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THE ELECTRICAL EQUIPMENT OF AUTOMOBILES

A BOOK ON PRINCIPLES FOR MOTOR MECHANICS AND MOTORISTS

BY

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PREFACE TO FOURTH EDITION

THE first edition of this book, published in 1927, was written primarily as a textbook for a class at the Royal Technical College, Glasgow, on "The Electrical Equipment of Automobiles." Such classes are now widespread, and an examination in the subject has been established by the City and Guilds of London Institute. It is hoped that the revised text will continue to meet the needs of both teachers and students, as well as those engaged in private study.

Although no attempt has been made to change the character of this book, the present edition has entailed as thorough revision and as much enlargement as the earlier editions. The reason for this is not far to seek. The use of electricity on motor vehicles has become so extensive, and the accessories have been so improved, that a wider knowledge of fundamental principles is called for. The laws of light underlying the design of headlamps and avoidance of glare, and the laws of sound underlying the design of motor horns, afford good examples of the wider applications of physics.

In the present edition subjects that have received greater attention include starting conditions both in petrol and in compression-ignition engines, the compensated automatic voltage regulator, and ignition.

The author is anxious to make ample acknowledgment for the help he has received in preparing this work. While he is solely responsible for what is in the book, it is no exaggeration to say that without the active assistance of Mr. E. A. Watson, Chief Engineer of Messrs. Joseph Lucas Ltd., of Mr. W. H. Glaser, of Messrs. C.A.V. Ltd., and of Dr. E. Giffen, Director of the Research Laboratories of the Institution of Automobile Engineers and their colleagues, the work could not have been treated so fully or authoritatively. Ungrudging help has also been given by Mr. J. A. Cowan, M.I.E.E., a lecturer on the Author's staff, who for many years has made a special study of this subject.

S. PARKER SMITH.

THE ROYAL TECHNICAL COLLEGE,
GLASGOW.

October, 1941.

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CHAPTER I

THE STORAGE BATTERY

A STORAGE battery is necessary for electric lights, signals, fuel pump, horn, starting motor, coil ignition, in short, for all electrical accessories except the magneto.

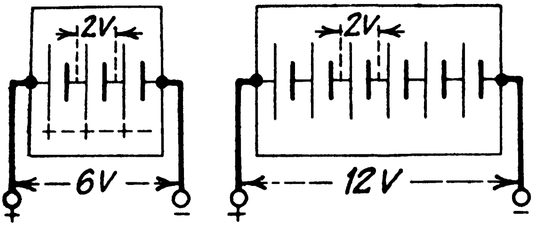
Automobile batteries must be made sufficiently robust to withstand the severe conditions to which they are subjected. Troubles in service can often be traced to negligence, improper maintenance or gross abuse, any of which may arise through lack of familiarity with the simple necessary maintenance requirements. One or two years of trouble-free life should be obtained from even the cheaper types. Certain high-class batteries, indeed, are guaranteed for such periods, and they may give useful service for four years or longer.

An important point to remember is that a battery has a limited capacity—it is not a generator. If the amount taken from the battery as discharge is not replaced, the battery in time will become exhausted. If the battery is brought to a full state of charge, its capacity cannot be increased by further charging.

A battery cannot be left to look after itself, but maintaining the battery in a proper condition is not a difficult matter when the elementary principles underlying the use of storage batteries have once been grasped. Some accessories used with the charging generator are automatic in their action.

STORAGE BATTERY

Definition and Types of Storage Batteries.—In addition to the name "storage battery," the names "secondary battery" and "accumulator" are also used. A battery consists of a number of cells, which, in the application we are considering, are joined together or "placed in series" to give the required voltage—usually 6 or 12 or 24 volts—the negative terminal of one cell being joined to the positive terminal of the next and so on, as in Figs. 1–4.



(*a*) (*b*)

FIG. 1.—Series grouping of acid cells to form: (*a*) 6-V battery, (*b*) 12-V battery.

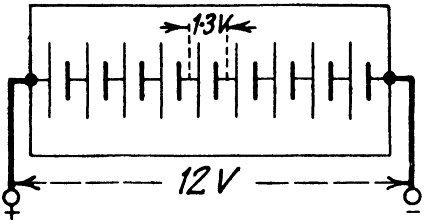


FIG. 2.—Series grouping of 9 alkaline cells to form 12-V battery.

A cell does not store electricity. Its action depends on the conversion of energy from one form to another, and is reversible. During charge, electrical energy is converted into chemical energy; during discharge, chemical energy is converted into electrical energy. The internal-combustion engine derives its power from the chemical energy stored in the fuel, but here the conversion is into mechanical energy and is not reversible. In this respect, both battery and engine are unlike the electric condenser, which stores electric energy and releases electric energy.

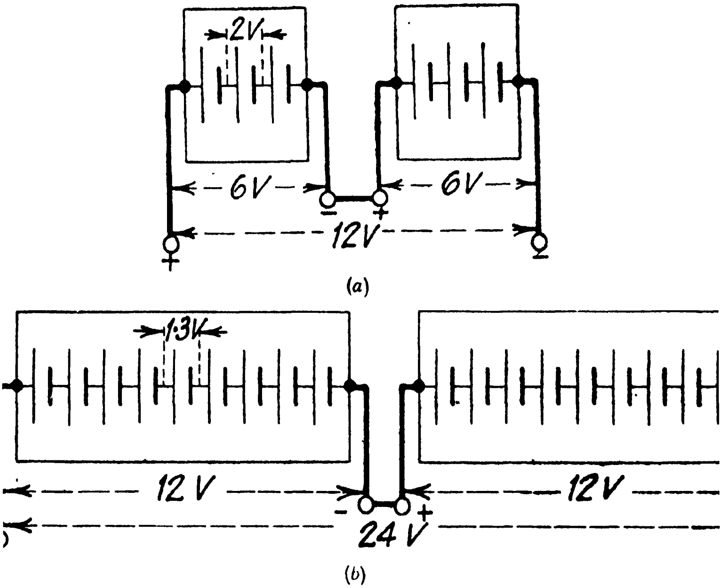


FIG. 3.—Series grouping of batteries to form: (*a*) 12-V acid battery, (*b*) 24-V alkaline battery.

There are two types of cell used on vehicles: the acid cell, and the alkaline cell. The older type, the acid cell, may still be regarded as standard for private cars and for lorries; but for passenger transport vehicles, the alkaline cell has found a place on account of its reliability. The high resistance of the alkaline cell, which made it less suitable for starting purposes, has been overcome to some extent. The alkaline battery is heavier and more costly than the acid battery, but its long life and low upkeep make it suitable for buses.

Capacity of a Cell.—The capacity of a cell is measured in *ampere-hours*, denoting that the cell will give a rated current for a specified period, usually extending from the fully-charged condition to the voltage beyond which discharge is practically out of the question. The normal discharge rate of a car cell is given either at the ten-hour or at the twenty-hour rate. In addition, the discharge current is given at the five-minute rate, this current being roughly that taken by the starting motor on switching in.

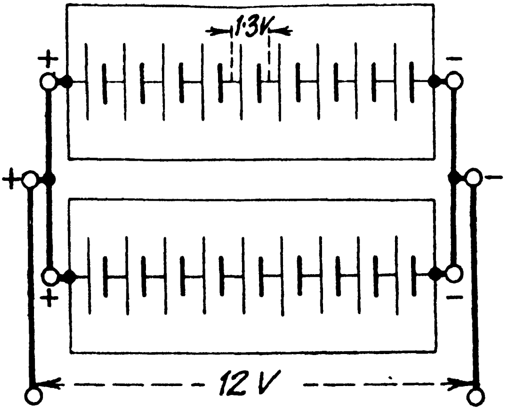


FIG. 4.—Parallel grouping of two alkaline batteries to form 12-V battery.

To test the ampere-hour capacity of an acid cell, discharge at normal rate, keeping the current constant by means of a variable rheostat, until the voltage falls to 1·8 volts.

The *watt-hour* capacity of a cell equals the ampere-

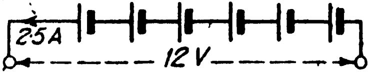
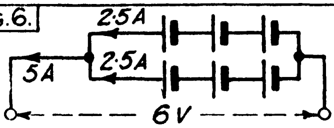
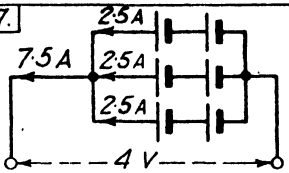
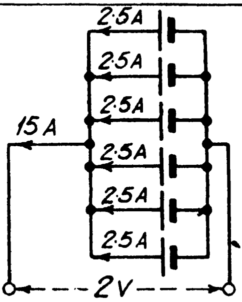
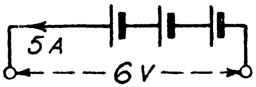
GROUPING	AMPERE-HOUR CAPACITY	WATT-HOUR CAPACITY
FIG. 5.  	20×2·5=50	50×12=600
FIG. 6.  	20×5=100	100×6=600
FIG. 7.  	20×7·5=150	150×4=600
FIG. 8.  	20×15=300	300×2=600
FIG. 9.  	20×5=100	100×6=600

FIG. 5.—Six 50-ampere-hour cells in series, giving a 12-volt, 50-ampere-hour battery.

FIG. 6.—Parallel connection of two sets of three 50-ampere-hour cells, giving a 6-volt, 100-ampere-hour battery.

FIG. 7.—Parallel connection of three sets of two 50-ampere-hour cells, giving a 4-volt, 150-ampere-hour battery.

FIG. 8.—Parallel connection of six 50-ampere-hour cells, giving a 2-volt, 300-ampere-hour battery.

FIG. 9.—Three 100-ampere-hour cells in series, giving a 6-volt, 100-ampere-hour battery.

hour capacity multiplied by the average voltage during discharge.

Capacity of a Battery.—The technical conditions determining the requisite capacity of a battery often conflict with the commercial conditions. Technically, where the dynamo is controlled by a voltage regulator, the starter determines the requisite capacity; where a three-brush dynamo is used, this may affect the capacity. A doctor's car or a delivery van may need a larger dynamo and battery than are needed by the standard car or van of the make in question. In an omnibus or motor coach, lighting may decide battery size. The upper limit of battery capacity depends on the maximum dynamo output. Commercial conditions may dictate minimum weight and cost, but should not entail manual cranking. This practice was never popular, and a user who installs a larger battery than the one provided in the standard equipment will have no cause to regret the small extra cost.

The ampere-hour capacity of a battery depends on the way in which the cells are connected. Suppose, for example, we have six 50-ampere-hour acid cells. These can be joined in four different ways, as shown in Figs. 5 to 8. Fig. 5 gives a 12-volt, 50-ampere-hour battery. The discharging current per cell is 2·5 amperes with a twenty-hour rating. With the six cells grouped as shown in Fig. 6, we have a 6-volt, 100-ampere-hour battery. The same result would be obtained by joining three 100-ampere-hour cells in series (*see* Fig. 9). In both cases the current is 5 amperes with a twenty-hour rating. By connecting the six 50-ampere-hour cells as in Fig. 7, we get a 4-volt, 150-ampere-hour battery; while the connections in Fig. 8 give a 2-volt, 300-ampere-hour battery.

It is thus seen to be misleading to compare the current or ampere-hour capacities of batteries.

In order to obtain a proper comparison, the energy or watt-hour capacities must be considered (watts = volts × amperes) as shown in Figs. 5 to 9.

The comparison is thus definite only when the voltage as well as the current is considered.

From this it follows that a larger energy output can be obtained from a 50-ampere-hour, 12-volt battery than from an 80-ampere-hour, 6-volt battery.

For the guidance of makers and users, maximum overall dimensions have been fixed for 6- and 12-volt batteries of given ampere-hour capacities to permit ready replacement.

Typical values for the capacity of 12-volt batteries on a 20-hour rating are: for cars, 70 ampere-hours; for lorries, 150 ampere-hours; for buses, 220 ampere-hours.

The recharging rates after a start vary from 10 to 40 amperes, according to the size of the battery. The current rapidly falls off as the battery becomes replenished.

Corresponding starting motor outputs range from 0·4 to 3 h.p. for cars, and from 1 to 6 h.p. for commercial vehicles.

Tests for Polarity.—When a battery is charged from an outside source—which must, of course, be direct current or rectified alternating current—there may be some doubt as to which terminal is positive and which is negative. Any of the following methods can be used to determine the polarity of a source of direct current:—

(1) Lay the two terminal leads ½ in. apart on damp pole-finding paper laid on wood. The end which turns red is negative.

(2) Pass a current through diluted acid, when gas is given off more rapidly at the negative pole.

(3) Lamps in series with battery are dimmed when connections are correct for charging.

(4) Use moving-coil voltmeter on which the positive terminal is marked.

(5) Place the two terminal leads on a slice of potato —the end which is positive turns green-black.

Warning.—When making polarity tests with loose leads, great care must be taken to avoid contact between them.

It is essential for charging that the positive pole of the charging supply (generator or battery or supply mains) be connected to the positive terminal of the battery.

Bench Charging of Batteries.—Most garages are now equipped with charging sets for giving a bench charge to single batteries or to a number joined in series. For converting alternating into direct current a rectifying device is used, transformer tappings being provided for rough voltage control. Fine control is obtained by resistance.

To recharge an acid battery and keep it healthy, 120 to 130 per cent. of the complete discharge is needed; an alkaline battery needs 130 to 140 per cent.

Terminal Voltage and Characteristic Curves.—Denoting the electromotive force of the cell by E volts and its internal resistance by R ohms, the potential difference, or voltage V, between the cell terminals when a current of I amperes flow through it will be :—

On charge : $V=E+RI.$

On discharge : $V=E-RI.$

With n similar cells in series, the terminal voltage will be nV volts.

Characteristic curves at normal rates of charge and discharge, plotted as volts per cell to a function of time, are shown in Fig 10. The effect of discharge rate on voltage and capacity is shown in Figs. 11 and 13.

Recharging Battery after Starting.—The most severe demand on the battery is made during starting when the engine is cold. Typical values of the quantity of electricity in coulombs (1 coulomb = 1 ampere × 1 second) taken from the battery when starting under different conditions, and the time taken to replace it, are given in the following table. In estimating the time taken to replace this quantity, a charging current of 10 amperes is assumed, and the loss in the battery is ignored. The figures given for the petrol engine are those for a small engine which took 280 amperes for 5 seconds (280 × 5 = 1,400 coulombs) when cold, and 150 amperes for 3 seconds (150 × 3 = 450 coulombs) when hot.

ENGINE		Battery discharge to start engine, in coulombs (ampere-seconds)	Time in seconds to recharge at 10 amperes, ignoring loss
Type	Condition		
Small Petrol	Cold	1,400	140
	Hot	450	45
Heavy-oil	Cold	10,000	1,000
	Hot	2,500	250

From these figures it is seen that the battery on a small car is rapidly replenished, but for the oil-engine it is a different matter—the worst case requiring 17 minutes for recharging. If the battery efficiency is as low as 50 per cent., then the time taken to replenish will be double that shown in the last column. Actually the charging current would be much larger for the battery on the heavy vehicle, which offsets the effect of inefficiency. It can be safely concluded that cases occur when as long as 20 minutes is needed to restore the battery to its original condition.

In practice, the time taken to recharge becomes important where starting is frequent, e.g., a delivery van; here, unless a satisfactory charging device is installed on the vehicle, bench charging must be resorted to. The voltage regulator has been developed to meet such severe demands as those on buses due to starting, internal lighting and night driving. The least demand occurs in a car with magneto ignition used solely for long runs in the daylight—here, maintaining a charging current of 5–10 amperes might rapidly ruin the battery through overcharging. Although the lamps and the multitudinous accessories on the modern car may be an appreciable load on the battery when the car is stationary, when running the bulk of this load would be taken by the dynamo.

CALCULATIONS.

To obtain an idea of the magnitude of the quantities involved when the heaviest demands are made on the battery, the following examples on starting and manœuvring are given. They also show the relation between the electrical and mechanical quantities involved.

Example 1.—It is of interest to know how many times a *cold* engine could be started from a battery on a single charge.

