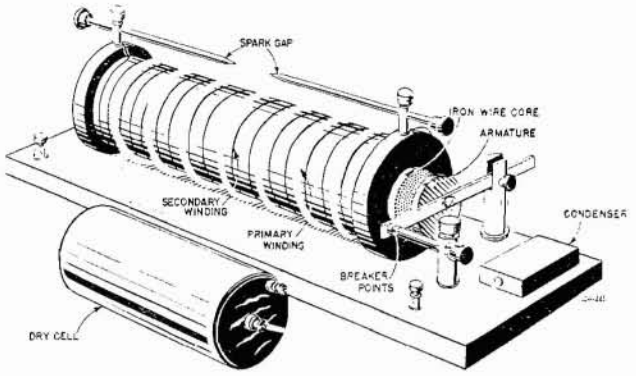


Figure 29—Spark Coil

and back to the battery. When the circuit is closed current flows through the primary winding and establishes a magnetic field, one of the results being that the iron core becomes magnetized and attracts the armature, which in turn opens the contact points and breaks the primary circuit. With the current cut, the magnetic field collapses and the armature is released, closing the contact points and repeating the cycle.

The high voltage circuit consists of a secondary winding on the coil, usually having a very high ratio of turns to that of the primary. The ends of the secondary winding are connected to a spark gap. Each time a magnetic field is established by current in the primary winding, the lines of force of the field cut the turns of the secondary winding and an electromotive force is induced, great enough to break down the spark gap and permit current to flow in the circuit. A similar condition exists when the primary circuit is broken and the field collapses.

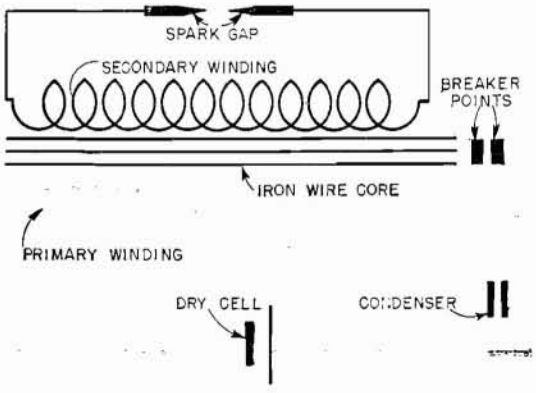


Figure 30—Circuit Diagram of Spark Coil

In a circuit such as this a condenser is usually connected across the contact points. When the armature separates the contact points the self-induction of the coil acts to prevent a break in the circuit by arcing across the points. The condenser acts to store this surge of energy and the break is much cleaner, which increases the secondary spark. After the circuit is broken, the condenser discharges back into the primary to demagnetize the core.

ELECTRO-MAGNETIC INDUCTION

When a magnet is so moved that the lines of its field are cut by a conductor, an electromotive force is induced in the conductor. Similarly, if a conductor is so moved that it cuts the lines of a magnetic field (Figure 31 "a"), an electromotive force is induced in the conductor. When the conductor is part of a closed circuit (Figure 31 "b"), an induced current will flow in the circuit.

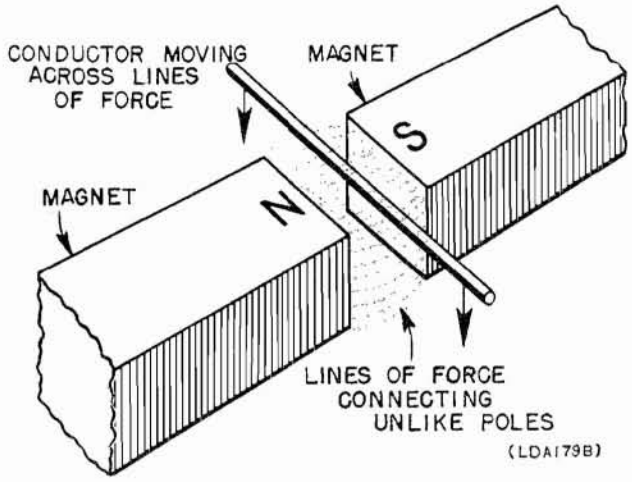


Figure 31 "a"—Electro-Magnetic Induction

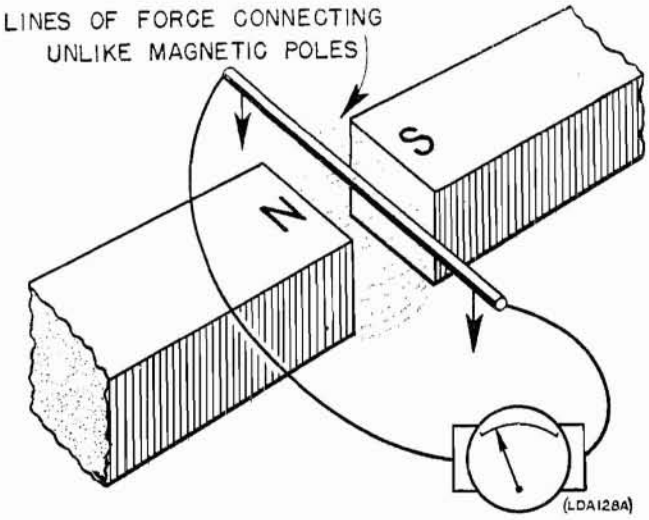


Figure 31 "b"—Induction of an Electric Current

The induced current is proportional to the strength of the magnetic field, to the rate at which the conductor cuts the lines of the field and to the number of conductors cutting the lines of the field.

The direction of the induced current is such as to establish a magnetic field which opposes the movement of the conductor. A variation of the right hand rule applies: Let the forefinger of the right hand point in the direction of the lines of the magnetic field, turn the hand so that the extended thumb points in the direction the conductor is moving; the middle finger bent at right angles to both the thumb and forefinger will then indicate the direction of the induced current.

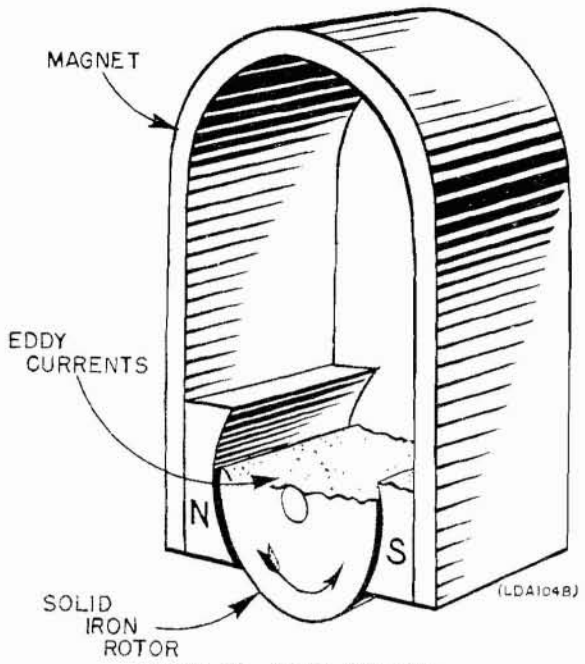


Figure 32—Eddy Currents

EDDY CURRENTS

Induced currents as a result of a changing magnetic flux appear not only in wires but also in conductors such as plates or blocks. If a solid iron rotor is turned rapidly within a magnetic field (and at right angles to the field), a definite heating effect will soon be noticed in the rotor. This heat is produced as the result of the flow of eddy currents in the rotor (Figure 32). Eddy currents flow in such a direction as to establish a field which opposes movement of the rotor. Except in the case of speedometers, watt-hour meters and similar instrument, eddy currents serve no useful purpose, but often are the cause of dangerous temperature increases due to the heat generated. Eddy currents are a direct loss in the efficiency of electrical machinery, but good design practices tend to reduce such loss to a minimum.

LAMINATED ASSEMBLIES

Since the path of induced eddy currents is at right angles to the magnetic field which causes them, it is possible to reduce such currents to a negligible factor by using what is known as a laminated assembly.

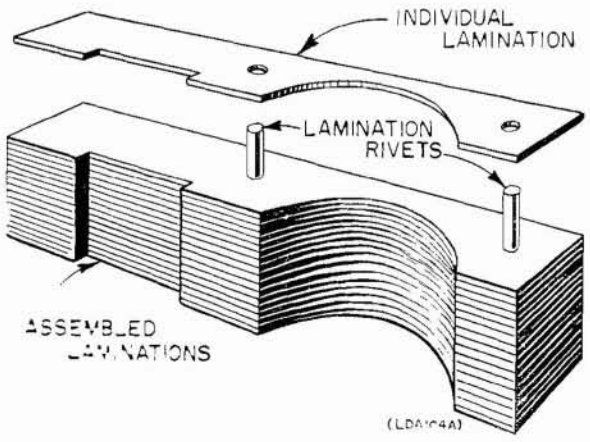


Figure 33—Laminated Field Assembly

A laminated assembly is made by stacking thin iron or steel punchings together (Figure 33) until the required pole piece, core or rotor is formed, then riveting the sheets together and machining the assembly if necessary. The plane of the laminations must be perpendicular to the direction of the induced eddy currents in order to prevent their flow; the oxide on the surfaces of the laminations usually provides sufficiently high resistance to the formation of eddy currents, although the surfaces are sometimes painted or varnished. Insulated rivets are often used in binding the assembly into one piece. The thinner the laminations and the better they are insulated from each other, the more effectively eddy currents are prevented.

Some types of ignition coils (Figure 29) are made with cores of varnished or painted iron wire, the purpose being identical with that of laminated sheet assemblies.

CAPACITANCE

In its simplest form (Figure 34) a capacitor (or condenser, as it is more commonly known) is a pair of flat metal plates, placed parallel to each other and separated by air. When the metal plates are connected to a source of electric potential, the air separating the plates undergoes a definite stress. When the electric potential is disconnected this condition of stress remains, but it may be relieved by short-circuiting the two plates, the electrical discharge which occurs indicating the amount of energy stored in the condenser.

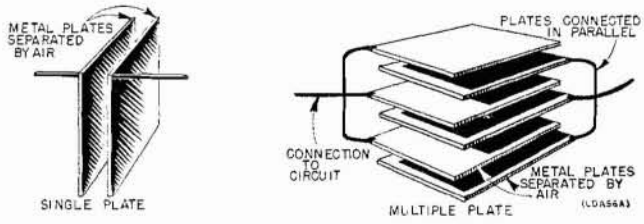


Figure 34—Simple Parallel Plate Condensers

The function of a condenser in an electric circuit corresponds with the use of a diaphragm in a water circuit.

The capacitance of a condenser depends upon the adjacent area of the plates, the distance they are separated and upon the substance separating the plates (known as the dielectric). Extensive research has been made concerning dielectrics. Probably the most familiar type of condenser (Figure 35) is of wound-construction with metal foil strips separated by wax-impregnated paper, but many other materials such as glass, mica and oil make excellent dielectrics.

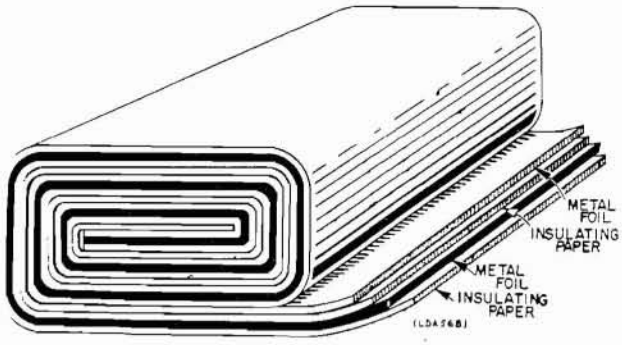


Figure 35—Paper-and Foil-Wound Condenser

INDUCTIVE & NON-INDUCTIVE CONDENSERS

Commercial condensers for ignition circuits are usually of the wound design and in order to secure the necessary capacitance often consist of comparatively long strips of foil separated by a dielectric such as paper.

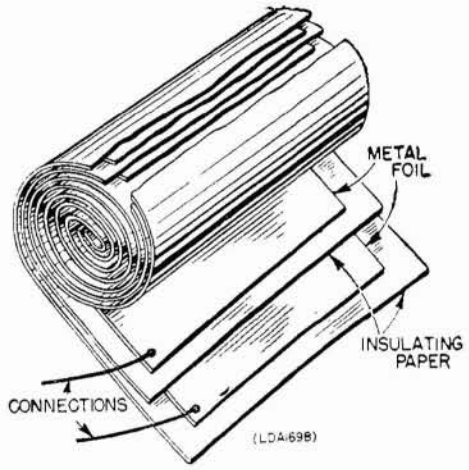


Figure 36—Inductive Type Wound Condenser

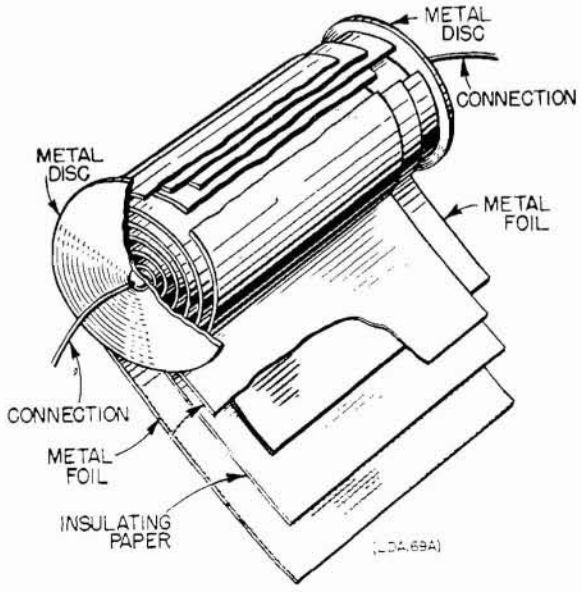


Figure 37—Non-Inductive Type Wound Condenser

Such a condenser provides the capacitance for the ignition circuit, but it has been found that when the connections are made at the extreme end of each strip of foil (Figure 36), an undesirable inductance effect also enters the electrical circuit. This type of condenser has therefore been termed an inductive condenser.

To avoid this inductance effect, a non-inductive condenser is obtained by making the connections at a number of points along the foil strips (Figure 37) instead of just at the ends. Actually this construction amounts to an arrangement of condensers in parallel, the total capacitance being the sum of the individual values.

LEAKAGE CURRENT

Insulators such as rubber or glass have enormous resistance to the flow of electric current, but it has been established that, regardless of the material, when a difference of potential exists some current actually flows. This current is called leakage current.

Leakage current results in heat, light or chemical reactions and, while the energy loss is usually negligible, the changes caused in the chemical composition of the insulator may in time destroy its insulating value.

Moisture, temperature and voltage gradient are important factors influencing the effects of leakage currents.

MEASUREMENT OF HIGH VOLTAGE

Ordinary voltmeters cannot be used to measure the high voltage of ignition spark discharges, which lie within a range of 10,000 to 30,000 volts, usually expressed as 10 to 30 kilovolts. For laboratory work a specially designed instrument known as the electrostatic voltmeter is used, but its cost and limited use hardly make such equipment worthwhile in service stations.

High voltages can be approximately measured by using

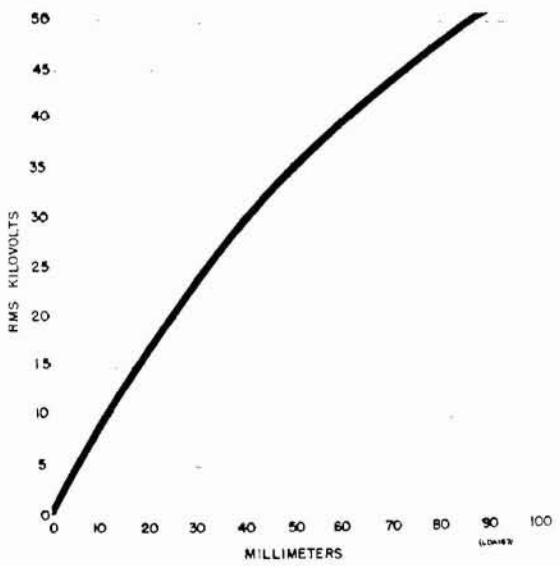


Figure 38—Spark Gap Values

an adjustable spark gap, but great care must be taken in the construction of the apparatus and in meeting certain test conditions. The values shown in the graph (Figure 38) are given for a temperature of 25°C. and 760 mm. barometric pressure.

The test apparatus consists of two No. 00 sewing needles supported axially at the ends of linear conductors which were at least twice the length of the gap and clear space surrounded the gap for a radius of at least twice the gap length. It should be noted that once the air gap between the points has been broken down by a spark discharge subsequent tests do not become dependable until all traces of ionization are removed.

For voltages over 50 kilovolts a gap between metal spheres must be used, an entirely new set of values being necessary in such a case.

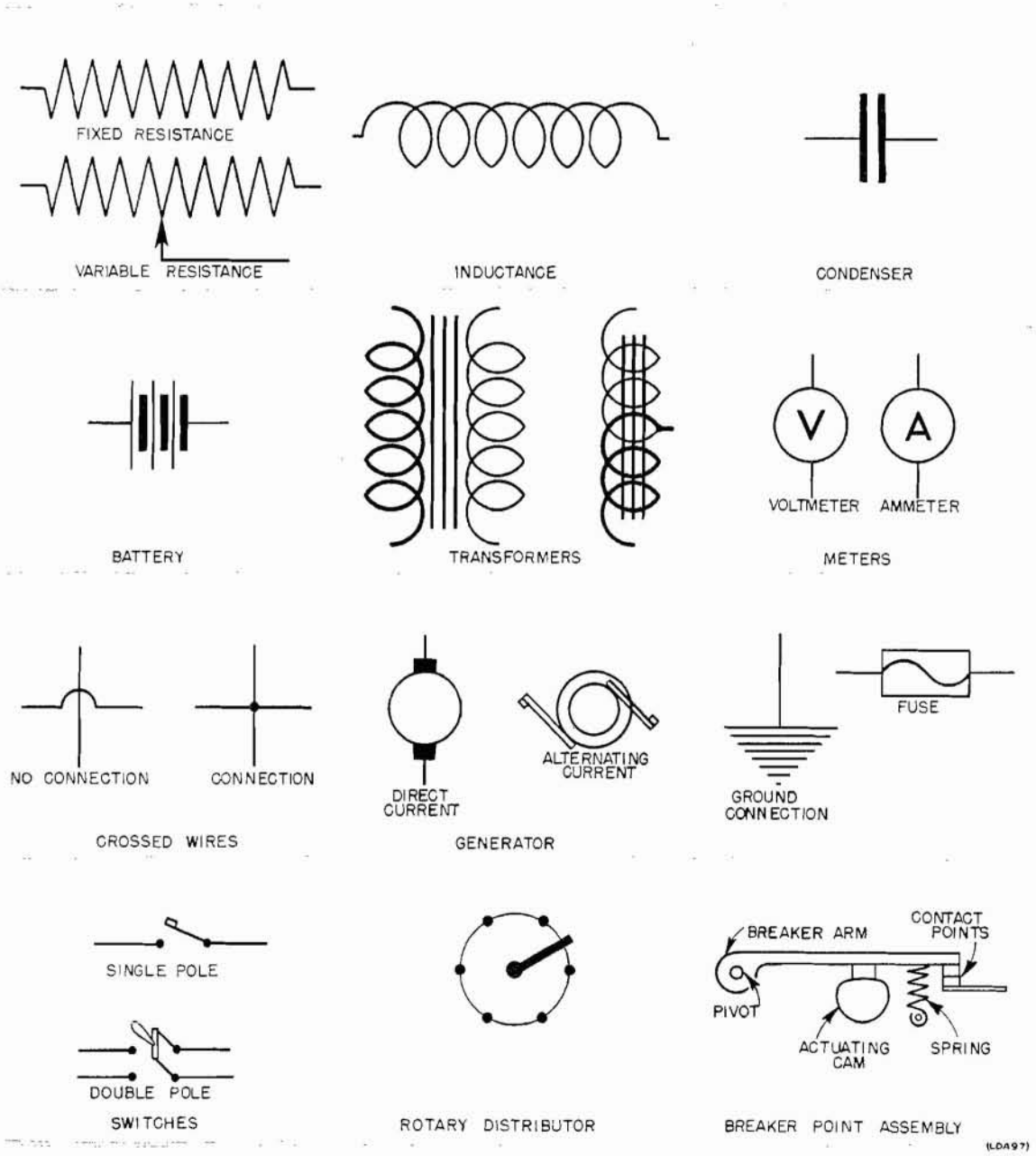


Figure 39—Conventional Drawing Symbols for Electrical Parts

SECTION THREE

IGNITION REQUIREMENTS

INTERNAL COMBUSTION ENGINES

Any discussion of ignition requirements necessitates a general knowledge of internal combustion engine design principles and operation. Internal combustion engines operate on the fundamental principle that when a combustible substance is ignited under pressure an explosion occurs, the force of the resultant expansion of the burning gases being transferred to the engine crankshaft by means of the reciprocating action of a piston.

Internal combustion engines are divided according to ignition into two main classes: (a) Compression-ignition (Diesel) engines and (b) spark-ignition engines. Engines may also be grouped according to the arrangement of their cylinders: (a) in-line, (b) v-bank, (c) radial, (d) rotary, (e) opposed piston and (f) opposed cylinders. An even broader classification divides all engines into either two or four cycle engines or into either horizontal or vertical engines.

COMPRESSION-IGNITION ENGINES

In a compression-ignition engine the air in the cylinder is compressed until it reaches a certain maximum point at which liquid fuel is injected into the cylinder, the heat of the compression at this point being sufficient to ignite the fuel. The compression ratio of the Diesel engine is several times greater than that of the average spark-ignition engine and consequently it is a decidedly more expensive engine to build. Furthermore, an intricate and costly fuel injection system is required.

Cheap, low grade fuel can, however, be burned in compression-ignition engines with a comparatively high efficiency, the result being that operating costs are often considerably lower than for other types of engines.

Some compression-ignition engines are so designed and built that they can be started and "warmed up" as spark-ignition engines, after which they are switched over to run as compression-ignition engines.

SPARK-IGNITION ENGINES

In the spark-ignition engine the fuel and air mixture is usually controlled and supplied to the cylinders by a carburetor. The combustible mixture is drawn into each cylinder by piston action, being compressed during the piston's upward stroke and ignited by an electrical discharge occurring across the points of a spark plug.

By far the greater number of internal combustion engines in use are of the spark-ignition design. This is true mainly because such engines can be built at a fraction of the cost of comparable compression-ignition engines, and because both operation and service are considerably simpler. Spark-ignition engines in general require a refined type of fuel such as gasoline, although special adaptations permit the use of natural or artificial gas, kerosene and light fuel oils.

The weight per horsepower of the spark-ignition engine is ordinarily much less than that of a corresponding compression-ignition engine, a definite advantage in the application to vehicles and aircraft.

TWO CYCLE ENGINES

A two cycle engine is one which requires two full

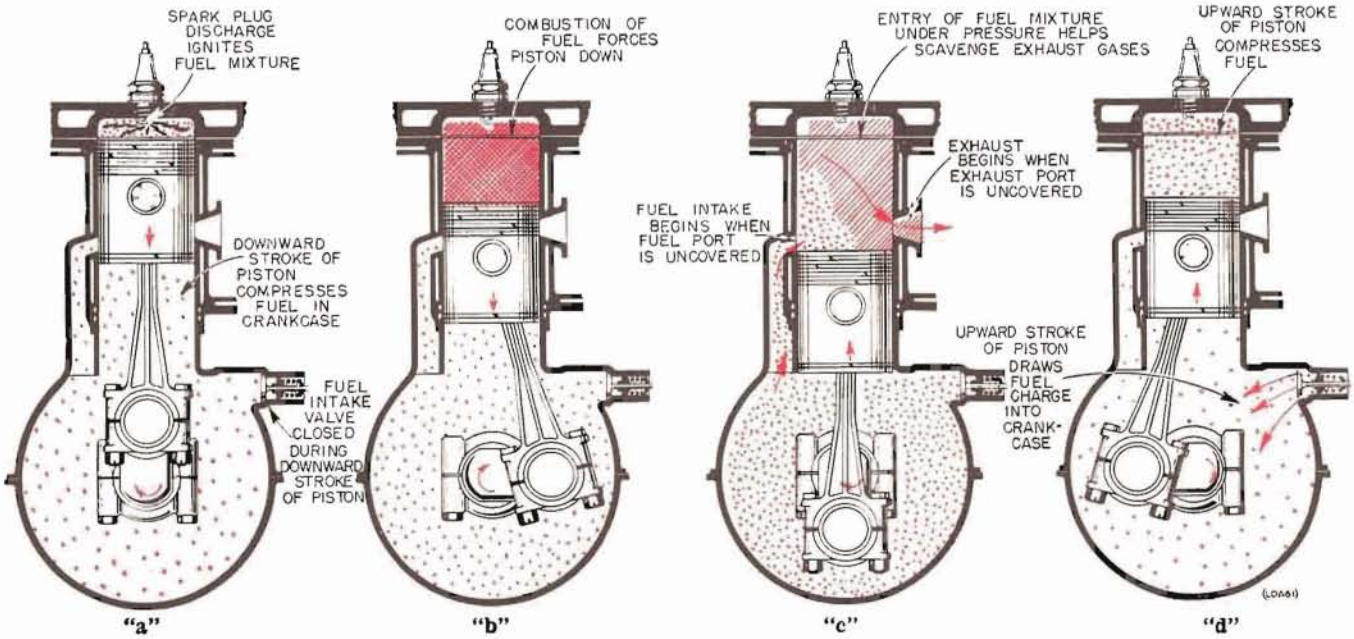


Figure 40—Sequence of Operations—Two Cycle Spark-Ignition Engine

strokes (one upward, one downward) of the piston assembly to complete the sequence of operations involved.

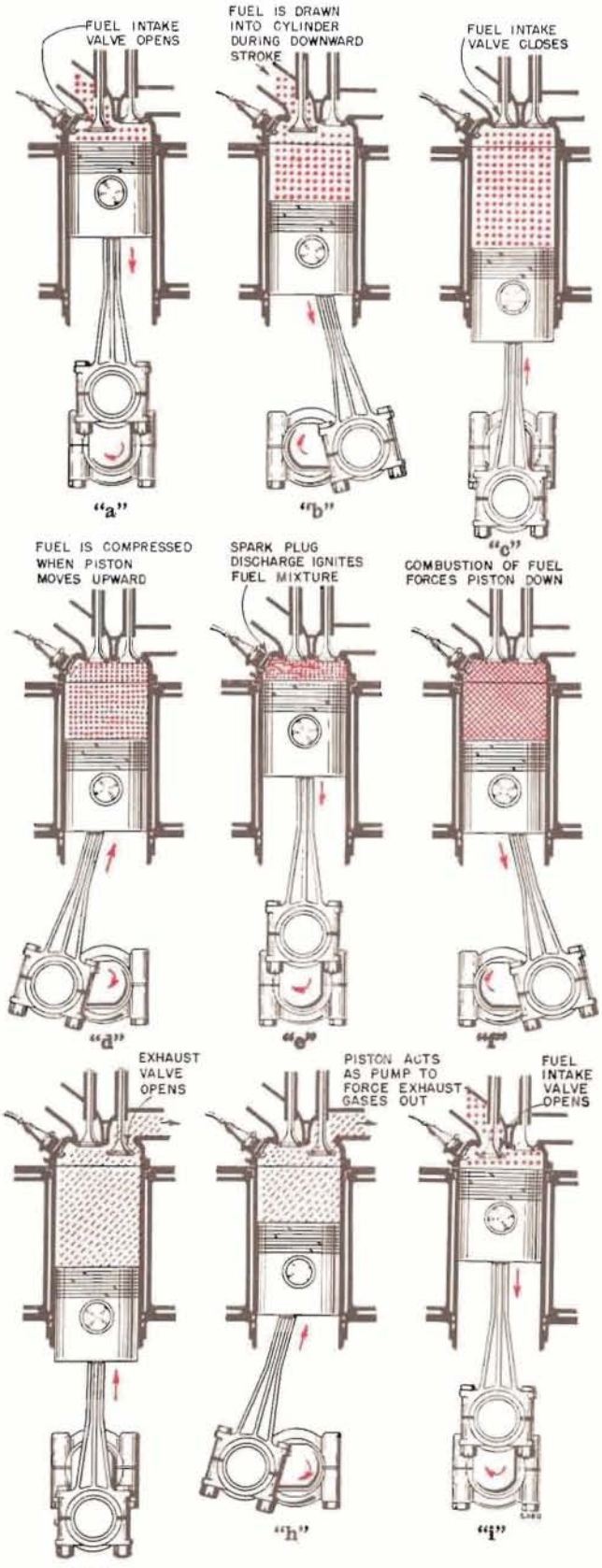


Figure 41—Sequence of Operations—Four Cycle Spark-Ignition Engine

Beginning with the ignition by the spark plug of the compressed combustible mixture of fuel and air (Figure 40 "a"), the expansion of the burning gases in the cylinder drives the piston down (Figure 40 "b") until the cylinder exhaust ports are uncovered (Figure 40 "c"). Meanwhile, this downward movement of the piston has compressed the fuel and air mixture which fills the crankcase, the intake valve being closed during this period. When the inlet ports of the cylinder open as the result of further downward movement of the piston the compressed fuel and air mixture rushes into the cylinder. The design of the inlet ports and top of the piston is such as to promote a swirling effect which aids in scavenging the exhaust gases from the cylinder. The piston then begins its upward stroke, first closing the inlet ports, then the exhaust ports and continuing upward (Figure 40 "d") to compress the fresh combustible mixture in the cylinder until the point is reached where ignition again occurs (Figure 40 "a"), and the sequence of operations is repeated. During the upward stroke of the piston (Figure 40 "d") the crankcase intake valve opens and a new charge of fuel and air mixture is drawn into the crankcase.

FOUR CYCLE ENGINES

A four cycle engine is one which requires four full strokes (two upward, two downward) of the piston assembly to complete the sequence of operations involved.

Beginning with the piston starting its first downward stroke (Figure 41 "a"), a combustible charge of fuel and air is drawn from the carburetor into the cylinder through the open intake valve (Figure 41 "b"). When the piston reaches the bottom of its first downward stroke the intake valve closes (Figure 41 "c") and the piston begins moving upward (Figure 41 "d"), compressing the fuel and air mixture in the cylinder. This compression reaches its maximum when the piston reaches top dead center (Figure 41 "e"), at which point an electric spark jumps across the spark plug point gap and ignition of the combustible fuel mixture occurs. The expansion of the burning gases then forces the piston downward (Figure 41 "f") until the bottom of the stroke is reached. At this point (Figure 41 "g") the exhaust outlet valve opens and the piston begins its upward stroke, the exhaust gases being forced out of the cylinder (Figure 41 "h"). When the piston reaches the top of its stroke the exhaust outlet valve closes and the fuel inlet valve opens (Figure 41 "i"), the sequence of operations then being repeated.

IMPORTANCE OF IGNITION

Because engine performance is so vitally affected, the problem of ignition is one of major importance to every designer of spark-ignition engines. The following list indicates some of the factors directly related to the ignition system which must be considered when the original engine layouts are made:

(a) Shape of combustion chamber

(b) Type of spark plug

(c) Possibility of pre-ignition

(d) Intensity of ignition spark

(e) Ignition during starting period

(f) Effects of compression and speed

(g) Ignition sparks during exhaust strokes.

(h) Timing of the ignition spark

Decisions on design work such as this are best made when a complete summary of modern ignition units and their application is available for reference.

IGNITION SPARK TIMING — ENGINE SPEED

During the starting period of an engine the speed of rotation is low and it is obvious that for safe operation the ignition spark should occur either at or just after top dead center is reached in the piston stroke (Figure 42 "a"). The abrupt reversal of engine rotation known as "back-firing" which often results at slow speeds when the fuel is ignited before top dead center is reached is likely to cause damage to the engine and injury to the operator.