A 40-ampere-hour battery on a ten-hour rating has a capacity of about 10 ampere-hours when giving 250 amperes for 5 seconds with 5-second pauses. Taking the average discharge voltage as 8 volts, the battery gives:

$$10 \text{ ampere-hours} \times 8 \text{ volts} = 80 \text{ watt-hours}$$
$$= 288{,}000 \text{ watt-seconds.}$$

Taking the 2·5 litre, 6-cylinder engine referred to on page 55, the resisting torque at 60 r.p.m. and 0° C. (32° F.) is 75 lb.-ft. The power needed to drive the engine at this speed is:

$$\frac{75 \times 2\pi 60}{33{,}000} = 0{\cdot}855 \text{ horse-power}$$
$$= 0{\cdot}855 \times 746 = 640 \text{ watts.}$$

With this power, the energy taken at the crankshaft to drive the engine for 5 seconds $= 640 \times 5 = 3{,}200$ watt-seconds. Allowing 5 seconds for each start, 30 per cent. efficiency for motor and 85 per cent. for gearing, energy taken from battery per start $= 3{,}200/0{\cdot}255 = 12{,}500$ watt-seconds.

Hence number of starts per battery charge $= \dfrac{288{,}000}{12{,}500} = 23.$

This calculation is rough owing to the assumptions made, but it is close enough for practical purposes.

Example 2.—As an instance of manœuvring, it was stated in the *I.E.E. Journal*, Vol. 87, p. 238, that a 60 ampere-hour battery of 30 acid cells weighing 400 lb. propelled a bus weighing 7 tons 17½ cwt. a distance of 4·25 miles at an average speed of 4·1 m.p.h., using 48 ampere-hours.

To allow for loss in gearing and motor, we shall assume an overall efficiency of 0·7.

(*i*) Estimate the tractive effort in pounds per ton.

Assuming 2 volts per cell, battery voltage $= 2 \times 30 = 60$ volts. Then,

battery energy expended $=48$ ampere-hours $\times 60$ volts
$=2{,}880$ watt-hours
$=7{\cdot}62\times 10^6$ ft.-lb.

since 1 watt-hour $=2{,}655$ ft.-lb.

At efficiency $=0{\cdot}7$,

useful energy $=0{\cdot}7\times 7{\cdot}62\times 10^6=5{\cdot}33\times 10^6$ ft.-lb.

Distance propelled $=4{\cdot}25$ miles $=22{,}440$ ft.

Hence, total tractive effort $=\dfrac{5{\cdot}33\times 10^6}{22{,}440}=237$ lb.

Weight of bus $=7{\cdot}875$ tons.

whence, tractive effort per ton $=\dfrac{237}{7{\cdot}875}\doteq 30{\cdot}1$ lb.

(*ii*) Estimate the watt-hours per ton-mile.

Battery energy expended $=2{,}880$ watt-hours.

At efficiency $=0{\cdot}7$,

useful watt-hours $=2{,}880\times 0{\cdot}7=2{,}016$

Weight of bus $\times$ distance travelled
$=7{\cdot}875\times 4{\cdot}25=33{\cdot}4$ ton-miles.

Hence, watt-hours per ton-mile $=\dfrac{2{,}016}{33{\cdot}4}=60{\cdot}4$.

This figure represents the energy actually available per ton-mile after motor and gearing losses have been deducted.

(*iii*) Estimate the current and the horse-power.

Time of journey $=\dfrac{\text{distance travelled}}{\text{speed}}=\dfrac{4{\cdot}25}{4{\cdot}1}=1{\cdot}04$ hr.

Battery energy expended $=2{,}880$ watt-hours.

Power $=\dfrac{\text{watt-hours}}{\text{hours}}=\dfrac{2{,}880}{1{\cdot}04}=2{,}780$ watts.

Current $=\dfrac{\text{power}}{\text{voltage}}=\dfrac{2{,}780}{60}=46{\cdot}3$ amperes.

Total horse-power $=\dfrac{\text{power}}{746}=\dfrac{2{,}780}{746}=3{\cdot}72$ h.p.

Useful horse-power $=3{\cdot}72\times 0{\cdot}7=2{\cdot}6$ h.p.

THE ACID CELL

Construction and Active Materials.—The design of a car battery must necessarily be a compromise. Obviously the ideal is maximum capacity for minimum weight and volume. When starting the engine, the battery must be capable of giving an initial kick up to 500 amperes for petrol engines and up to 1,000 amperes for oil engines, and maintaining a large current for several seconds. The chemical action which takes place between the active material of the plates and the electrolyte can occur only where the two are in contact; and since, at any given temperature, there is a definite rate at which chemical action proceeds, a definite surface per ampere must be provided. After the outer layers of active material have undergone their change, fresh electrolyte has to penetrate inwards to replace the used electrolyte. Although thick plates are obviously more durable, the fact that the maximum current which a cell can give is proportional to the surface area of the plates, leads to the use of a large number of thin plates, the limitation being mechanical strength. Thus to meet the demand for large starting currents the plates must be thin in order to obtain large surface area for given weight, and to shorten the time for the diffusion of the electrolyte in the paste. Further, to reduce weight, the plates are worked at a much higher current density (in amperes per square centimetre) than the plates of stationary batteries; while additional capacity is obtained by increasing the density of the electrolyte. The wear and tear of the plates in practice arises chiefly from overcharging.

In the ordinary acid cell the active materials are lead peroxide (PbO_2) on the positive plates, and finely-divided or spongy lead (Pb) on the negative plates. These active materials are held in cast-lead grids which are immersed in a solution (approximately 25 per cent.) of sulphuric acid (H_2SO_4) in water, called the electrolyte. The positive and negative grids are cast with lugs, to which the terminals of the cell are attached. Each cell is accommodated in a sealed multi-compartment container of moulded ebonite or other suitable composition—a neat construction which has replaced the separate celluloid or ebonite containers in an outer wooden case. The cells are joined in series by burnt lead or screwed connections with lead-coated terminals, and each cell is closed by a ventilated stopper. The plates are $\frac{1}{8}$ to $\frac{3}{32}$ in. in thickness, while the height and width are usually $4\frac{15}{16}$ and $5\frac{5}{8}$ in. respectively. To prevent short-circuiting, due to buckling or dislodged paste, separators (usually of wood) are employed. The internal resistance of the acid battery is very low—0·01 to 0·001 ohm, depending on the size of the plates, temperature and state of charge. It is this low resistance which makes the acid battery suitable for starting petrol engines.

Action.—The chemical actions in an acid cell are complicated. A simple explanation, although not complete, is that when current is taken from the cells, chemical changes take place, whereby some of the lead oxide on the positive plates and some of the spongy lead on the negatives is converted to lead sulphate ($PbSO_4$). During this process sulphuric acid is reduced and water (H_2O) is formed, which accounts for the lowering of the density or specific gravity of the electrolyte as the discharge proceeds. Only a small proportion of the total amount of active material is involved in this chemical change. To charge the cells, current is sent through the battery in the opposite direction, viz., from positive to negative, and the reverse chemical action takes place, lead sulphate being converted to lead peroxide on the positive and reduced to spongy lead on the negative plates, while the density of the electrolyte rises, due to the formation of sulphuric acid from lead sulphate and water.

These conversions can be represented as follows:—

$$\begin{array}{ccccccccccc}
\multicolumn{5}{c}{\text{During charge.}} & & \multicolumn{5}{c}{\text{During discharge.}} \\
\text{Positive plate.} & & \text{Electrolyte.} & & \text{Negative plate.} & & \text{Positive plate.} & & \text{Electrolyte.} & & \text{Negative plate.} \\
PbO_2 & + & 2H_2SO_4 & + & Pb & \rightleftharpoons & PbSO_4 & + & 2H_2O & + & PbSO_4
\end{array}$$

It is not permissible to convert the whole of the active material in this way. The extent of conversion depends on the rate of discharge—the higher the rate of discharge, the smaller the capacity in ampere-hours yielded by the battery. The termination of the discharge is indicated by an arbitrary final voltage—1·85 to 1·8 volts at slow rates of discharge, 0·5 volt at maximum rate of discharge.

Charging.—During the process of charging, the voltage between the terminals of a cell rises slowly to 2·4 to 2·5 volts, and then rapidly to 2·6 to 2·7 volts, the nature of the rise depending on the charging current (*see* Fig. 10). As the cell becomes fully charged, the current has to penetrate more deeply into the active material, and for this reason the charging current should be reduced towards the end of the charge. When the cell is fully charged, i.e., when no more sulphate is broken up, the density of the electrolyte in an automobile battery will be 1·25 to 1·28, depending on the original strength of the acid. Further passage of the current merely decomposes (electrolyzes) water into its constituents of hydrogen and oxygen, and produces heat—the electrolysis and the heat being the results of passing electrical energy into a battery which the plates cannot absorb. In addition to the voltmeter, which indicates the cell voltage, and the hydrometer, which indicates the density of the electrolyte, further indications that the cell is fully charged when a current is still passed through it are given by "gassing," that is, by the numerous gas bubbles being given off at the plates, oxygen at the positive and hydrogen at the negative, and by a rise in temperature of the electrolyte.

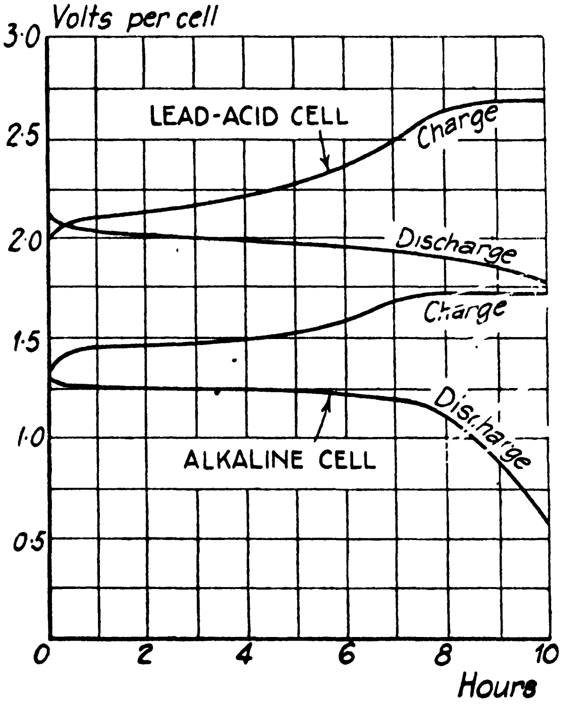


FIG. 10.—Charge and discharge curves of acid and alkaline cells at normal rates (10-hour rating).

As soon as the charging current is switched off from a fully-charged cell the voltage at once drops to about 2·25 volts, and then settles down slowly to between 2·1 and 2·0 volts.

Discharging.—The voltage on discharge depends on the rate of discharge. With a normal continuous discharge current, the voltage falls off somewhat as shown in Fig. 10. Starting at about 2·1 volts, the voltage rapidly falls to about 2 volts, after which it sinks slowly to about 1·8 volts, the density of the electrolyte being then about 1·15. If the discharge is interrupted, the weaker acid in the plates becomes strengthened by diffusion; and the voltage rises owing to the existence of unchanged active material in the plates; but it falls quickly to its previous value when discharging is resumed. Under a heavy discharge-rate, as when starting, the voltage may drop below 1 volt, and the cell only approaches or recovers its normal voltage after a more or less protracted rest. Should the engine not start with the first trial, the battery should be given a brief rest before a second attempt, to enable new electrolyte to diffuse into the pores of the plates. The voltage of a cell falls off very rapidly as soon as the density of the electrolyte has fallen to the neighbourhood of 1·15, and the cell should be recharged forthwith. To carry discharge further is not only decidedly harmful, owing to the formation of insoluble lead sulphate and the possible distortion and buckling of the positive plates, but it is practically useless, as very little more energy is obtainable from a battery in this condition.

Effect of Discharge Rate on Voltage and Capacity.—Characteristic curves at normal rates of charge and discharge are given in Fig. 10. The greater the discharge current, the less the capacity, owing to the reduced time for the diffusion of the acid, leading to correspondingly lower terminal voltage. In addition, the internal resistance of the cell causes a large voltage drop when a large current flows, as at starting.

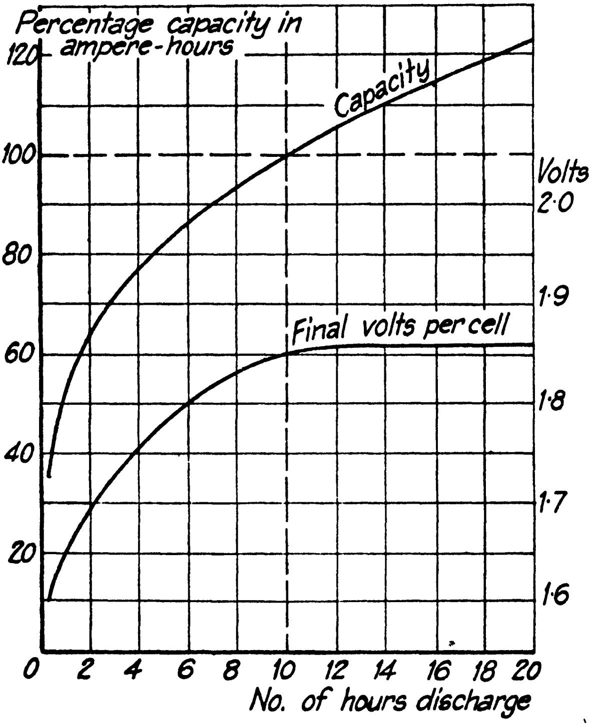


FIG. 11.—Effect of discharge rate on final voltage, and on capacity, as percentage of 10-hour capacity, of acid cell.

Repeated attempts at starting in rapid succession temporarily exhaust the battery. A pause between attempts enables the battery to recover by giving time for diffusion; but even with intervals of 10 seconds, the voltage may not rise above 1·8 volts per cell. If attempts at starting are persistently repeated, the battery ultimately gives out, though this may not occur before 20 to 50 repetitions, depending on circumstances. Before this occurs the battery voltage may fall so low that the current is insufficient to drive the starting motor at firing speed or even to crank the engine at all.

The manner in which the ampere-hour capacity falls as the discharge rate is increased is illustrated in Fig. 11, which shows typical curves of capacity and final voltage of a 50-ampere-hour cell rated to give 5 amperes for ten hours. The twenty-hour rating would be $50 \times 122/100 = 61$ ampere-hours, or $61/20 = 3{\cdot}05$ amperes for twenty hours. The fifteen-minute rate would be $50 \times 35/100 = 17{\cdot}5$ ampere-hours, or $17{\cdot}5/0{\cdot}25 = 70$ amperes for quarter of an hour. Conditions are aggravated when the cell is only partly charged, for the resistance of the electrolyte depends on its density. The lower the density—that is, the lower the state of the charge—the higher the resistance, and therefore the lower the terminal voltage.

Effect of Temperature on Voltage and Capacity.—Temperature has an important influence on capacity. Unlike a metal, the resistance of the electrolyte rises as the temperature falls. Also as the temperature falls, the density of the electrolyte rises, thereby permitting the liquid to diffuse less readily into the pores of the active material. Other things being the same, then, the capacity of a battery is lower in winter than in summer. In figures, a ten-hour rating at 20° C. (68° F.) may fall to 80 per cent. at 0° C. (32° F.), and to 60 per cent. at −10° C. (14° F.). The fall in capacity with fall in temperature is equally severe at high-discharge rates.

As a rough illustration to show the effect of discharge rate and temperature on the voltage drop in a battery when the initial starting current flows, the following figures are given :—

Condition of Battery.	Voltage Drop in Battery.
Fully charged at 15° C. (60° F.) . .	25 per cent.
Fully charged at 0° C. (32° F.) . .	33 ,,
Half charged at 0° C. (32° F.) . .	50 ,,

Thus the drop in temperature reduces the available starting voltage of a fully-charged 12-volt battery from 9 to 8 volts ; but if the battery is only half charged as well as cold, the battery voltage is halved, leaving but 6 volts for the motor. This indicates the importance of keeping the battery well charged. Temperature effect is unavoidable ; low state of charge is avoidable. Thus, if the internal resistance of a givencharged 12-volt battery at 15° C. be 0·001 ohm and the current on switching on the starting motor be 300 amperes, the voltage drop in the battery will be 3 volts. This is unavoidable. Any increased drop due to partially charged conditions can, and should be, avoided.

Effect of Overcharging.—Strictly speaking it is not possible to give the battery an overcharge, because, when the battery is fully charged, a further passage of current produces electrolysis of the water in the electrolyte, oxygen being given off at the positive, and hydrogen at the negative, plate. This highly explosive mixture renders it dangerous to hold a naked light near a "gassing" cell. The fully-charged state is evidenced by a rapid evolution of gas bubbles, known as "gassing." Consequently, if overcharging is persisted in, water is decomposed and driven off as gases and must be replenished (or "topped-up"). For this reason it is desirable for the charging dynamo to be so controlled that the risk of overcharging is avoided.

Other bad effects of overcharging are overheating, loss of acid through spray, and dislocation of active material from the plates.

(*a*) *Over-Heating* is the result of passing an excessive current through the cell towards and after the completion of the charge, for the electric energy is then expended in heat and electrolysis. The working temperature of a battery is 21° to 27° C. (70° to 80° F.). If a battery on charge should attain a temperature of 43° C (110° F.), the current should either be reduced or interrupted forthwith. Too rapid charging may make even a discharged battery gas actively and become too hot. Should a temperature of 60° C. (140° F.) be approached, destructive chemical actions occur and internal gassing dislodges active material.

(*b*) Acid *spray* is caused by acid being thrown off with bubbles during gassing.

(*c*) *Dislocation of Active Material and Bulged Plates* are produced by sending too large a current through the battery towards the end of the charge. Dislodged active material not only reduces the capacity of the battery, but may cause internal short-circuits. This is what is meant by wear and tear of the plates shortening the life of the battery.

It will be gathered that a battery can be ruined by overcharging as well as by undercharging. To protect the battery against the harmful effects of overcharge, it is desirable to have a charging system in which the charging current is automatically reduced as the battery charge approaches completion. (*See* "Adjustment of Charging Current," p. 26 and Chapter IV.)

Sulphation.—The formation of lead sulphate, in a finely divided form, is the normal result of chemical action on discharge ; but if it is not reduced in time by recharging, basic lead sulphate is produced, which permeates the plates as a hard, white, non-conducting, crystalline substance. In this form it becomes injurious to the cells. Among the conditions under which this occurs are over-discharge (discharge continued after the density of the electrolyte has fallen to 1·15 or the cell voltage to 1·8 volts) ; prolonged discharged state ; insufficient charging ; too infrequent charging ; local action ; incorrect density or level of electrolyte. When the deposited lead sulphate reaches this chronic state, the phenomenon is known as "sulphation." Sulphated plates feel very hard and gritty ; the positive plates are pale brown or yellowish brown instead of a healthy chocolate colour ; the negative plates are almost white. As this excessive sulphate is non-conducting, sulphating increases the internal resistance of the cell and so lowers the voltage and capacity on discharge ; while on charge a sulphated cell may require 3 volts or more to send the normal current through it. This is misleading, as the observer may conclude from the high reading that the cell is fully charged ; it is one reason why hydrometer readings are always preferable to voltmeter readings in cell testing. Further, owing to the excessive bulk of sulphated material, the positive plates become buckled and the cell life is shortened in consequence.

A chronically sulphated cell is useless, but this stage is reached only by sheer neglect or gross misuse.

Desulphation.—Moderate sulphation can be removed by prolonged charging at low rates. Heavily sulphated plates may not respond to such treatment, in which case it is necessary to charge them up in a very weak sulphuric acid solution. During the process, when the electrolyte reaches a density of 1·15 it is well to replace it by pure water. On completion of the process, the plates should be immersed in electrolyte of correct density, as specified by the maker.

Battery makers strongly discourage the use of advertised remedies for sulphated cells. Battery troubles should usually be attended to in the maker's works or service depots.

From time to time a deliberate overcharge at a low rate is desirable to ensure that the plates are thoroughly desulphated, but overheating must be avoided.

Topping Up.—In addition to proper charging, a storage battery needs topping up with pure water to keep the level of the electrolyte about ½ in. above the top of the plates. It has been explained already how water may be lost by electrolytic action in overcharging, and there may also be some loss from evaporation, especially in warm weather, or if the exhaust pipe is near the battery.

To top up, use distilled water and clean vessels. Do not leave distilled water in an unstoppered bottle. Impure water causes local action (i.e., discharge inside the battery), owing to the presence of chlorine and iron.

In some places, e.g., Glasgow, tap water is satisfactory for topping up. This, however, must not be taken as a general rule, and when any doubt exists as to the purity of the water, distilled water should be used.

Although evaporation in a starter battery may be negligible, the level of the electrolyte will fall in proportion to the amount of water lost due to gassing. It is therefore essential to top up the cells periodically. If the level of the electrolyte falls below the top of the plates, the exposed portion dries out and becomes sulphated. On topping up and recharging, this dried-out active material may fall away, thereby permanently reducing the capacity of the cell, and possibly producing internal short-circuits. Again, while there is an exposed part of the plates, the capacity of the battery is correspondingly reduced.

As water is less dense than the electrolyte, it is useless to take the density of the electrolyte just after the battery has been topped up. Also, just after topping up, the battery should not be left in a place where the water can freeze. In cold weather, therefore, the battery should be charged after topping up. When the battery is well charged, there is practically no danger of the electrolyte freezing, for at a density of 1·3 the freezing point is below −60° C. (−76° F.) At a density of 1·1 the electrolyte freezes at about −5° C. (23° F.), so that freezing may well occur in a discharged battery. The vent holes in the stoppers should be kept free from ice, as well as from dust and dirt. Neglect of these precautions may result in a burst container.

Topping up should be attended to when the density of the electrolyte is checked—the hydrometer, used as a syringe, will be found very useful for replenishing the lost water.

Some batteries are fitted with vent plugs which do not have to be removed when topping up. Electrolyte level indicators may also be attached to the battery.

New Batteries.—The maker's instructions are the safest guide, and as a rule they are simple to follow. Usually they call for a soaking period after the cells are filled with acid prior to the first charge. The specific gravity of the filling-in acid is stated by the battery maker.

A high quality sulphuric acid must be used diluted with distilled water to the required specific gravity.

This may differ from the actual working specific gravity of the electrolyte to make allowance for residual acid in the plates, or water in the wood separators where employed. At the end of the initial charge the density of the electrolyte may have risen above the working specific gravity, in which case it should be reduced by the addition of water.

A new battery needs particular care, for it is no unusual thing for a new cell to soak up 20 per cent. of the electrolyte in the plates and separators. The topping up necessitated by this initial absorption should be done with dilute acid of the correct density. Subsequently, however, water only must be used, unless some of the electrolyte is lost by spilling, etc.

When diluting, acid should always be added to water, and not water to acid. The acid should be added slowly, while the mixture is continuously stirred.

Care of Idle Batteries.—An acid battery cannot be left on open-circuit for prolonged periods without deterioration. To keep it fully charged, it must either be given an occasional freshening charge, or it may be "trickle" charged. Trickle charging is the term applied to the passing of a minute current continuously through the battery to compensate for local action and leakage. Such loss may be as much as 1 per cent. of the battery capacity per day.

Trickle Charging.—The type of plate dictates to a certain degree the mode of keeping them in condition. A stationary battery is usually fitted with formed (Planté) type positive plates, whereas the automobile battery has pasted plates. Trickle charging can be used indefinitely with Planté positives. With pasted plates, as used in starter batteries, prolonged trickle charging is not recommended.

A satisfactory rate of trickle charge for batteries up to 100 ampere-hour capacity is 1 milliampere per ampere-hour at the 10-hour rate.

Removal from Service.—When car batteries (pasted plates) have to stand idle, it is better to charge them periodically about every month or two months (depending on the condition indicated by the hydrometer), without giving any cycles of charge and discharge or any trickle charging. Trickle charging a starter battery should not be extended over several months, even at very low rates.

If the cells are to be definitely taken out of service, drying off the plates is only worth while if the battery is comparatively new and of an expensive type. For drying out, some makers recommend charging the battery, withdrawing the plates and separators, swilling with water and drying the positive plates ; swilling the negative plates, soaking in pure water for forty-eight hours and then drying.

Other makers advocate discharging to zero, filling up with water and short-circuiting the terminals for forty-eight hours and then drying out. When recommissioning, treat as a new battery, allowing acid to soak for twelve hours before charging. Continue charging until density remains constant for twelve hours.

Before removal from service, it is well to reduce any sulphation in the way indicated on page 22.

Adjustment of Charging Current.—The adjustment of the charging current must necessarily be done automatically to a large extent. A discharged battery can safely absorb a current much larger than the normal charging rate ; a charged battery should be given no more than a trickle current. In Chapter IV it will be shown that a voltage regulator can satisfy these conditions, and also limit the current given to a flat battery to the value permitted by the dynamo rating. The three-brush dynamo does not regulate the charging current to the required value, and the driver is given two or three charging rates which he must adjust to suit requirements, if the best result is to be obtained.

Clearly the cut-in speed must be low enough to keep the battery charged under all conditions, such as traffic work, frequent stops and night driving.

If a healthy battery needs continual topping up, or if electrolyte density is always high, persistent overcharging is indicated. On the other hand, if a healthy battery is continually run down, or if the electrolyte density is always low, insufficient charging is indicated. This may need adjustment of the third brush or regulator, which, in turn, may overload the dynamo. (*See* Chapter IV.)

Tests for State of Battery Charge.—(1) A rough test on the state of charge of the battery is to switch on all the lamps. Bright, white filaments denote a fully charged, reddish filaments denote a nearly discharged, battery. A rapid falling off in light denotes an exhausted battery, or possibly a wiring fault.

(2) The hydrometer gives a much more reliable indication of the state of charge of an acid cell. For accurate results, temperature must be corrected for, as shown on page 30. A density of 1·15 denotes that the cell is fully discharged, while 1·25 to 1·28—according to the maker's specification—denotes that the cell is fully charged. Half discharged will then be about 1·20 to 1·22, and similarly other states of charge by proportional differences.

(3) A more severe test is to use an instrument consisting of a short length of resistance metal and a voltmeter. The two ends of the resistance metal are placed

across the cell terminals (*not* battery terminals), and the reading on the voltmeter noted. The resistance is so designed that the voltmeter reads approximately 1 volt (depending on the battery capacity) when the cell is fully charged. This test is pretty severe, and the current should not be allowed to flow longer than is necessary for the reading to be taken.

An alternative to this test is to connect the terminals of a 12-volt battery across a resistance of 0·07 ohm. If properly charged, the terminal voltage does not fall below 10 volts, and all cells show the same voltage drop. The voltage drop is smaller in large batteries than in small batteries, owing to the difference in internal resistance. Failure to pass test (3) indicates either a discharged or a faulty cell.

The Hydrometer.—During charge the density of the electrolyte gradually rises. When the cell is fully charged, this reaches about 1·25 to 1·28, depending on original conditions. In stationary batteries, the density, when charged, seldom exceeds 1·2. By using such strong acid in car batteries greater capacity for a given weight is obtained, though at the expense of shortening the life of the cell. On discharge, the density falls, reaching about 1·15 when fully discharged. A density of 1·2 would indicate a battery about half-charged. Consequently the density or specific gravity of the electrolyte is a measure of the state of charge of the acid cell, and is a more reliable guide than the voltmeter, because of possible sulphation.

Every one concerned with batteries, therefore, should accustom himself to test his cells from time to time by measuring the density of the electrolyte by the aid of a hydrometer.

How to Use a Hydrometer.—A form of hydrometer commonly used for testing car batteries consists of a glass or celluloid tube containing a graduated float, as shown in Fig. 12. At one end of the tube is a rubber bulb, and at the other end is a rubber extension for inserting into the cell. Before removing the stopper from each of the cells, it is as well to remove any moisture or dirt, on or near the battery. In using the hydrometer it is also well for the observer to place himself as advantageously as circumstances permit, to enable him to get reliable readings. Insert the rubber extension below the level of the electrolyte and draw in enough electrolyte to raise the float ; then read the level of the liquid at the base of the meniscus (*see* Fig. 12). Repeat the test and compare the second reading with the first. In case of disagreement repeat tests until agreement is obtained. This test is not difficult to carry out, but patience and care are needed to do it properly. It is well, when reading, not to withdraw the hydrometer right out of the cell. Be careful to return electrolyte to its own cell.

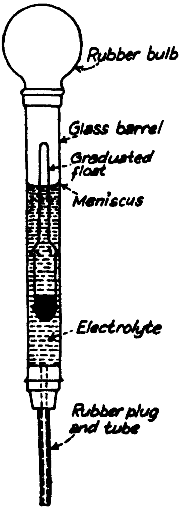


FIG. 12. Car-battery hydrometer.

There are a few further precautions to be borne in mind. Be sure that the float does not stick to the walls of the tube. After "topping-up," do not take the density until the cells have been charged, for only then is the electrolyte thoroughly mixed. Do not hold a naked light near the battery for fear of an explosion due to the release of oxygen and hydrogen by electrolysis. Do not let any of the electrolyte come near clothes or any metal-work.

Other devices, such as floating balls, are also used for measuring density—these must be used with the instructions supplied.

A hydrometer which has been used for lead acid batteries *must not* be used with alkaline batteries.

Effect of Temperature on Density of Electrolyte.—Density is effected by temperature. The hydrometer readings are to be taken as correct at a temperature of 15° C. (60° F.). Below this temperature the hydrometer reads too high, and above it too low. To correct for this, subtract 0·0007 from reading for every 1° C. below 15° C., or add 0·0007 to reading for every 1° C. above 15° C.; alternatively, subtract 0·0004 for every 1° F. below 60° F. or add 0·0004 for every 1° above 60° F.

Example—

Hydrometer reading at −5° C. =1·260
Correction (15+5) 0·0007 =0·014

True density =1·246

It should be noted that in some hydrometer scales the decimal point is omitted: thus 1·2 appears as 1,200, and the above corrections 0·0007 and 0·0004 become 0·7 and 0·4 respectively.

Example—

Hydrometer reading at 85° F. =1,250
Correction (85−60) 0·4 = 10

True density =1,260

Corrosion.—Corrosion is caused by the deposition of lead sulphate on the battery terminals, holding bolts, etc. In time, such corrosion may eat away the metal.

It has been noticed that, when the negative pole is earthed, corrosion readily forms at the positive terminals when they are damp with electrolyte and the lead coating is damaged. Continued corrosion disintegrates the terminals, which may ultimately fall to pieces—intermediate stages being pitting and high resistance. Corrosion may be largely prevented by keeping the top of the battery dry. With the positive terminal earthed, the fixing bolt nearest the negative terminal may corrode, if damp with acid. At the terminals, contact resistance is increased by corrosion leading to arcing and pitting. Corrosion effects are cumulative and may ultimately suffice to break the circuit. (*See* example on page 63.) To prevent corrosion of brass or copper terminals, smear these with vaseline or thick oil, but do not allow this to run on to the compound. Corroded surfaces should be wiped with a cloth soaked in soda or ammonia. Lead or lead-coated terminals, which are now widely used, do not corrode so readily, but they should be kept smeared with vaseline.

Maintenance Rules and Precautions.—To sum up, keep the battery well charged. Ensure that the charging current is adjusted to meet the demands made on the battery. Do not overcharge persistently. Keep the electrolyte topped up. Keep the outside of the battery clean, particularly remove any dirt, water, oil, or petrol from the cover. Keep connexions clean and tight. (A loose connexion may not only prevent starting, but it may cause an arc which will explode the gas. With the three-brush dynamo, the increased resistance due to a loose connexion raises the voltage of the system, and so may destroy lamps or field winding.) Do not hold a naked light near the battery, as it may cause an explosion. Do not let any of the electrolyte come near clothes or metal-work. Wash the hands after attending to battery. Follow the maker's instructions.

A battery needs more attention—density testing, topping up, terminal cleaning and tightening—with third-brush than with voltage-regulator control.