Ignition of the fuel charge does not, however, take place instantaneously, a certain amount of time being required for the complete combustion. As the engine speed increases the time during which the fuel may burn decreases; a point soon being reached where incomplete combustion results in very poor engine operation. To gain more time for the fuel combustion period the ignition point must be advanced considerably ahead of top dead center of the piston stroke (Figure 42 "b"). Backfiring does not occur because the fuel combustion is relatively slow in comparison with the speed of the piston and top dead center is reached before the expansion force of the burning gases has reached its maximum.

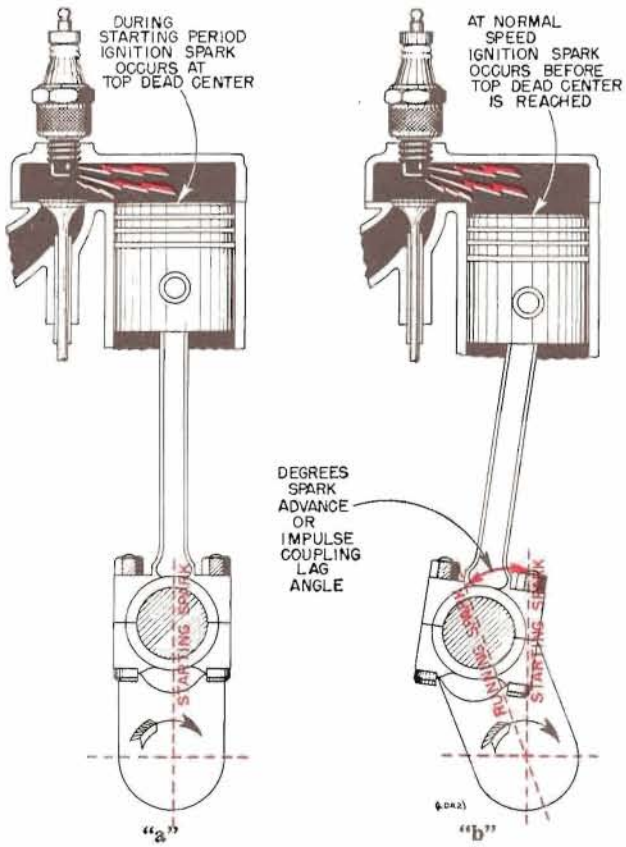


Figure 42—Starting and Running Spark

SPARK PLUGS

The actual occurrence of the ignition spark within the engine cylinder takes place across the points of a spark plug, the importance of which must not be overlooked, since the performance of the entire ignition system is completely dependent upon the proper functioning of this part. Spark plugs are specifically constructed for different types of service and should be selected carefully according to the manufacturer's recommendations.

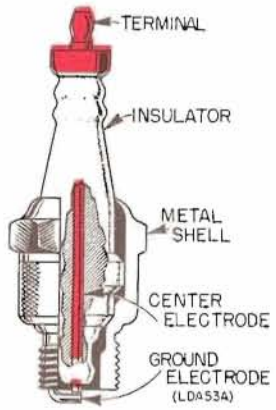


Figure 43—Spark Plug Construction

A spark plug (Figure 43) consists of a metal shell on which one of the electrodes is mounted, and an insulated centerpiece through which the second electrode is passed. Since the metal outer shell and its electrode are grounded to the engine head, only the one electrical connection to the center electrode is necessary. The spark plug must be set into the cylinder head gas-tight, usually accomplished by inserting a copper compression gasket between the plug and the head.

SPARK PLUG ELECTRODES

During engine operation the ignition sparks occur between the electrodes of the spark plug and as a result one or both of the electrodes is gradually eaten away. This action changes the width of the spark gap and eventually impairs engine operation to the point where readjustment of the gap must be made. By making the ends of the electrodes blunt instead of sharp the length of time the gap remains constant is increased, but a higher voltage spark is required to bridge the gap.

The center electrode is usually made of a nickel alloy wire while the insulator in which it is set is generally made of porcelain, although steatite (soapstone) and laminated mica have also been used. Requirements of the insulator are that it possess high electrical resistance, high heat resistance and high resistance to mechanical pressure.

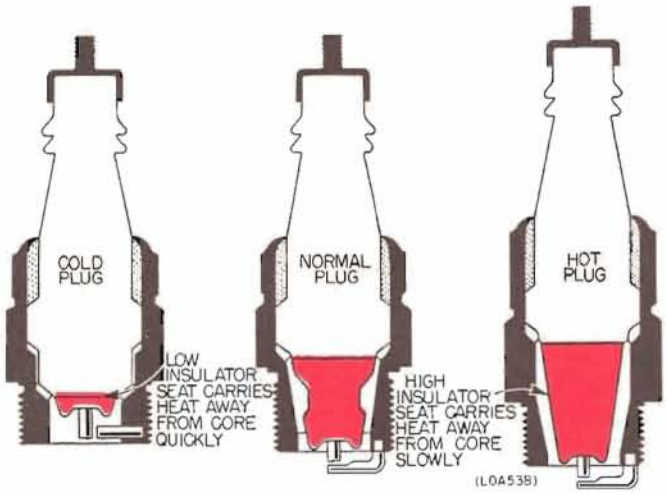


Figure 44—Cold-Normal-Hot Spark Plugs

HOT-NORMAL-COLD PLUGS

The inner end of the spark plug insulator should be so designed that under normal conditions the temperature it reaches is sufficient to burn off carbon deposits but not great enough to result in pre-ignition of the fuel charge. Since it is obvious that such a characteristic depends upon the operating conditions, spark plug manufacturers have offered (Figure 44) "hot" plugs in which there is considerable distance between the top of the insulator and the nearest point at which contact is made by the shell, and "cold" plugs in which there is only a short distance between the tip of the insulator and the shell contact, in addition to "normal" plugs which have a medium distance between the insulator and the shell. Cold plugs are ordinarily used for engines subjected to long continuous runs, while hot plugs are recommended for engines used for short intervals.

The recommendations made by the engine manufacturer should be carefully consulted before making any change in the type of spark plug used.

ENGINE SPEED & COMPRESSION

Spark-ignition engines are built to operate at rotative speeds ranging from 75 to 6000 rpm. It is obvious that the magneto specified must be able to function throughout the speed range of the engine. Furthermore, the impulse coupling used to provide the starting ignition must be of such design as to cut-out before idling speed is reached.

It is common practice to operate magnetos on slow speed engines at either crankshaft or twice crankshaft speed, and to operate magnetos on high speed engines at half crankshaft or camshaft speed. In all applications the required spark interval is the original determining factor.

Heavy duty magnetos with oversize coils and magnets are likely to be required on low speed engines in order to secure sufficiently strong ignition sparks.

As the compression within the cylinders of an engine increases the voltage required (Figure 45) to produce ignition sparks also increases. In effect this means that standard magnetos are unlikely to provide suitable ignition for very high compression engines, although the operation of high compression engines at a relatively higher rotative speed often acts as a counter-balance, in that the magneto produces higher voltage discharges.

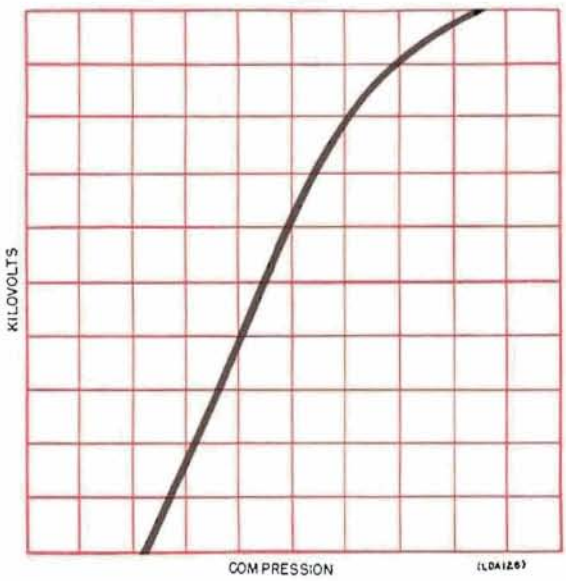


Figure 45—Compression/Kilovolt Spark Curve

SECTION FOUR

EARLY IGNITION SYSTEMS

ENGINE IGNITION REQUIREMENTS

From the very beginning of internal combustion engine design the problem of ignition has been a major item. In comparison with the principles of internal combustion engines, which have undergone comparatively minor changes, the development of electrical ignition systems has been rapid during recent years and has passed through several definite stages of engineering design.

It was realized almost at once that an electric spark system was highly suitable to engine ignition, but a simple means of providing a spark of sufficient intensity in the proper place at exactly the desired time eluded designers. The low tension ignition system was one of the first developments along this line and presents an interesting historical background for modern advances.

LOW TENSION IGNITION SYSTEMS

When a series circuit consisting of a battery and coil is interrupted, a strong spark is produced at the break. The intensity of the spark is the result of self-induction in the coil, the voltage maintaining the spark across the gap being many times greater than that of the battery.

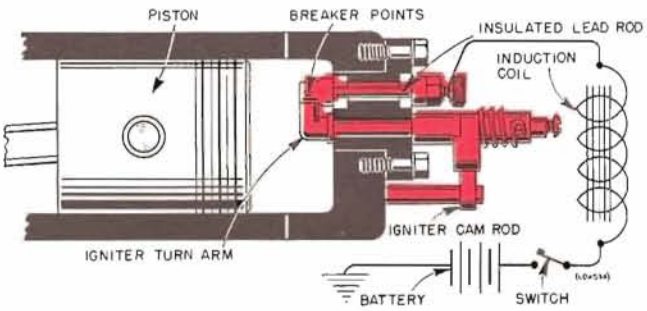


Figure 46—Turn Rod Breaker Points

In order to utilize the low tension spark for ignition purposes in what was known as the "make and break" system, the breaker points themselves had to be placed and operated within the cylinder in a position where the spark could ignite the fuel. To open and close the points several devices and arrangements were used, the most common being a push or turn rod (Figure 46) which operated through a tight bushing in the cylinder head. Another system used extensively provided for the actuation of the breaker points by a pin located on the top of the piston (Figure 47) which, in striking the breaker arm at the top of its stroke, would separate the breaker points

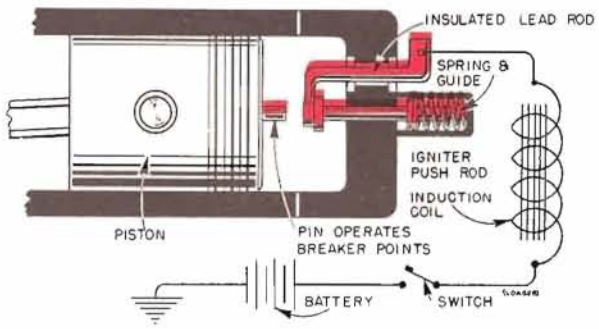


Figure 47—Push Rod Breaker Points

and thereby produce a spark. The chief disadvantages of these systems were the difficulty of maintaining the mechanical actuating linkage and the low voltages of the ignition spark produced. Both of these factors definitely limited the compression and speed of the engines.

LOW TENSION MAGNETO IGNITION

The low tension magneto was developed primarily to replace or supplement the batteries of the original low tension ignition systems. The ignition circuits were not changed in any other way (Figure 48), the same make-and-break arrangements being used to secure an ignition spark at the desired time and place.

Construction of the low tension magneto was very simple, consisting of an assembly in which a single coil armature was rotated in the field of one or more heavy horseshoe magnets. A collector ring on the armature connected the alternating current output to the ignition system wiring.

A somewhat higher system voltage was used with the low tension magneto circuit than when batteries were used.

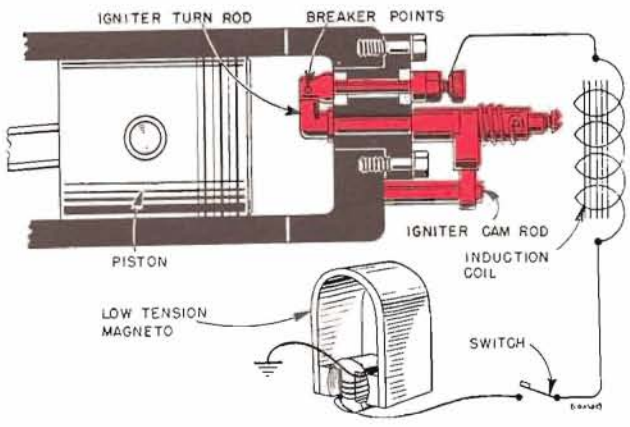


Figure 48—Low Tension Magneto Ignition Circuit

SECTION FIVE

MAGNETO DESIGN & CONSTRUCTION

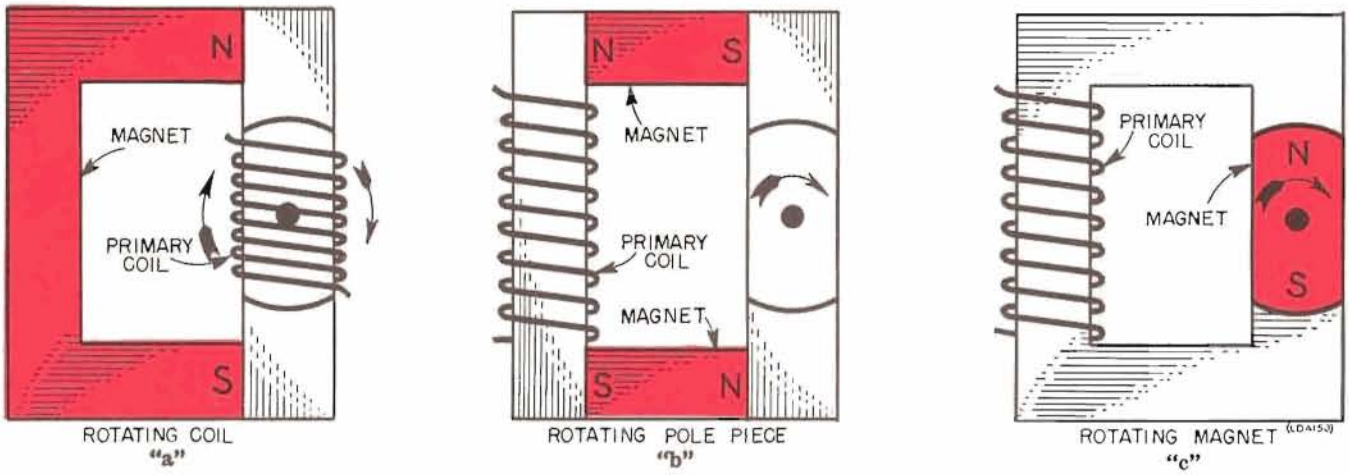


Figure 49—General Classification of Rotary Magneto Designs

GENERAL CLASSIFICATION

Fundamental magneto design is based on the principle of relative movement at right angles between the turns of a primary winding and a magnetic field. Such movement may be in a straight line as in the case of a reciprocating magneto, or along an arc as in the case of a rotary magneto.

The relative movement between the primary winding and the magnetic field may be accomplished by moving the coil (Figure 49 "a"), moving some component of the magnetic field (Figure 49 "b"), or moving the magnet (Figure 49 "c").

In the earliest magneto designs the primary winding was placed on an armature and rotated between the poles of a horseshoe magnet. Because of the shape of the armature this type magneto is often called the shuttle-wound armature design.

Both the magnet and the coil are mounted in stationary positions in the inductor type magneto, relative movement of the winding and field being secured by breaking and re-establishing the magnetic circuit.

The recent development of permanent magnets of greatly increased strength per unit volume led to the revolving magnet design. In this arrangement the coil, together with a short magnetic circuit, is mounted in a stationary position, while one or more magnets are rotated between the pole pieces.

SHUTTLE-WOUND ARMATURE MAGNETOS

The first high tension magneto designs were of the shuttle-wound armature type, following closely the principles of the earlier low tension units. In its conventional form (Figure 50) the shuttle-wound armature type magneto consisted of a large, stationary horseshoe magnet mounted on a frame in which the pole shoes were locked in place, and of a wound-armature assembly which could be rotated between the pole pieces of the frame.

The wound-armature assembly (Figure 51) was made up of a shuttle-shaped lamination assembly on which both the high and low tension coils were wound, a condenser and the breaker contact points. All connections were made within the armature, only the high tension ignition spark being transferred to the exterior circuit by means of a collector ring and carbon brush.

The principal disadvantages of the shuttle-wound

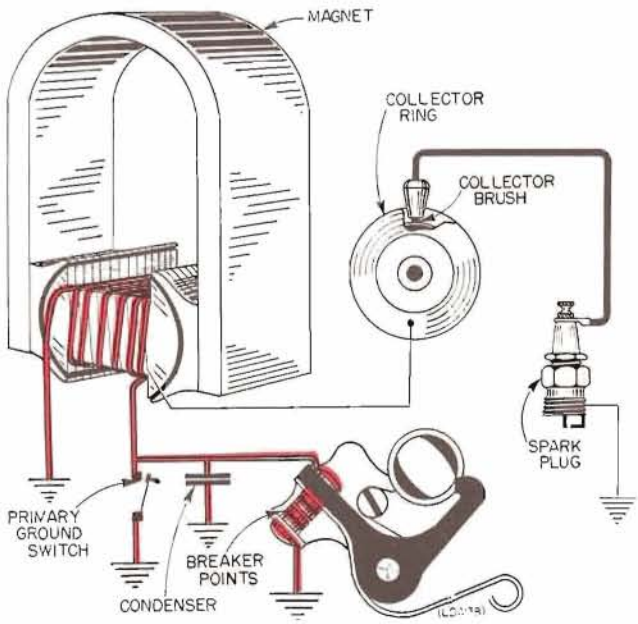


Figure 50—Shuttle-Wound Armature Magneto Circuit

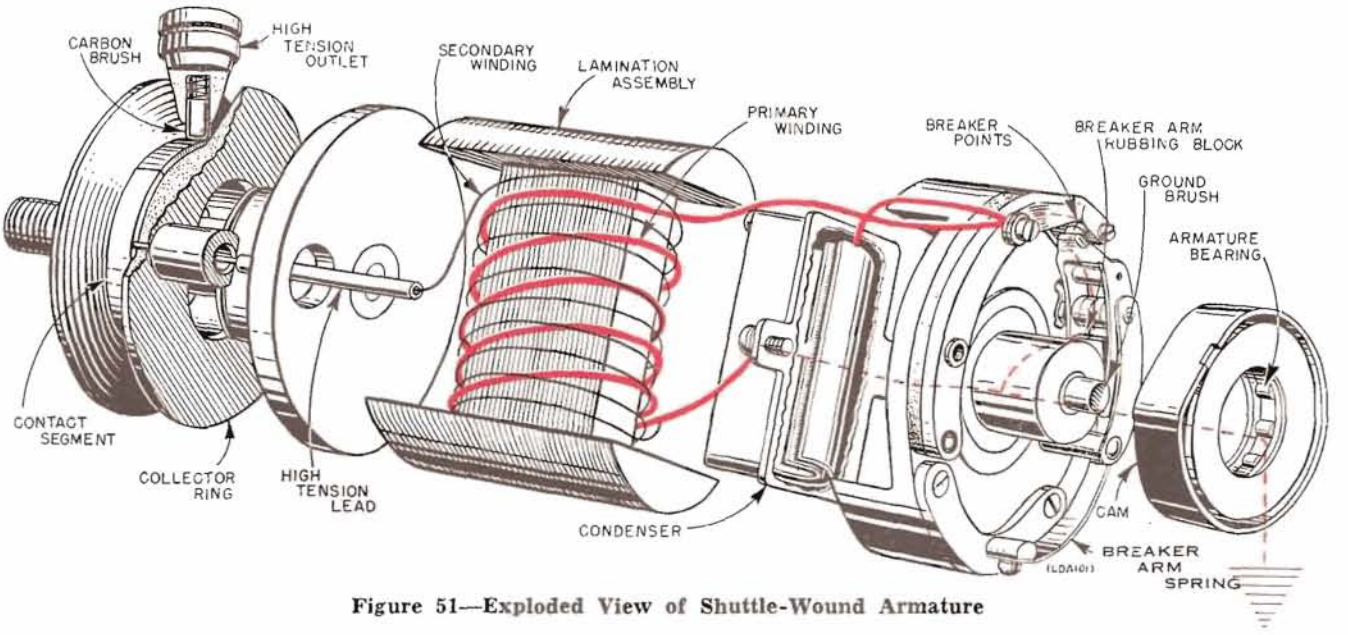


Figure 51—Exploded View of Shuttle-Wound Armature

armature design magneto were its bulkiness, the complexity of the armature assembly and the rotative strain to which the coil, condenser and breaker points were subjected.

ROTATING PRIMARY COIL VARIATION

An interesting variation of the standard shuttle-wound armature magneto was developed in a design (Figure 52) in which only the primary coil is rotated, while the breaker contact points, condenser and secondary coil are mounted in a stationary position. Actually the magneto has two primary windings, one being wound on the armature and connected through a collector ring to another primary winding mounted on a laminated core together with the secondary winding. The primary circuit is completed to ground through the breaker points.

When the armature is rotated a low voltage current is induced in the armature winding which flows through the stationary winding and breaker points to ground in order to complete its circuit. This current establishes a field which links the turns of the secondary winding of the stationary coil. When the primary circuit is abruptly opened by breaker point action, the field established in the coil instantly collapses, with the result that a very high voltage is induced in the secondary winding of the stationary coil. This voltage is strong enough to bridge the gap across the spark plug points to furnish the ignition spark.

ROTARY INDUCTOR MAGNETOS

In the inductor design magneto both the magnet and coil are mounted in a stationary position, a primary current being induced in the coil by rotating one or both legs of the magnetic circuit. When only one leg of the magnetic circuit is broken, the magnetic flux in the coil

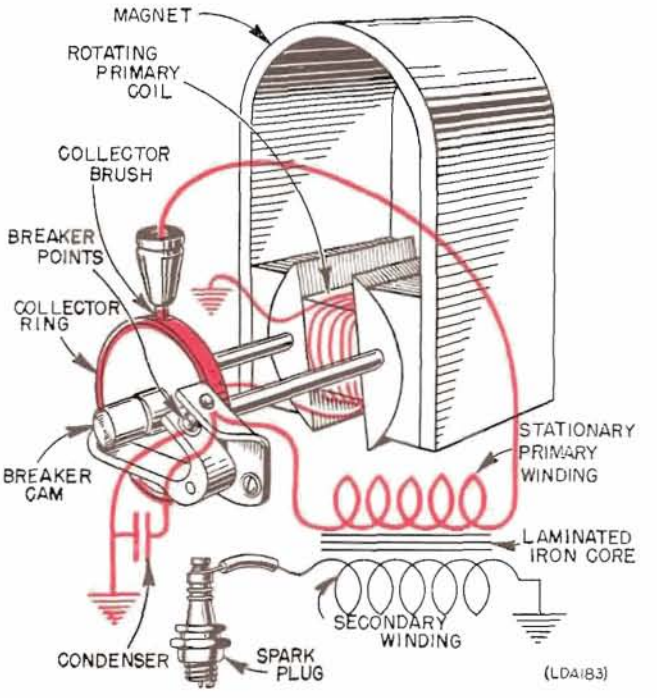


Figure 52—Rotating Primary Coil Variation

alternates from minimum to maximum, but does not undergo complete reversal as in the case where both legs of the magnetic path are interrupted (Figure 53). Reversals of flux in the coil cause corresponding reversals in the primary current with the result that wear due to arcing at the breaker points is evenly distributed between the two contact surfaces.

The construction of the rotary inductor type magneto is similar to that of the rotating magnet design except for its comparatively long magnetic circuit. The original scheme contemplated the use of a large horseshoe magnet as in the case of a shuttle-wound armature magneto,

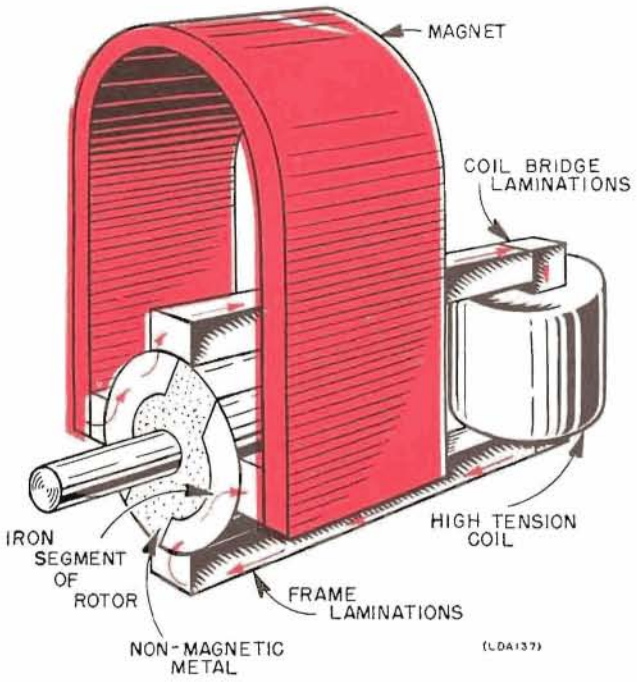


Figure 53—Rotary Inductor Design Magneto

but at the same time secured the advantages of a stationary coil, condenser and breaker point assembly.

Standard design rotary distributor systems are readily adaptable to the rotary inductor type magneto.

RECIPROCATING INDUCTOR MAGNETOS

Reciprocating drive inductor design magnetos (Figure 54) have been adapted with good results to certain slow speed internal combustion engines, usually of the horizontal type. The application is limited to engines of either one or two cylinders.

The mechanical connection (of which there are many variations) between the engine and the magneto consists basically of a push rod arrangement which, working against a spring, trips the actuating lever of the magneto at the instant an ignition spark is desired. As the result of tripping this lever, a second spring snaps the armature away from the coil core laminations, thereby breaking the magnetic circuit and causing the field through the coils to collapse. Since the collapse of this field induces a current in the primary circuit, the opening of the breaker points when the armature has moved about ⅛" away from the core pieces results in a high voltage current surge in the secondary winding which furnishes the ignition spark in completing its circuit to ground.

THE ROTATING MAGNET MAGNETO

A sweeping change in magneto design and manufacture resulted from introduction of the rotating magnet type magneto. Its advantages are both numerous and outstanding, with performance standards being raised, service being simplified and the original cost being decreased. Present commercial rotary magnetos are nearly all of the rotating magnet design.

Possibly the greatest single advance in this change is the simple, one-piece magnetic rotor which replaces the intricate, wound-armature of former designs. In the rotating magnet design magneto the coil, condenser and breaker points are all mounted in a stationary position with the result that construction is much more substantial, that moving connections are eliminated and that tests and repairs are easily accomplished.

The size of the unit is considerably reduced because the stationary coil and breaker point assemblies are more compact, because short, powerful Alnico magnets can be used to full advantage and because parts such as the collector ring and collector brushes have been eliminated.

The simplification of the magneto construction has been a major factor in reducing both its original cost of manufacture and its cost of upkeep.

DESCRIPTION OF OPERATION

Rotation of the magnetic rotor (Figures 55 & 57) sets up an alternating magnetic flux in the magnetic circuit which cuts the primary winding each time it rises and falls. As the result induced electric currents, alternating in direction, flow in the primary circuit during the intervals the breaker points are closed. Since the induced primary current is proportional to the rate of flux linkages, it varies in value, a maximum being reached each time a complete magnetic flux reversal occurs in the magnetic circuit.

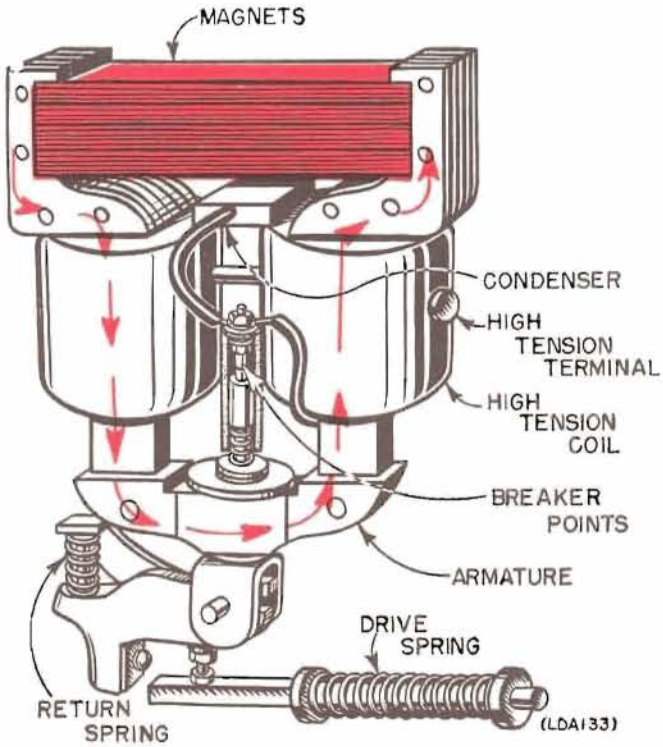


Figure 54—Reciprocating Inductor Design Magneto

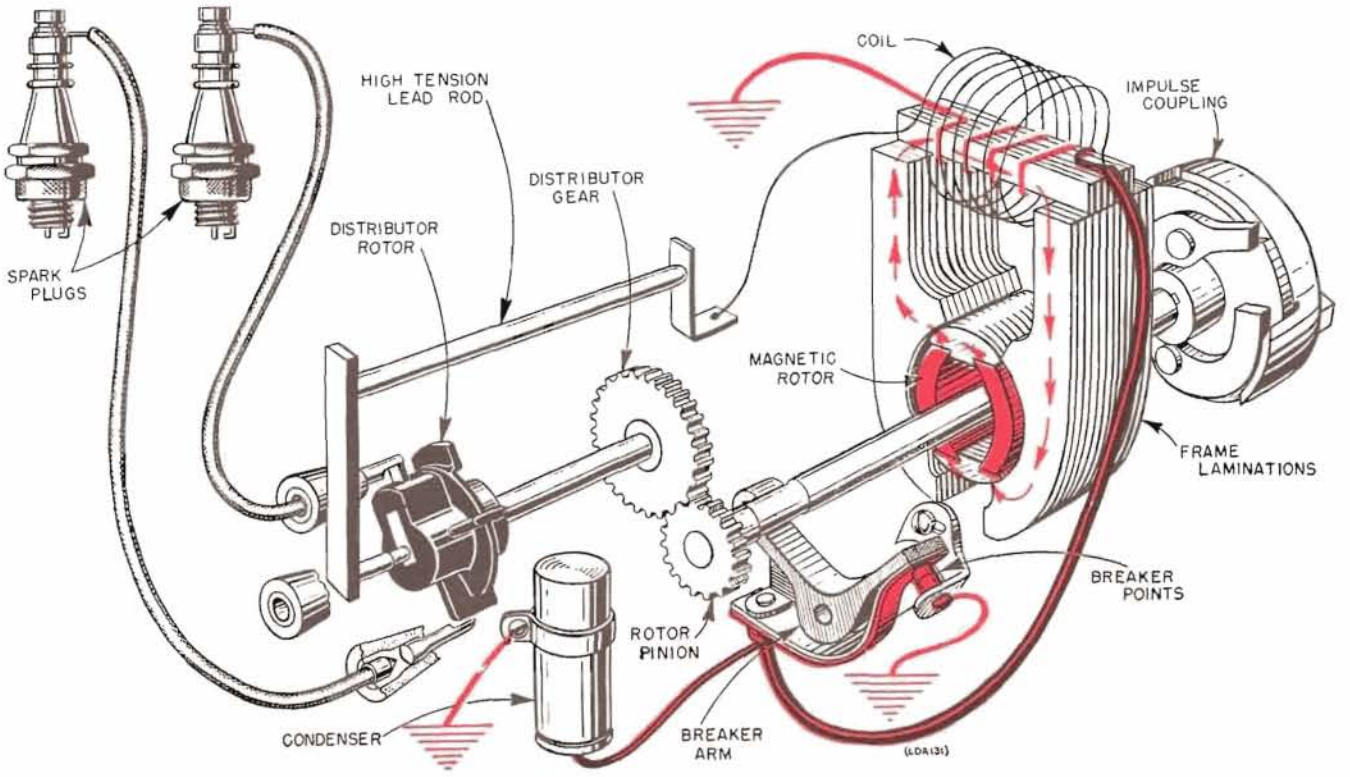


Figure 55—Schematic Diagram of Rotating Magnet Magneto with Jump-Spark Distributor

The current in the primary winding of the coil establishes a magnetic field which interlocks the turns of the coil secondary winding, this field reaching its maximum extent simultaneously with the primary current. Breaker point action at the instant of maximum primary current and field opens the primary circuit with the result that the primary current cannot flow, causing the immediate and complete collapse of the magnetic field existing in the coil.