Care should be taken not to abuse a battery by repeated attempts to start when something is out of order, e.g., incorrect carburation, fault in ignition circuit, etc. For "Battery Faults," *see* page 280.

THE ALKALINE CELL

The development of the alkaline cell is the result of attempts to find a storage cell with all the advantages and none of the disadvantages of the acid cell.

The difficulties presented by the alkali cell were price, weight and high internal resistance—the two former made it hard to compete against the acid cell, while the last was inimical to starting and to the life of lamps.

Construction and Active Materials.—Two well-known types of the alkaline cell are the nickel-iron and the nickel-cadmium cell. In both types the active material on the positive plate is nickel peroxide, and the electrolyte is a solution of potassium hydrate (caustic potash) in water. The normal density of the electrolyte is 1·17 to 1·19 according to maker's specification. The density remains constant during charge and discharge. The types differ in the active materials on the negative plates, iron being the active material in the nickel-iron cell and cadmium in the nickel-cadmium cell. Iron is added in the latter to prevent flaking and it assists in forming a good electrode.

The active materials of the plates are held in steel tubes perforated with innumerable minute holes over the whole surface, the tubes being assembled in steel retaining plates to form complete positive and negative plates. The steel plates do not buckle, and since vibration does not dislodge active material there is no sludge. The plates of the alkali cell are housed in a metal container, so that both poles of each cell and the cells themselves must be separately insulated. The robust construction of these cells is a great advantage, leading to durability.

Action.—On discharging a nickel-iron cell, nickel peroxide on the positive plate is reduced to nickel oxide, while the iron on the negative plate becomes iron oxide. On charge, the nickel oxide is converted into nickel peroxide and the iron oxide or iron, oxygen being liberated at the positive plate and hydrogen at the negative plate. Gassing is continuous during charge, and to compensate for loss, the cells must be frequently topped up with distilled water. The electrolyte acts mainly as a conductor. It must be kept from exposure to the air to prevent deterioration due to carbon dioxide.

Internal Resistance.—With the normal construction this is appreciably higher than in the acid type and leads to the large difference between the minimum discharge voltage and the maximum charge voltage. The high resistance renders the alkaline cell less suitable for starting where heavy currents are needed, though it protects the battery in case of accidental short-circuit or earth. Wide voltage variation has also injurious effects on the life of the lamps. To reduce these drawbacks, the development of the alkaline cell for automobiles has been directed towards lowering the internal resistance. In this respect the nickel-cadmium cell appears to have advantages, and it is claimed that both the weight and internal resistance of this cell have been reduced to make it suitable for automobile work. The alkaline cell is not sensitive to the value of charging and discharging current, and it does not suffer harm from overcharge and over-discharge. Consequently a lower maximum charging voltage can be used without detriment to the battery, thereby reducing the risk of burning out the lamps and, at the same time, giving higher watt-hour and ampere-hour efficiencies.

As a further means of reducing the internal resistance of the alkaline cell, thin plates (as in the acid cell) and narrow pockets give a greater plate area for a given amount of active material, while thin separators reduce the electrolyte resistance. In this way it is possible to obtain a 12-volt nickel-cadmium battery with nine cells, though the normal number of ten cells might be preferred for use with a heavy-oil engine starter.

Charging.—In the nickel-iron cell, where iron oxide is reduced to iron, the charging voltage rises from 1·55 to 1·8 volts. In the nickel-cadmium cell, where cadmium oxide is reduced to cadmium, the charging voltage rises from 1·35 to 1·5 volts.

The open-circuit voltage in each type is 1·25 to 1·4 volts, depending on the state of charge (*see* Fig. 10).

If time is insufficient to charge battery fully on vehicle, the battery must be given a bench charge for six hours at normal rate, or for twelve hours if completely exhausted. The alkaline battery benefits from occasional overcharging, e.g., one hour at the two-hour rate, or ten hours at the five-hour rate. When charging, the temperature must not be allowed to exceed 43° C. (110° F.), for above this temperature the active materials become adversely affected.

Discharging.—This is best done at normal rate of discharge. Repeated over-discharging is injurious. Normally an alkaline battery is discharged when the voltage is down to 1·1 volts per cell at normal discharge rate. It is inadvisable to go below this value. The battery is liable to damage if regularly and completely exhausted.

Effect of Discharge Rate on Voltage and Capacity.—From Fig. 10 it is seen that at the normal discharge rate the voltage of the alkaline cell remains fairly steady at 1·2 volts. At high rates of discharge, it is claimed that the voltage of a low-resistance nickel-cadmium cell falls off less rapidly than that of an acid cell.

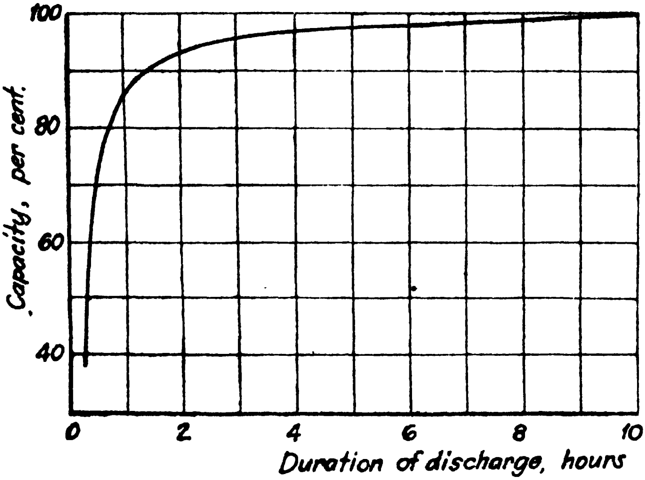


FIG. 13.—Effect of discharge rate on capacity of alkaline (nickel-cadmium) cell, as percentage of 10-hour capacity.

Fig. 13 shows the effect of discharge rate on capacity in ampere-hours of the nickel-cadmium cell (the graph for the acid-cell is shown in Fig. 11). It is seen that the capacity of the alkaline cell is almost independent of the rate of discharge. This is attributed to the fact that the electrolyte takes no part in the chemical action. In the acid cell on the contrary, under heavy discharge the sulphuric acid does not diffuse quickly enough, causing the cell voltage to fall rapidly before the full rated capacity is taken out. It is claimed that the operating results of a low-resistance, nickel-cadmium cell are equal to those of a lead cell.

Effect of Temperature on Voltage and Capacity.—Temperature affects alkaline cells as it affects acid cells. Between 15° C. (60° F.) and 50° C. (122° F.) capacity and voltage increase. At temperatures below normal, both capacity and voltage of the alkaline cell fall.

Tests for State of Battery Charge.—Neither hydrometer nor voltmeter is a criterion of the state of charge of an alkaline cell. An approximate idea can be obtained by noting the battery voltage at a given charge or discharge current.

The only sure guide is an ampere-hour meter, if corrected for the variation of ampere-hour charging efficiency, which varies from about 93 per cent. to 50 per cent. between the voltages per cell of 1·3 to 1·5 and 1·5 to 1·67 respectively, at the 10-hour rate of charge.

First Charge.—Before putting an alkaline battery into service, the first charge must be at normal current but for twice the normal time. This is necessary to ensure that the battery receives the proper number of ampere-hours. The requisite charging voltage per cell must be gradually increased from 1·4 volts at commencement to keep the current constant at its normal value.

Topping up.—Distilled water only is to be used for topping up. The electrolyte level should be from

½ inch to 1½ inches above the tops of the plates, depending on the type of cell and the clearance provided.

Electrolyte Renewal.—In regular use the solution becomes gradually weaker, and after about two years' constant service the density will fall by about 0·01, e.g., from 1·17 to 1·16. Such a fall makes the battery sluggish and the electrolyte should then be completely renewed. To do this the battery must be completely discharged and thoroughly washed out with water. After draining for about half-an-hour, the cells must be filled up with new electrolyte of density 1·19 and recharged. The battery is then ready for service.

A hydrometer which has been used for lead acid batteries *must not* be used for alkaline cells.

Maintenance Rules and Precautions.—Owing to danger of explosion, the cells must not be examined with a naked light.

The tops of the cells and terminals are to be kept smeared with petroleum jelly (vaseline).

Electrolyte Burns.—Care should be taken to prevent the electrolyte coming into contact with the hands or clothing. Skin burns from the electrolyte should be treated with a weak boracic-acid solution ; or apply a 10 per cent. solution of citric acid in distilled water. For the eye, a 1 per cent. solution of citric acid and then Home Office eye-drops (castor-oil and cocaine) for soothing and healing is recommended.

It is advisable to dip the fingers in citric acid solution after handling electrolyte.

Loose Metal.—Tools or other metal should never be left on the top of cells, and no metal should be allowed to fall between the cell cases, as these are live and contact between them will cause short-circuits which may do considerable damage.

Injurious Effect of Atmosphere.—Alkaline cells must not be left open to the atmosphere, and so when electrolyte is being renewed it should be done as quickly as possible. Never leave the filler caps open.

Removal from Service.—Before storage, the alkaline battery should be fully charged and then half discharged. The electrolyte should be kept at the correct level, and a first charge applied before the battery is brought back into service.

Use of Alkaline Batteries on Commercial Vehicles.—On a commercial vehicle, especially for passenger carrying, reliability has a high value. Against the extra cost of the alkaline battery for the same ampere-hour capacity, there are great advantages; low upkeep, long life, ability to withstand shock and vibration, absence of self-discharge, insensitiveness to rate of charge and discharge, immunity from injury when short-circuited or when overcharged.

It is safe and common to reduce the charging current to zero before full charge (maximum voltage) is reached in order to reduce loss of electrolyte by gassing and the danger to lamps by over-running. This is done by setting the regulator to give a very small current at maximum voltage. With the low-resistance type, it is possible to use nine cells for a 12-volt battery (instead of 10, as previously), thereby keeping the maximum voltage down to 15 volts—the same value as in an acid battery. Such a nine-cell alkali battery can be used to replace a six-cell acid battery for starting and lighting, using the same charging generator and voltage regulator.

For average conditions it is customary to use five cells for six-volt systems, nine cells for 12-volt and eighteen cells for 24-volt systems.

For starting heavy-oil engines—and it is here where the alkali battery is widely used—it may be necessary to crank the engine for over two minutes at a speed of 200–300 r.p.m. For such starters, 24-volt batteries are commonly employed. Where these consist of eighteen low-resistance, nickel-cadmium cells it is claimed that the weight is not so very different from that of acid batteries of the same capacity.

CHAPTER II

ELECTROMAGNETS AND ELECTRICAL MACHINES

In this chapter an elementary account is given of the principles of the electromagnet (or solenoid) and the electromagnetic machine. The electromagnet in one form or another finds application in the self-starter switch with remote control, dipping reflector, electric horn, direction indicator, electric fuel-pump, cut-out, automatic voltage regulator, and elsewhere where a relay is employed. Instances of electromagnetic machines on the motor vehicle include the starting motor, charging generator (or lighting dynamo), magneto, and windscreen-wiper motor.

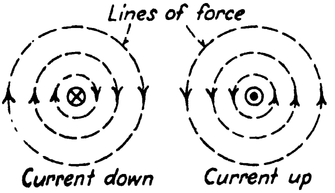


FIG. 14.—Magnetic field due to current in straight conductor.

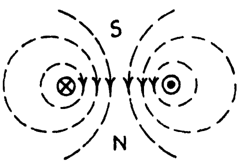
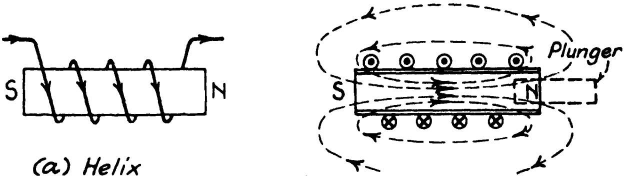


FIG. 15.—Magnetic field due to current in looped conductor.

Electromagnetism.—A magnetic field is produced when an electric current flows in a wire. By convention, such a magnetic field is represented by lines of force. The number of lines per unit area is called the density of the magnetic field. In the case of a straight current-carrying conductor the magnetic lines of force are concentric circles about the wire. The direction of these lines of force relative to that of the current is shown in Fig. 14. The magnetic field produced by a current flowing through a loop of wire is indicated in Fig. 15. The shape of this field is explained by the fact that lines of force tend to shorten in length and repel one another sideways ; also, where the lines of force emerge from the loop a N-pole is produced, where they enter, a S-pole is produced. The following cases show other examples of magnetic fields.

Electromagnet. Solenoid.—A current flowing in a coil of wire wound in the form of a helix is called a solenoid (Fig. 16 (*a*)). If the length of the helix is great compared with its diameter, the magnetic field along the axis is uniform. If an iron core is placed inside the solenoid, the magnetic effect is greatly increased. Alternatively, if an iron core, or plunger, be placed at one end of the solenoid (Fig. 16 (*b*)), it would be attracted ; and, if free to move, the plunger would be drawn with increasing force into the solenoid. The magnetic circuit is then completed partly through the iron and partly through the air.



(a) Helix carrying current

(b) Magnetic field of solenoid

FIG. 16.

More powerful electromagnets are obtained when the magnetic circuit is nearly all iron. Fig. 17 shows different methods of winding electromagnets. For such magnets soft-iron is mostly used both for the core and the armature, so that the magnetism vanishes when the current is interrupted. This is the opposite from the permanent magnet used in the magneto, where magnet steels are employed which retain their magnetism (*see* p. 246). In order that the armature of the electromagnet shall be released when the current is switched off, the armature is not allowed to come into actual contact with the core. For this purpose a short brass pin or some other means is adopted to provide a small air-gap between armature and core when the magnet is excited. The winding of the electromagnet or solenoid is called the magnetizing, or exciting, winding.

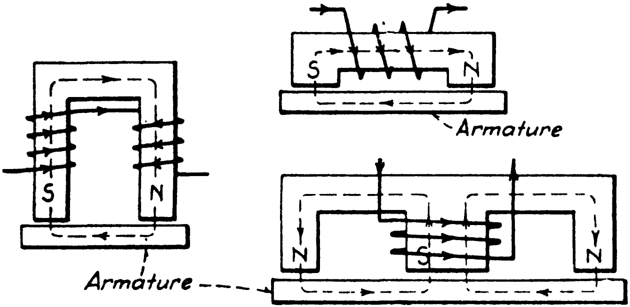


FIG. 17.—Types of electromagnets.

The Fundamental Principles of Electrical Machines.—Two principles underlie the action of the electric generator and the electric motor :—

(1) A coil carrying an electric current and lying in a magnetic field is acted upon by a mechanical force.

(2) If there is relative movement between a coil and a magnetic field, an electromotive force (e.m.f. or voltage) is induced in the coil.

These principles are illustrated in Fig. 18, where a coil, capable of revolving about *O*, is represented as it exists in an actual machine. There are two ways in which both these fundamental principles may become apparent to us: (1) in the electric motor; (2) in the electric generator.

(1) **The Electric Motor.**—When the force, due to the interaction between the magnetic field and the coil carrying the current, causes the coil to move in the direction of the arrows marked "force," mechanical work is done and at the same time the electromotive force induced by the motion of the coil opposes the current. In order to maintain the current, therefore, an external source of electric energy is needed, such as a battery or supply mains. If the coil is of negligible resistance, the product of the current and the applied voltage required to overcome the induced electromotive force represents the electric power supplied to the coil; while the product of the force and the velocity of the coil represents the mechanical power supplied by the coil. The name given to a machine which converts electrical energy into mechanical energy is "an electric motor." Here then is the principle of the starting motor.

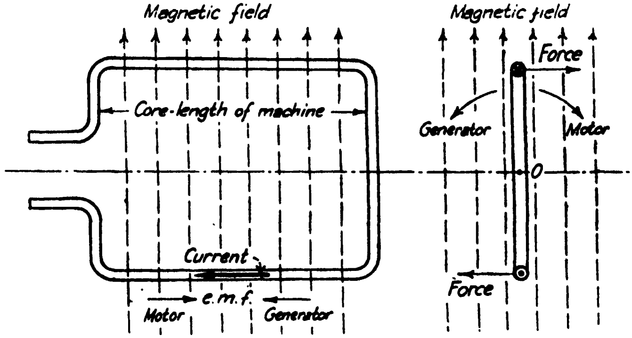


FIG. 18.—Action of the electric motor and the electric generator.