The ratio of turns in the coil secondary winding to those of the primary is very high and since each line of force of the collapsing primary field must cut the turns of the secondary winding, an exceedingly high rate of flux linkages is obtained. Consequently, the value of the induced voltage in the secondary winding is very high. The secondary circuit is established when this induced high voltage is sufficient to bridge the gap between the spark plug points.

The self-induced voltage occurring in the primary winding as a result of the quick break of the primary circuit is absorbed by the condenser which is shunted across the breaker points. In effect this action promotes a more rapid collapse of the primary field and at the same time reduces contact point burning caused by arcing.

OSCILLOGRAPH ANALYSIS

The operation of a magneto can be analyzed graphically through the use of the cathode-ray oscillograph (Figure 56). Curves are obtained representing the transitory values of the resultant magnetic flux, the primary current or voltage, and the secondary current or voltage.

Typical performance curves (Figure 58) for a two-pole magneto have been reproduced, the resultant magnetic flux curve being superimposed upon the static flux along the upper axis, while on the lower axis the primary current and secondary voltage curves are shown.

The static flux is a basic reference curve usually obtained by measuring the magnetic flux with a fluxmeter at significant intervals through a complete cycle, the

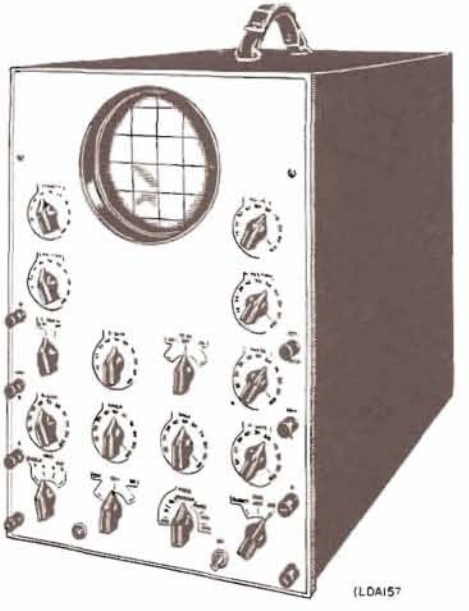


Figure 56—Laboratory Type Cathode-Ray Oscillograph

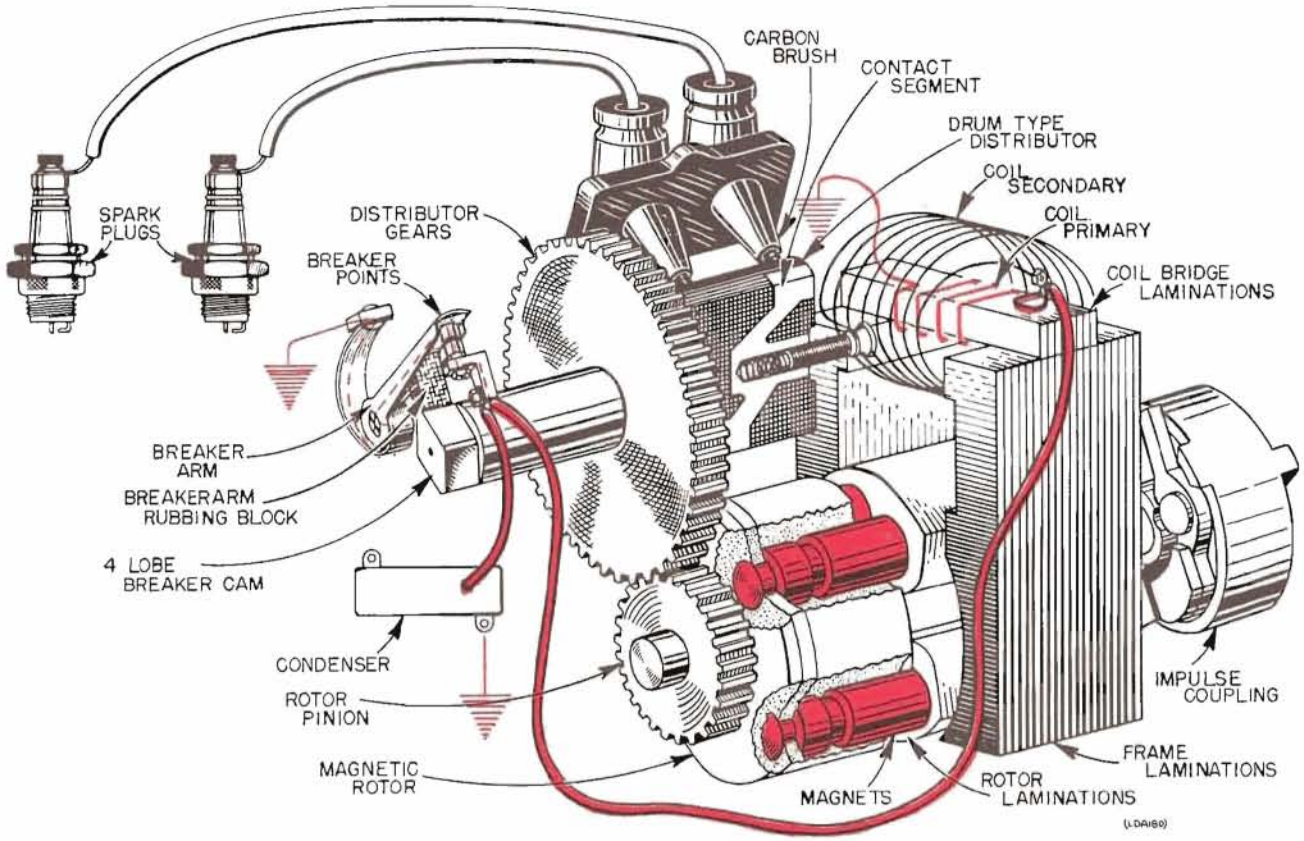


Figure 57—Schematic Diagram of Rotating Magnet Magneto with Carbon Brush Distributor

magnetic rotor being held stationary during each measurement. The curve indicating resultant flux is obtained while the magneto is in normal operation and shows clearly the magnetic flux lag due to rotation and the flux distortion caused by the secondary current discharge.

The steepest portion of the resultant flux curve indicates the greatest flux change in the magnetic circuit and examination of the corresponding primary current curve shows that maximum primary current occurs simultaneously as the result. The sharp break in the primary current comes when the breaker points open the primary circuit and the current immediately falls from its maximum value to zero. This abrupt change in value of the primary current induces the very high voltage in the secondary winding, the secondary circuit being established when the induced voltage is sufficient to bridge the spark plug gap. The voltage necessary to maintain the gap oscillates in value after the original breakdown occurs.

The oscillograph curves are important chiefly in laboratory work connected with original magneto design. The resultant flux curve indicates any possible saturation of the magnetic circuit, while the primary current curve locates the point at which the primary circuit should be broken for greatest secondary voltage. The effect of a condenser shunted across the breaker points is determined by the incline of the primary current curve as it falls from maximum to zero value as the result of breaker point action.

THE MAGNETO HOUSING

The iron laminations through which the magnetic circuit between the coil and the magnet is established are held in place by a main housing assembly, which also provides the mounting for the rotor bearings or bearing plates. Since the laminations are usually shaped to function as the pole pieces adjacent to the armature or magnetic rotor, construction of the housing assembly must provide for the maintenance of a very small and constant air gap when the rotor is turned. As a consequence the construction of the housing must be sturdy and absolutely rigid, the one-piece diecast method of manufacture having been found especially suitable.

THE BREAKER POINT ASSEMBLY

The breaker point assembly is mechanically actuated through the rotation of a breaker cam. This cam may be located on the distributor shaft (Figure 59 "a"), in which case its speed of operation is reduced by the ratio of the gear teeth; or the cam may be located on the magnetic rotor shaft (Figure 59 "b"), where it rotates at the same speed as the rotor. The mechanism must be so adjusted that the contact points open at the exact instant a break in the primary circuit will induce the maximum secondary voltage.

Many factors influence the design of the breaker point assembly with the result that there are hundreds of variations. In general, however, the three types com-

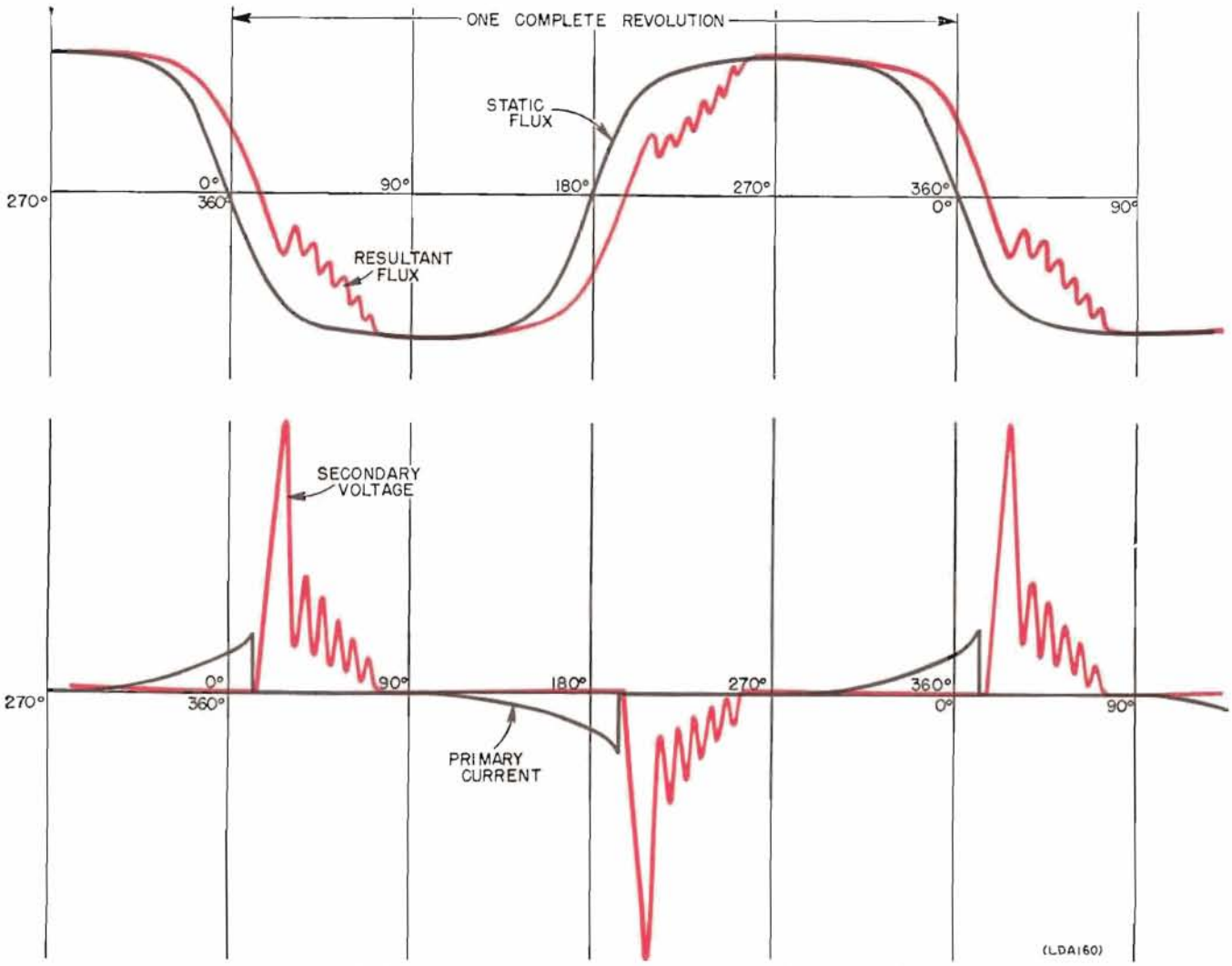


Figure 58—Oscillograph Curves of Operation of 180° Spark Magneto

monly used on commercial rotary magnetos are: (a) the breaker arm with its fulcrum at the end (Figure 60A), (b) the breaker arm with its fulcrum at the center (Figure 60B) and (c) the two-piece, indirect action breaker arm assembly (Figure 60C).

The essential parts of the breaker arm are the rubbing block, the pivot bearing, the actuating spring, the contact point and the contact point connection. The rubbing block is designed to ride smoothly on the surface of the cam, its wear being balanced as nearly as possible with the wear of the contact surfaces. The pivot bearing must function smoothly in order not to cause any appreciable mechanical lag in the breaker arm action. The actuating spring must have the correct tension to maintain rubbing block contact with the cam at the various speeds of operation encountered.

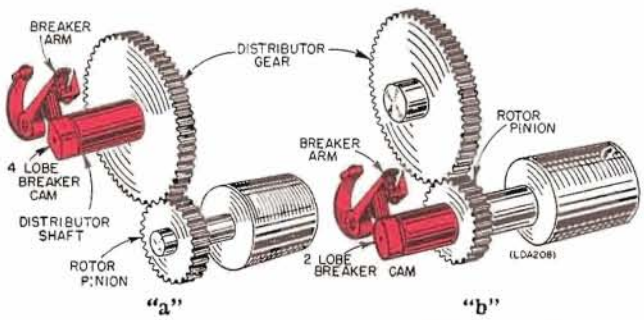


Figure 59—Location of Breaker Point Assembly

Possibly one of the most important factors in the overall design of the breaker point assembly is the simplicity of contact point adjustment or replacement. Since adjustment is usually accomplished by moving the stationary contact point, arrangements have been made on recent magnetos to mount this point on a semi-fixed bracket controlled by an eccentric head screw. The convenient screwdriver adjustment thus obtained is considered most advantageous, since it permits fine adjustment of the contact point gap as well as providing a positive locking arrangement.

CONTACT POINT MATERIAL

A good deal of research work and field experience has not yielded full, conclusive facts concerning contact point materials. This situation is somewhat further obscured by certain long-held prejudices and preferences.

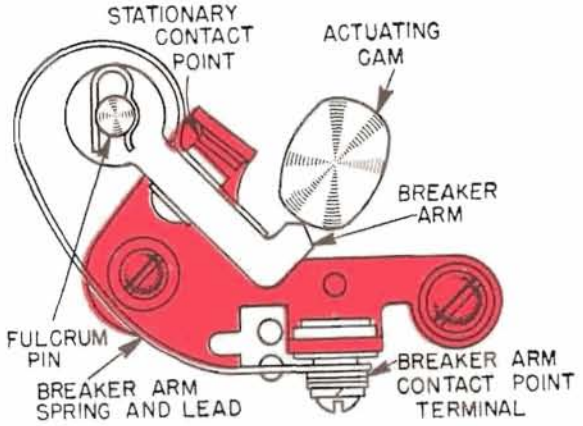


FIGURE 60A – BREAKER ARM WITH END PIVOT

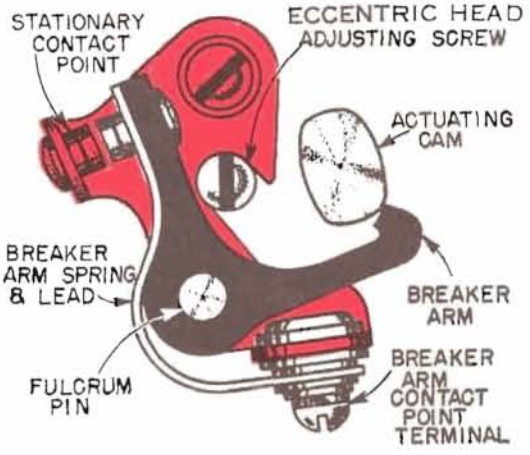


FIGURE 60B–BREAKER ARM WITH CENTER PIVOT

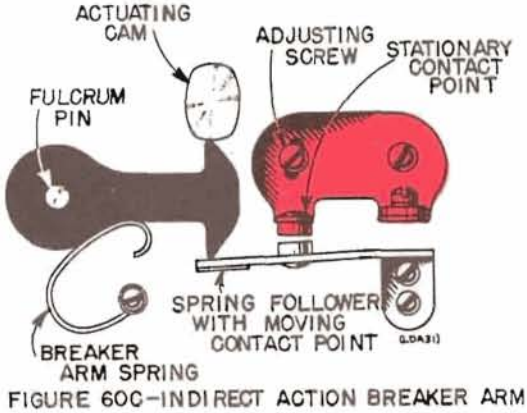


FIGURE 60C–INDIRECT ACTION BREAKER ARM

Two metals, tungsten and platinum, are outstanding in their use as contact points. As might be expected, each has definite advantages as well as disadvantages. In the final analysis the application of the magneto unit is usually the deciding factor in the choice of contact point material.

Since tungsten is one of the hardest metals known, tungsten points will stand continual "pounding" and will give long, efficient service under normal conditions. Tungsten points can be readily reconditioned by resurfacing with a suitable file or stone and can be replaced economically, since their cost is less than a fourth of the cost of platinum points.

Platinum is a comparatively soft metal, but in its use for contact points iridium is added as a hardening agent. Platinum-iridium points are advantageous because of their ability to handle primary current with minimum loss, and as a result are often specified for the shuttle-wound armature design magnetos as well as for some special heavy duty units. Platinum-iridium points are considered essential for aircraft ignition units, but it should be noted that such units are subject to frequent and periodic maintenance and overhaul.

Contact point adjustment has been found to be necessary more often with platinum-iridium points than with tungsten.

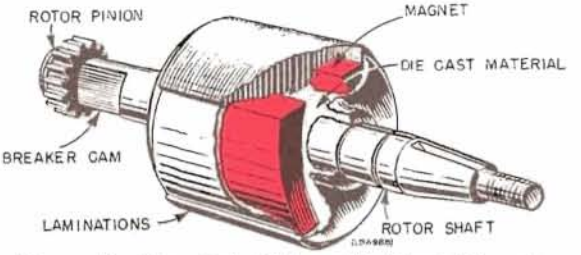


Figure 61—Two-Pole Rotor with Block Magnets

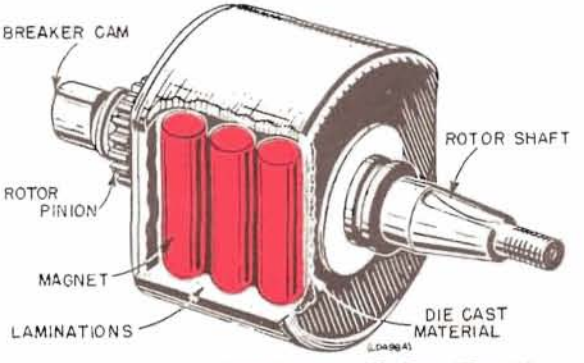


Figure 62—Two-Pole Rotor with Bar Magnets

THE MAGNETIC ROTOR

The magnetic rotor of the rotating magnet design magneto is a solid, one-piece assembly consisting of the magnets, laminations and rotor shaft. The shape and position of the magnets vary widely according to design requirements, the most common arrangement being the two-pole magnetic rotor with either two block magnets (Figure 61) or with multiple bar magnets (Figure 62), the axes of the magnets being set perpendicularly to the

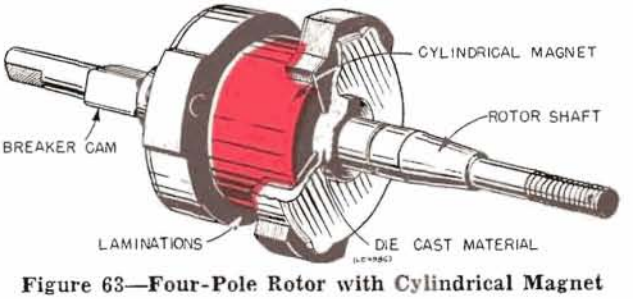


Figure 63—Four-Pole Rotor with Cylindrical Magnet

rotor shaft. The four-pole rotor (Figure 63) has one large cylindrical magnet with its polar axis set parallel to the rotor shaft, the relative position of the rotor laminations providing the four pole sequence. The number of magnets used in a magnetic rotor does not determine the number of effective magnetic poles.

Magnetic rotors used in Fairbanks Morse magnetos are of diecast construction, the one-piece rotor shaft, magnets and laminations being locked together in a single, compact assembly. The size of the rotor depends greatly upon the kind of magnets used. Early models of the rotating magnet design magneto had rotors with chromium steel magnets, the size of such a rotor being several times as large as present type rotors with Alnico magnets.

Remagnetization of the chromium and cobalt steel rotors was occasionally necessary in order to maintain a high output, but the greater original power and retentivity of the Alnico magnets now used has made recharging less essential.

THE HIGH TENSION COIL

A specially designed step-up transformer type coil (Figure 64) is used to convert the low voltage primary current to the high voltage secondary spark discharge. The primary winding of the high tension coil, as it is commonly known, consists of a relatively low number of turns of heavy wire, while the secondary winding has a large number of turns of very fine wire, the ratio of turns varying for different applications, but being on the order of 100 to 1.

The primary coil is formed by winding coated copper wire, in layers, around a laminated iron core. Each layer of wire is insulated by paper inserted between the layers.

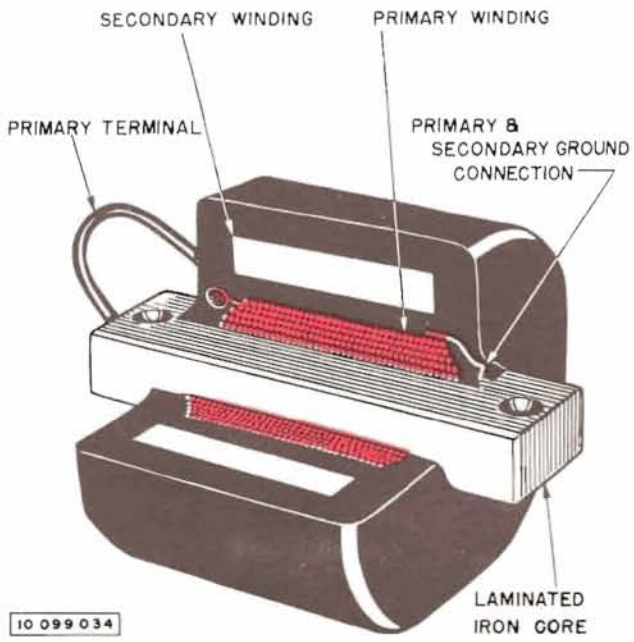


Figure 64—Construction of High Tension Coil

The secondary coil is wound, in the same manner as the primary coil except it is wound on a paper core. The two coils are then assembled and the primary and secondary terminals are soldered in place. The assembled coil is inserted in a mold, coated throughout with liquid plastic and baked in a thermostatically controlled oven.

Since the coil in the rotating magnet and inductor type magnetos is mounted in a stationary position, extremely low resistance connections permit the primary current to reach its true maximum value, a correspondingly greater secondary output thereby being secured. Coils mounted in this manner can also be wound to be sturdier, more compact and more efficient than those used in a rotating armature, and are not subject to the mechanical strains resulting from high speed rotation.

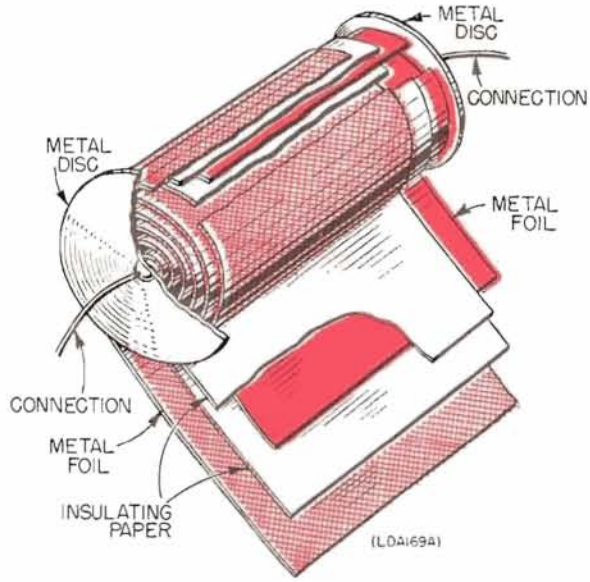


Figure 65—Paper-Wound Condenser

CONDENSERS

Paper-wound condensers have been proven highly satisfactory for ignition circuit applications and are almost universally used. Construction of this type of condenser (Figure 65) is very simple, two separate strips of aluminum foil of predetermined length being wound together with insulating strips of paper into a tight roll. Electrical connections are provided along the edges of the strips in order to obtain a non-inductive condenser. The rolled foil and paper assembly is then wax-impregnated and hermetically-sealed in a metal container.

In certain applications where the condenser is subject to considerable heat, it has been found advisable to use oil-impregnated units, since a breakdown of standard condensers may result if the impregnating wax melts.

The capacitance of the condenser used in a magneto ignition circuit depends upon a number of factors, among which are the voltage, current and type of breaker contact points.

SECTION SIX

APPLICATION OF MAGNETO IGNITION

BASIC REQUIREMENTS

The analysis of the ignition requirements of internal combustion engines made in Section Three deals with the problem from the theoretical viewpoint of the engine designer. In adapting a magneto ignition system to a specific engine many other factors must also be considered.

A general survey of standard magneto application practices as well as of certain outstanding special variations has been made in the following paragraphs. It should be noted that many important details of the construction of the magneto itself are often determined by the type of service in which it is to be used.

The extent to which facilities must be provided for field changes or adjustments also has a definite influence on application plans. There appears to be some trend recently toward limiting the amount of adjustment permitted on carefully engineered applications.

PRACTICAL CONSIDERATIONS

There is a definite tendency to build magnetos to comply with the adaptation specifications set up by the individual engine designers and manufacturers, and as a result there are thousands of variations in the field. Some effort has been made to standardize the mountings of magneto ignition units, but it appears that most of the factors which cause the variations are beyond arbitrary control.

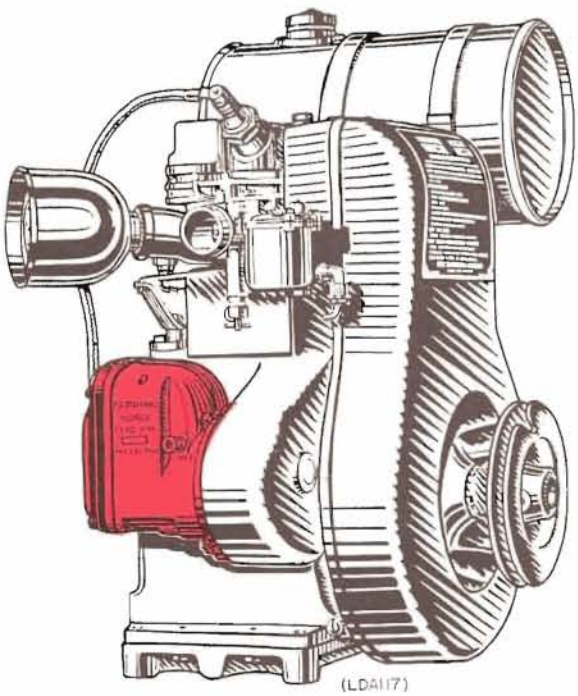


Figure 66—Single Cylinder Wisconsin Engine

A number of items enter into the specification of a magneto for application to an engine:

(a) The number of cylinders

(b) The spark interval between consecutively-firing cylinders

(c) The timing relation between starting and running ignition

(d) The speed and compression of the engine

(e) The magneto mounting

(f) The magneto drive arrangement

(g) The necessity of protection from oil, dust or moisture

(h) The necessity of radio-shielding

(i) Facilities for stopping the engine

It cannot be emphasized too strongly that best engine performance is obtained when the magneto is engineered for the particular installation, especially in its original application.

SINGLE CYLINDER ENGINES

The ignition unit required by a single cylinder engine (Figure 66), either two or four cycle, is relatively simple in construction since the high tension secondary circuit of the magneto can be connected directly to the spark plug terminal and the entire distribution system thereby eliminated. Magnetos for single cylinder engines are usually built with one lobe breaker cams, the magneto then producing only one ignition spark per complete revolution of its rotor. On two cycle engines such a magneto would have to be driven at crankshaft speed, while on a four cycle engine it could be driven at camshaft speed (½ crankshaft speed).

Arrangements are often made on four cycle engines, however, to drive the magneto at crankshaft speed, allowing alternate ignition sparks to occur during the exhaust strokes. In special slow speed engine applications magnetos with geared distributors have been used in order to obtain only one ignition spark per two revolutions of the magneto rotor (See Paragraph "Unequal Spark Intervals" Page 33). In such a case the magneto is driven twice engine speed in order to increase the strength of the ignition spark at normal speeds and also to provide the speed range necessary for satisfactory impulse coupling operation.

MULTI-CYLINDER ENGINES

A large proportion of the internal combustion engines built have more than a single cylinder, the usual combinations being two, four or six cylinders. In effect a multi-cylinder engine smooths out operation, for while

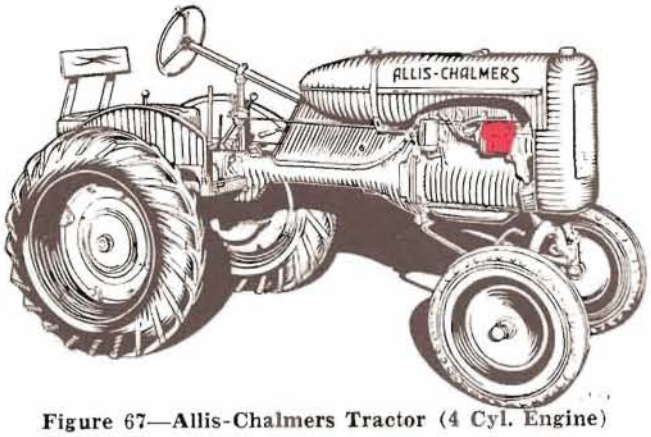


Figure 67—Allis-Chalmers Tractor (4 Cyl. Engine)

power is being supplied to the crankshaft by one of the pistons, others are going through different parts of the engine cycle. As the result a four cylinder engine, for example, with a 180° firing interval (Figure 67) has two complete power strokes during each revolution of its crankshaft. Various designs of multi-cylinder engines have different firing orders for the cylinders, as well as different crankshaft arrangements.

To supply ignition to a multi-cylinder engine a magneto with a distributor must be used, such an assembly usually consisting of a rotating electrode which contacts leads to each of the spark plugs in the proper sequence and at the correct intervals.

MAGNETO SPARK INTERVAL

The spark interval of a magneto refers to the angular degrees rotation of the magneto drive shaft between the production of consecutive ignition sparks, and covers a complete cycle of operation of the magneto.

The required spark interval is established by the engine on which the magneto is to be installed. The minimum angular degrees of crankshaft rotation between any two consecutively firing cylinders divided by the ratio of magneto speed to engine speed determines the minimum spark interval which must be obtained.

A two-pole magneto of conventional design with a two-lobe breaker cam produces two equally spaced ignition sparks per complete revolution of the magnetic rotor; the spark interval is therefore 180° (Figure 68). If alternate sparks are grounded out, the spark interval becomes 360°.

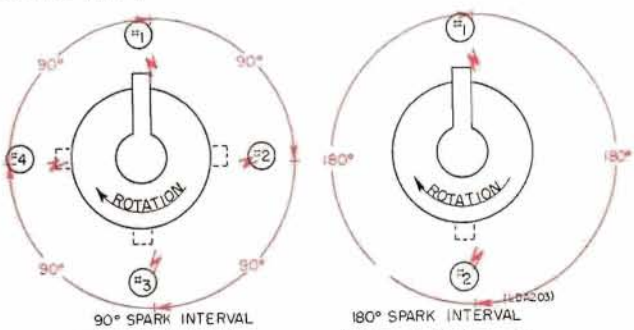


Figure 68—Diagrams of Spark Interval

A four-pole magneto of conventional design with a four-lobe breaker cam produces four equally spaced ignition sparks per complete revolution of the magnetic rotor; the spark interval is therefore 90° (Figure 68).

The spark interval of a magneto depends upon the number of poles of the magnetic rotor and the number of lobes on the breaker arm cam.

UNEQUAL SPARK INTERVALS

As an inherent characteristic of rotary magnetos, ignition sparks are produced at regular intervals. In many applications all of these ignition sparks are not needed and it is common practice to allow the spark plugs to fire during the exhaust strokes. In some cases, however, this means of disposing of unused ignition sparks is not desirable, and a special grounding device must be built into the distributor assembly. In Figure 69 a standard four cylinder unit firing each 180° has been converted

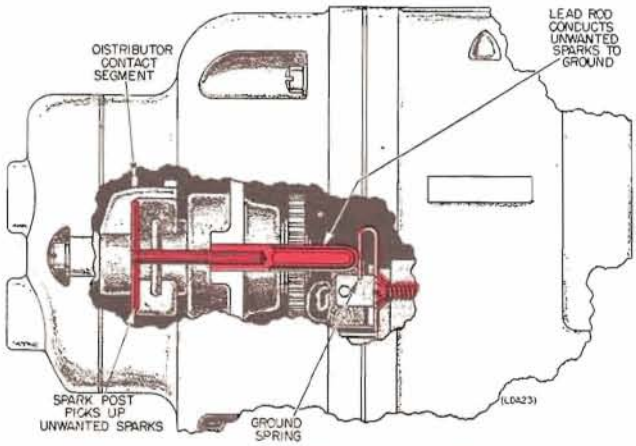


Figure 69—Ignition Spark Grounding Device

into a two cylinder unit with a spark interval of 180°—540° by a grounding device, which conducts the ignition sparks from two consecutive distributor posts to the ground connection. A similar arrangement (three distributor posts grounded out) could be used on the same magneto to obtain a one cylinder unit firing 720°.

BREAKER CAM CONTOUR

An ignition spark is produced when the breaker contact points open the primary circuit at a point of maximum current. The breaker points are actuated mechanically in accordance with the path the breaker arm rubbing block follows on the breaker cam. The design of this cam must be carefully determined in order to provide the desired movement of the breaker arm throughout the speed range of the magneto. Since a slow break in the primary circuit results in arcing between the contact surfaces as well as reducing the rate of flux linkages occurring in the high tension coil, the lobes of the breaker cam must act quickly to provide a clean break in the primary circuit. This action must be secured without causing breaker arm chatter or undesirable vibration.

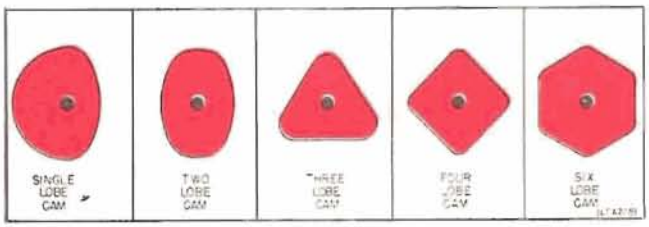


Figure 70—Commonly-Used Breaker Cam Contours

The number of times the contact points open per complete revolution of the breaker cam is determined by the number of lobes which the cam has. Commonly used breaker cams (Figure 70) have from one to six lobes depending upon the spark interval of the magneto and upon the ratio of the rotative speeds of the breaker cam and magnetic rotor.

MAGNETIC ROTOR POLES

Magnetic rotors are built with two or more poles, nearly all standard commercial magnetos being based on the two-pole design. While the number and size of the magnets in a rotor does not determine the number of poles, the arrangement of the magnets and the lamination assemblies is the decisive factor. The necessity of using a rotor with more than two poles arises primarily from consideration of the rotative speed of the magneto and the minimum spark interval required. The two-pole rotor produces an ignition spark each 180° of its rotation, while the four-pole rotor gives a 90° spark and the eight-pole rotor a 45° spark. The use of a geared-distributor in connection with doubling the rotative speed of the rotor gives the same results as doubling the number of poles of the rotor, but it is obvious that this method of reducing the spark interval is limited by the excessive rotative speeds required.

The simplified diagram of a two-pole magneto (Figure 71) illustrates a magnetic rotor with two bar magnets, set into the rotor with their magnetic axis at right angles to axis of rotation. This arrangement is completed by placing lamination assemblies across the like ends of the magnets, concentrating the magnetic flux within the limits of the desired type of pole piece. Since these pole pieces are 180° apart and of opposite polarity, rotation of the magnetic rotor causes two complete flux reversals in the magnetic circuit per revolution. Each complete reversal of flux provides the basis for the production of an ignition spark; two sparks spaced 180° can therefore be obtained per complete turn of the rotor.

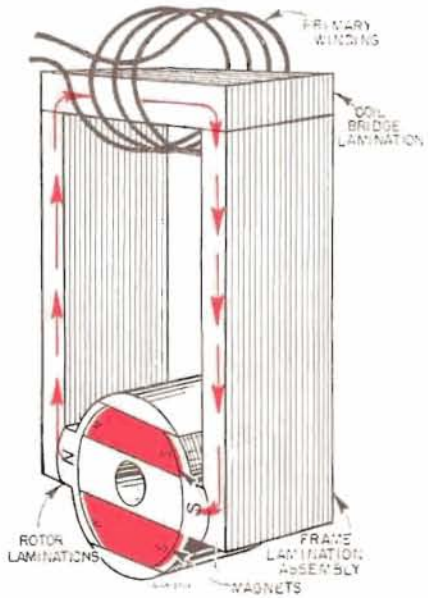


Figure 71—Magnetic Circuit of Two-Pole Magneto

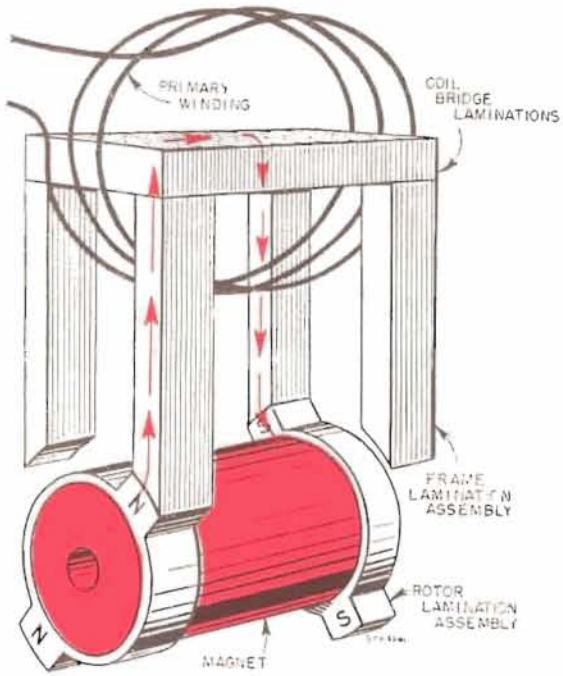


Figure 72—Magnetic Circuit of Four-Pole Magneto

The four-pole magneto shown similarly (Figure 72) is built with a magnetic rotor having a single cylindrical magnet, the ends of which are its poles. Over each end of this cylindrical magnet is placed a lamination assembly having projections each 180° of its circumference. The projections of the corresponding laminations at the ends of the magnet are turned 90° to each other and locked in place. The rotor operates in a frame having a four-legged field lamination assembly so placed that four complete reversals of the magnetic flux through the coil occur per revolution of the magnetic rotor. Consequently, four ignition sparks spaced 90° apart can be produced per complete turn of the rotor.

CARBON-BRUSH DISTRIBUTION

Since sliding contact is made by the carbon-brush distribution system, high voltage sparking is reduced to negligible proportions and it is possible to seal the distributor into the same housing as the magneto without danger of corrosion.

The two general types of carbon-brush distribution

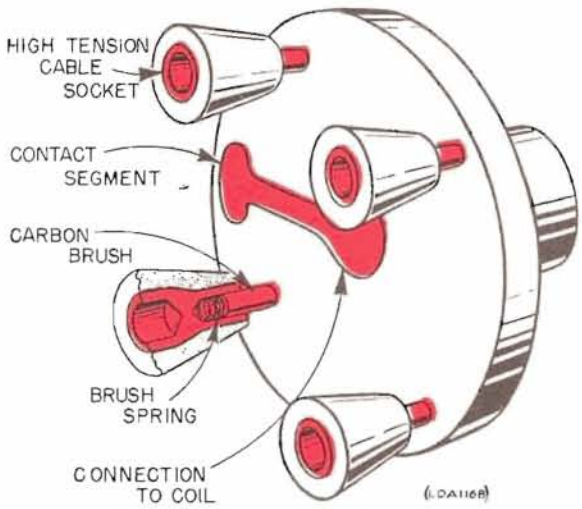


Figure 73—Disc Type Carbon-Brush Distributor

systems are the disc type and the drum type, according to the rotor used. The principle is identical and operation similar.

In the disc type distributor (Figure 73) the brushes track on a flat, revolving surface made of insulating material into which a contact segment has been imbedded The contact segment extends from the center of the disc, where contact is made to the secondary lead of the coil. to the outer edge of the disc, where contact is made during rotation with each of the brushes leading to the individual spark plug cables.

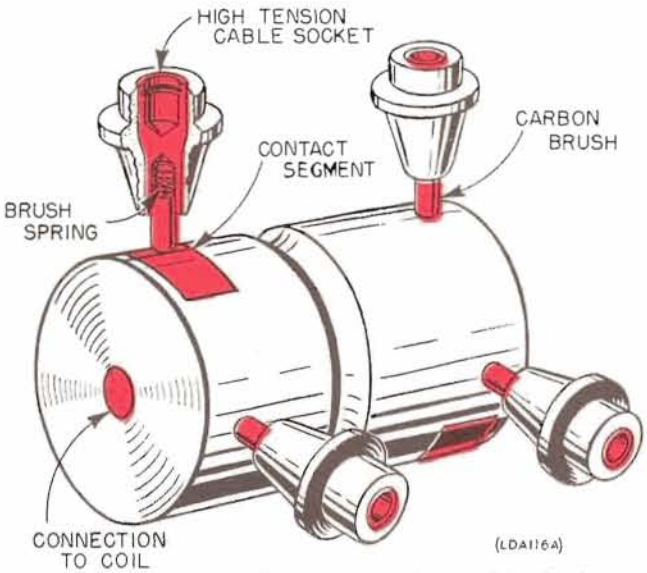


Figure 74—Drum Type Carbon-Brush Distributor

In the drum type distributor (Figure 74) the brushes track on a revolving cylinder made of insulating material into which one or more contact segments have been imbedded. Each contact segment is connected within the cylinder to a central point from which connection is made with the secondary terminal of the coil. The drum-type distributor makes it possible by alternate placing of brushes to extend the separation of consecutively firing contact positions.

JUMP-SPARK DISTRIBUTION

In the jump-spark system of distribution (Figure 75) the contact segment of the distributor passes very close to each contact post, although no actual contact is made. The distributor rotor is so timed to the magneto that its electrode approaches each spark post at the exact instant secondary voltage reaches a maximum; this voltage is sufficient to break down the resistance of the distributor air gap as well as the spark plug point gap. Since the distributor gap is subject only to atmospheric pressure, its resistance in comparison with the point gap is small and very little additional secondary voltage is required.

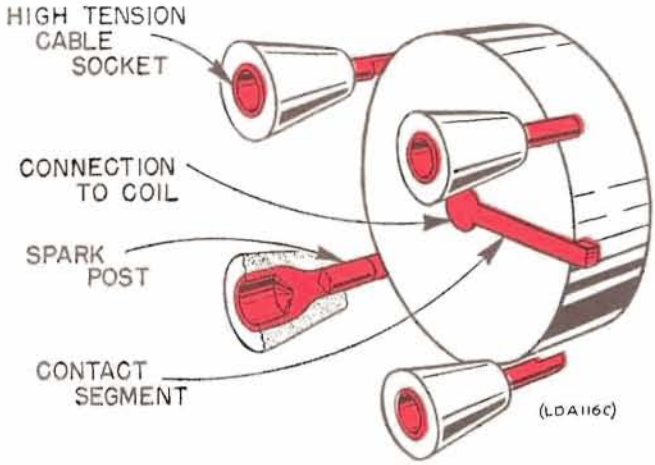


Figure 75—Jump-Spark Distributor

The action of the jump-spark distributor system functions to some extent in preventing pre-ignition due to fouled spark plugs. The additional air gap in the secondary circuit forces the secondary voltage to build up until it reaches a value great enough to break down the combined resistance of the two gaps. Under such circumstances there is less chance that leakage current at the plugs will be sufficient to interfere with normal ignition.

Jump-spark distributors must be operated in a ventilated housing since an active oxidizing agent (ozone) is formed as a result of the sparking across the distributor gaps.

SEALED AND VENTILATED UNITS

Magnetos completely sealed against the entry of dust and moisture are used to advantage in many sections of the country and in many different types of service. Built with carbon-brush distributors, such units provide highly dependable ignition over long periods and require a minimum amount of attention.

Under certain operating conditions improved performance can be obtained from the ventilated design magneto, especially in localities where there is little possibility of the entry of dust or moisture. Ventilation appears to be of considerable advantage in cases where the magneto is subject to excessive engine heat during operation, together with the resultant possibility of condensation when cooling occurs.

Jump-spark systems of distribution necessitate ventilation, since the electro-chemical reactions of the open spark result in the formation of ozone, which in turn is an active oxidizing agent. Some designs of jump-spark magnetos, such as the Fairbanks Morse Types FM-J4 and FM-R, separate the distributor assembly from the magneto proper, thereby permitting adequate ventilation of the distributor compartment, while still maintaining the dust and moisture-proof sealing of the remainder of the magneto.

The problem of recommending a sealed or ventilated magneto for a specific application is a difficult one because it depends to such an extent upon the actual operating conditions encountered in the field. As a result the decision can usually best be made by the experienced operator or serviceman.

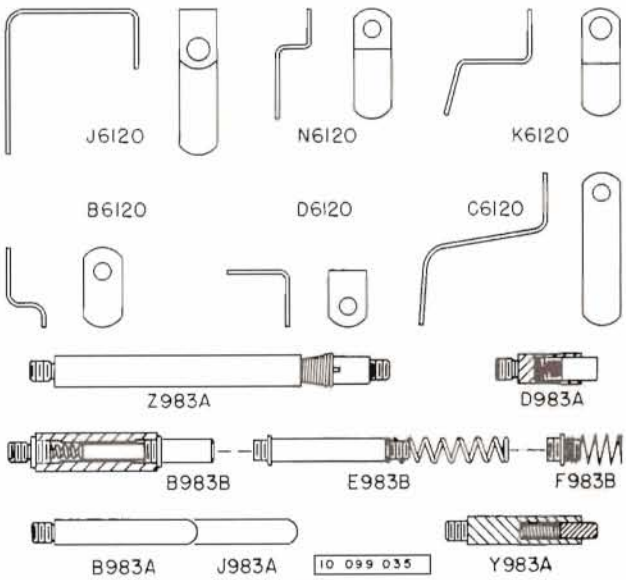


Figure 76—Coil Clips and Lead Rods

COIL CLIPS AND LEAD RODS

The development of the entirely new encapsulated molded high tension coil of epoxy compound has altered somewhat the manner in which the high tension voltage from the coil is transmitted to the distributor rotor or disc and on to the high tension outlets.

Application of this new type of coil to the various magnetos in the field and to the new units being developed has evolved a variety of coil clips, Fig. 76 which are attached to the coil by means of a flat head screw or coil clip button.

Similarly a variety of lead rods and lead rod assemblies have been developed to use in connection with the new coil clips.

Regardless of the combination of coil clips and lead rods used, the contact surfaces of these two parts must be smooth and tight at all times to prevent high voltage arcing at this point which would result in damage to all component parts.

This precaution is also necessary to protect the windings of the coil, since an interruption of the circuit might cause a secondary circuit discharge from the windings of the coil thru its insulation to the ground thus damaging the coil windings beyond use.

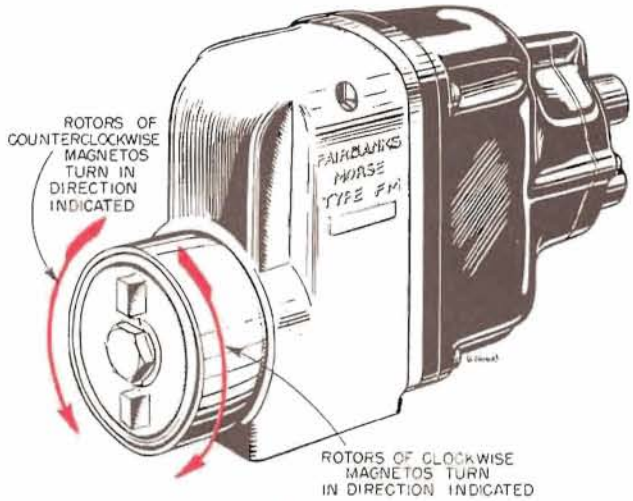


Figure 77—Rotation Diagram

ROTATION OF MAGNETO

The rotation of a magneto is indicated by the direction in which the rotor turns when viewing the unit from the drive end (that is, from the end which is mechanically-coupled to the engine). Magnetos are built for either clockwise (righthand) or counter-clockwise (lefthand) rotation (Figure 77).

The rotation of a magneto fitted with an impulse coupling can usually be ascertained by turning the coupling by hand; the coupling pawls engage the stop pin when the magneto rotor is turned in its proper direction.

Changeover of rotation of many service models of magnetos is not a difficult operation, usually consisting only in changing the impulse coupling, the breaker points and breaker point mounting plate.

MAGNETO MOUNTINGS

Magnetos must be mounted rigidly on engines in order that accurately-timed, positive drive arrangements can be used. A number of entirely different types of mountings have been widely used, special adaptations by individual engine manufacturers resulting in hundreds of variations of the basic designs.

Until recent years all magnetos were of the base mounting design. To provide for this type of mounting engines were built with a small platform bracket on the side of the cylinder block to which the magneto could be fastened. Commonly used base mounting magnetos have either a 35 millimeter (Figure 78) or 45 millimeter (Figure 79) shaft height, this distance being measured from the level of the mounting surface to the centerline of the magneto rotor shaft. An adjustable, flexible coupling is generally used to connect the engine drive shaft to the magneto.

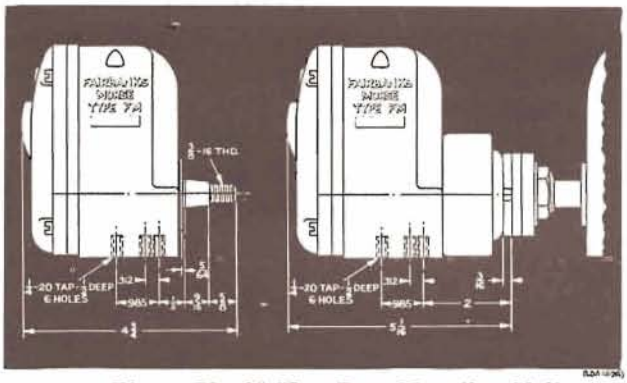


Figure 78—35 Mm. Base Mounting Unit

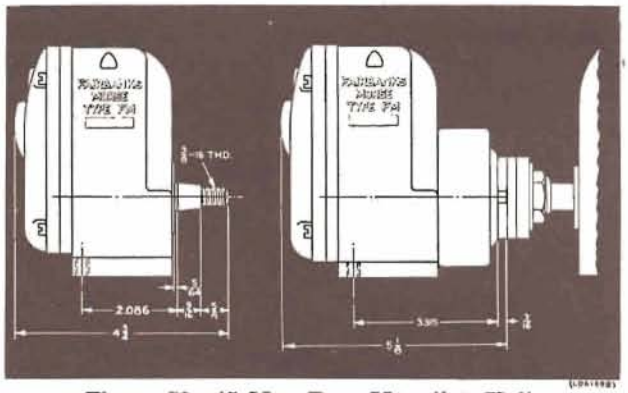


Figure 79—45 Mm. Base Mounting Unit

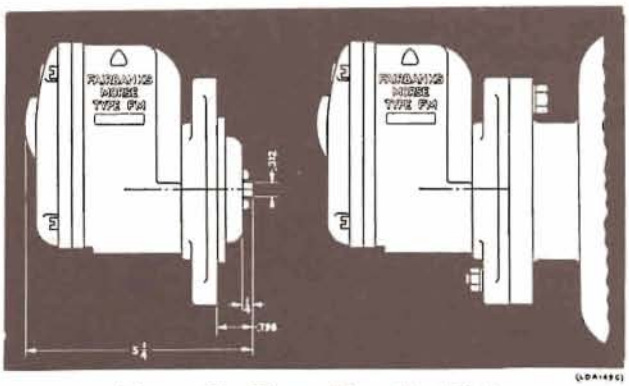


Figure 80—Flange Mounting Unit

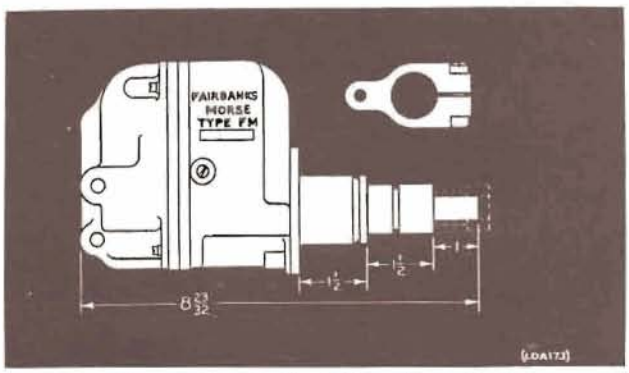


Figure 81—Vertical Mounting Unit

The flange type magneto (Figure 80) has been introduced as an improved method of mounting, being especially adapted to tractor and power unit engines. The flange of the magneto fits directly to a mating flange on the governor housing or crankcase of the engine, thereby enclosing the entire magneto drive assembly within a dust and moisture-proof housing. The machined fit of the mounting flange eliminates the necessity of a flexible coupling and simplifies timing the magneto to the engine.

Some tendency toward a vertical mounting for magnetos has lately become apparent, especially in applications where engine manufacturers desire to offer as optional equipment either battery or magneto ignition. The vertical design mounting (Figure 81) is sometimes referred to as a distributor mounting, since it replaces the complete distributor assembly used on the standard battery ignition engine.

ROTARY DRIVE ARRANGEMENTS

Since a magneto must be precisely timed to an engine in order to furnish ignition sparks exactly in accordance with the sequence of engine operations, provision must be made for a positive drive arrangement. Furthermore, in some instances, it is desirable to provide some means of adjusting the timing of the running spark to compensate for unusual operating conditions.

Rotary magnetos are driven either by a gear train from the crankshaft or camshaft, or directly off the end of the camshaft or crankshaft. The spark interval of the engine is usually the decisive factor in determining the ratio of the rotative speed of the magneto to that of the engine. In cases where the magneto must operate at engine speed, it is driven from the crankshaft; while if it need turn at only half crankshaft speed, it is driven from the camshaft.

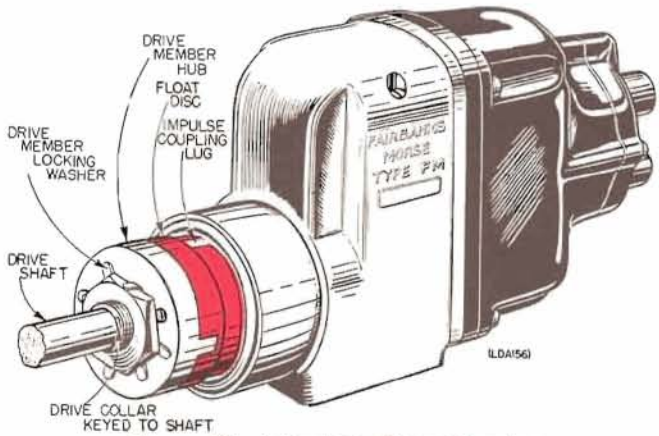


Figure 82—Adjustable Drive Member

Base mounting magnetos are usually connected to the engine drive shaft by means of an adjustable drive member (Figure 82), which also serves as a flexible coupling. The drive member consists of a drive collar which is keyed to the engine drive shaft, a hub with drive lugs to engage the float disc which in turn engages the impulse coupling lugs of the magneto, and a nut and lockwasher for locking the assembly. Since the relative position of the drive member hub and drive member collar can be changed as desired, the assembly permits full adjustment of the magneto spark to meet engine requirements.

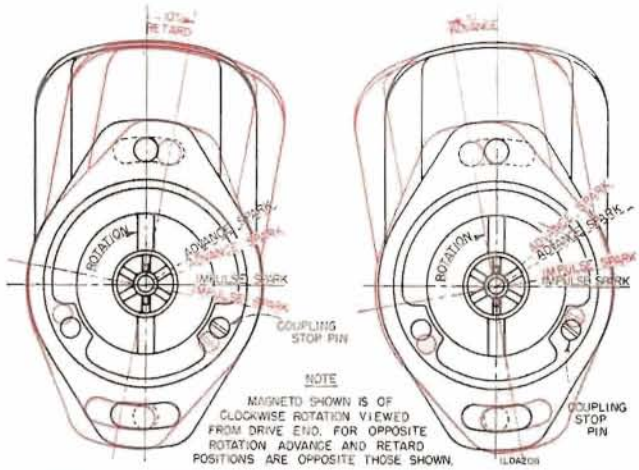


Figure 83—Turning Flange Magneto to Change Spark

The amount of adjustment of the ignition spark of a flange mounted magneto is limited to the extent the magneto can be turned in its mounting. Special slots in the flanges usually provide the possibility of advancing or retarding the spark about 10° (Figure 83). The adjustment can be easily accomplished by loosening the mounting bolts and turning the entire magneto assembly to the desired position, then tightening down the mounting bolts.

FLYWHEEL MAGNETOS

A number of manufacturers of small internal combustion engines, notably in the washing machine engine, garden tractor and outboard motor fields, build the magneto into the flywheel of the engine. The basic magneto assembly, however, is usually purchased from an independent magneto manufacturer. While most widely used on single cylinder engines, flywheel type magnetos have also been adapted to two and four cylinder engines.

The construction of the flywheel magneto depends to a large extent upon the individual engine design, but the theory of operation is identical to that of the rotary magneto. Many of the same developments which have influenced the design of rotary magnetos have been equally effective in respect to flywheel magnetos, and much of the descriptive material covering the self-contained units can also be applied to the flywheel magneto.

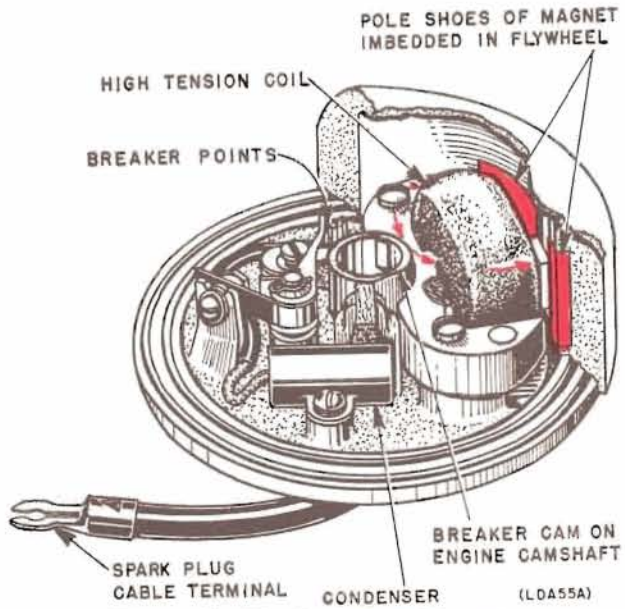


Figure 84—Flywheel Type Magneto

In the typical flywheel magneto (Figure 84) the magnet is located in the outer rim of the flywheel, which revolves around the stationary coil, condenser and breaker point assembly. As the ends of the magnet pass by the pole pieces, an alternating magnetic flux is established through the coil and primary current is generated as long as the contact points remain closed. These points are opened by the cam located on the crankshaft at the instant maximum primary current is obtained, causing the complete collapse of the primary field within the coil and inducing a very high secondary voltage. An ignition spark occurs across the points of the spark plug when the induced secondary voltage becomes sufficiently great to bridge the point gap.

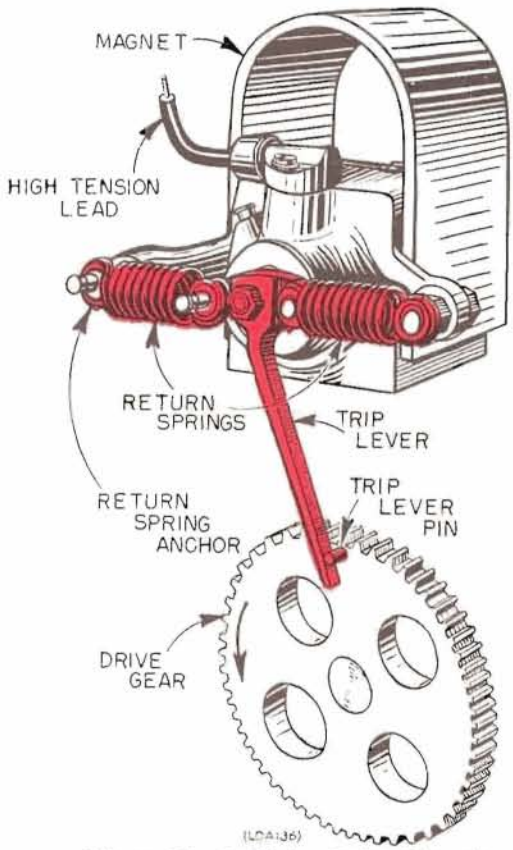


Figure 85—Oscillator Drive Magneto

OSCILLATOR MAGNETOS

Oscillator design magnetos were developed specifically for slow speed, single cylinder engines and differ from conventional magnetos chiefly in the drive arrangement. The construction of the oscillator magneto proper is identical, or nearly so, with that of a standard rotary magneto and can be of the shuttle-wound armature type, inductor type or rotating magnet type.

The important difference in the action of the oscillator

magneto is that the rotor is rocked rather than turned. The action can be classed as a form of impulsing, since the engine drive gear (Figure 85) engages the magneto trip lever once each revolution and, as movement continues, extends the springs which establish the normal position of the rotor. When the trip lever is released by the drive gear, these springs act instantly to pull the lever and the rotor back into their normal position. Since this quick rocking of the rotor is designed to occur across the point at which maximum change of magnetic flux takes place, maximum primary current is induced. Simultaneously the cam functions to open the contact points and break the primary circuit, causing a very high voltage to be induced in the secondary winding, which furnishes the ignition spark in completing its circuit to ground.

The use of oscillator magnetos is limited to slow speed engines, because of the mechanical lag in the tripping device. This mechanical lag must also be accounted for in timing the magneto to the engine.