Change of Direction of Rotation.—An inspection of Fig. 18 will indicate that if it be desired to alter the direction of rotation of a motor, the direction of the mechanical force produced must be changed. This can be done by reversing the direction of *either* the magnetic field *or* the armature current, but not both. Thus, either the field or the armature terminals can be interchanged.

(2) **The Electric Generator.**—If, instead of allowing the force due to the interaction between the magnetic field and current to move the coil, we couple up or belt the coil to an engine and drive it against the force, mechanical work is supplied to the coil. Now reversing the direction of rotation of the coil also reverses the direction of the electromotive force induced by the relative motion between the coil and the field. In this case the induced electromotive force produces the current. Here then is a machine in which the mechanical power of the engine is converted into electrical power, represented by the product of the induced voltage and the current it causes to flow in a circuit placed across the terminals. Such a machine is called an "electric generator (or dynamo)." This is the principle of the car dynamo (or charging or lighting generator), and it is also embodied in the magneto.

In principle there is no difference between the electric motor and the electric generator; they are interchangeable—the action is reversible. If the working conditions are such that the induced e.m.f. opposes the current, the machine is an electric motor; if the induced e.m.f. produces the current, the machine is an electric generator. Perhaps the reader has already thought of the "dynamotor" in this connexion.

The magnitude of the mechanical force due to the interaction between the magnetic field and the current is proportional to the product of the current, the density of the magnetic field, the number of conductors in which the current flows, and the length of the conductors lying in the field (or the "core-length").

The value of the induced electromotive force is proportional to the rate of change of the magnetic lines linking the coil (or coils). In other words, the induced electromotive force depends on the product of the speed of rotation and the number of magnetic lines linking the coil (or coils).

CHAPTER III

THE STARTING MOTOR AND THE DYNAMOTOR

The Starting Motor

Starting an Internal-Combustion Engine.—The internal-combustion engine, unlike the steam engine, develops no inherent torque when at rest. Consequently some auxiliary device must be employed to start the engine and to bring it to such a speed that it continues to run under its own driving torque. The requisite starting torque varies not only in different engines, but in the same engine, according to conditions. In a petrol engine, the firing speed is determined by the speed at which an explosive mixture can be drawn into the cylinder from the carburettor, unless with magneto ignition a higher speed is needed to produce a spark. A British petrol engine in good order should start and run at a speed of 60–80 revolutions per minute at a temperature of about 0° C. (32° F.)—at this temperature an American engine will generally start at about half this speed. (*See* p. 54.) A compression-ignition engine may have to be driven at a cranking speed of 100–200 revolutions per minute, depending partly on the auxiliary devices used. According to conditions, a petrol engine may take 1 to 10 seconds before it fires; or longer if the hand-primer is not used when the engine is cold; heavy-oil engines may have to be cranked for as long as two minutes before they get away.

At the present day almost every automobile is fitted with a starting device or self-starter. The main use of the starting handle is for cranking the engine when setting the tappets.

Many types of starting mechanism have been tried and discarded. Among the survivals are the inertia-engaged drive (*see* p. 65), and the axial or sliding-armature drive (*see* p. 70). The former is used very widely with petrol engines. The sliding-armature type of starter is used on compression-ignition engines.

Torque.—The term "torque" is used to denote the turning moment or effort of the motor or engine, as the case may be. It is the product of the applied force and the radius at which it is acting. Thus if a force of 20 lb. is applied at the grip of a starting handle which has a throw of 9 inches from the crankshaft, the torque applied is 20 lb. × 0·75 ft. = 15 lb.-ft.

(*a*) *Engine Torque.*—In starting, there are different torques to consider. The torque which has to be applied before an engine at rest will turn is called the *breakaway* torque; the torque of a turning engine which opposes motion is called the *resisting* torque. In a petrol engine, the breakaway is about double the resisting torque when the engine is just turning, because of the imperfect lubrication owing to the lack of oil at pressure points. If allowed to stop for about two minutes, the original value of the breakaway torque is needed to move the engine again.

(*b*) *Motor Torque.*—The corresponding torques of the starting motor are the *locked* torque developed by the motor at the instant of closing the switch with the armature locked (i.e., before it has started to rotate); and the *driving* torque which the motor exerts when running in mesh with the flywheel. If the pinion be slid into mesh before the starting circuit is closed and there is no spring cushioning, then, unless the locked torque of the starter exceeds the breakaway torque of the engine, no motion results ; with the more usual inertia-engaged pinion, the armature acquires considerable momentum before the pinion meets the flywheel, and in consequence is able to overcome a breakaway engine torque much in excess of the locked starting-motor torque.

(*c*) *Cranking Speed.*—As long as the driving torque exceeds the resisting torque, the engine will accelerate. As the speed of the engine rises its resisting torque increases, while the driving torque of the motor decreases ; so that eventually a speed is reached at which resisting and driving torques are equal, and there is no available torque to accelerate the engine further. The speed thus attained with the ignition switch off is steady except for the variations due to overcoming the compression in the cylinders. This is called the *cranking* speed.

Similarly, when the engine is running and the accelerator pedal is depressed to increase the speed of an automobile, acceleration occurs until the resisting force offered by the road, the wind, the gradient and the mechanism combined equals the driving force exerted by the engine. When this happens a steady speed is reached. Conversely, when the resisting torque is greater than the driving torque, the speed falls until these again become equal. The reader should clearly understand the mechanics of motion : acceleration, retardation, centrifugal force, and braking are important factors in motor-vehicle working.

STARTING PETROL ENGINES

Conditions under which a Petrol Engine will Start.—In order that a petrol engine will start and run under its own power, it is essential that, (*a*) the starting torque of the motor exceeds the breakaway torque of the engine; (*b*) the carburettor supplies a readily-ignitable mixture to the cylinders; (*c*) the ignition device produces a correctly-timed spark; (*d*) the driving torque produced by the engine after firing exceeds the resisting torque of the engine.

If (*a*) is satisfied, conditions (*b*) and (*c*) together are necessary to produce firing. If (*a*), (*b*) and (*c*) are all satisfied, (*d*) is necessary to ensure that the engine will continue to run after the starter is disengaged.

Condition (*a*) will usually be satisfied if the starting equipment is in order. Condition (*b*) depends on the design of the engine and its accessories for producing efficient carburation. With given engine, temperature and grade of fuel, a particular speed must be reached to produce a mixture rich enough to fire. When the engine is cold, the fuel does not vaporize readily, and much of it is deposited on cold surfaces (including manifold and sparking-plug points) in liquid form. To make up this loss, the mixture, as it emerges from the carburettor, has to be much richer in petrol than when the engine is warm. Condition (*c*) is satisfied at the lowest speeds with coil ignition, but magneto ignition may require a speed as high as 60 to 80 r.p.m.

In a cold engine, with magneto ignition, the speed requisite for sparking is usually sufficient to produce a readily-ignitable mixture. With coil ignition a spark is produced at a speed lower than that at which a satisfactory explosive mixture can be formed and the starter must ensure that the latter condition is reached. If condition (*d*) is not satisfied, the engine, though firing, will not get away under it own power, but it will be stalled by overloading. In such case, the starter must come to the aid of the engine and assist in turning it until the resisting torque, due mainly to oil viscosity, falls sufficiently to enable the engine to run under its own power. The reduction in the resisting torque due to oil viscosity is in consequence of the rise in temperature from the work done on the oil in the bearings and the warming of the oil on the cylinder walls by the explosions. Dilution of the oil on the cylinder walls by incoming petrol also reduces the resisting torque. It may also be stated that if an over-heated engine is stopped, non-firing may result on attempting to restart while too hot, owing to faulty carburation.

Starting Conditions at Low Temperatures.—The self-starting equipment must be capable of starting the engine under the most adverse conditions. Such occur at low temperatures, and influence the following: carburation, ignition, resisting torque of engine, battery voltage (*see* also p. 20). Consider the case of a car with antifreeze solution in the radiator which has been standing out-of-doors in frosty weather long enough for the mechanism to attain the temperature of the air. The cylinders are then coated with cold oil at a temperature below freezing point, oil films are squeezed out at pressure points; while battery electrolyte, fuel, and sump oil are all thoroughly cold.

The breakaway torque of the engine has first to be overcome. At low temperatures, the torque needed to turn the engine at a steady low speed may be very high, and comparable to the breakaway torque. The resulting cranking speed will rise only as the resisting torque falls. Provided the starting equipment is in order, it is extremely unlikely that the engine will refuse to turn, for the motor can almost invariably overcome the breakaway torque. Whether the engine will fire depends on the cranking speed (determined by the driving torque of the starting motor and the resisting torque of the engine) and on the volatility of the fuel, i.e., on satisfactory carburation and sparking. Whether running will succeed firing depends on the capability of the engine to develop sufficient power to overcome its own resistance.

If the engine will start satisfactorily at low temperatures, no difficulty will be met at higher temperatures.

Resisting Torque of Engine.—The resisting torque depends on the size of the engine, the speed at which it is turned, the temperature, the grade of lubricating oil, the nature of the frictional surfaces, the clearance between working parts (tightness of engine), and only to a minor extent on the compression-ratio.

(*a*) *Influence of Oil.*—In any one engine the variant is the oil, and this can make all the difference between the starter producing a laboured turn-over of the engine with no firing at all and a rapid getaway in two or three seconds.

The effect of temperature on oil is particularly important, because in the region of the freezing point of water engine oils become rapidly thicker. The ability of oil to oppose motion depends on its viscosity. As the temperature is lowered the viscosity is increased, and at −5° C. (23° F.) oil may be 300 times as viscous as at 80° C. (176° F.).

Fig. 19 shows the resisting torques at −1° C. (30° F.) as a function of speed for a low-power automobile engine when four different grades of oil *A* to *D* are used. The dotted curve *E* denotes the driving torque-speed curve of the starting motor with a gear-ratio between starter and engine of 10 : 1. The cranking speed—the speed at which the starting-motor driving torque and the engine resisting torque are equal—

is shown by the intersection of the resisting torque curves *A*, *B*, *C* and *D* with the driving-torque curve *E*. It is seen that the speed attained with light winter oil (curve *C*) is 73 r.p.m., whereas with summer oil (curve *B*) it is only 30 r.p.m. The former speed is ample for firing—the latter much too low.

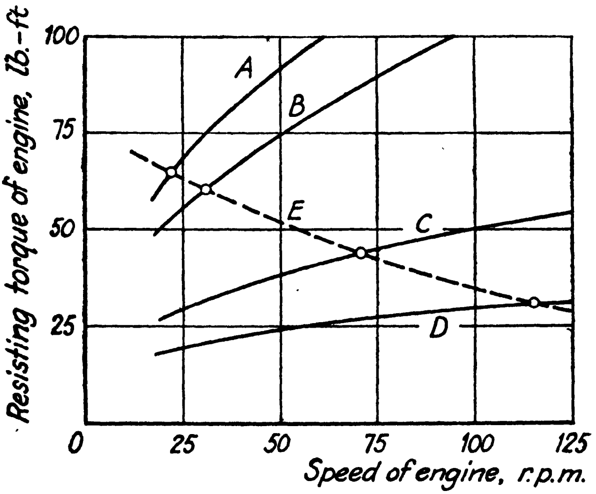


Fig. 19.—Resisting-torque curves of a low-power British petrol engine with various oils at – 1° C. (30° F.).
A—Racing Oil.
B—English summer oil.
C—English winter oil.
D—American winter oil.
E—Starting-motor speed-torque curve with 10 :1 gear ratio.

It has been found that the resisting torque of a petrol engine varies as the square root of the product of the speed and the viscosity of the oil ; that is to say, the required cranking speed and the oil viscosity equally influence the torque required from the starter. (The resisting torque-speed curve of an oil engine that is being cranked is much flatter than the curves in Fig 19.) The remaining factor affecting the resisting torque depends on the total sliding surfaces—virtually the swept cylinder wall area. If this constant be determined for a particular engine, the resisting torque can be calculated when using any oil the viscosity-temperature characteristic of which is known.

It is therefore a desirable practice to use a winter grade of oil during the cold months of the year. In addition, the more fluid the oil, the more rapid its delivery from the pump to the bearings and cylinder walls, resulting in less wear when many starts are made from cold.

In some instances the gear-box oil may also load the engine when cranking. To determine this point, it is only necessary to depress the clutch : if there has been an appreciable load, the gain in cranking speed will be audible to the driver.

(*b*) *Firing Speed.*—The firing speed of a petrol engine is the lowest speed at which an explosive mixture is fired by a spark. It is determined either by the speed at which efficient carburation—i.e., the supply of an ignitable mixture to the cylinders—occurs (as with coil ignition), or by the speed at which the ignition device produces sparks (as with magneto ignition). Many high-efficiency British engines do not produce a readily-ignitable mixture in the cylinders much below 60 r.p.m., owing largely to mixture weakening caused by petrol condensation in a cold manifold.

(*c*) *Get-away Speed.*—This is the minimum speed at which the engine will run under its own power. A starter may turn an engine fast enough for firing, but excessive engine resistance arising from high oil viscosity may prevent the engine from running under its own driving torque. In such cases, the driver may find it necessary to keep the starter in action ; that is, to run the starter and engine together, to allow the explosions to warm up the oil on the cylinder walls until the viscosity is low enough to permit the engine to work under its own power. During the transition period from excess engine resistance to excess engine torque the starter pinion may be ejected before the engine is capable of continuing to run. Where this is troublesome, a starter may be fitted in which the pinion is forcibly held in mesh until withdrawn by the driver.

(*d*) *Comparison between American and British Engines respecting Starting.*—It has often been observed that American engines imported into this country fire at a lower speed and need less driving torque at starting than British engines of similar capacity. In this connexion the following facts should be noted. The British engine has hitherto been designed to start under the comparatively moderate temperatures experienced in a British winter—say at about 0° C. (32° F.) ; while the lower winter temperature reached in the U.S.A. requires an engine to start at −18° C. (0° F.). To meet this severe condition the American designer may reduce the resisting torque of the engine by using an oil of a low viscosity and by reducing the sliding surfaces by employing a large cylinder bore for a given capacity. In this way the driving torque required from the starting motor is lowered. Further, by using small cross-sectional area of inlet manifold and small valve opening, high mixing speed and good carburation result. In this way the required speed of the starting motor is kept low at the expense of fuel, but petrol is cheap in America.

Even so, to get away it is often necessary to keep the starter in circuit after firing begins. For this reason, a pedal which holds the pinion in mesh is often fitted.

Obviously an engine designed to start at −18° C. (0° F.) readily produces a firing mixture at 0° C. (32° F.), the temperature at which British engines are designed to start, and explains why an American engine in Great Britain may easily start at 20 r.p.m. after one or two seconds. To obtain true comparison between the starting properties, each engine must be started under the conditions for which it is designed.

By obtaining a sufficiently rich starting mixture (as is given by most modern carburettors), and by using oils of low viscosity at low temperatures, the difference in ease of starting between English and American engines has been greatly reduced in recent years.

Requisite Starting Current.—Knowing the torque, the motor output in horse-power follows from the usual expression :—

$$\text{horse-power} = \frac{2\pi \times \text{r.p.m.} \times \text{torque}}{33{,}000}$$

Taking as an example a six-cylinder, 2·5 litre engine with an oil of fairly high viscosity, and a resisting torque of 75 lb.-ft. at 0° C. (32° F.) (or a cranking torque of 75/10=7·5 lb.-ft. with a gear ratio of starting motor of 10 : 1), the power required at the flywheel to crank the engine at 60 r.p.m. is :

$$\text{horse-power} = \frac{2\pi \times 60 \times 75}{33{,}000} = 0{\cdot}855 \text{ h.p.}$$

If the efficiency of the gearing be taken to be 85 per cent., the motor output =0·855/0·85=1·01 h.p.