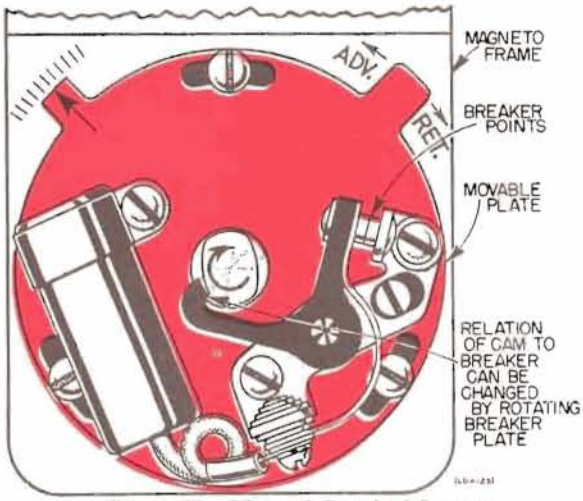


Figure 86—Manual Spark Advance

MANUAL SPARK ADVANCE

Since a magneto produces an ignition spark at the instant its breaker points open, it is reasonable to assume that the time-relation of the ignition spark to the engine cycle can be controlled to some extent by shifting the point at which the breaker contacts begin to open.

To illustrate this principle a simple, movable breaker point mounting plate, concentric with the breaker cam, is shown in Figure 86. Turning the plate so that the points would open before the optimum position is reached would produce a spark earlier in the engine cycle and is commonly referred to as "advancing" the ignition spark, while turning the plate in the opposite direction produces a spark later in the engine cycle and is known as "retarding" the spark.

The amount of advance or retard which can be actually obtained by this method is definitely limited since the strength of the ignition spark falls rapidly as the points open farther away from the point of maximum primary current.

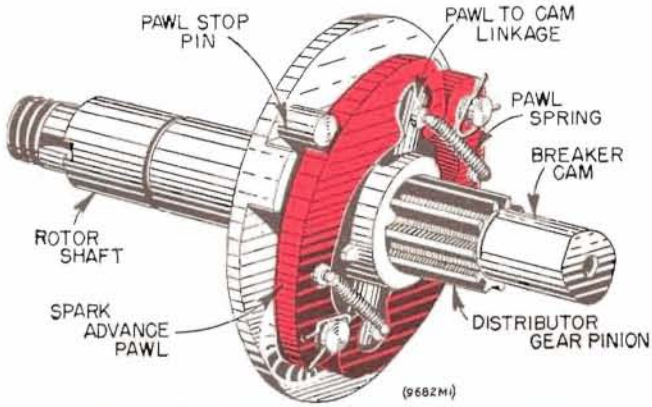


Figure 87—Automatic Spark Advance Rotor

AUTOMATIC SPARK ADVANCE

In certain applications the necessity arises for automatically advancing the ignition spark as the rotative speed of the engine increases. This can be accomplished by using a centrifugally controlled spark advance rotor.

The automatic spark advance rotor (Figure 87) depends upon two spring-loaded pawls for its action. These pawls, which are held close to the center of the rotor at low speeds (Figure 88 "a"), swing gradually outwards as the speed increases (Figure 88 "c") until the pawl stop is reached.

The outward movement of the pawls is transferred by a mechanical linkage to the breaker cam shaft with the result that the cam changes its relative position in re-

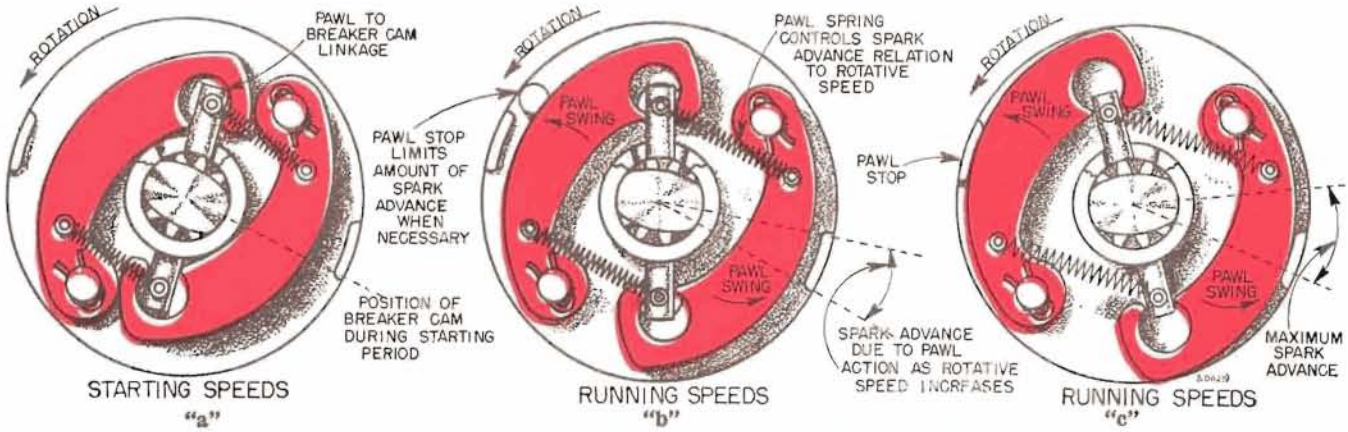


Figure 88—Operation of Automatic Spark Advance Rotor

spect to the drive shaft. Since the shift in the cam to shaft relation as the engine speed increases causes the breaker points to open earlier in the engine cycle, the ignition spark is said to be advanced.

CONTROLLING IGNITION SPARK ADVANCE

The maximum amount of spark advance which can be obtained with a rotor of this type is controlled by the position of the pawl stop which is located on the outer circumference of the rotor. Smaller advances are secured by stopping the pawl movement before it reaches the outer circumference stop (Figure 88 "b"). It is also possible through the selection of proper pawl springs to predetermine the speed at which maximum spark advance will be obtained and also the amount of spark advance obtained per unit increase in rotative speed.

IGNITION SYSTEM WIRING

The efficiency of any ignition system can be immeasurably reduced by poor or inadequate wiring. In both original applications and service work care should be taken to be certain that suitable ignition cables and terminals are used.

The absolute necessities of a suitable wiring harness are high tension cables of sufficient capacity and with proper insulation; clean, tight electrical contacts and terminals adapted to their specific use, and soldered joints. Often overlooked is the low voltage cable (primary ground cable on magnetos); the same care should be given its condition as is given other parts of the system.

A clean, neat arrangement of the high tension cables is of great value in securing top-notch performance. If possible, long ignition cables should be avoided because of the inductance effect involved. Cables should not, however, be so shortened that contact is made with the engine head or block.

Theoretically, high voltage currents travel on the surface of a conductor in what is known as "skin-effect." In practice this accounts for the use of cables of finely-stranded wire because of the increased surface thus obtained, as well as the flexibility. Recent experimental results indicate the desirability of stainless steel ignition cables for certain applications. Because of the greater strength of the stainless steel wire, the individual strands can be reduced in cross-section and the effective surface thereby increased. If the effective surface is kept constant, the number of strands can be reduced with a noticeable reduction in the capacitance effects of the cable.

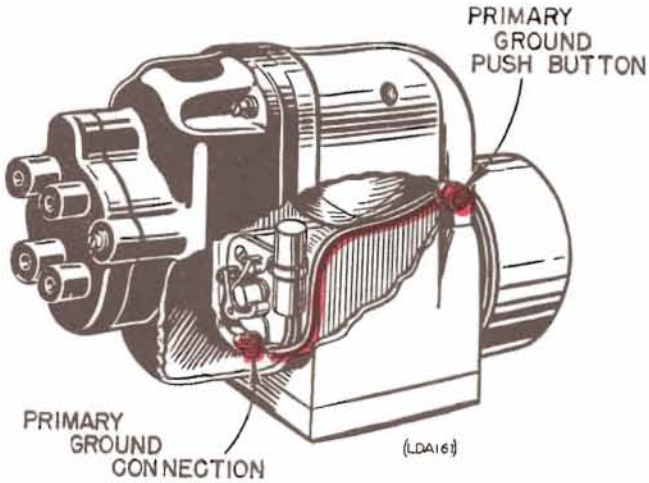


Figure 89—Self-Mounted Primary Ground Switch

PRIMARY GROUND SWITCHES

Engines are stopped either by closing off the fuel supply to the carburetor or by cutting or grounding the ignition circuit.

The disadvantages of closing off the fuel supply are that an immediate engine stop is not secured and that restarting of the engine is sometimes difficult since the carburetor must completely empty itself before the engine stops, the final intake charge of each cylinder being plain air. In some cases, however, where distillate is used as fuel, it is considered desirable that the engine be stopped by burning out the fuel in the carburetor and cylinders.

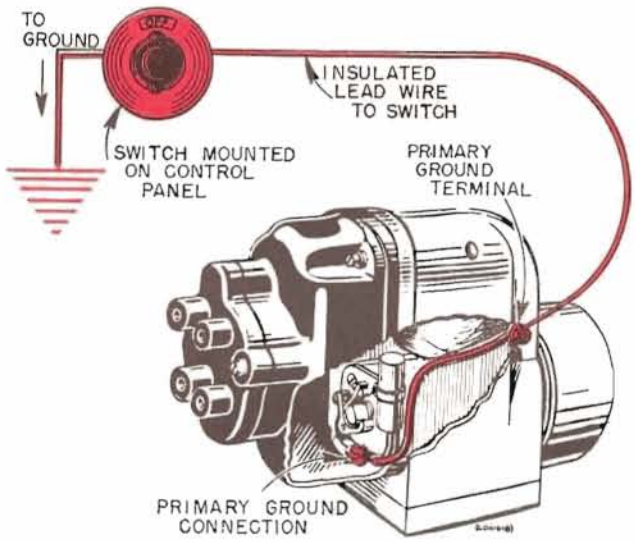


Figure 90—Remote-Mounted Primary Ground Switch

Battery ignition circuits are opened for engine stopping, while magneto ignition circuits must be grounded. The switches must be located in the primary circuit of either type, but their action is instantaneous and the engine fuel system is left ready for re-starting.

There are many types of primary ground switches, but in general they may be divided into two groups: (a) those located directly on the unit and (b) those located some distance away, as for example, on the engine control panel.

On a self-mounted ground switch (Figure 89) a wire is run from the primary terminal of the coil to a spring switch on the metal frame; so arranged that when the switch is actuated the primary circuit is grounded out

and no high voltage sparks are produced. On a remote-mounted switch (Figure 90) the same wire from the primary terminal of the coil is extended to the control panel, usually through an intermediate terminal mounted on the magneto.

It should be noted that, in stopping an engine by grounding the ignition circuit, the switch must be held closed until the engine is motionless.

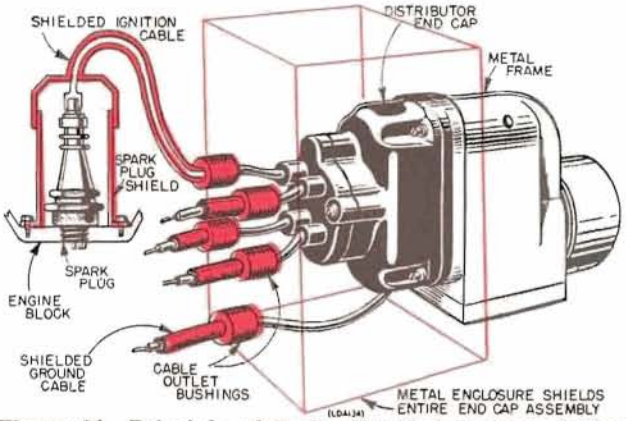


Figure 91—Principle of Radio-Shielded Ignition System

RADIO-SHIELDED IGNITION SYSTEM

The high voltage spark discharge which provides ignition for the engine is an oscillatory surge of electricity and as such causes considerable interference in nearby radio receivers, especially those operating on high frequency bands. In many cases it is therefore necessary or desirable that this interference be eliminated at its source. There is a definite trend toward radio-shielding the ignition systems of all engine-driven light plants and power units.

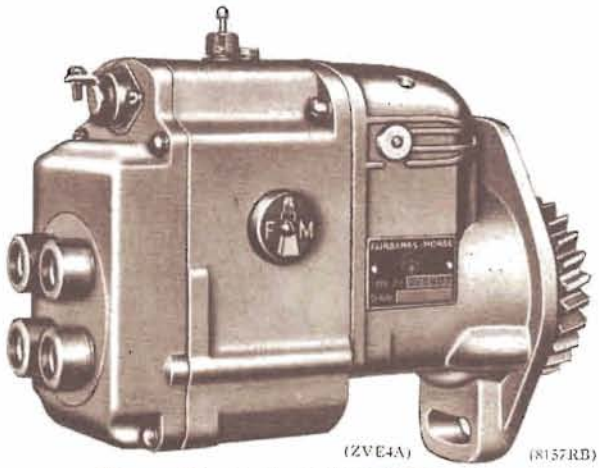


Figure 92—Radio-Shielded Magneto

The principle on which ignition systems are radio-shielded is shown in Figure 91. A metal cover has been so arranged as to completely enclose the plastic end cap, metal sheaths encase the ignition cables and the spark plugs are mounted within metal housings. All of this exterior metal housing is interconnected and grounded and functions as a shield, since it absorbs the interference-causing waves.

In practice a metal cover such as that shown is not used, but the entire end cap of the magneto is made of metal with a plastic distributor block mounted on the inside (Figure 92). Lead gaskets are used to seal joints between the metal housings of the unit. All cables are enclosed in metal sheaths, the ground or switch cable must be shielded as well as the high tension cables. While standard spark plugs mounted in metal enclosures are used in some applications, spark plug manufacturers have developed a special type of spark plug which has an all-metal exterior.

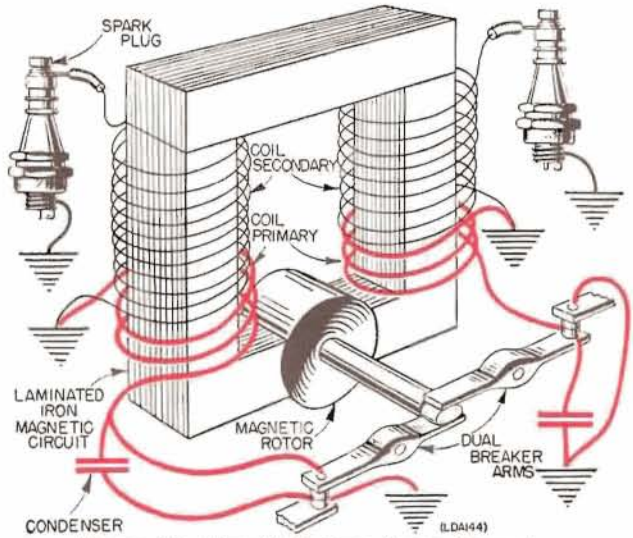


Figure 93—Two-Coil, Two-Spark Magneto

TWO-SPARK MAGNETOS

Occasionally engine designers try to increase the dependability or performance of the ignition system by locating two spark plugs in each cylinder head instead of the customary one. In cases such as this two separate magnetos, timed to spark simultaneously, can be used, but more often a two-spark magneto is specified.

There are two general types of two-spark magnetos. In the first system (Figure 93) two separate coils, con-

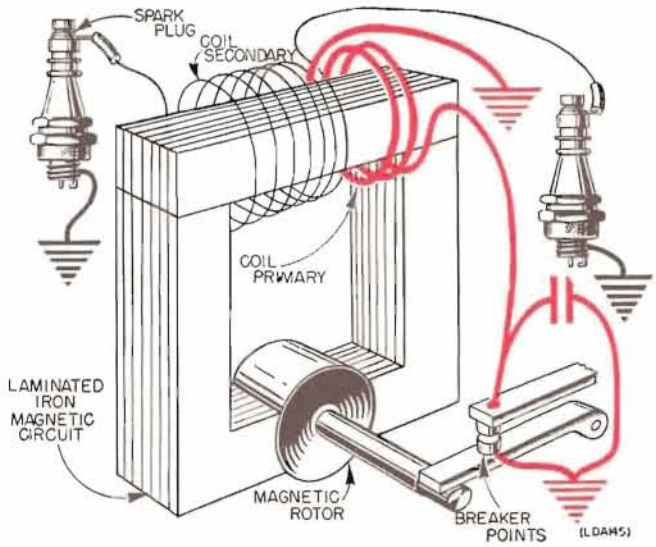


Figure 94—Single Coil, Two-Spark Magneto

densers and breaker point sets are super-imposed upon the same magnetic circuit. Since the same magnetic break produces maximum primary current in each of the coils, the breaker point sets can be so synchronized that two simultaneous ignition spark discharges are obtained. In the second method (Figure 94) only a single coil, condenser and breaker point set are used, the important variation being the fact that each end of the secondary winding of the coil is brought out to a spark plug terminal. To complete the secondary circuit the ignition spark must bridge both spark plug point gaps.

In the event of application of a two-spark magneto to a multi-cylinder engine, two complete and separate distributor systems are required.

DUAL IGNITION

A number of ignition systems can be classified as dual ignition, as, for example, either of the two-spark magneto arrangements described above.

It seems advisable in most respects, however, to think of dual ignition systems as systems which are made up of two complete sets of ignition apparatus. Often such an arrangement is comprised of a complete battery ignition system and a complete magneto ignition system, installed in such manner as to provide the engine operator the possibility of switching from one to the other. Many dual ignition systems, especially on aircraft engines, use two identical magneto ignition units.

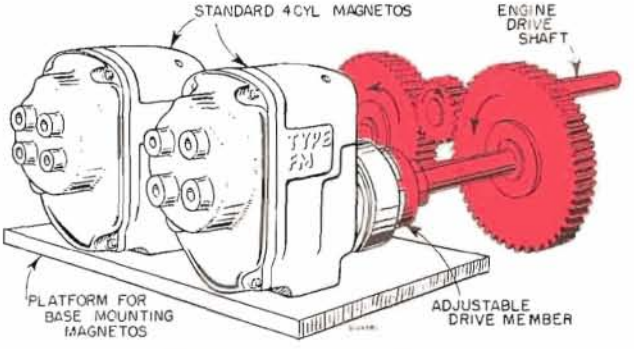


Figure 95—Multiple Installation for 8 Cyl. Engine

EIGHT & TWELVE CYLINDER UNITS

The use of spark-ignition engines of more than six cylinders is uncommon in the tractor and power engine field and most installations encountered are likely to be special adaptations. Magnetos specially built for these installations can be obtained, but because of their infrequent use and increased mechanical intricacy, their cost is relatively high and service facilities limited.

Multiple installations of standard four and six cylinder magnetos have certain advantages, chiefly in their universal service and replacement. An eight cylinder engine is fitted with two four cylinder units, while a twelve cylinder engine requires two six cylinder magnetos. In such installations the two units are interlocked with a gear drive (Figure 95) which permits flexibility in timing.

USE OF MAGNETOS

Even men who work with magnetos and magneto service are likely to overlook part of the tremendous field in which magnetos are used. From the tiny single cylinder gasoline engines used with generators, pumps or washing machines to the huge, multi-cylinder engines of the modern bombers and airline transports, the magneto serves its vital purpose of supplying engine ignition.

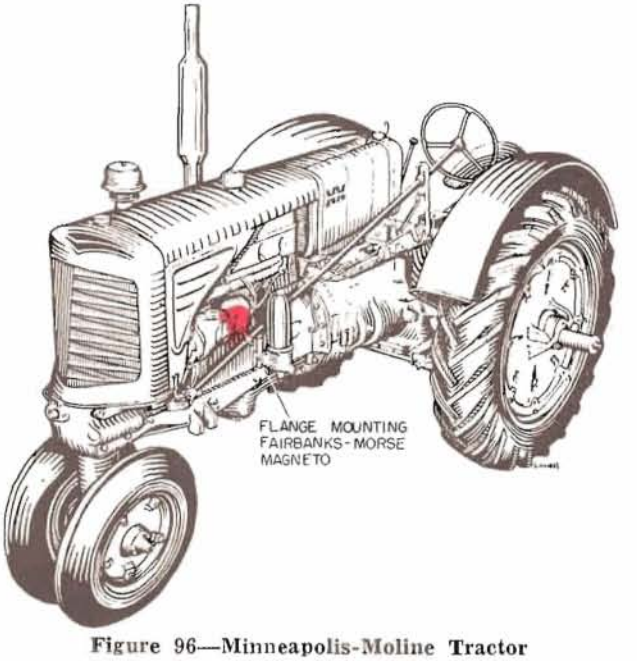


Figure 96—Minneapolis-Moline Tractor

A partial list of the applications of engines equipped with magneto ignition is as follows:

Tractors	Oil Burners	Outboard Motors
Combines	Gas Burners	Washing Machines
Trucks	Cement Mixers	Air Compressor Units
Buses	Pumping Units	Generating Sets
Hoists	Portable Saws	Airplane Engines
Power Units	Marine Engines	Natural Gas Engines

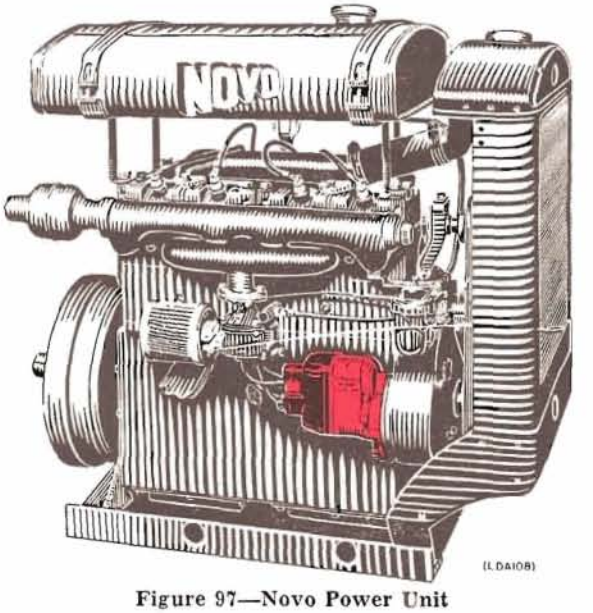


Figure 97—Novo Power Unit

SECTION SEVEN

IMPULSE COUPLINGS

GENERAL PURPOSE

A mechanical device, known as the impulse coupling or starter, is installed between the engine drive and the magneto proper on a majority of rotary magneto installations. Its primary function is to intensify the ignition spark at low rotative speeds in order to facilitate engine starting. The construction of the coupling in addition provides the means for automatically retarding the ignition spark during the starting period, thus reducing the possibility of damage to the engine or injury to the operator due to engine back-firing.

TYPES OF IMPULSE COUPLINGS

There are many variations of impulse couplings in general use, each magneto manufacturer having done considerable development work in this field. The principles of operation are much the same for the various designs and once understood should be readily applicable to similar units.

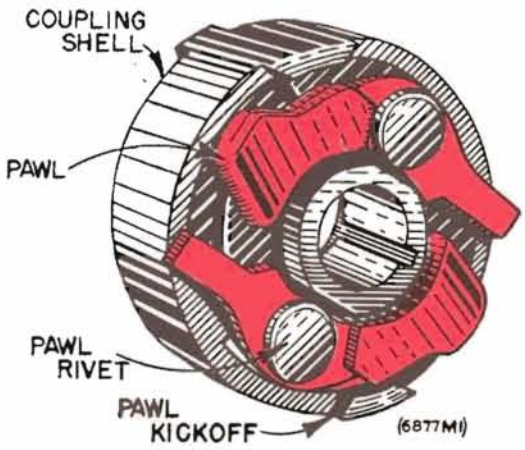


Figure 98—Pivoted Pawl Impulse Coupling

An arbitrary grouping of current impulse coupling designs can be made by classifying the couplings by their pawl action. In the pivoted pawl design (Figure 98) each pawl is securely fastened to a hub plate, its movement being confined to a turning action in an arc about its pivot point. In the sliding pawl design (Figure 99) the pawls are free, but move in a guide which restricts their motion to a straight line action.

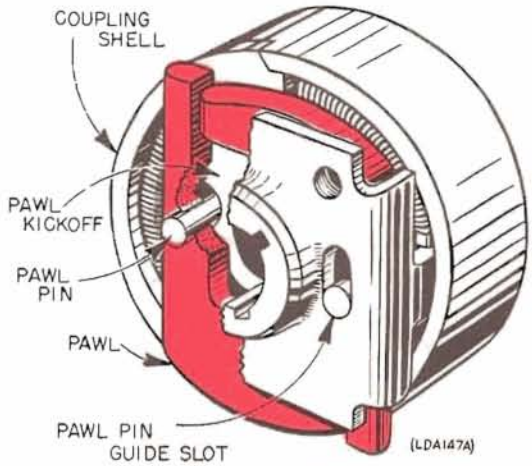


Figure 99—Sliding Pawl Impulse Coupling

DESCRIPTION OF OPERATION

The impulse coupling functions as a mechanical reservoir to store the energy which is available at a low rate during the engine starting period. Then, when the point is reached in the engine cycle where ignition of the fuel mixture should occur, all of this accumulated energy is instantly released to the magneto with the result that a strong ignition spark is produced. Since the point at which the energy release occurs can be controlled in the construction of the coupling, it is possible to provide an automatic retard of the ignition spark during the starting period.

Basically the impulse coupling consists of a shell and a hub, connected together by a strong spring. One half of the coupling (the shell) is fitted to a drive member on the engine drive shaft, while the other half (the hub) is keyed to the magneto rotor shaft. In operation at slow speeds (Figure 100) a pawl on the magneto half of the coupling engages a stop pin mounted on the magneto

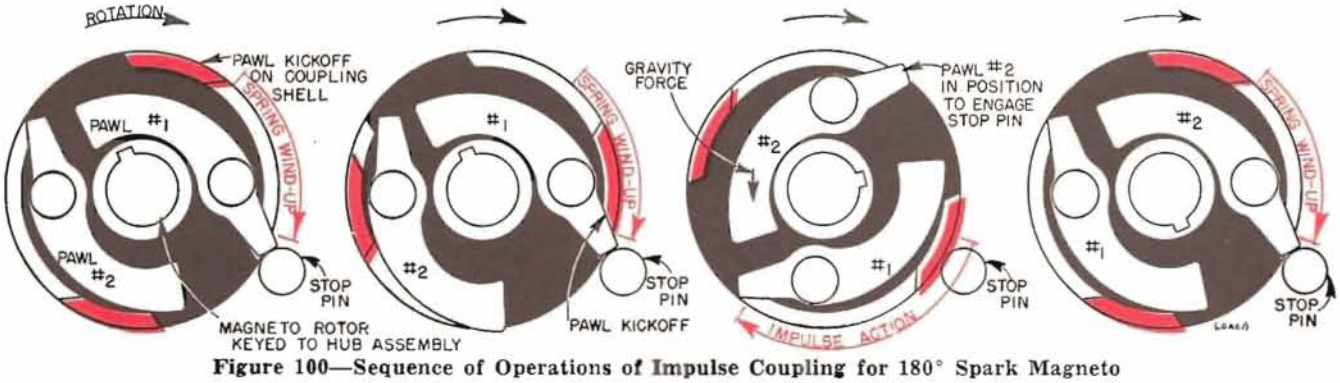


Figure 100—Sequence of Operations of Impulse Coupling for 180° Spark Magneto

frame, which acts to prevent further movement of the rotor, while the engine half of the coupling continues to rotate; the relative change in position winds up the connecting spring. When the point is reached where an ignition spark is desired, the pawl is released and the drive spring permitted to snap the magneto rotor forward at high speed through its firing position. As the speed of the engine picks up, centrifugal force acting on the pawls withdraws them to a position where they no longer engage the coupling stop pin, the impulse coupling then acting as a solid drive member.

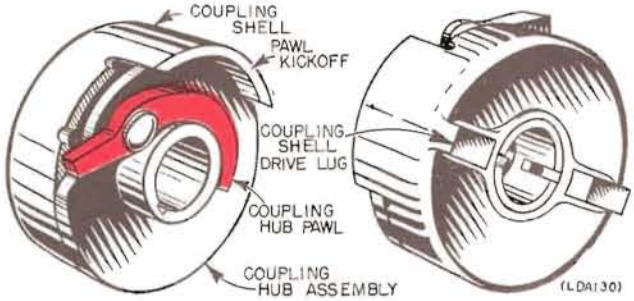


Figure 101—Single Pawl Coupling

SINGLE PAWL COUPLINGS

Where only one impulse spark per revolution of the magneto rotor is desired, a single pawl coupling (Figure 101) is used. This requirement is usually found in connection with single cylinder engines and with two cylinder engines firing each 360° of crankshaft rotation.

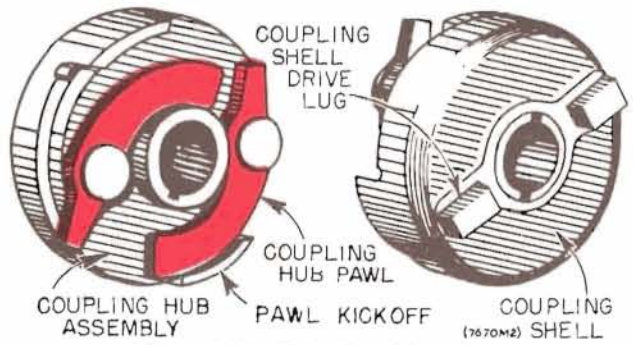


Figure 102—Twin Pawl Coupling

TWIN PAWL COUPLING

To produce two impulse sparks per revolution of the magneto rotor a twin pawl coupling (Figure 102) is used. Since these pawls are placed symmetrically on the coupling hub plate, each 180° of rotation brings a pawl into position to engage the stop pin.

With only slight changes the twin pawl coupling can be arranged to produce four impulse sparks per revolution (Figure 103). In such a case two stop pins are used instead of the usual one, and are located 180° apart. The pawls are spring-loaded to make them independent of gravity-operation and to speed up their action. A stronger drive spring is provided to compensate for the shorter wind-up period.

COUPLING PAWL OPERATION

In nearly all cases, both sliding and pivoted pawls operate automatically as the result of the two natural forces gravity and centrifugal. At slow speeds the gravity force dominates the pawl action, holding the pawl in such a position as to force it to engage the stop pin. With an increase in rotative speed, there is a corresponding increase in the centrifugal force acting upon the pawl, this force gradually overcoming the original gravity force and thus becoming dominant in the pawl action. Centrifugal force acts to prevent the pawl from engaging the stop pin.

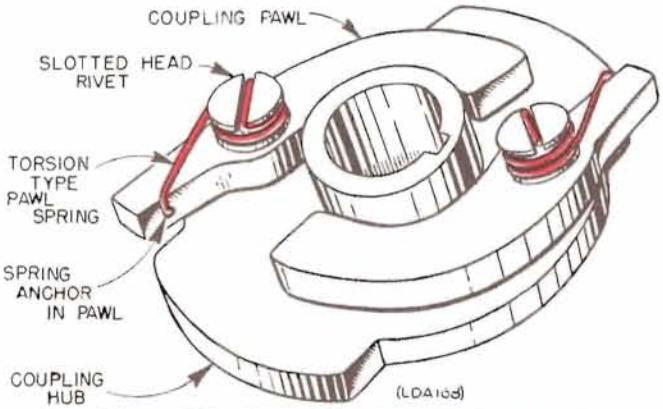


Figure 104—Spring-Loaded Coupling Pawls

SPRING-LOADED COUPLING PAWLS

While centrifugal force always acts at right angles to the axis of operation and therefore depends only upon rotative speed, gravity force always acts downward and is therefore dependent upon the coupling position. In the application of most magnetos the rotor shaft is horizontal and the downward gravity force accordingly is at right angles to the axis of operation. In other applications, however, the magneto is mounted at such an angle that the gravity force cannot operate the pawls during

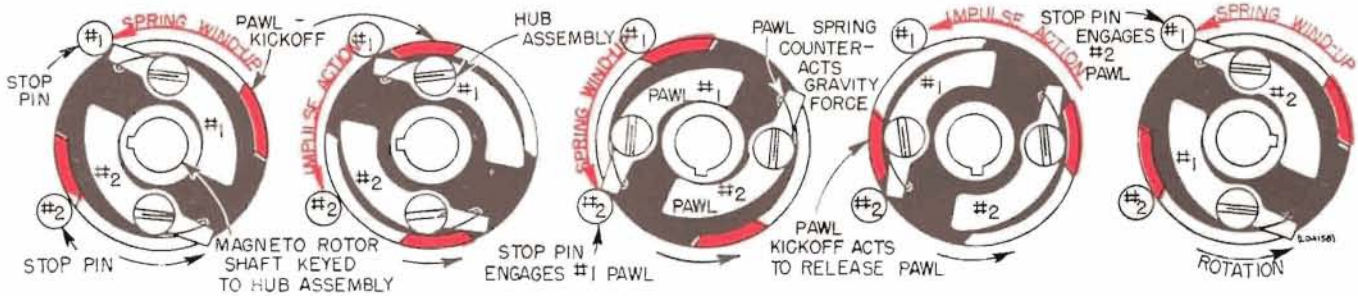


Figure 103—Sequence of Operations of Impulse Coupling for 90° Spark Magneto

the starting period. To cause the necessary engagement action, small wire springs (Figure 104) are attached to pawls to act opposite the centrifugal force and are of such strength as to replace the gravity force entirely.

The same arrangement (that is, pawl springs) is used to strengthen the gravity force in some applications in order to cause engagement of the pawl through higher than normal rotative speeds, or to speed up the action of pawls in order to engage stop pins located relatively close together.

COMBINED DRIVE GEAR & COUPLING

In certain special engine applications, the magneto drive gear has been made an integral part of the impulse coupling, serving as the outer shell. In a typical design (Figure 105) a single pawl hub is mounted in the conventional way on the magneto rotor shaft, while the drive gear is machined to fit the outer edge of the hub. In assembly the inner end of the coupling drive spring is anchored in the coupling hub, after which the spring is wound to the proper tension and its outer end fastened to the gear. The assembly is closed off with a large flat washer which fits under the coupling nut.

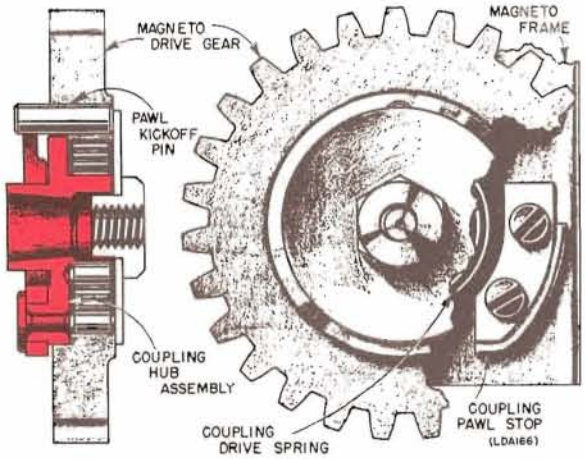


Figure 105—Combined Drive Gear and Coupling

In operation at slow speeds the coupling hub pawl engages the stop plate mounted on the magneto and winds up the drive spring. When the spring wind-up is complete, the pawl kickoff pin which is inserted in the gear strikes the pawl and forces it off the stop, releasing the hub and providing an impulse spark.

A more common type of combined drive gear and coupling is the two-piece design (Figure 114, Page 47) in which the drive lugs of a standard impulse coupling are fitted into a slot on the face of a drive gear, the assembly being mounted on an extended magneto rotor shaft. The drive gear and coupling shell turn together and must move in relation to the rotor shaft during the impulse period. Provision for this movement is usually made by inserting a bushing between the drive gear and rotor shaft.

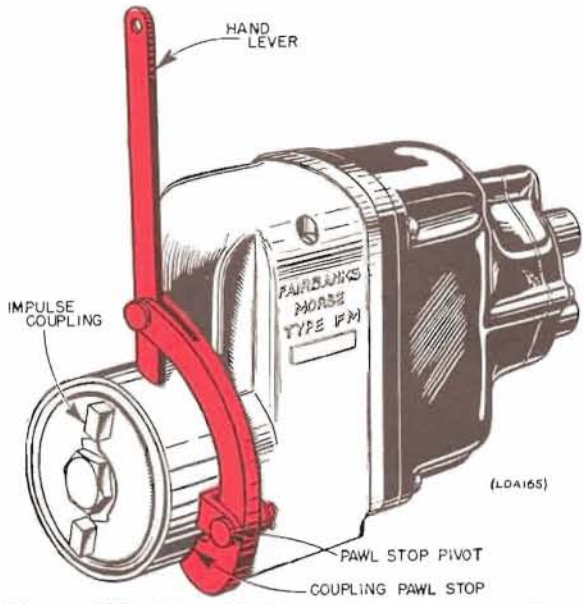


Figure 106—Manually-Engaged Impulse Coupling

MANUALLY-ENGAGED IMPULSE COUPLINGS

In certain types of magneto applications, usually in connection with slow speed oil or gas engines, there appears to be considerable advantage in manually-controlled impulse couplings. In such installations the operator moves the impulse coupling stop pin into position to engage the coupling pawl before engine starting is attempted. This procedure provides an intensified impulse spark, automatically retarded for starting. After the engine is running the coupling continues to impulse until the operator moves the pawl stop into the inactive position.

The manually-engaged impulse coupling is a simple assembly (Figure 106), usually consisting of a lever and pivot arrangement by which the impulse coupling pawl stop can be moved and locked into position. Remote control of the engagement lever can be provided by a system of wires and pulleys.

IMPULSE COUPLING DRIVE SPRINGS

During the starting period of the engine the impulse coupling stores up mechanical energy in the drive spring which connects the engine half of the coupling with magneto half. When the pawl releases, the drive spring snaps the magneto rotor through the arc necessary to produce an ignition spark.

Two types of impulse coupling drive springs are used in current designs. Most widely used is the torsion type spring (Figure 107), which resembles closely the mainspring of a clock. When the coupling is assembled, this spring is given an initial tension of approximately one or two turns, the impulse action providing additional tension. In the compression type spring (Figure 108), the coil spring must be compressed in order to assemble it into the shell, and additional compression takes place

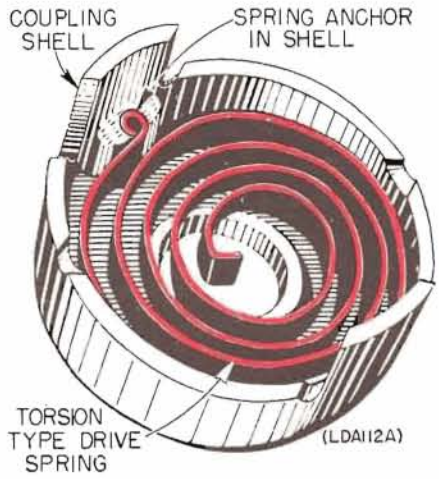


Figure 107—Torsion Type Drive Spring

during the impulse action.

The strength of the impulse coupling drive spring varies with the amount of wind-up (Figure 109) permitted by the coupling design and application. Obviously a long wind-up can be secured with a single pawl coupling where engagement occurs only once per revolution, while a very short windup is obtained in the case of an impulse coupling which is subject to four impulse actions per revolution.

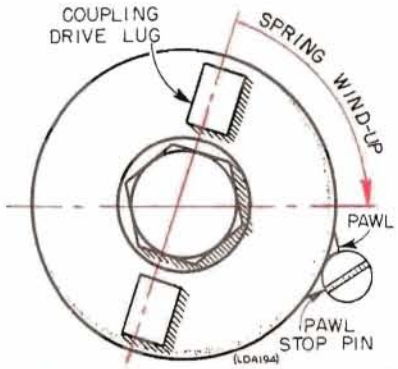


Figure 109—Drive Spring Wind-Up

IMPULSE COUPLING SPARK RETARD

The impulse coupling acts to intensify the starting spark, and at the same time to automatically retard this spark to the extent that it occurs at approximately top dead center of the compression stroke of the engine piston.

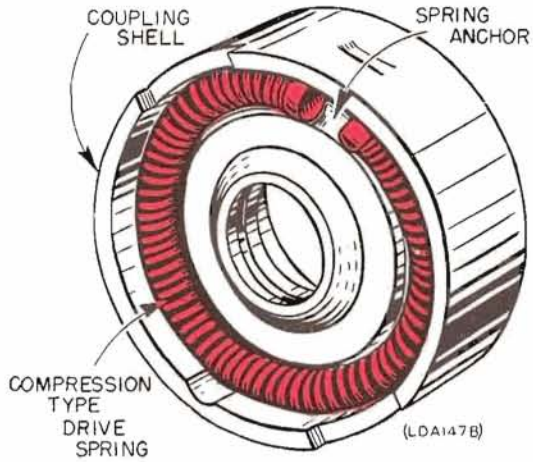


Figure 108—Compression Type Drive Spring

In distinguishing the ignition spark positions the retarded starting spark is usually termed the impulse spark, while the normal running spark is often called the advance spark.

To analyze the method by which the normal spark of the magneto is automatically retarded while the impulse coupling functions, the angular relation between the coupling and the magneto rotor must be closely observed.

In Figure 110 the action of the impulse coupling is illustrated in terms of the angles involved in its operation. The first step (a) occurs when the coupling pawl engages the stop pin, at which point the magneto rotor is prevented from further rotation, while the coupling shell continues to turn through angle A. During this period the mechanical energy supplied to the magneto is stored in the coupling through the wind-up of the drive spring.

The second step (b) of the impulse action occurs just as the wind-up period of the drive spring is completed and the pawl kickoff projection on the shell functions to release the pawl from the stop pin. The angle D shown on the coupling end of the assembly indicates the mechanical lag from the instant the pawl kickoff strikes the pawl to the instant the drive lugs of the shell reach the horizontal centerline. Note that in both steps (a) and (b) the magneto rotor is held stationary in a position preceding its spark point by an angle C which includes the edge gap distance.

In the third step (c) the drive spring of the coupling

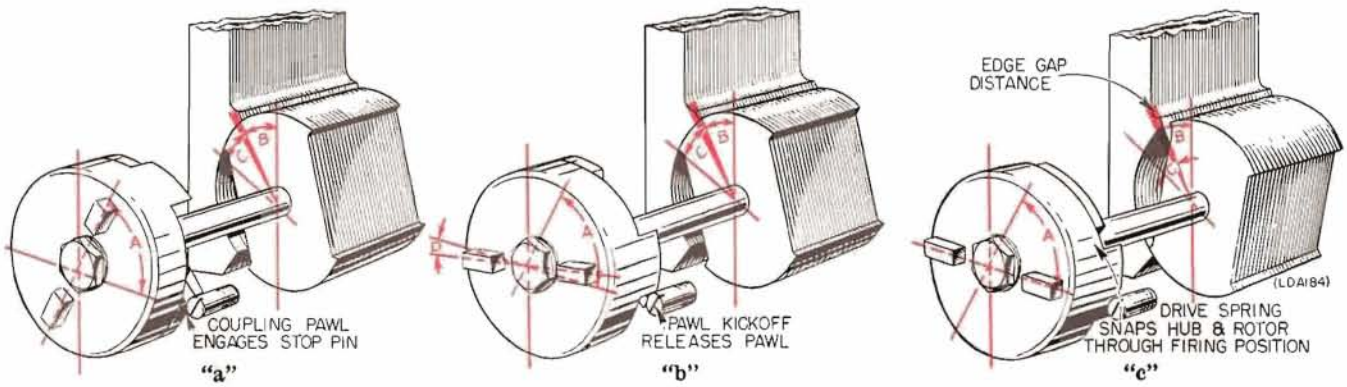


Figure 110—Relation of Impulse Coupling to Magneto during Impulse Action

functions to snap the hub of the coupling together with the magneto rotor through its wind-up angle A, the magneto rotor passing through the entire spark angle C, including the edge gap distance. Since the speed of this action is determined by the strength of the drive spring, a very strong ignition spark can be produced during the starting period of the engine.

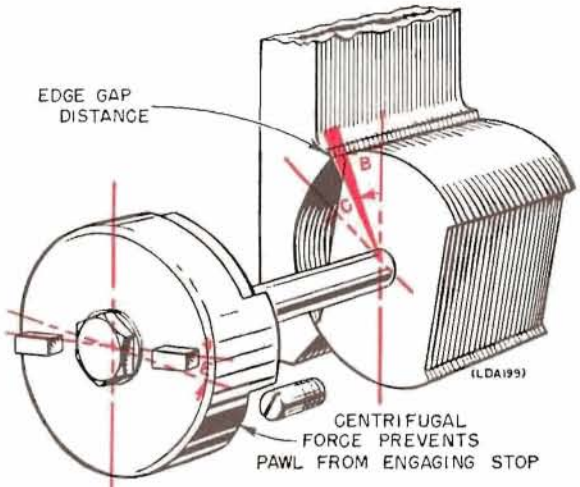


Figure 111—Angular Relation at Normal Running Speed

As the engine speeds up after starting, the impulse action of the coupling ceases, since the pawls no longer engage the stop pin. In Figure 111, the coupling is shown as it operates at speeds greater than those permitting impulse action. Since the pawls do not engage the stop pin, no drive spring wind-up occurs and the coupling acts as a solid drive member, the magneto rotor turning at exactly the same rate as the coupling shell. Consequently the magneto rotor passes through its spark position, as indicated by the edge gap distance, when the coupling drive lugs are at an angle E before the horizontal centerline is reached. This angle E is the amount the ignition spark has been advanced in the change from impulse spark to running spark. Conversely, it is the angular degrees the running spark is retarded during impulse action, and is commonly referred to as the lag angle of the coupling.

The angle E of an impulse coupling is determined by the location of the keyway in the hub; the lag angle can be increased or decreased within limits by moving the keyway when making the hub.

LOCATION OF COUPLING SHELL DRIVE LUGS

The location of the coupling shell drive lugs in relation to the advance and impulse spark positions varies according to the specifications of different engine manufacturers. Two practices, opposites in method, are commonly used in determining these spark positions:

(a) SAE standards have attempted to establish the method by which the impulse spark always occurs when the coupling drive lugs reach the horizontal centerline (Figure 112), the position of the advance spark then being at a point preceding the horizontal by the specified lag angle degrees.

(b) In the second method the advance spark position is fixed at an arbitrary point (for example, 30° before the horizontal as in Figure 113), the impulse spark positions then following this point by the specified lag angle degrees.

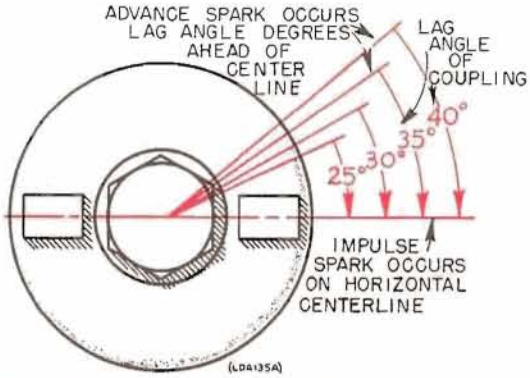


Figure 112—Impulse Spark on Horizontal Centerline

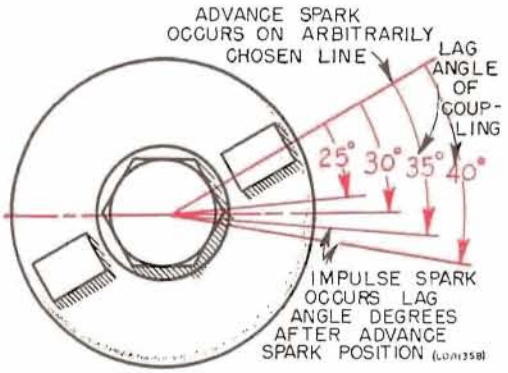


Figure 113—Location of Advance Spark Constant

REMOVAL OF IMPULSE COUPLING

In dismantling the impulse coupling assembly the first

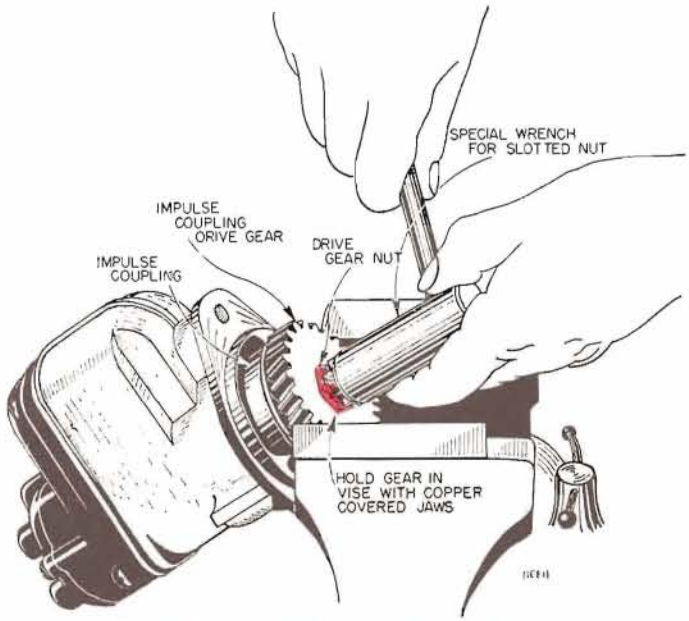


Figure 114—Removing Drive Gear Nut

operation is to remove the coupling nut. This nut is usually locked in place by means of a special washer or wire, which must be broken. The coupling must then be held stationary in order to turn the coupling nut off the shaft end. In some cases where a drive gear is assembled to the coupling shell, it is convenient to catch the gear in a vise (Figure 114), being careful not to injure the teeth of the gear, and then remove the coupling nut with a wrench. A special slotted wrench can be obtained to hold the drive lugs of completely enclosed couplings (Figure 115) while turning off the coupling nut.

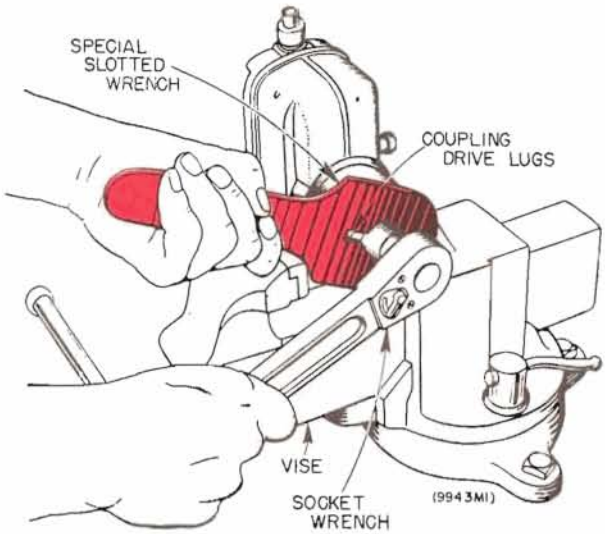


Figure 115—Removing Coupling Nut

To disengage the coupling shell, one of the drive lugs of the shell should be grasped firmly with a pair of pliers, and the shell turned and pulled at the same time (Figure 116) until the drive spring releases. Do not try to force the shell to separate itself entirely from the assembly; the drive spring should first be pried out of its anchor slot by means of a screwdriver.

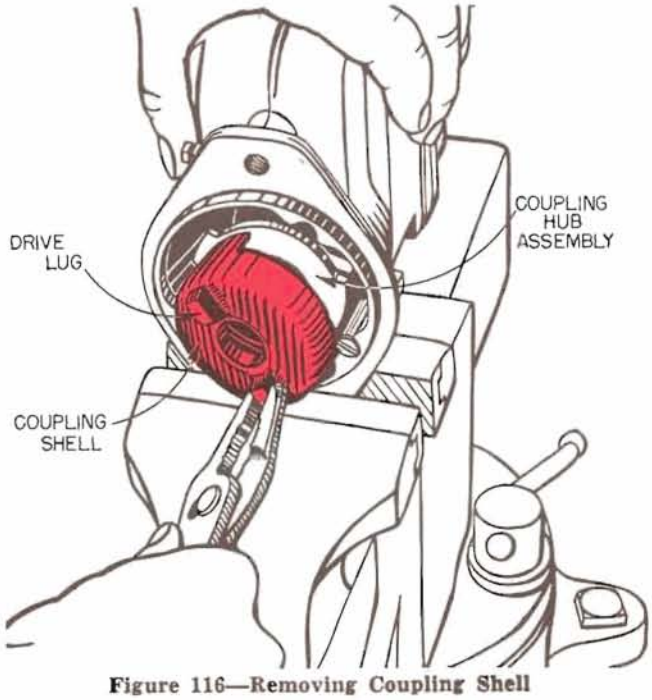


Figure 116—Removing Coupling Shell

A puller should be used to remove the impulse hub from the rotor shaft, since it is keyed and pulled down tightly on the taper shaft. In using the puller (Figure 117) care should be taken not to damage the end of the rotor shaft by excessive tightening of the puller screw.

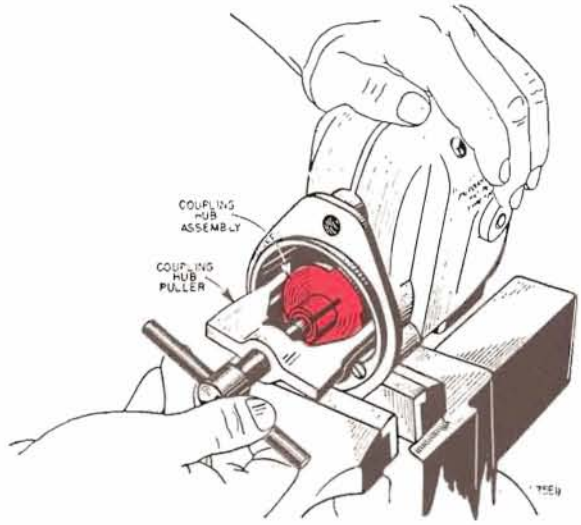


Figure 117—Pulling Coupling Hub

REASSEMBLY OF IMPULSE COUPLING

The first step in the reassembly of the impulse coupling is to insert the drive spring in the coupling shell. Before this can be done the rotation of the coupling unit must be definitely ascertained, since the drive spring must be wound in accordance (Figure 118).

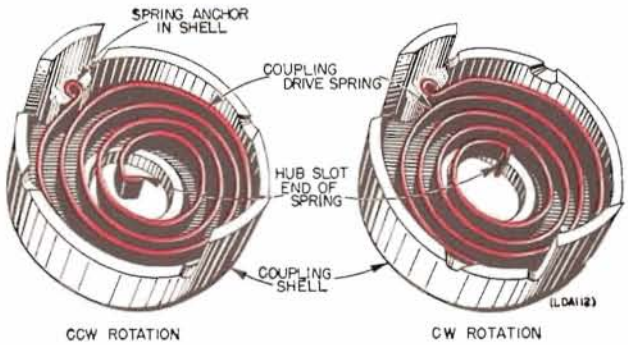


Figure 118—Location of Coupling Spring in Shell

With one end of the drive spring anchored in the shell, the coupling hub assembly should be fitted to its opposite end and the hub turned until the spring is wound sufficiently, then pushed into its final position. The turns necessary to wind the coupling drive spring vary with different types and the manufacturer's specifications must be followed closely.

To replace the coupling on the magneto, the key must first be inserted in the shaft, after which the coupling can be placed in position and tightened down on the shaft by turning the coupling nut.

SECTION EIGHT

MAGNETO SERVICE PRACTICES

MAGNETO SERVICE

Since a magneto is a precision type instrument, it should be serviced by expert technicians who are thoroughly familiar with this kind of work. Major overhauls should be undertaken only under suitable shop conditions, where the special tools and equipment specified by the various manufacturers are at hand.

A complete service routine applicable to each of the many makes and models of magnetos encountered in the field cannot, of course, be established, but an attempt is made to set up a general outline of service work. The procedures described should serve as a foundation for the specific service instructions issued by the individual magneto manufacturers.

As a whole, magneto adjustments and repairs can be classified in two groups: field service and shop service.

MAGNETO FIELD SERVICE

The prime requisite of field service work is that the make and model of the magneto be completely and accurately known before going out on the job. Service Stations who use a card file of magneto installations in their territory, together with a record of service work performed to date (Figure 119), find their field service work considerably simplified. If only the tractor or engine model is known, some idea of the application can be gained by referring to **Application 1-4**— Replacement Information—in the Fairbanks Morse Service Manual.

Field service work should be limited to spark tests, adjustments and minor repairs. Such work can be done by the operator of the engine, provided careful attention is given the directions accompanying the magneto.

TESTING THE IGNITION SPARK

The ignition spark can be tested in several ways, but it should be remembered that a spark produced within an engine cylinder with the fuel mixture compressed is not identical to a spark produced by the same equipment in open air.

Probably the best field test of ignition spark strength is provided when a short air gap is added to the standard gap of the spark plug and then making the ignition spark jump both gaps. This test must be made while the engine is operating, but it is quite easily accomplished by holding the end of each high tension cable in turn about 1/16" away from its spark plug terminal. If the spark plug continues to fire in the cylinder, the strength of the ignition spark can be assumed sufficient. Unless the spark plugs are in good condition, an ignition spark test such as this is of little value.

(LOA120)

THE MAGNETO SUPER-SERVICE STATION

NAME Henry Smith PHONE 1437-R-8

ADDRESS RR #4 Rockton (3 mi. east on Highway #72)

APPLICATION Mpls. Moline Universal "V" tractor (1960)

MAGNETO MFR. Fairbanks Morse MAGNETO MODEL FMZ4B4

PURCHASED FROM Rock County Impl. WHEN 11-1-60 SERIAL NO. 4130639

MAGNETO SERVICE RECORD

DATE	BRKR. PTS.	COIL	CONDENSER	OVERHAUL	OTHER WORK	CONDITION	CHARGES
3-1-61	ok	ok	ok	"	"	Excellent	$2.00
2-1-62	New	ok	New	no	no	Good	7.00
6-10-63	ok	ok	New	no	Cleaning	Good	3.00
4-20-64	New	New	New	Yes	"	Good	15.00
7-12-65	ok	ok	ok	No	Oil Slinger	Good	2.00

Figure 119—Card Record of Magneto Service Work

TESTING THE MAGNETO SPARK

Remove the high tension cables from the magneto outlets and insert a short piece of stiff wire in one of the outlets. Bend this wire to within ⅛" of the engine block. Crank the engine slowly and watch carefully for the spark discharge which should occur at the instant the impulse coupling releases. Several turns may be necessary before the impulse spark for the particular outlet under test is located. The test should then be repeated for each of the remaining terminals. If a strong spark is observed at each terminal, no dismantling of the magneto should be begun until cables, spark plugs and terminals have again been thoroughly inspected.

If no spark is observed, a careful examination of the ground switch and ground cable should be made as the first step towards locating the difficulty.

CARBON BRUSHES

In opening the magneto without removing it from the engine, the distributor end cap or cover is usually taken off first, permitting examination of the carbon brushes. These brushes should move freely in their holders and should exert a slight spring pressure when depressed. Remove the brushes and clean the brush holder sockets. Irregularly-worn or "stuck" brushes should be discarded and new brushes installed. It should be noted that nearly all multi-cylinder, jump-spark distribution magnetos have a single brush connection from the coil to the center of the distributor rotor. This brush should receive the same attention as that given distributor brushes.

FIELD SERVICE OF BREAKER POINTS

After the end cap has been removed from the magneto unit, the breaker point assembly is ordinarily easily accessible for cleaning and adjustment. The contact surfaces should be examined carefully and, if there are evidences of pitting or pyramiding, a small tungsten file or fine stone should be used to recondition the surfaces. It is considered highly advisable to remove the points from the magneto assembly and hold them in a vise during the resurfacing operation. Breaker points should be cleaned with a petroleum solvent, using a small brush such as a toothbrush. Oil and grease of any kind must be kept away from the points.

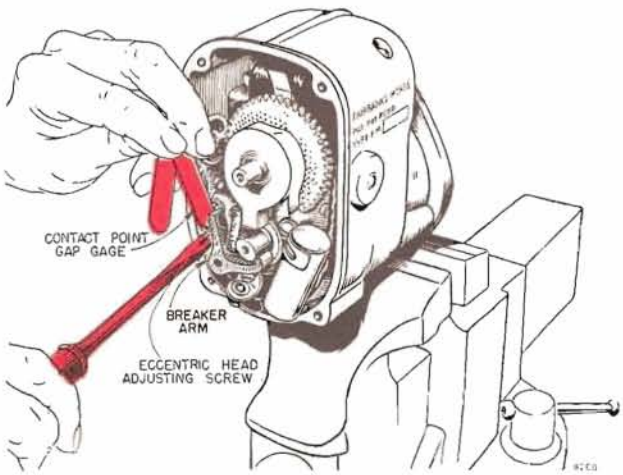


Figure 120—Adjusting Breaker Points

In cases where the contact surfaces cannot be renewed satisfactorily, or when there appears to be excessive wear of the breaker arm rubbing block, the breaker point assembly should be replaced by an entire new set. Improper functioning of the breaker arm actuating spring, a loose fit or any indication of binding at the pivot bearing are other reasons for complete replacement.

The recommended contact point gap must be ascertained from the magneto manufacturer's specification, and the points should be adjusted to within approximately ± .001" of this figure. An accurate feeler gauge should be at hand and should be used carefully (Figure 120) in determining the point separation. The value given for the contact point opening is defined as the separation of the contact surfaces while the rubbing block of the breaker arm rides one of the high points of its actuating cam.

FIELD LUBRICATION

Magnetos are lubricated independently of the engine and as a result have often been neglected in the field. This condition has led to the development of permanently-lubricated designs in which sufficient lubricant for the life of the unit is placed in the bearings or bearing reservoirs during the original assembly at the factory. The lubricants used in such cases are usually special greases of a consistency suitable for operation through a wide temperature range. No field lubrication of magnetos of this type is necessary or advisable.

Other magneto models require the periodic addition of a light, highly-refined lubricating oil, but special care should be exercised not to over-lubricate the unit. The instructions found on the oiling plate should be followed closely insofar as quantity, grade and frequency of lubrication are concerned.

Whenever replacement of the breaker contact points is made, the small cam wick should be replaced. It is not considered good practice to oil or grease a wick such as this, since great difficulty is encountered in controlling the quantity of lubricant added as well as in matching the original impregnation.

SUBSTITUTION TESTS FOR COIL & CONDENSER

Urgent cases of magneto field service may necessitate the checking of the coil and condenser without dismounting the magneto from the engine. Since portable test equipment is rarely available, the substitution type of test must be used.

Assuming that a new, identical part is available, the questionable coil should be removed from the assembly

and the new coil mounted in its place. If a test of the magneto spark then gives acceptable results, the original coil may be assumed to be at fault, although it should be retained and checked on standard test equipment at the next opportunity.

The condition of the condenser can be tested in a similar manner: dismount the questionable condenser from the magneto assembly and install in its place a new, identical condenser. Then test the magneto spark and, if satisfactory, return the original condenser to the Service Station for conclusive test.

IMPULSE COUPLING

Disconnect the ignition cables and crank the engine slowly. Listen carefully for the characteristic snap of the impulse coupling which occurs as each pawl releases. On most single cylinder four cycle engines the coupling impulses once each full revolution of the crankshaft, while on multi-cylinder four cycle engines there are two impulse actions per revolution of the crankshaft.

If no impulse snap can be distinguished, the magneto must be removed from the engine and the impulse coupling cleaned, repaired or replaced (See Section Seven).

Fairbanks-Morse recommendations concerning the lubrication of the impulse coupling consist in the addition of a small amount of FMCO11 grease to the drive spring.

SHOP SERVICE

The successful service station bases a large part of its business on a clean, well-equipped shop, conducted by expert technicians. A study of shop routine, working conditions and available equipment usually pays real dividends due to the improved methods adopted.

Probably the one factor which most affects shop work is the actual condition of the shop. Oil, grease, dirt and grime are the greatest contributing causes of magneto breakdowns; it is logical to assume that the place to begin eliminating such trouble is in the repair shop. Furthermore, a clean, orderly shop promotes systematic work and results in a fuller customer confidence in the work. Make sure that the service bench and its tools are clean, well-painted and in good order.