To find the input to the motor, we can use the data in Fig. 24, whence the motor efficiency at 600 r.p.m is 0·3, so that :

$$\text{motor input} = \frac{1{\cdot}01}{0{\cdot}3} = 3{\cdot}4 \text{ h.p.}$$

$$= 3{\cdot}4 \times 746 = 2{,}500 \text{ watts}$$

$$= \text{battery output.}$$

The battery current needed to drive the engine at this speed is found by dividing by the battery voltage. From Fig. 24 this is 8·5 volts, then motor current at cranking speed=2,500/8·5=295 amperes.

The current on switching in is the ratio of the battery voltage to the circuit resistance, say 7·5 volts and 0·02 ohm respectively; whence starting current= 7·5/0·02=375 amperes.

Good Starting of Petrol Engines.—Ease of starting, especially from severe cold, is a desirable feature, and the intelligent driver can materially assist by ensuring that the engine and the electrical equipment are in good order.

(*a*) *Carburation.*—The carburettor must be correctly set to give the proper mixture. Starting or idling jets (where fitted) must be clean. There must be no air-leaks at the junction of the carburettor and manifold, or between manifold and engine. The worst condition clearly exists when the engine is cold, for a longer time is then required for the fuel to volatilize and for the correct mixture to fill the cylinders. In this connexion winter grades of fuel, i.e., grades with high volatility at low temperatures, are helpful during cold months. It is not generally realized that only about 10 per cent. is vaporized during cranking at freezing point. Pumping petrol by hand into the carburettor not only relieves the motor and battery by bringing the fuel nearer the place where it is required, but at the same time serves to confirm that the fuel system up to the carburettor is in order. Condensation in a cold engine may also be troublesome.

(*b*) *The Ignition System.*—Ignition conditions are also worse when the mixture in the cylinder is cold. The voltage needed to send a spark across the sparking-plug electrodes depends on the density of the gas, and at constant pressure the density of a gas varies inversely as the absolute temperature; also a higher sparking voltage is needed when the plug electrodes are cold than when hot. In consequence, when starting cold the requisite sparking voltage may be 10,000 volts or higher; whereas after running, i.e., when the engine is hot, a voltage of 4,000 may suffice. Thus, when starting cold the ignition system is called upon to produce a much higher voltage than later when the engine is running. It must, therefore, be in good order. The contact-breaker points should be clean and correctly set. The high-voltage cables between coil and distributer, and between distributer and plugs, should be in good condition and tightly held down in their sockets. The sparking plugs must be sound, clean internally and externally, and correctly set. The low-voltage terminals on the coil and distributer must be tight. The distributer should be examined occasionally, and dust likely to cause flash-over from one electrode to another should be wiped away.

(*c*) *The Engine.*—There must not be air-leaks at the inlet valves, nor troubles arising from pitted valves and seats, nor from wrongly adjusted tappets or other parts. The engine compression must not be faulty, due to slack piston rings or leaky valves. At the approach of winter, the oil should be changed to the recommended grade, otherwise the resisting torque of the engine may increase to such an extent that insufficient cranking speed is attained. Also the clutch should be depressed when cranking if the speed is increased thereby.

(*d*) *The Battery and Dynamo.*—If the dynamo has not been charging sufficiently to deal with the lighting and coil load, the battery may not be in a state to cope satisfactorily with an extremely cold engine, Care should, therefore, be taken to see that the dynamo is giving its correct output (brushes and commutator in good condition, driving belt—if fitted—not slipping). The battery must be kept topped up with distilled water. Assuming the battery to be in a healthy condition, its performance depends on its temperature and its state of charge. As the temperature falls, the resistance of the electrolyte rises ; further the resistance rises as the density falls, so that a discharged battery has a higher resistance than a charged battery. Other things being the same, then, the terminal voltage of a battery supplying a current will be lower on a cold than on a hot day, and will be lower when a battery is partly charged than when it is fully charged, owing to its higher internal resistance under these conditions. The effect of the state of charge is most pronounced when the discharge current is greatest, i.e., at the instant the starting switch is closed. In this case, at a temperature of 0° C. (32° F.), the voltage drop in a half-charged battery is about 50 per cent. of the open-circuit voltage, compared with 33 per cent. in a fully-charged battery. In a 12-volt system the terminal voltage in the former case is then 6 volts and in the latter 8 volts. A semi-discharged battery will crank the engine at a speed about 80 per cent. of that at which a fully-charged battery will crank it.

At the instant of closing the starting switch the battery is practically short-circuited, the current being equal to the terminal voltage of the battery divided by the resistance across its terminals (leads, motor, etc.). This is true whether the engine is cold or hot, but in the latter case the current falls and the voltage rises more rapidly because the engine speeds up more quickly. The starting current falls to about half the switching-in value as cranking speed is reached, and remains more or less constant until the engine fires. The demand on the battery at starting can be relieved by pumping petrol into the float chamber, by using an oil of low viscosity, and by disengaging the clutch.

Of the influences, then, which affect the battery adversely, the drop in terminal voltage caused by low temperature is unavoidable, while that caused by the discharged state of the battery is avoidable. A flat battery may or may not be able to move the engine ; but even if the short-circuit current is sufficient to turn the engine, the cranking speed may be too low for satisfactory carburation, or for sparking with magneto ignition. After a period of service, the wear and tear on a battery may render it incapable of starting the engine. This can be tested in a simple way by provisionally replacing the car battery by a fully-charged battery. If the engine now starts, the remedy is obvious. For effects of corrosion, *see* page 30.

STARTING COMPRESSION-IGNITION ENGINES

In the Diesel engine liquid fuel is injected into air which has been compressed to raise the temperature enough to cause spontaneous combustion. The fuel enters as a fine spray, and outside temperature has not the effect here as on carburation in the petrol engine. The cooling action of the cylinder walls of a cold engine has an adverse effect on starting, and in some cases this loss of heat is compensated by a heater plug. To obtain the high temperature needed to ignite the fuel, the compression-ratio is about 15 : 1, or three times that of a petrol engine. This high pressure demands a correspondingly high turning effort by the starting motor and large current from the battery. Of the other resisting forces at starting that due to compression is found to fall off as the cranking speed rises. Resisting factors which increase with the cranking speed include engine friction and fuel-pump friction; also friction due to oil viscosity. Measurements on various types of oil engines for commercial vehicles show that the resultant resisting torque is roughly constant over a wide range of cranking speeds—between temperatures as wide apart as −18° C. (0° F.) and 18° C. (64° F.).

The cranking torque of an oil engine of a given horse-power is higher than that of a petrol engine of the same power, but the resisting speed-torque of the former rises less rapidly. Although firing may occur as low as 40 to 75 revs. per minute, a high cranking speed is desired to avoid loss of the heat of compression. These call for a correspondingly large motor and battery. Unlike the petrol engine, the oil engine once started, needs no further warming-up period, even under coldest conditions.

Aids to Starting.—*Compression Release or Decompressor Control.*—An engine may be fitted with a decompressor shaft to open one set of valves. After sufficient speed has been reached, the decompressor control is released, and the energy of the flywheel is enough to carry the engine over its heavy compression and ensure starting. This device is less used than previously owing to improved starting equipment.

Heater Plugs.—To compensate for heat generated by compression and lost to the walls of the combustion chamber when the engine is cold, devices have been developed for warming the intake air or fuel. The commonest of these is the heater plug shown in Fig. 20, the function of which is to heat the air in the cylinders, the incoming air and the compression space. In appearance, the heater plug resembles the sparking plug, but the points are replaced by a heater coil which projects into the compression space. Originally, two-volt, single-pole plugs were used. These were joined in parallel and connected to one of the battery cells which supplied a current of 100 or more amperes. In later arrangements two-pole plugs were joined in series, which was less severe on the battery and all

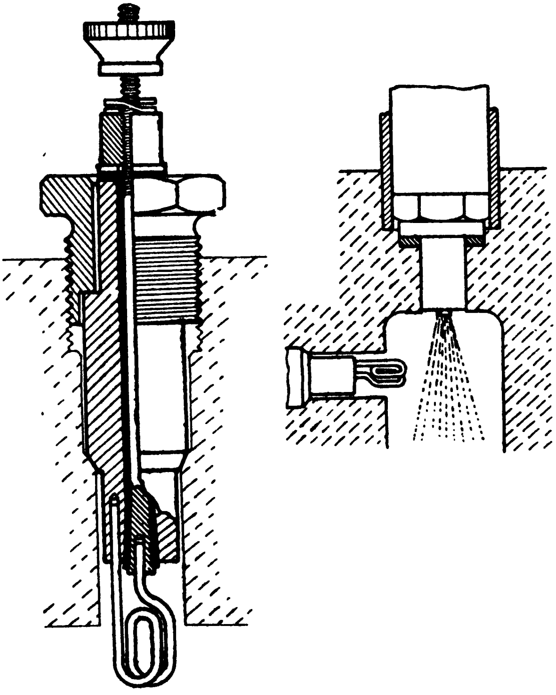


FIG. 20.—Single-pole heater plug.

cells were equally loaded. The plugs are switched on 30 to 60 seconds before the engine is started and are switched off as soon as the engine fires. Glowing plugs made starting much easier.

As starting conditions have become better understood, batteries and motors have been designed to meet requirements, consequently auxiliary aids are falling into disuse.

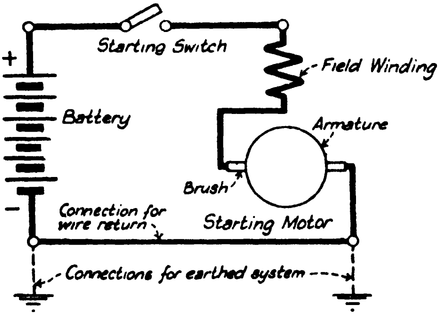


FIG. 21.—Connexion diagram for starting motor and battery. (Some manufacturers now earth the positive pole.)

STARTING CIRCUIT AND MOTOR.

The Starting Circuit.—The electric circuit of the stating system is controlled by a switch and is arranged to exclude the ammeter. The switch may be operated by hand, foot, or a relay. This switch has to carry a large current, and it should therefore be closed firmly, otherwise the contacts will soon become pitted and troublesome starting may easily result. The connexion diagram for the battery, the motor, the switch and the wiring is shown in Fig. 21.

Solenoid-operated starting switches are widely used. These are controlled by a small auxiliary switch on the dashboard, and enable the starting switch to be placed close to the motor, thereby reducing the length of starting cable and the consequent voltage drop. All connexions in the starter circuit must be sound. There must be neither loose connexions nor poor contacts at the battery terminals, at the switch, at or in the chassis, or between brushes and commutator.

The starter leads and switch may introduce a resistance of 0·003 to 0·01 ohm under normal conditions. Much higher values result from bad connexions—corrosion or pitting at the battery terminals may even interrupt the circuit.

Example: Suppose, owing to a poor contact, the resistance of the starter circuit were increased from 0·02 to 0·025 ohm, i.e., by 0·005 ohm. With a terminal voltage of 7 volts, the switching-in current would then drop from 350 to 280 amperes. Where the engine is mounted on rubber blocks, a flexible connexion of ample proportion between engine and chassis should be provided.

The Starting Motor.—This is commonly a 4-pole series motor with single-turn armature coils of copper strip pushed axially into tunnelled slots. A solenoid-operated switch is usually mounted on the starter to reduce the voltage drop in the cable carrying the starting current, the solenoid being actuated from a switch on the dashboard.

Commutator Brushes for Starting Motors.—Like the battery, the motor has been designed to withstand the severe conditions of intermittent starting, but not for continuous operation under these conditions. The commutator brushes form a good illustration. Normally current densities under the brushes do not exceed 50 to 100 amperes per square inch. Here values up to 2,000 are met with. In the ordinary case of a $\frac{5}{8} \times \frac{5}{16}$ inch commutator brush on a starting motor taking 200 to 300 amperes on switching in, the current density reaches 1,500 amperes per square inch. Such enormous values are only permissible instantaneously, and they decrease rapidly as the motor speed increases. For this purpose highly metallic brushes with graphite are employed, arranged to give a contact drop of 0·3 to 0·5 volt per brush. The carbons with the lower values of contact drop are for 6-volt systems ; the higher for 12-volt systems. For 24-volt systems a copper-graphite brush of medium metallic content is used. Box-type brush-holders are replacing the grip-type. Further means employed for reducing the voltage drop under the brushes consist of carefully bedding the brushes and pressing them firmly on to the commutator. The brushes are bedded in position by working a piece of glass-paper or carborundum cloth (not emery) to and fro until the curvature of the brush is the same as that of the commutator (*see* also p. 105). The brush springs are adjusted to exert a pressure of about 8 to 11 lb. per square inch. Brushes should always be fitted with flexibles. Suitable brushes should not need replacement under 5,000 to 10,000 starts.

Care must be taken to ensure smooth working of the brushes in the holders and of the brush levers in their pivots. The boxes must be kept clean, and the clearance between carbon and holder should not be less than two-thousandths of an inch ; contacts must be tight. Brush springs sometimes lose their temper. Neglect of any of these precautions may render starting difficult. Moisture, fuel-oil and dirt must be kept away from the interior of the starting motor, commutator and brushes.

STARTER DRIVES

The Battery-Motor Starting System with Inertia-engaged Pinion.—This system of starting consists essentially of a storage battery and a starting motor. It is used almost universally with the petrol engine. In order to obtain the requisite turning moment, the motor is usually geared to the flywheel, while automatic engagement and disengagement is effected by means of a loose pinion running freely on a screwed quill or sleeve at one end of the motor shaft. With this inertia-engaged pinion the armature torque is transmitted to the threaded sleeve and pinion through a torsion spring, the blow of engagement being softened by the sleeve moving against a compression spring. Common gear-ratios lie between 8 : 1 and 12 : 1. Thus, when the motor is started, the loose pinion at first, owing to its inertia, revolves more slowly than the shaft, and in consequence it acquires a translatory motion along the screw. This brings it into mesh with the teeth on the flywheel, and it then causes the engine to revolve. As soon as a speed is reached at which a spark fires the explosive mixture, the engine acts under its own power and increases its speed. The starting switch should not be released however until the engine begins to fire regularly, and the motor and gearing should be designed to prevent automatic disengagement of the pinion before the engine fires and continues to run. On releasing the switch the flywheel automatically causes the pinion to fly back along the screw, thereby disengaging the gears.

In another arrangement the pinion rides directly on the armature shaft. The consequent reduction in the diameter of the driving pinion permits a higher gear-ratio to be used, resulting in higher speed and output of starter motor. Also the motor efficiency is greater at the higher speed. This drive is made as a self-contained unit having a friction coupling and a rubber coupling embodied to control the torque transmitted from the starter to the flywheel and to absorb the energy in the rotating armature at the moment when the pinion engages. There is a relief spring which enables the pinion to work its way into engagement if the teeth of pinion and flywheel should meet end to end. In the event of attempted meshing when the engine is rotating backwards, due to backfire, an overload release mechanism operates. The driving torque is transmitted partly through the rubber coupling and partly through the friction disc.

Torques in excess of a definite limit cause slipping between the rubber bush and the outer and inner sleeves of the coupling. Under normal conditions slipping will not take place until the relative angle of twist exceeds 30°.

Misuse and Overloading of Inertia-engaged Starting Mechanism.—Though capable of giving satisfactory service, this starting device can easily—indeed, unwittingly—be abused. Great injury may result if, for example, the starting switch be closed when either engine or motor is not at rest, for the increased stresses then set up may well destroy some part of the mechanism. The commonest case of incurring this danger is when, for some reason, firing does not occur at the first attempt. Before re-closing the switch, the driver should pause long enough to ensure that both flywheel and pinion have come to rest. It is particularly dangerous to try to engage the starter during reverse running of the engine—the result will probably be a broken outboard-bearing housing or a bent shaft.