A work card (Figure 121) should be issued immediately for each magneto brought into the shop for service. The complete type designation, make, model and serial number of the magneto should be entered on the work card. The use of such a work card avoids confusion in identification, replacement parts used and labor charges.

ESSENTIAL SHOP EQUIPMENT

Specialized shop service for magnetos requires a combination of skilled personnel and suitable equipment. Because the amount of special equipment depends on the size of shop and on the territory it serves, no list of standard requirements can be arbitrarily established.

MAGNETO WORK CARD

DATE 8-28-64 NO. 864

Mfr	Type	Serial No.	No. Cyl.	Application	Date Purchased	When Rec'd
Fairbanks Morse	FM Z4B4	4130639	4	Mpls. Moline	3-62	8-64

Spark Test	Starting Speed	Idling Speed	Normal Speed
	OK	Misses	Misses

TEST & SERVICE RECORD

	Condition as Rec'd	Service Work Performed	Parts Used: Quantity	Parts Used: Part No.	Parts Used: Price	Labor Hours
Exterior	Caked	Removed dirt and grease	—	—	—	1/4
Interior	OK	—	—	—	—	—
Brushes	Worn	Replaced brushes	4	P2463	0.85	1/4
Breaker Points	Worn	Replaced point set complete	1	P2437	3.00	1/4
Condenser	OK	—	—	—	—	—
Coil	OK	—	—	—	—	—
Impulse Coupling	OK	Cleaned and greased	—	—	—	1/4
Distributor Rotor	Tracks	Resurfaced distributor disc	—	—	—	1/2
Bearings	OK	—	—	—	—	—
					3.85	1 1/4

Customer John Smith

Address RR #4 Minot, N. Dakota

Labor Charge $ 7.50

Cost of Parts 3.85

Total 11.35

Figure 121—Shop Card for Magneto Repair Work

It seems reasonable, however, to expect every service station to be equipped with reliable coil and condenser testers, and to have some arrangement for driving the magneto so that the ignition spark produced can be tested on a standard spark gap. Provision should be made for slow speed tests, during which impulse coupling action may be observed as well as for tests at normal speeds. Possibly only service stations with a large volume of magneto repair business will find the synchroscope a worthwhile investment, but its convenience, accuracy and general usefulness should not be underestimated.

Tools for magneto repair work should be chosen very carefully, since it is highly important that they be suitable for such use. Bearing replacement tools in particular are important because the quality of the work performed is directly dependent upon the tools used. A substantial arbor press or screw type press is essential in bearing replacement procedures.

While the new Alnico magnets used in most modern magnetos rarely require recharging, the chromium, cobalt and tungsten magnets of older design magnetos often can be remagnetized with good results. The special equipment of most service stations includes a magnet charger of some kind.

PRELIMINARY CLEANING

When a magneto is brought into the shop, the first actual step in any service work should be a complete and thorough cleaning of its entire exterior. Use compressed air, a wire brush and a suitable petroleum solvent to remove completely the accumulated sludge.

PRELIMINARY TESTS

After exterior cleaning has been completed the magneto should be mounted on the test block and the rotor turned over slowly by hand. If there is a noticeable binding or rubbing action, no further rotative testing should be undertaken before dismantling, since such a condition indicates badly worn bearings, or a damaged distributor or breaker contact assembly. The pull due to the magnetic break which occurs during rotation should not be confused with binding.

If the rotor turns freely (except for the magnetic break), the testing should be continued, the rotative speed being stepped up to about 100 rpm. Observation of the impulse coupling action can usually be made at this speed, although it may be desirable to reduce the speed in cases where there are a number of engagements per revolution. Provision should also be made to increase the speed to the point where engagement no longer takes place in order to determine the cutout speed of the coupling.

The cable outlets of the magneto should be connected to individual spark gaps and observation made of the spark produced each time the impulse coupling releases. The rotative speed should be roughly comparable to the starting speed of the engine. If no sparks occur across the spark gaps or if there are misses or the spark quality is weak, notation should be made on the work card so that steps can be taken to correct this difficulty.

The rotative speed of the magneto should be increased just beyond the point where the impulse coupling cuts out completely and the spark produced again carefully inspected. The speed of this test should correspond approximately to the idling speed of the engine. A record of results should be kept on the work card.

A third spark test should be made at the normal operating speed of the engine and observations again tabulated. During this test the primary ground switch should also be closed to check its effect on the ignition spark.

CLEANING BREAKER POINTS

The use of a small, stiff brush such as a toothbrush, moistened with a petroleum solvent, provides the most suitable means of cleaning the breaker points. The assembly should be completely removed from the magneto before cleaning is begun. Special care should be taken to keep the breaker points entirely free from oil, lint or dust. In cleaning the breaker arm the fulcrum pin bearing hole should receive special attention and the fulcrum pin, mounted on the breaker plate, should also be polished.

BREAKER POINT ASSEMBLY WEAR

Long, continued use of a magneto produces signs of wear on the breaker arm rubbing block and possibly at the point of pivot. Wear of the rubbing block has an important effect on the operation of the magneto since the point at which the contact points open must come at the time the maximum magnetic flux lines are being cut. Examination of the rubbing block will usually establish an idea of the amount of wear which has occurred; excessive wear is often indicated when the contour of the rubbing block matches that of the cam. A worn breaker arm rubbing block is also indicated when it is impossible to make the specified edge gap adjustment. Excessive wear of the breaker arm pivot is indicated when the pin fits so loosely that point action is erratic. In either case, replacement of the assembly is necessary.

EDGE GAP ADJUSTMENT

In the analysis of the operation of rotary magnetos (Section Five) it has been explained that the maximum ignition spark discharge is obtained by interrupting the primary circuit at the instant the primary current reaches its maximum value. Since the current in the primary circuit is proportional to the rate of flux change in the magnetic circuit, maximum current occurs at the point the polarity of the magnetic circuit is reversed.

The location of the point at which maximum primary current is obtained can be determined electrically, at which time the actual distance between the edge of the

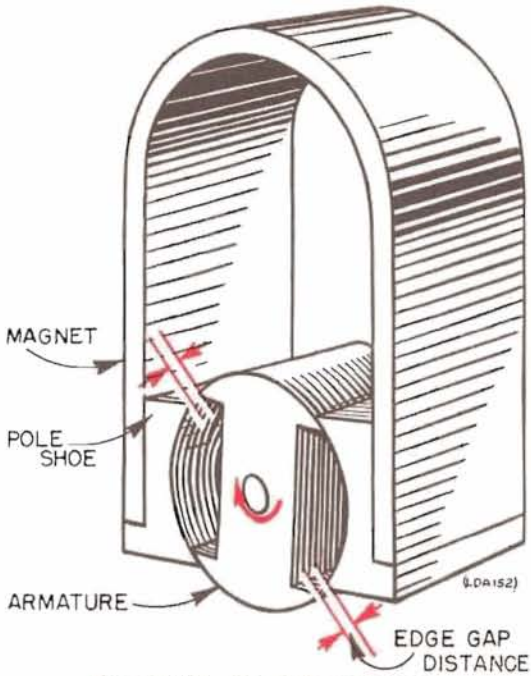


Figure 122—Edge Gap Distance

rotor laminations and the edge of the pole shoe laminations can be measured (Figure 122). For magnetos requiring such an adjustment this distance is usually specified as the "edge distance" in servicing instructions and special gauges are often available for convenience in its measurement.

With the edge distance measured and the rotor held in this position, the breaker points must be adjusted so that they are just beginning to open. The check which this gives on the proper functioning of the breaker points is important; if long periods of use have resulted in unbalanced wear of the contact surfaces and the rubbing block, a condition may have been reached where the points cannot be adjusted to open when the rotor is set at the correct edge distance. In such a case the breaker point set must be replaced.

Edge gap adjustment is of particular importance in many of the older design magnetos where the strength of the magnetic circuit is low in comparison with more recent models equipped with Alnico magnets.

MAGNETO BEARINGS

Field performance of magnetos and other similar units is highly dependent upon the design and construction of the bearings used. The three general types of bearings used are the ball bearing (Figure 123), sleeve bearing (Figure 133) and needle (or roller) bearing (Figure 135).

Since the magneto rotor must turn with a very small and uniform air gap between its laminations and those of the frame, the construction of its supporting members is of primary importance. Rotor bearings must be able to handle a certain amount of axial thrust caused by the engine drive as well as a certain amount of pounding which results from impulse coupling action.

The bearing support for the distributor shaft and gear assembly must provide uniform operation, since a definite spark gap must be maintained at all times between the distributor rotor and the end cap spark posts or, in the case of brush-distributor units, must provide a smooth operating surface for the brushes.

Other bearing surfaces in a magneto are located at the pivot point of the moving breaker point arm, at the pivot point of the impulse coupling pawls and along the center of the coupling hub where the shell moves in relation to the hub during impulse action.

BALL BEARINGS

Ball bearings are widely used in magnetos to support the armature or magnetic rotor, and are sometimes used to mount the distributor shaft. The chief advantages of the ball bearings are their long life, self-alignment, ability to withstand shock and thrust, and freedom from lubrication difficulties. Both oil and grease-lubricated ball bearings are available, the grease-lubricated type being almost universally used in magneto construction because further lubrication, except during complete overhauls, is unnecessary.

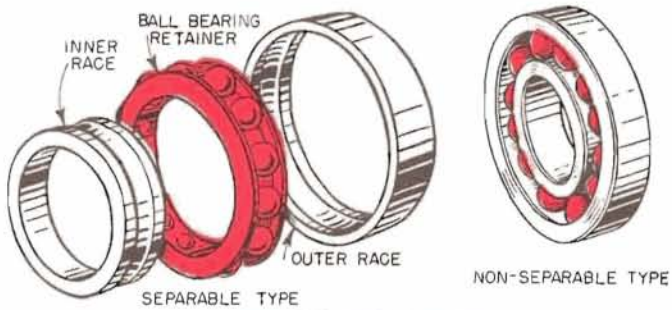


Figure 123—Ball Bearings

There are two general types of ball bearings which have been extensively used in the manufacture of magnetos. These are the open (separable) design and the non-separable design. The separable type ball bearing (Figure 123) consists of an inner race, a ball retainer with balls and an outer race. The fact that such a bearing can be pulled apart provides simplified dismantling of the magneto assembly, but difficulty is sometimes encountered in removing and replacing the races. Separable type ball bearings must always be used in pairs, faced opposite each other, in order to withstand axial thrust. The non-separable type ball bearing (Figure 123) is a one-piece assembly and must be so mounted and removed. Its advantage over the separable type lies in its ability to absorb a considerable thrust in either direction, making it possible to use such a bearing singly.

CLEANING BALL BEARINGS

It is much easier to prevent dirt from entering a ball bearing than it is to clean the dirt out. In cleaning ball

bearings a perfectly clean surface should be provided on which to work.

Use a suitable petroleum solvent, such as Stoddard solvent, in a clean container. Swish the bearings in the cleaning fluid and finally revolve by hand while submerged. Compressed air, if absolutely free of dust or moisture, can be used to complete the cleaning.

RELUBRICATING BALL BEARINGS

After removing the ball bearing from the cleaning fluid, it should be immersed in a clean, light oil and spun until the solvent has been removed. Grease-lubricated bearings should then be repacked; the quantity of grease used should not exceed ⅓ to ½ of the total capacity of the bearing. Too much grease is a common cause of bearing failure due to overheating. *Fairbanks Morse recommendations specify 1C9 Ball Bearing Grease as particularly suitable for magneto bearings.*

REPLACEMENT OF BALL BEARINGS

Replacement of ball bearings is largely a matter of having the proper tools for the particular job. If ball bearing work is performed using makeshift tools, the possibility is very great that the bearings will be ruined insofar as further use is concerned. In general ball bearings are removed and replaced by either pulling or pressing; damage is likely to result from pounding or prying.

In replacing separable type ball bearings, the inner race must be pulled from the rotor shaft (Figure 124),

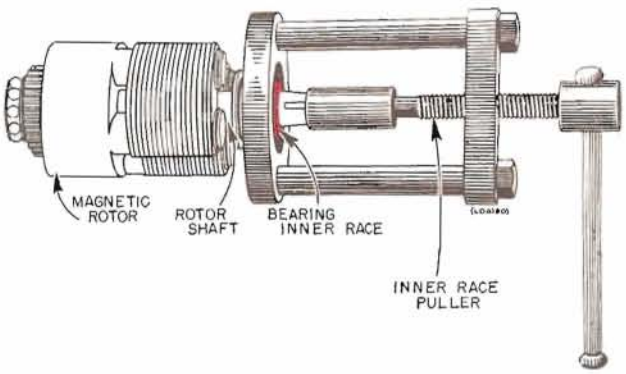


Figure 124—Pulling Inner Race from Rotor Shaft

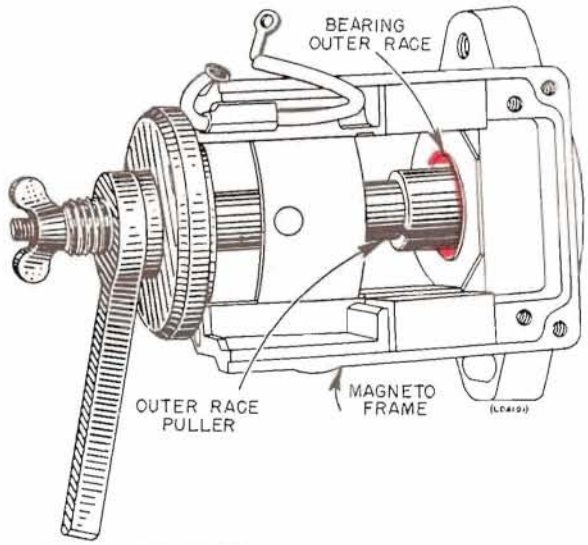


Figure 125—Pulling Outer Race from Frame

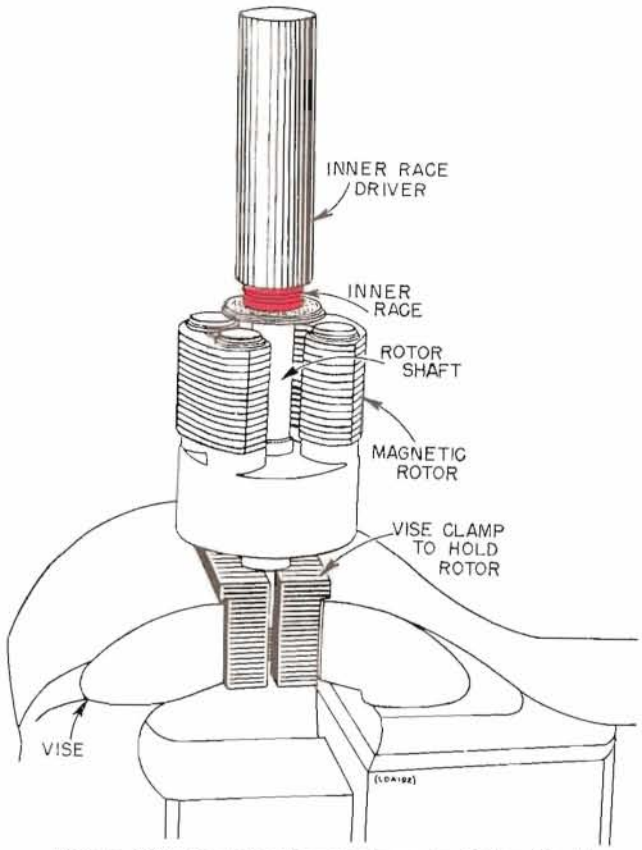


Figure 126—Pressing Inner Race on Rotor Shaft

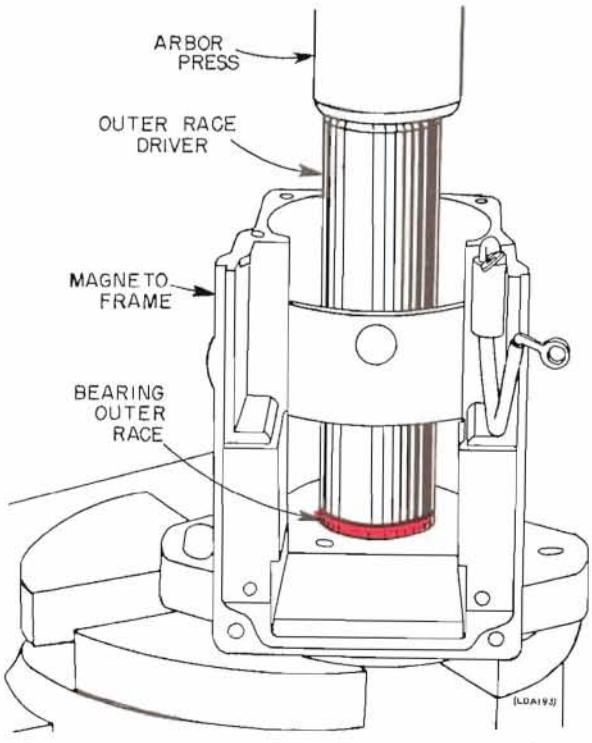


Figure 127—Pressing Outer Race into Frame

while the outer race must be pulled out of the frame recess (Figure 125). When reassembly is made, the inner race must be pressed on the rotor shaft (Figure 126), while the outer race is pressed into the frame recess (Figure 127). Wide variations in procedure are necessary according to the bearing support design.

In replacing non-separable type ball bearings, the rotor must first be unlocked by releasing the snap ring (Figure 128), then pressed out of the bearing (Figure 129). The snap ring holding the bearing in place must be released before the bearing can be pressed out of the frame recess

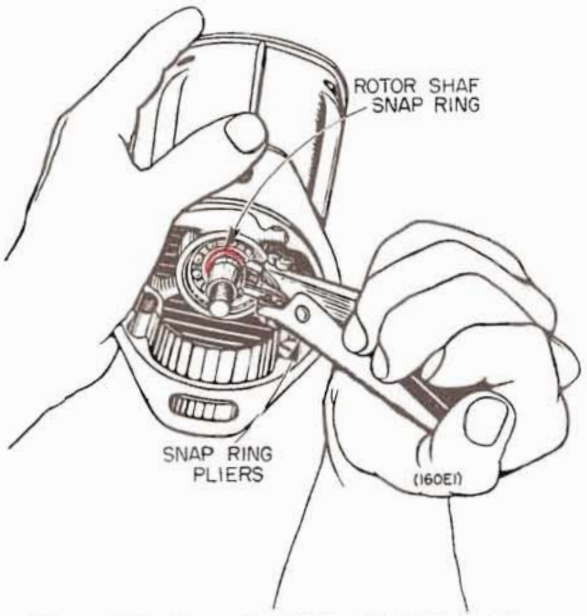


Figure 128—Removing Rotor Shaft Snap Ring

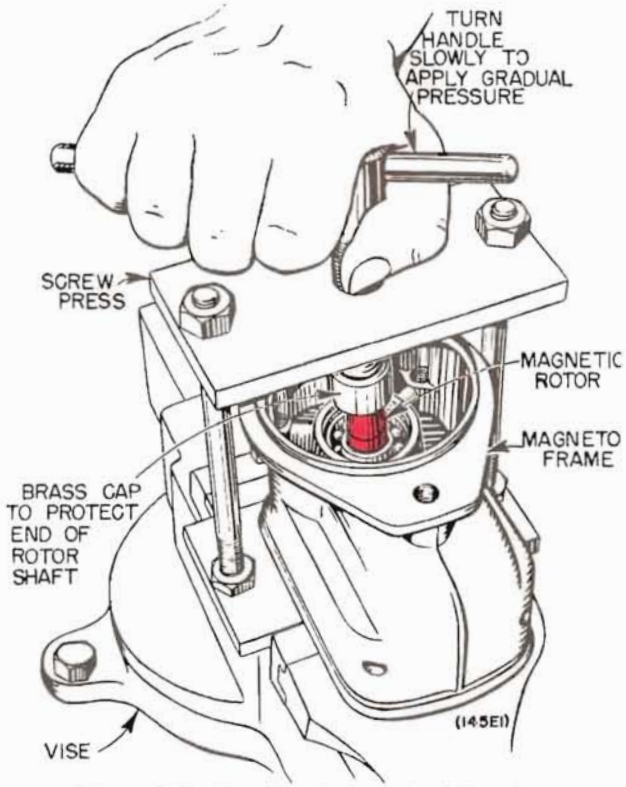


Figure 129—Pressing Rotor out of Bearing

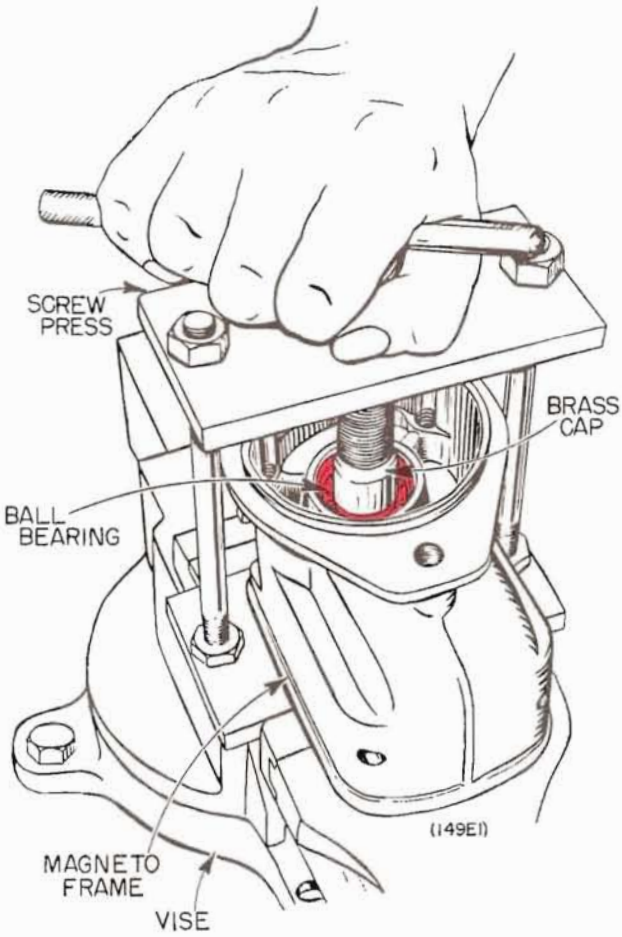


Figure 130—Pressing Ball Bearing out of Frame

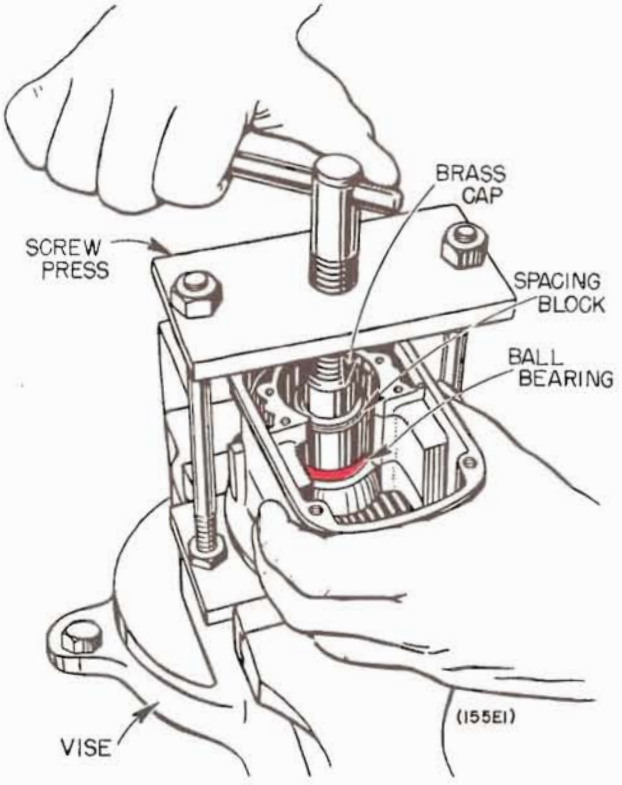


Figure 131—Pressing Ball Bearing into Frame

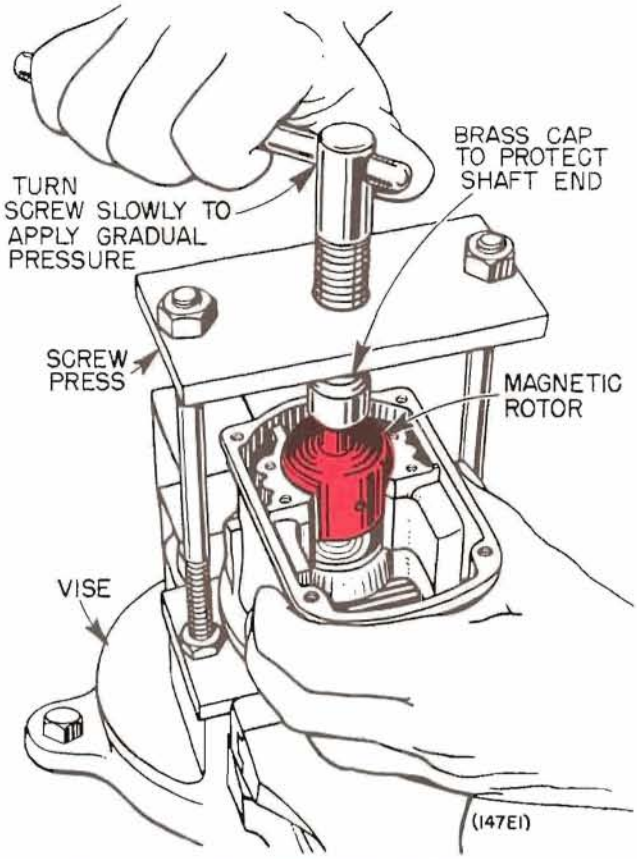


Figure 132—Replacing Rotor in Ball Bearing

(Figure 130). In reassembly the bearing is first pressed into the frame (Figure 131) and locked in place, then the rotor is pressed into the bearing (Figure 132) and locked in place.

Correct procedure for pressing or pulling one-piece ball bearings is to exert the pressure on the binding race in order that force does not have to be transferred from one race to the other across the balls.

SLEEVE BEARINGS

In a carefully designed magneto unit, sleeve type bearings (Figure 133) provide highly satisfactory service at comparatively low cost. Sleeve bearings are compact,

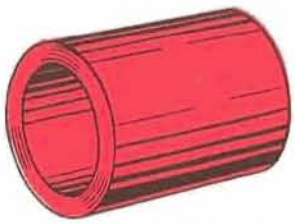


Figure 133—Sleeve Type Bearing

easy to replace and have an exceptionally long life under suitable operating conditions. The lubrication of sleeve type bearings has been greatly simplified through the recent development of the porous "metal sponge" type bearing materials. Bearings made of such a material, as for example Oilite, are factory-impregnated with lubricating oil, which greatly increases their length of service without the necessity of field lubrication. The porous nature of the bearing material also makes it possible to provide an additional lubricant reservoir in the bearing housing which functions to replenish any oil lost during operation.

REPLACEMENT OF SLEEVE BEARINGS

Removal of sleeve type bearings is usually accomplished by inserting a sizing tool of the proper diameter in the bearing and pressing both the tool and bearing through the bearing support (Figure 134). The diameter of the shoulder of the sizing tool must not be greater than the outside diameter of the bearing. If the sleeve bearing is located in a blind hole, removal can be made by using a properly-sized pipe tap to grip the inside surface of the bearing.

Before a new bearing is pressed into the support all traces of former lubricants should be removed, especially if there is a lubricant supply groove in the bearing housing. Clean, fresh lubricant of the grade specified for the particular application should be used to replenish the reservoir.

To insert the new sleeve bearing, it should first be placed on the sizing plug, after which the assembly of tool and bearing should be centered on the hole in the support and pressed into place. Observe carefully the instructions covering each specific bearing, since the position of the bearing in its housing is often of considerable importance.

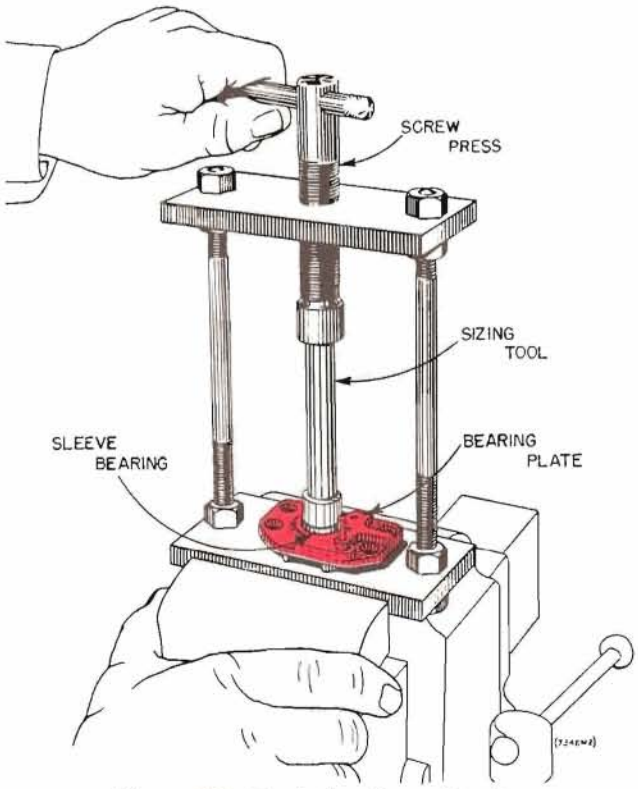


Figure 134—Replacing Sleeve Bearing

NEEDLE BEARINGS

Needle bearings (Figure 135) are actually small diameter roller bearings. The use of needle bearings is often advantageous because of their exceedingly small outside diameter in proportion to their load capacity. Relatively low in cost, needle bearings present certain additional problems in lubrication and service.

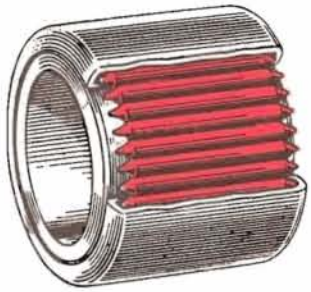


Figure 135—Needle Bearing

SERVICING DISTRIBUTOR ROTORS & DISCS

In many magneto models the distributor rotor or disc is tightly fitted to the end of the distributor shaft; after removing the pin which locks the rotor in position, two screwdrivers can be used to pry it off the shaft (Figure 136).

The working surface of distributor discs and rotors is originally given a very fine, smooth polish and refinishing in the field with sandpaper or emery cloth is extremely likely to mar this surface. As a result heavy carbon paths soon reappear, and the surfacing must be repeated.

Carbon deposits on the surface of the distributor can be loosened and removed, however, by wiping the surface with a clean, hard cloth, moistened in Stoddard solvent. It is also possible to smooth the surface by using a very fine polishing paper furnished by the factory, but such work should be undertaken with care and strictly according to instructions. In the case of drum rotors such as used in the Fairbanks-Morse Type RV, the part need not be removed from the magneto but should be rotated slowly with the polishing paper pressed to its surface. When resurfacing discs such as used in the Type FM (Figure 137), the polishing paper should be fastened to a flat surface, such as a piece of plate glass, and the disc moved with a circular motion on the polishing surface.

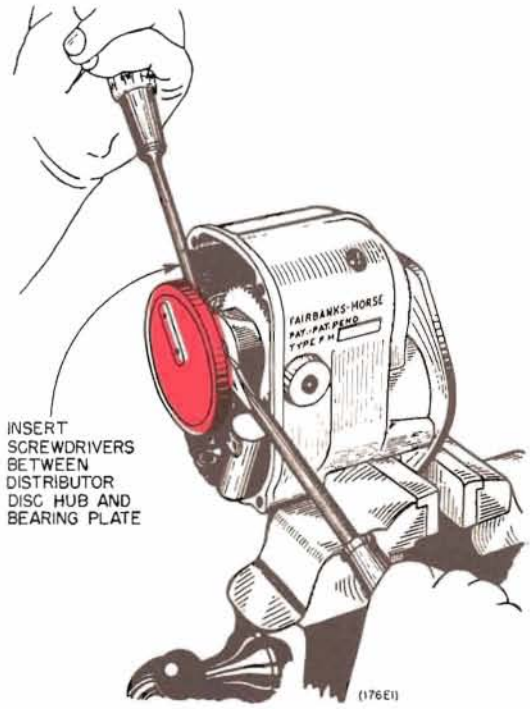


Figure 136—Removing Distributor Disc

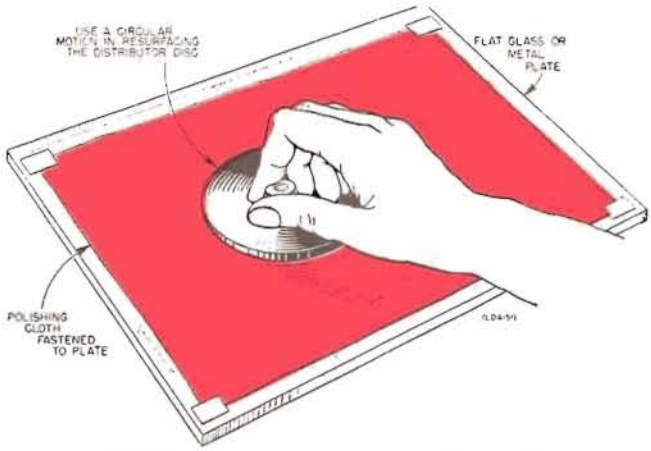


Figure 137—Resurfacing Distributor Disc

TIMING GEARS

Nearly all magnetos designed for multi-cylinder engines are built with a geared distributor assembly. On four cylinder engines where the magneto runs crankshaft speed, a 2 to 1 reduction gearing is used to cut the speed of the distributor to one complete revolution per two revolutions of the engine. On six cylinder engines where the magneto runs 1½ times crankshaft speed, a 3 to 1 reduction gearing is used to cut the speed of the distributor to one complete revolution per two revolutions of the engine.

The distributor electrode must move into the proper position to transfer the ignition spark to the correct spark post or brush each time the contact points begin to break. Any deviation from this position results in undesirable sparking or burning of the distributor contacts and of the breaker points.

To accomplish accurate timing the interlocking teeth of the distributor gear and the rotor pinion are marked, and care should always be taken in reassembling a dismantled magneto to be certain that the proper gear teeth are meshed. Common practice (Figure 138) is to mark a single tooth of the rotor pinion to be used for either rotation, while the distributor gear is marked in two places according to its use in a clockwise or counter-clockwise magneto.

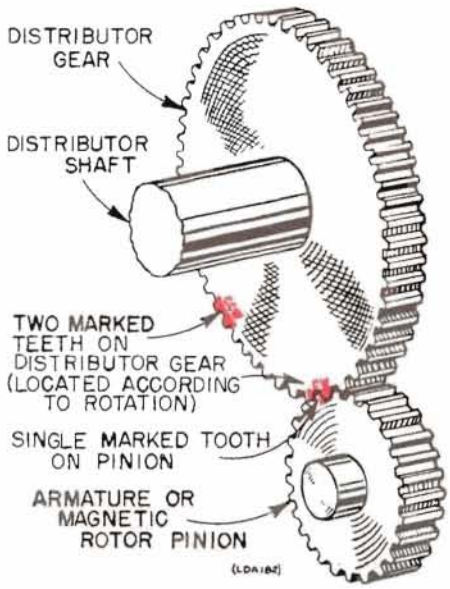


Figure 138—Meshing Distributor Gear Teeth

REMOVAL OF ROTOR PINION

The construction of certain magnetos makes it necessary that the rotor pinion be removed before service operations such as bearing or bearing plate replacement can be performed. The first step is to lift off the snap ring which locks the pinion to the rotor shaft; a special snap ring pliers (Figure 139) can be used to advantage. Careful prying with two large screwdrivers may separate the pinion from the rotor without damage, but it is recommended that a small puller (Figure 140) be used. Damage to the pinion is especially serious since it is almost certain to affect the distributor gear and thereby cause a complete magneto failure.

LEAKAGE PATHS

The high voltage surge of the secondary circuit occasionally establishes a path to ground by a different route than across the spark plug gap. Once such a path is established, the ignition spark is likely to continue to spark across to ground. Among the various causes of leakage paths are the following:

1. Broken cables or poor cable connections.
2. Too high engine compression.
3. Too wide a spark plug point gap.
4. Moisture, dirt, carbon or corrosion within the magneto.
5. Breakdown of air insulation within sealed units.

A surface leakage path can usually be located because of the burning effect the high voltage spark has on plastic or other insulating materials.

The first step in servicing units having one or more leakage paths is to remedy the condition which causes the high voltage spark to stray from its established circuit. The actual repair of the unit should be made very carefully, usually discarding any insulating parts which give evidence of high voltage flashover. Leakage paths may be cleaned from the surface of end caps and other similar pieces, but their subsequent use should be limited to temporary, emergency service. Smoothing off sharp edges or corners will also help prevent sparking across air gaps to ground.

CORROSION CAUSED BY OXIDATION

Continued high voltage arcing within a sealed magneto housing results in oxidation, a likely cause of complete failure. Interior corrosion is readily apparent once the unit is opened, since it causes a green discoloration of copper and brass parts (the ozone formed by the high voltage arc reacts with copper to form an oxide). A brown deposit is usually also found throughout the unit and there is sometimes some evidence of moisture condensation.

To eliminate oxidation, if the condition of the unit is noticed in time, the cause must first be located. There are several common causes:

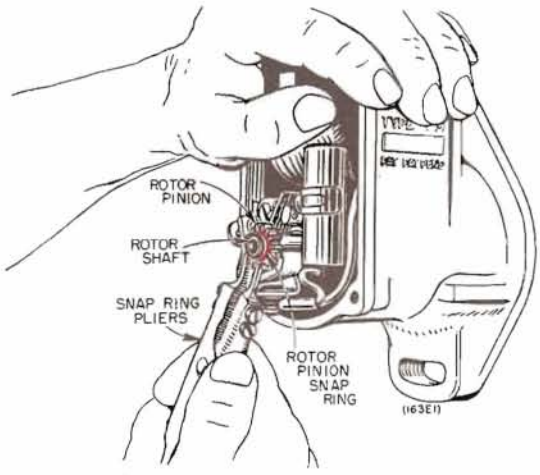


Figure 139—Removing Rotor Pinion Snap Ring

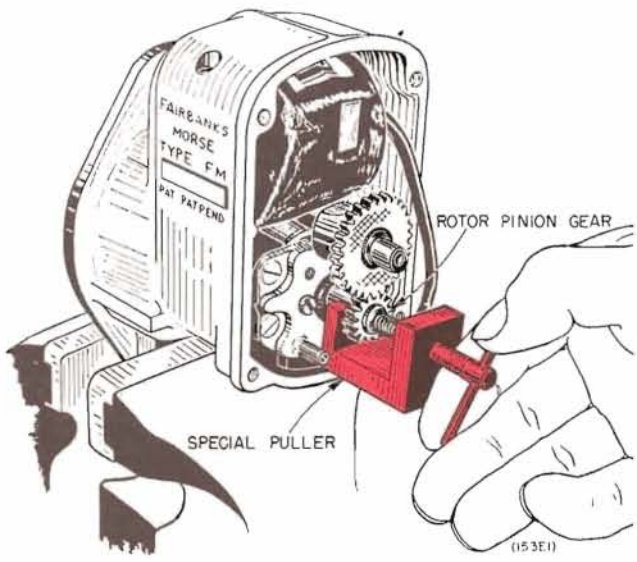


Figure 140—Pulling Rotor Pinion

1. A spark gap across a loose connection in the secondary (high voltage) circuit within the magneto.
2. High voltage arcing between coil and coil lead rod.
3. Carbon paths within the magneto.
4. Broken or sticking distributor brushes.
5. Inadequate ventilation of jump-spark magnetos.

OVERHAUL OF OXIDIZED UNITS

In most cases magnetos subjected to interior oxidation can be cleaned and put into satisfactory shape for re-use. The situation must first be very carefully analyzed so that the cause of the difficulty will not act to continue the trouble.

The magneto must be completely dismantled and each part cleaned individually. Bearings present an especially difficult problem since the lubricant is usually oxidized; in most cases it is advisable to discard the original bearing. In cleaning metal parts fine emery cloth may be used to advantage while rotors may be buffed, but parts so cleaned should be blown entirely free of dust particles with compressed air. All original brushes should be discarded and the brush holder sockets carefully cleaned. Where sticking brushes have been a result of the interior oxidation, attention should be given the surface of the distributor disc or rotor since it is possible that the face has been marred (See Par. Servicing Distributor Rotors & Discs). All gaskets, seals and washers should be replaced by new parts.

A close watch should be kept for indications of carbon paths on the bakelite parts. It is recommended that where there is evidence of flashover the part be discarded, since re-use is likely to result in further oxidation.

TESTING MAGNETO COILS

Conclusive coil tests can be made only through the use of reliable commercial coil tester (Figure 141). Simple circuit tests are of little value. It should also be noted that commercial battery ignition coil testers should not be used to test magneto coils unless provision is made for inserting a series resistor in the primary circuit in order to reduce the current to a suitable value.

The coil tester must check the primary and secondary windings for open circuits, shorts or high resistance. In addition the coil lead wire, its terminal and insulation should also be checked during this portion of the test.

One of the standard methods of determining coil efficiency (input to output) is to measure the amount of primary current which must be supplied in order to establish a standard spark discharge across the secondary terminals. The necessary primary current for individual coils varies, but if a tabulation of maximum values is at hand, coils requiring more than these established values can be assumed defective and discarded.

Coil testers usually provide for a heat test, which consists of passing sufficient current through the primary winding to cause the coil to approach actual operating temperature, at which time tests are made to determine possible insulation breakdown.

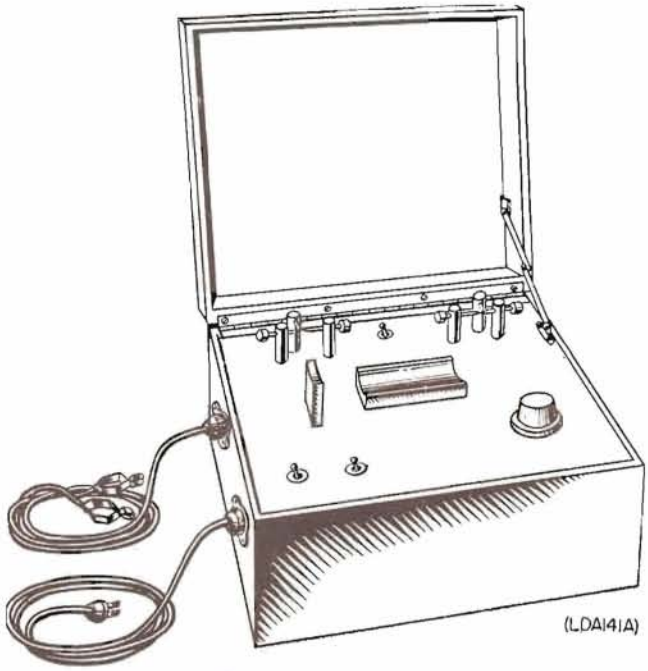


Figure 141—Commercial Coil Tester

A test of considerable importance, although infrequently performed, consists of connecting the coil for standard tests, then holding a grounded metal plate near the outside wrappings of the coil and watching closely for a leakage spark.

CONDENSER TESTING

A reliable condenser tester (Figure 142) is an essential part of a magneto service station's equipment. Makeshift devices seldom provide facilities for thorough testing.

Condensers should be tested for breakdown, leakage, capacitance and series resistance. Some testing instruments also provide for a test of the damping characteristic of the condenser.

While a direct-reading meter would show leakage and series resistance in ohms, most test instruments are furnished with a scale divided into a "GOOD" and a

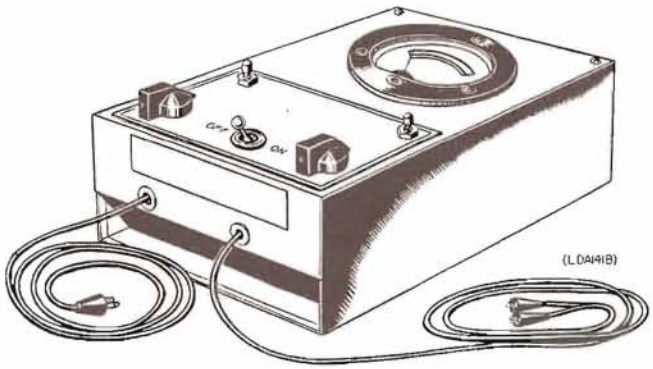


Figure 142—Commercial Condenser Tester

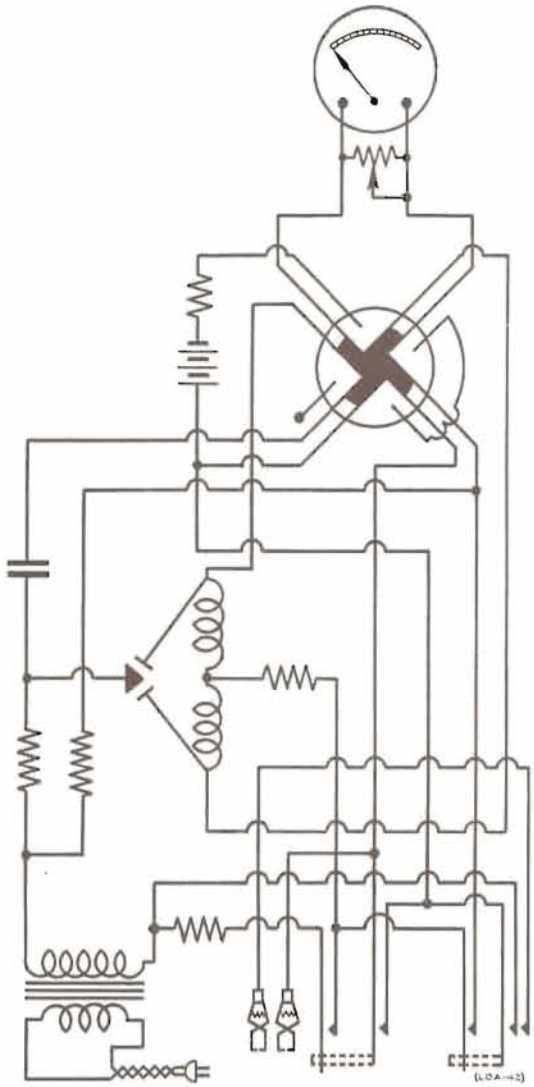


Figure 143—Condenser Tester Circuit Diagram

"DEFECTIVE" range. A calibrated scale, however, is necessary for capacitance tests, readings being made directly in microfarads.

Since it is both difficult and uneconomical to attempt to repair condensers, defective units should be destroyed. Limits for the capacitance test cannot be set for strict observance; it would seem that a 5% variation above or below the rated capacitance could serve as an approximate standard.

Condenser testers are basically an adaptation of an alternating current bridge circuit in which the capacitance of the condenser under test is balanced against that of a standard condenser. The circuit diagram of a representative tester (Figure 143) illustrates the intricate wiring necessary. Condenser testers are made to operate from 110 to 220 volt A.C. lines. This voltage is usually stepped up to provide 350 volts A.C. for capacitance tests, and stepped up and rectified to give 500 volts D.C. for breakdown tests.

MAGNET CHARGING

A magneto does not use up magnetism in producing ignition sparks. Other factors such as vibration, stray fields, temperature changes and ageing do, however, tend toward diminishing the strength of the permanent magnets, but the actual loss of magnetism varies widely with the magnetic steel used. The recently developed Alnico magnets retain their original magnetism to a remarkable degree and rarely require re-magnetization.

The technique and equipment necessary for efficient magnet recharging has been subject to extensive changes as the result of the introduction of Alnico magnets. The

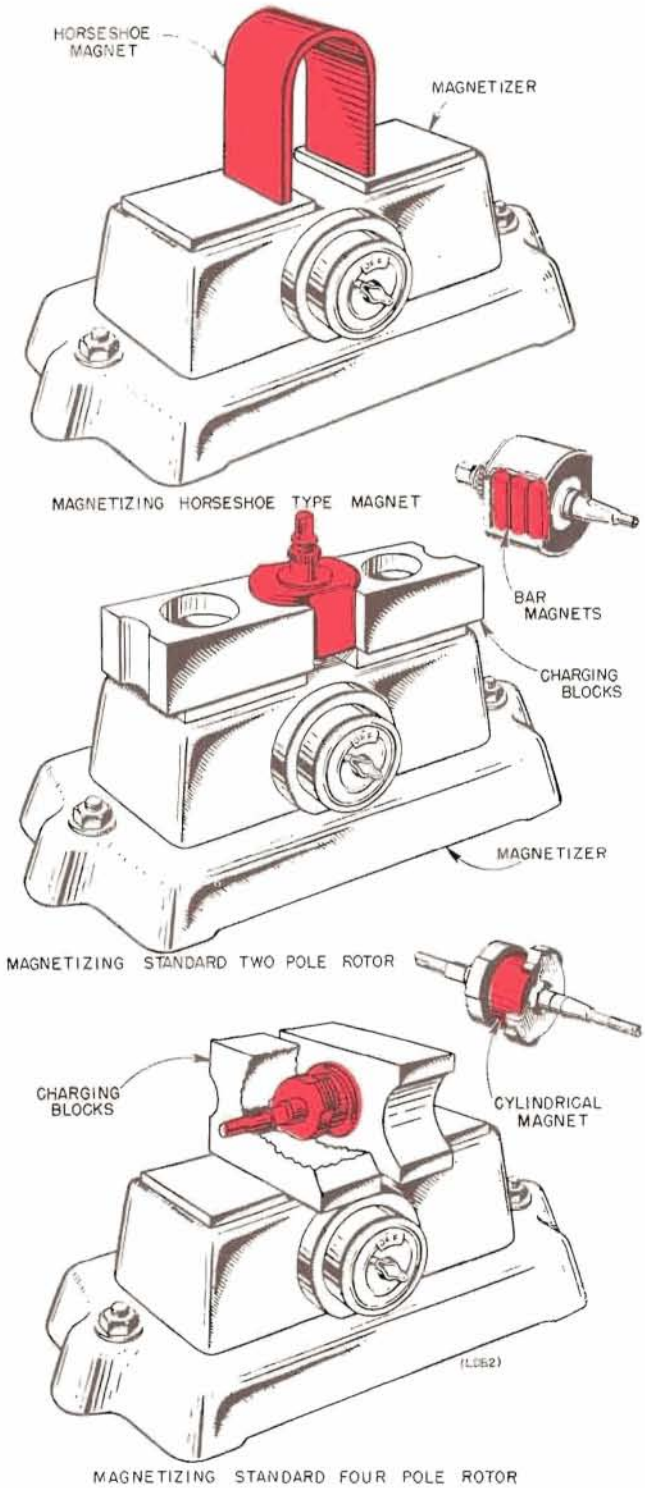


Figure 144—Magnetizing Procedures

old style horseshoe magnet made of tungsten, chromium or cobalt steel was easily and quickly re-magnetized by simply placing it in the proper position (Figure 144) on a magnet charger; in many cases it was not necessary to remove the magnet from the magneto frame. A different treatment is required in recharging magnetic rotors, especially those having Alnico magnets. Since it is of primary importance that all possible magnetizing force reach the rotor magnets, a short, efficient magnetic circuit must be established. This is possible only by removing the rotor from the magneto and placing it on the charger together with charging blocks of dead-soft iron. Note that the arrangements (Figure 144) are entirely different for two-pole and four-pole rotors.

In re-magnetizing rotors the polarities of the charger and rotor magnets should be carefully checked and unlike magnetic poles placed adjacent to each other. There is nothing to be gained through the tedious procedure involved in reversing the original polarity of the magnets.

THE SYNCHROSCOPE

The magneto testing instrument used at the factory and in many well-equipped service shops is the synchroscope. This device enables the serviceman to make a comprehensive check of the operation of both the magneto and the impulse coupling, as well as permitting accurate adjustment of the breaker point opening.

Synchroscope construction depends a good deal upon the power available. Since both clockwise and counterclockwise magnetos must be run at various speeds in order to secure complete test data, a variable speed, reversible source of power is necessary. If direct current electricity is available, these requirements are easily fulfilled by using a rheostat-controlled motor with a reversing switch (Figure 145). Synchroscopes for operation on alternating current power are often built with double-end drive motors in order to provide testing at either rotation, while a gear-reducer unit permits a selection of rotative speeds. A tachometer is usually mounted on the test board to indicate the test speed.

The synchroscope proper is a relatively simple arrangement of a metal pointer turning radially within a calibrated metal ring. The pointer is grounded to the synchroscope frame, thereby establishing an electrical connection to the magneto housing, while the calibrated ring is mounted on an insulating bracket, its electrical connection to the high tension outlets of the magneto being made through the spark test board.

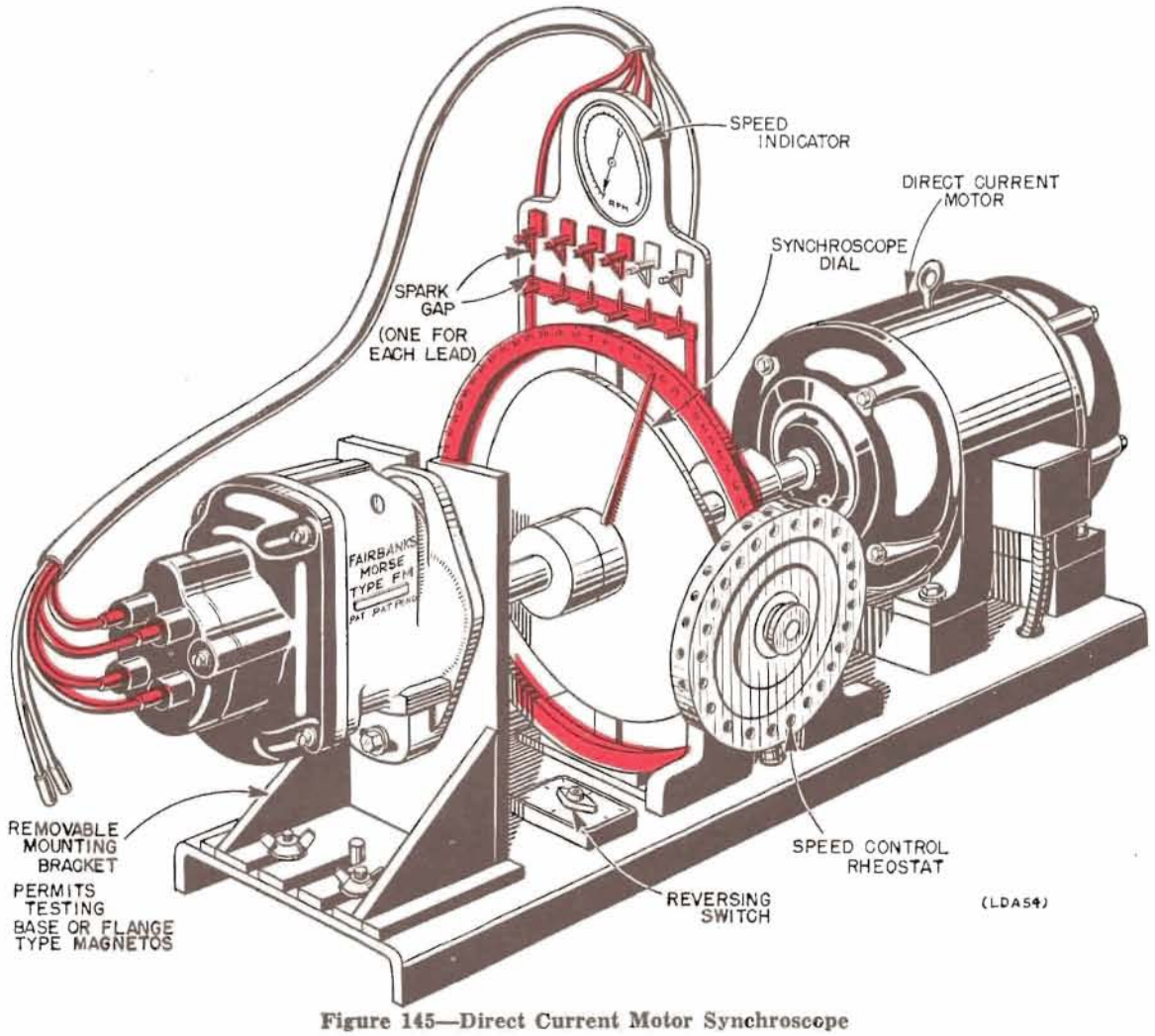


Figure 145—Direct Current Motor Synchroscope

The principle of operation of the synchroscope consists essentially in the fact that the ignition sparks produced by the magneto under test occur across the air gap which exists between the end of the pointer and the calibrated ring. Since the position of the pointer is definitely fixed in relation to the magneto rotor keyway, the angular sequence of the ignition sparks produced during rotation is indicated by the points along the ring at which they occur (solid pointer in Figure 146).

There are a number of important tests and adjustments which can be made quickly and accurately on the synchroscope. One of the most frequent operations consists of placing the magneto, without its impulse coupling, on the synchroscope stand and adjusting the breaker point gap until the ignition sparks occur at the exact points on the calibrated ring specified by the magneto manufacturer. Actually this adjustment is a more convenient and accurate method of setting the magneto for edge gap distance (See Page 52). The impulse coupling can then be assembled to the magneto and, if tested above the cut-in speed of the coupling, the location of the sparks on the ring will indicate the angular relation of the impulse coupling drive lugs to the magneto rotor keyway. Knowing the location of the running spark points on the calibrated ring, the synchroscope should be stopped and the drive shaft to the magneto turned slowly by hand permitting full impulse action. The points at which the impulse sparks occur indicate the amount of retard provided by the impulse coupling (dotted pointer in Figure 146). The mechanical operation of the impulse coupling can be checked by running the synchroscope at slow speed (50-100 r.p.m.), while the cutout speed of the coupling can be determined by gradually increasing the synchroscope speed to the point at which all coupling action ceases.

SPARK GAP ASSEMBLIES

Another essential item of magneto test equipment is an efficient, multiple spark gap assembly. There are many variations in the design of such apparatus, the simplest probably being the three-point unit construction (Figure 147) used by many service stations. Spark gap assemblies are usually built to provide for testing as many as four or six separate, consecutive ignition sparks.

In operation the single point spark post is connected to the magneto frame (ground), while the twin point terminal is connected to the high tension outlet of the magneto. The purpose of the static post and point is to dissipate the ionization which occurs in the vicinity of the spark points as a result of the electrical discharge. Ionization lowers the voltage required in bridging the spark gap and consequently causes an erratic spark.

Care should be taken to keep the spark gap assembly entirely free of oil, moisture and dust to avoid the possibility of damage due to high voltage leakage paths across the insulating base. The spark points, which are usually made of tungsten steel or monel metal, must be kept sharpened to needle fineness and adjusted precisely according to the requirements of the test. The width of the spark gap depends primarily upon the rotative speed of the test.

Figure 146—Synchroscope Dial

REPLACEMENT PARTS

Every service station should have an adequate stock of genuine replacement parts at hand. Replacement parts should never be removed from their containers until it is definitely determined that the part is necessary in the repair of the magneto. Reference should always be made to the repair parts list in the Service Manual to be certain that the part number is the one specified for the particular type magneto. Keeping parts in their original containers prevents the loss of their identity, as well as the damaged or shopworn appearance which often results when parts lie around on the service bench or shelf.

To build up an adequate replacement parts stock a service station must have some knowledge of the magneto applications existing in his territory. Such a survey can be made in a number of different ways as, for example, by direct post card inquiry to engine operators or by checking with local tractor and engine dealers.

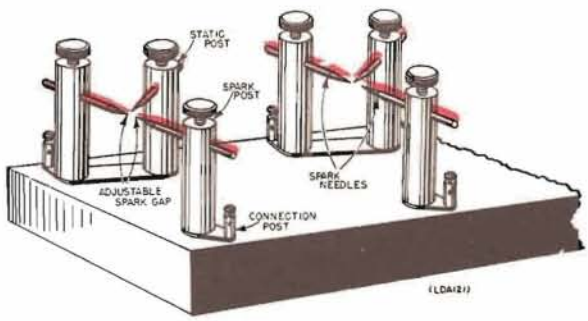
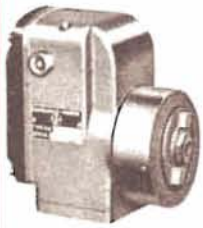


Figure 147—Three-Point Spark Gap Assembly

FAIRBANKS MORSE MAGNETOS

for Single Cylinder Engines



Type FM-X1A

Type FM-X1A and FM-X1B

The Type FM-X1 magnetos incorporate the latest in design and magnetic metal development. This type unit is ventilated to provide the necessary changes in air, yet is dust and moisture proof. The Type FM-X1 magnetos are available in SAE flange, SAE (45MM) base mounting, (35MM) base mounting for special applications and in standard or radio shielded versions. These magnetos are designed for the use of an impulse coupling and are permanently lubricated at the factory.

Type FM-X1B

for Medium Compression Engines

Type FM-X2B

TYPES FM-X2A & FM-X2B

Of the gearless carbon-brush distributor design, Type FM-X2 magnetos have a spark interval of 180° and are suitable for use at crankshaft speed to two cycle engines, while at half crankshaft speed they are adaptable to four cycle engines with cranks at 360°. Type FM-X2 magnetos may also be used on engines firing 180 - 540° by allowing waste sparks to occur during the exhaust strokes.

TYPES. FM-X4A & FM-X4B

Type FM-X4 magnetos have established outstanding ignition standards for four cylinder tractor and industrial engines. The troublefree jump-spark distributor operates in a ventilated compartment separate from the sealed housing in which the magnetic rotor, coil and breaker points are contained. Construction is simple and sturdy in all details, assuring dependable service.

Type FM-X4B

for Tractor & Commercial Applications

Type FM-XR4B

TYPES FM-XR4A & FM-XR4B

Larger and heavier than standard commercial units, Type FM-XR4 magnetos provide additional reliability. A separate, vented compartment is provided for the jump-spark distributor, while the breaker points, condenser, magnetic rotor, and bearings are housed in the main body of the unit, which may be vented or sealed according to operating conditions.

TYPES FM-XR6A & FM-XR6B

Similar to the Type FM-XR4 magnetos in design and construction, the Type FM-XR6 is recommended for six cylinder engines when additional reliability is required. Component parts are carefully made of the finest materials. Breaker points are long-lasting tungsten and are non-critical in adjustment. Dependable ignition is assured by painstaking design.

Type FM-XR6A

for Heavy Duty Service

Type FM-XOR4B

TYPES FM-XOR4A & FM-XOR4B

Type FM-XOR4 magnetos are rugged, powerful units with jump-spark distribution, intended primarily for heavy-duty service on power unit engines. Built with a separate, vented distributor compartment, the ball bearing rotor, coil and breaker mechanism operate in a frame which may be sealed or vented, as operating conditions dictate.

TYPES FM-XOR6A & FM-XOR6B

Built specifically for continuous, heavy-duty ignition service, Type FM-XOR6 magnetos have rotors with 50% more Alnico magnetic alloy than magnetos for standard applications. The jump-spark distributor operates in a separate, vented compartment and the ball bearing magnetic rotor, coil, and breaker mechanism are mounted within the magneto frame, which may be sealed or vented, depending on operating conditions. Ball bearings are used throughout.

Type FM-XOR6A

The Fairbanks Morse factory in Beloit, Wisconsin

870370-016602M-BLC

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