Reverse running may occur when the engine has been cranked long enough for unburnt mixture to be carried through the engine into the exhaust and silencer, and a compression stroke is reached when the mixture is suitable for firing. The engine will continue to run backwards until the silencer is exhausted. The earlier the ignition, the more likely the backrunning. Since the starter is capable of holding against backfire, reverse running is unlikely when the starter is in mesh. Also when a hot and dirty engine is switched off and fuel is passed to the exhaust system as the engine slows down, backfiring may be caused by the presence of glowing particles in a cylinder. By lengthening the contact arm of the distributer rotor, which is permissible in a four-cylinder engine, the spark following the backfire finds its easiest path in the cylinder in which the gases are already burnt, thus avoiding further explosions. Without the horn-shaped electrode the spark occurring as the contacts open could readily pass to a cylinder filled with explosive mixture and enable the back-running of the engine to continue. In a six-cylinder engine there is not room for the extended electrode, but against this it may be said that a backfire is less powerful than from a four-cylinder engine of equal power. The simplest remedy is in the hands of the driver—in no circumstances should he close the starting switch unless the engine and motor are at rest.

If the engine refuses to move, the switch should be released at once, for in this state the battery is nearly short-circuited ; the gear lever may not have been left in neutral, and the hand-brake may have been left on in addition. If the flywheel teeth are worn, the pinion may rise over them and jamb, instead of engaging properly, when the switch is closed. A jambed pinion may often be released by moving the car to and fro with gear in mesh, or by turning the extended end of the motor shaft. At times it is necessary to remove the motor to free it. Large starters are sometimes fitted with protective devices against overloading and overrunning, e.g., in the form of a free-wheel clutch with overload release.

Behaviour of Inertia-engaged Pinion during Starting.—As an indication of what occurs in the motor and battery during starting, the oscillograms in Fig. 22 are of interest. These are taken from a paper by Messrs. Smith-Rose and Spilsbury in the *Journal I.E.E.*, Vol. 67, p. 133, in which the results of tests carried out at the National Physical Laboratory are recorded. The engine in question was rated at 11 h.p., and was of the four-cylinder type. The ambient temperature was 14° C. (57° F.), so that while starting was effected with the engine cold, conditions were not as adverse as they might be in winter, nor as favourable as they might be in summer.

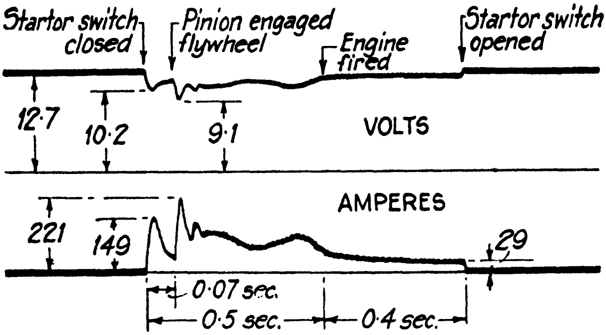


FIG. 22.—Oscillograms of voltage and current during starting.

Studying the oscillograms, it will be seen that on switching in the battery the voltage fell from 12·7 to 10·2 volts and the current rose to 149 amperes. The starter armature now accelerated while the pinion slid into mesh (attaining possibly a speed of 2,000 r.p.m.). During the period of engagement with the flywheel, the current fell as the motor speed increased; on coming into mesh, however, the stressed spring fitted in the drive not only brought the armature to rest, but caused it to reverse for an instant, as shown by the current jumping to 221 amperes, accompanied by a voltage drop to 9·1 volts. Following this the engine moved and the current surged until after 0·5 second the engine fired. (This surging is common with the tension spring, but is practically damped out with the compression spring.) After a further lapse of 0·4 second, the starting switch was opened, the current having fallen to 29 amperes. From this it will be seen that the total period during which the starting switch was closed was 0·9 second. The demand on the battery during this period was 63 coulombs (1 coulomb = 1 ampere × 1 second), the actual consumption before the engine fired being 49 coulombs. To show the small amount of energy involved in this operation, if we assume that the charging current of the 50-ampere-hour battery used was 8 amperes, then 63 coulombs could, ignoring loss, be replaced in about 8 seconds. When starting with the same engine hot (85° C.), the total demand from the battery was 50 coulombs, but the current rushes were practically the same. The maximum quantity recorded for a similar 14-h.p. engine starting cold was 123 coulombs; while a 12-h.p. engine, started when cold by means of a dynamotor unit, used 128 coulombs. In the 14 h.p. engine with a loose-pinion starter the current reached peaks up to 270 amperes, while the highest peak with a dynamotor was 195 amperes. It was also found that the current required to turn the idle engine was 40 per cent. less when hot than when cold, while the speed in the former case was 50 to 60 per cent. higher than in the latter. With engines well-tuned, as in the above tests, both energy consumption and starting period were small. In normal practice, conditions are seldom ideal—in many cases a heavy current for 5 to 10 seconds may be needed to enable the engine to get away (*see* p. 9). The above data are chiefly useful to show the behaviour of the inertia-engaged pinion during starting.

The Axial or Sliding Armature Starter.—For starting heavy-oil engines, motors up to 6 h.p., developing breakaway torques up to 70 lb.-ft., may be needed. The current on switching in may rise to 1,000 amperes, while a current of 500 amperes may be required to turn the engine at the firing speed of 120 to 150 r.p.m. The inertia-engaged pinion is not suitable for coupling an oil engine with the starter motor because the high compression pressure causes such rapid acceleration that the pinion is ejected.

A common practice is to use a sliding-armature starter and a multiplate friction clutch fitted with overspeed and overload release. In this starter the armature can slide axially in its bearings and is drawn into its central position under the action of the magnetic field. In addition to the main series winding, the field may be provided with a shunt winding and an auxiliary winding. On switching in, the shunt and auxiliary windings limit the speed and slide the armature forward during engagement of the pinion. The shunt winding also limits the speed after the engine has started and before the push-button of the automatic starter has been released. Alternatively, a free-wheel clutch may be used to prevent overspeeding of the starter-armature when the engine starts. The gear-ratio is of the same order as with the inertia-engaged pinion, i.e., about 11 : 1.

The heavy starter currents required for such engines, together with the generous lighting requirements of double-deck omnibuses, led to the introduction of the 24-volt system, obtained from 12 acid or 18 alkaline cells. Should an oil engine fire (e.g., on one cylinder) and not start, the flywheel may oscillate over a wide arc. Any attempt to start before oscillations have ceased may twist the shaft or break teeth.

SERIES MOTOR CHARACTERISTICS

Series Motor with Constant Applied Voltage.—The motor used for starting the engine is called a "series" motor, because the field winding is in series with the armature winding, so that the same current passes through both. In this motor, therefore, the main current is also the exciting or magnetizing current (Fig. 21). The speed and torque characteristics with the series connexion are ideal for a starting motor.

The induced electromotive force is proportional to the product of the speed and the field. This can also be written :—

$$\text{Speed of motor} = \text{constant} \times \frac{\text{induced e.m.f.}}{\text{field}}$$

Consequently, for a given strength of field the electromotive force induced varies directly as the speed.

If the voltage applied to a series motor is constant and the voltage drop in the motor resistance is negligible, then :

$$\text{Induced e.m.f.} = \text{applied voltage},$$

and, $\text{Speed of motor} = \text{constant} \times \dfrac{\text{applied voltage}}{\text{field}}$

Thus the speed of a series motor varies inversely as the field and directly as the applied voltage. The characteristics of a series motor to which a constant voltage is applied are shown in Fig. 23. From these curves it is seen that for each value of current there is a corresponding value of speed and of torque. With a given set of conditions the performance of a motor cannot be altered. Whether a particular motor is suitable for a given duty depends on whether the characteristics of the motor can satisfy requirements.

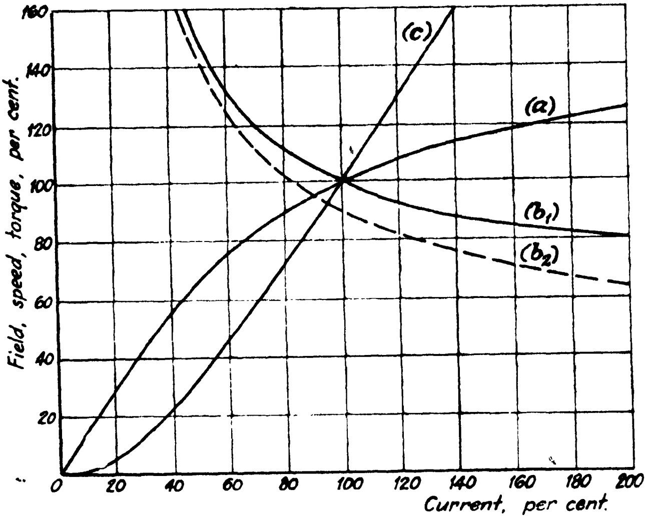


FIG. 23.—Characteristic curves of series motor for constant applied voltage.

(a) Magnetization curve.
(b_1) Speed curve, ignoring effect of motor resistance.
(b_2) Speed curve with 10 per cent. resistance drop.
(c) Driving-torque curve.

(*a*) *The Magnetization Curve.*—In the series motor the magnetic field is produced by the main current. The relation between the field and current is shown in curve (*a*) of Fig. 23, and is known as the magnetization curve. This is the fundamental characteristic of the motor, on which the other properties depend.

(*b*) *The Speed Curve.*—This characteristic is also shown in Fig. 23. Curve (b_1) is an ideal speed curve, because the effect of the resistance of the motor is ignored. Curve (b_2) is drawn for an actual case where the voltage drop due to motor resistance is 10 per cent. at normal current (100 per cent.).

It will be noticed how the speed rises as the current falls, and that at low speeds the current is very large. When the engine fires and the pinion is disengaged, the motor speed may reach an excessive value, owing to the removal of the load. For this reason the switch should be released immediately starting is effected. Starting motors of commercial vehicles are sometimes provided with a shunt winding also, to prevent racing.

(*c*) *The Driving-torque Curve.*—The torque developed in a motor is proportional to the product of the current and the field, and is independent of the motor speed, that is,

$$\text{driving torque} = \text{constant} \times \text{current} \times \text{field}.$$

This is shown as curve (*c*) in Fig. 23. At the lower values of current, the iron is unsaturated and the magnetic flux is proportional to the current : over this range then the torque varies as the square of the current. Beyond the knee of the magnetization curve, saturation begins, and when the flux becomes constant in value, the torque varies directly as the current. With the high saturation at which starting motors are worked, the torque curve soon becomes a straight line (*see* curve marked "useful torque" in Fig. 24). The straight-line torque curve of this motor gives the steady conditions needed at starting.

It is thus seen that with constant flux in a series motor the current determines the torque and the applied voltage the speed.

Starting Motor with Battery Supply.—In an automobile the applied voltage is not constant. Owing to the resistance of the battery, motor, switch and other parts of the circuit, there is a drop in voltage proportional to the current flowing. At starting, when the current is large, the drop is large. This has a serious effect on the motor characteristics and must be taken into account. The worst conditions occur when the battery is cold and not well charged.

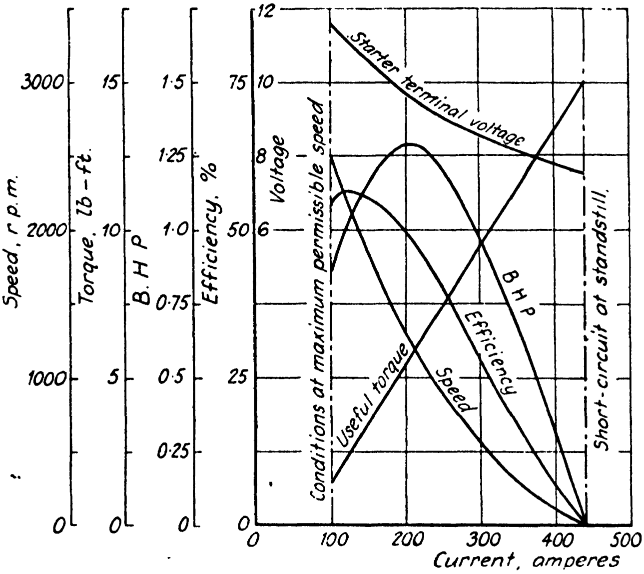


FIG. 24.—Performance curves, as a function of current, of a starting motor operated from a 12-volt battery.

Typical characteristics of a 12-volt starter are shown in Figs. 24 to 26, where the several curves are plotted to a base of current, torque and speed respectively. It is seen that the battery voltage applied at the motor terminals falls rapidly as the current increases. In addition to speed, current and torque, the curves of motor output in horse-power and of efficiency are given.

The speed-torque relation is of particular interest. On closing the starting switch, the current and torque reach their highest values. The engine starts to rotate and—assuming the ignition to be switched off—continues to accelerate until the cranking torque of the motor is counterbalanced by the resisting torque of the engine. The speed at which this occurs will depend on the temperature. When the engine is cold the cranking speed will be lower than when the engine is hot. Whether the cranking speed of the cold engine will enable the engine to get away when the ignition is switched on depends, with coil ignition, upon

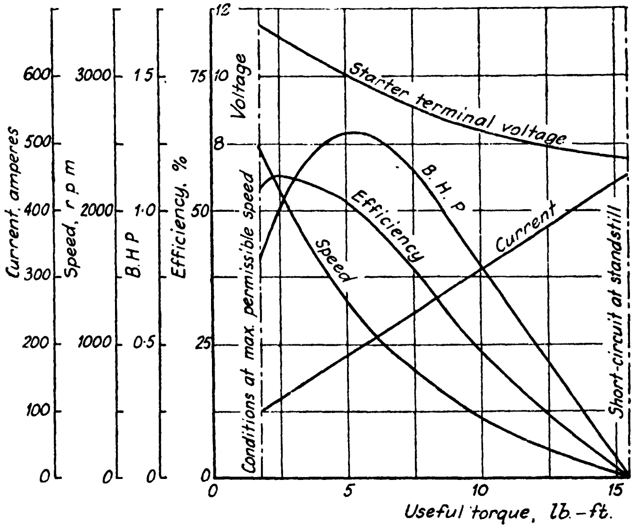


FIG. 25.—Performance curves, as a function of torque, of a starting motor operated from a 12-volt battery.

whether carburation is adequate, and, with magneto ignition, upon whether a spark is produced. When judging the starting system from this point of view, the state of the battery charge must be taken into account.

When used in conjunction with an inertia-engaged pinion, the starting system should be designed so that the pinion is not ejected until either the engine fires and runs, or the starting switch is opened.

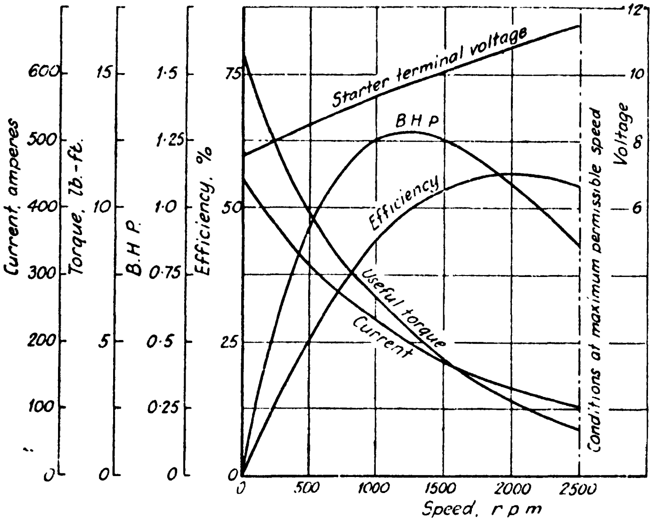


FIG. 26.—Performance curves, as a function of speed, of a starting motor operated from a 12-volt battery.

Automatic Starting Devices.—These have received a certain popularity in this country and America. An automatic starting system restarts the engine should it stop or should the speed fall much below idling value. These devices are merely referred to here in order to illustrate the underlying principles involved in automatic starting. The principle consists in connecting an electromagnetic starting switch with the ignition switch, so that the closing of the latter energizes and closes the former. In addition, a relay-trip device, depending on the operation of the dynamo, opens the starting switch as soon as the engine begins working. Should the engine stop, the absence of a dynamo voltage permits the starting switch to close and so restart the engine.

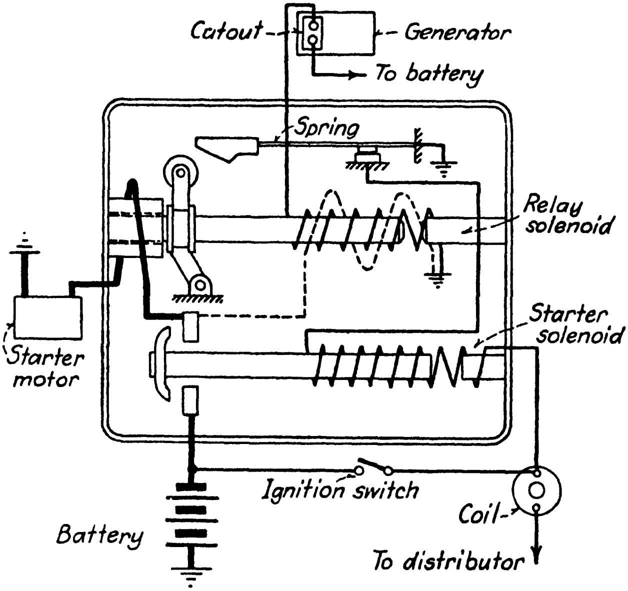


FIG. 27.—Connexion diagram of a self-starting device.

A fully automatic self-starting device is shown in Fig. 27. There are two solenoids. The lower one is the main starter switch solenoid, which is energized by a coil connected to the battery through the control-switch. The upper solenoid is the relay-trip-switch. It has three windings. The thick coil on the left consists of a single turn in the starter-motor circuit. So long as a heavy current flows through this turn the plunger is held back (i.e., to the left). Of the other two coils on the relay-trip, one is excited off the starter-motor terminals (dotted line) and the other off the dynamo terminals (continuous line)—both coils act in the same sense and attempt to pull in the plunger against the force of the single-turn coil. When the engine fires, the starting current falls, and the voltage across the battery coil (dotted line) rises, causing the plunger to be drawn into the solenoid. The relay-trip-switch operates by a roller attached to the plunger engaging a shaped block, opening a pair of contacts, and disconnecting the starting motor from the battery—the current in the dotted coil being also interrupted. The plunger is now held in this position by the coil excited off the dynamo voltage ; but if the engine stops, this voltage vanishes and the relay core is released. A delay device prevents immediate re-engagement, thereby giving time for the pinion to come to rest.

An alternative method of automatic self-starting—used in America—employs a vacuum-operated relay, actuated by the vacuum in the induction manifold. This relay must operate over a very wide range of pressure—high vacuum caused by throttle being suddenly closed when engine is running fast, and low vacuum when the throttle is opened wide with engine idling. The corresponding problem with an electromagnetic relay is the wide range of voltage over which the trip must hold in.

A semi-automatic scheme has the starting switch coupled to the accelerator pedal through a clutch, thereby eliminating one control and so leaving the hands free. After the engine has fired, the momentary releasing of the pedal disengages this clutch, allowing the pedal to operate as a normal accelerator pedal. The starter-clutch is kept out of engagement so long as the engine is running by a vacuum-controlled diaphragm connected to the induction manifold.

Comparison between 6-volt and 12-volt Starting Systems.—It is well to understand the conditions under which the speed attained by the engine shall be the same with a 6-volt system as with a 12-volt system.

These conditions are :—

(1) The motors must give the same torque at the same speed. For this purpose the current at 6 volts must be twice that at 12 volts when the field is made the same in both cases and the number of conductors in the armature of the 6-volt motor is half that in the armature of the 12-volt motor.

(2) The percentage voltage drop must be the same in both cases. To obtain this the ampere-hour capacity of the 6-volt battery must be twice that of the 12-volt battery, the cross-section of the cables and of the total armature path with 6 volts must be four times that with 12 volts ; also the percentage contact drop under the brushes must be the same in both cases.

The last condition is hard to satisfy, owing to the properties of the carbon brush. If the same grade of brush is used, there will be practically the same contact drop at the brushes in each case. If there is a drop of 0·5 volt under each brush, it is seen that the loss of $2 \times 0{\cdot}5 = 1$ volt is much more serious in the 6- than in the 12-volt system.

Ignoring the effect of brush contact drop, however, it follows that if the conditions under (1) and (2) have been satisfied, then there is no difference between the 6- and 12-volt systems as regards starting.

In some cases where a given engine is found to start with a 12-volt system but not with a 6-volt system, the failure of the latter may be due, not only to the large percentage drop under the brushes, but to the non-fulfilment of some of the other conditions detailed under (1) and (2).

In general, taking things as we find them, the 12-volt system, as installed, is more efficient than the 6-volt system for starting. Stated in another way, to provide a satisfactory starting system for some of the larger British engines would be more troublesome and costly with 6 than with 12 volts. The success of the 6-volt system with large American engines is explained by the lower resisting torques and by the fact that they will start at lower cranking speeds.

THE DYNAMOTOR

The interchangeability of the electric motor and electric generator was pointed out in Chapter II. While in principle it is rational to use one and the same machine as both starting motor and charging dynamo, in practice the design of such a dual-purpose machine is necessarily a compromise. Generally speaking, neither as dynamo nor as motor is the unit, commonly termed a dynamotor, as good as a separate dynamo and a separate motor. Nevertheless, like many other compromises on the automobile, the single unit works satisfactorily in many systems. If the dynamotor be direct-coupled to the crankshaft, the torque applied to the engine is the motor torque. To overcome a given resisting torque, a direct-coupled motor has to exert a more powerful torque than a motor geared to the engine, because, gearing the dynamotor to the engine, through, for example, a chain drive, multiplies the torque applied to the engine by the gear-ratio.

On the other hand, if the gearing is permanent, the speed imposes a serious limitation on the gear-ratio. For example, with a gear-ratio of 3 and a maximum engine speed of 4,000 r.p.m., the dynamotor must be capable of revolving at 12,000 r.p.m.

Though many chain-driven or gear-driven dynamotors with gear ratios up to 3 : 1 have been fitted, rising engine speeds have introduced noise troubles.

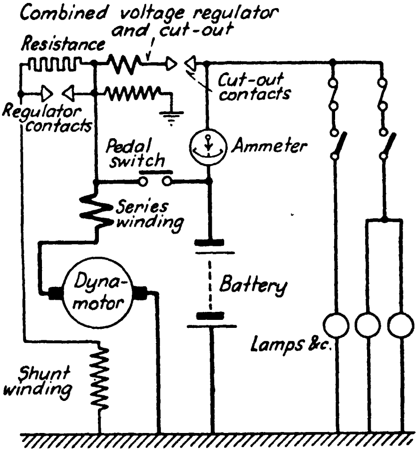


Fig. 28.—Connexion diagram of compound-wound dynamotor with combined voltage regulator and cut-out.

For these reasons only crankshaft-speed (i.e., direct-coupled) dynamotors appear to be feasible with high-speed engines. Though all gearing transmission losses are thereby avoided, the weight and cost of the dynamotor are increased by this severe speed restriction. The battery capacity, too, has to be increased proportionately. The alternative method of gearing the dynamotor to the crankshaft during starting and coupling it direct to the engine during normal running is a good enough solution in principle, but too complicated and costly for wide use.

From the point of view of simplicity, the compound-wound machine coupled to the crankshaft affords the best solution. The connexion diagram of such a dynamotor is shown in Fig. 28. The changeover from the series-motor condition at starting to the compound-generator condition when running is automatic; while a voltage regulator is employed to control the dynamo voltage.

The feasibility of the direct-coupled dynamotor is obviously largely settled by cost, for if this exceeds that of the motor and dynamo together there is clearly a case for employing two machines instead of one. If weight and cost were of no account, the double-purpose machine would probably be preferred, for, technically, there is no difficulty in providing the requisite torque given the requisite battery capacity.

Comparative examples may be of interest. A dynamotor of weight equal to the combined weight of motor and dynamo for a 1·5-litre engine can be made to give a cranking torque of about 21 lb.-ft. The resisting torque of a 1·5 litre British engine, however, may be about 30 lb.-ft. at firing speed, so that a cranking torque of 21 lb.-ft. is too small. For a 2·5-litre engine of foreign make the locked torque of the dynamotor was 87 lb.-ft., and the cranking torque about 44 lb.-ft. Taking the engine-resisting torque of the corresponding British engine to be about 75 lb.-ft., the same difficulty would be met as with the 1·5-litre engine. The obvious remedy is a larger dynamotor, and in favour of this is the absence of gear loss, and the fact that since one machine costs less than two of the same total weight, there is a margin to the good. One important feature of the dynamotor is its large capacity as a dynamo—150 and 250 watts in the cases just mentioned. The battery for the dynamotor, however, is more costly because of the larger demand at starting. Enough has been said to show that the direct-coupled dynamotor is not unsuitable for certain foreign engines, but rather costly for the stiffer British engines.

CHAPTER IV

THE AUTOMATIC CUT-OUT AND THE CHARGING GENERATOR

In order to charge the battery and supply current to appliances, a direct voltage is needed. Since the voltage of an acid cell varies from 1·8 volts on complete discharge to 2·7 volts on complete charge, the charging voltage must vary accordingly, and the lamps, coil, etc., must be made suitable for this variation. Also the percentage variation is no less for the alkaline cell. To provide the requisite direct current a charging generator or dynamo, driven by the engine and arranged for automatic operation, is fitted to most automobiles. Now the electromotive force induced in an electrical machine is proportional to the product of the magnetic field and the speed at which the machine rotates. Consequently, to obtain a constant voltage, the useful field must vary inversely as the speed. This condition is not easily satisfied, for while the machine voltage must vary over an outside range of 50 per cent. (1·8 to 2·7 volts for an acid cell), the engine speed varies over a much wider range—300 to 400 per cent., or even 800 per cent. in extreme cases.

There are two conditions for which automatic control must be provided. Firstly, the generator must be connected to the battery as soon as its induced electromotive force or terminal voltage is equal to the battery voltage, and it must be disconnected from the battery as soon as the voltage of the dynamo falls below that of the battery. This requirement is met by means of an automatic device called a cut-out or reverse-current relay, described on page 86. Secondly, at all speeds above that at which the cut-out operates, the generated voltage must be automatically kept at the value required by the battery. Thus, if 15 m.p.h. is the cutting-in speed and 75 m.p.h. the top speed, the generator voltage has to be controlled over a speed range of 1 : 5. With some engines this ratio may be as high as 1 : 8.

There are various ways of compensating for speed variation, but practical experience has reduced the number of satisfactory systems to a very small number. The types which have survived are often referred to as the constant-current system and the constant-voltage system. The constant-current system or the system of current regulation was exemplified by the three-brush dynamo used with a battery, and to a limited extent on motor-cycles by the dynamo with a portion of the armature winding short-circuited. The action of these machines depends on the distortion of the main flux by armature reaction and consequent reduction of the useful flux as the current increases, assisted by the reduced voltage applied to the exciting winding. Although the term "constant current" implies the same current under all conditions, it will be seen that the three-brush dynamo, when connected to a battery, gives characteristics similar to those shown in Fig. 44, the current rising to a maximum and then falling. In America the three-brush dynamo is still used to some extent on private cars, but it is rapidly disappearing in this country. The short-circuited system of control is now obsolete. In the constant-voltage system, or the system of voltage regulation, which is almost exclusively employed in Germany, the voltage is controlled by means of an automatic quick-acting regulator, the action of which is independent of the battery. The use of the voltage regulator is becoming general in Great Britain, and to a great extent in U.S.A.

THE AUTOMATIC CUT-OUT (OR REVERSE-CURRENT RELAY)

When a direct-current generator and a battery work in parallel it is usual to employ an automatic cut-out (or reverse-current relay), the function of which is to switch the generator into circuit as soon as its voltage reaches a predetermined value, and to cut out the generator when its voltage falls below a predetermined value. The switching-in is effected by means of a voltage coil, while the cutting out is achieved by a reverse (or discharge) current flowing from the battery through a current coil.

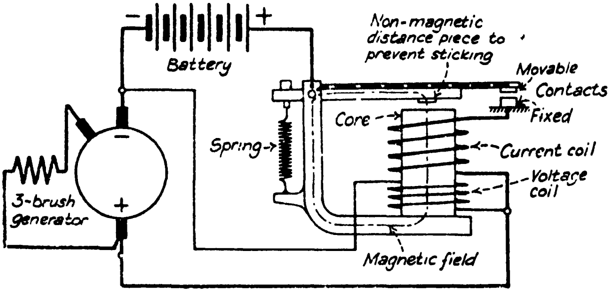


FIG. 29.—Elements of automatic cut-out or reverse-current relay.

Principle of the Reverse-current Relay.—On a soft-iron or in some cases on a polarized core two coils are wound: the one with fine wire, which is connected across the generator terminals, is called the *voltage* or *shunt* coil; the other with thick wire, which is in series with the generator and the battery, is called the *current* or *series* coil. Except for a small air-gap an iron path is provided for the magnetic field of the relay, as shown in Fig. 29. The upper part of the magnetic circuit is made in the form of a light movable arm with a contact at one end and hinged at the other. A spring is arranged to raise this arm so that, when the core is unexcited, the movable contact on the arm is kept away from a stationary contact. With the contacts apart the circuit is open; with the contacts together the circuit is closed.

When the generator field-switch is closed, the revolving armature produces a voltage at the generator terminals. This sends a current through the voltage coil, which produces a magnetic field in the reverse-current relay. As the speed rises, the current increases, and also the magnetic pull on the movable arm of the cut-out, until the tension of the spring is overcome and the contacts close. The value of the voltage at which this occurs depends on circumstances, and is usually somewhat higher than 12 volts in a 12-volt system; but on the contacts closing, the combination at once assumes the battery voltage.

The closing of the contacts connects the dynamo to the battery, and a further increase in speed has but little effect on the terminal voltage because this is now controlled by the battery, as explained in the section on the three-brush dynamo. Instead, a charging current flows into the battery. This charging current flows through the current coil of the relay, and the ampere-turns produced by it create a magnetic field in the same direction as those produced by the voltage coil, as shown in Fig. 30. As a result the pull on the armature is increased and the contacts are closed more tightly by the action of a charging current flowing in the series coil.

When, however, the speed falls to such a value that the generator-induced electromotive force is below the battery voltage, then the current reverses and a discharge current flows from the battery through the dynamo. The discharge current being in the reverse direction to the charging current, its magnetic effect opposes that of the current in the voltage coil. This demagnetizing action on the relay decreases the pull on the movable arm and allows the spring to open the contacts. The spring is adjusted to act when the current reaches about 0·5 ampere ; that is, when the contacts first close, the charging current immediately rises to 0·5 ampere ; while the contacts open when the discharge current reaches a somewhat higher value. The speed at which the contacts open is slightly lower than that at which they close. It is usual to insert a piece of non-magnetic material between the movable arm and the core to prevent sticking, unless the construction provides a short air-gap for this purpose. When the ignition-switch is closed, a warning lamp across the contacts shows red until the dynamo attains charging voltage and closes the cut-out. The lamp remains dark so long as the cut-out is closed.

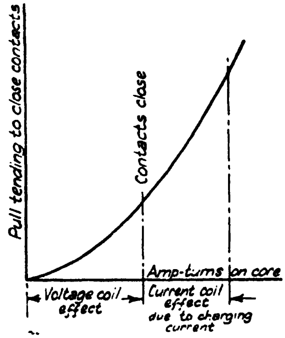


FIG. 30.—Magnetic pull in reverse-current relay.

Action of Cut-out in Charging Circuit.—In Fig. 31 the connexions of the charging circuit are shown, the coils being represented in a diagrammatic manner. The ammeter is a centre-zero instrument, and can therefore indicate either a charge or discharge current by the pointer deflecting to the left or right. The load—lamps, etc.—is seen to be placed between the ammeter and the cut-out. The starting motor, however, takes too large a current for the ammeter, and is therefore connected between the battery and the ammeter.

The charging circuit is controlled by the field-switch, one terminal of the generator being connected directly to the cut-out, and the other terminal to the battery, or to earth, as the case may be. When the field-switch is closed and a charging current flows, which is the normal condition, the currents in both voltage and current coils flow in the same direction. The contacts are then held together by the combined pull of the two coils acting against the spring.

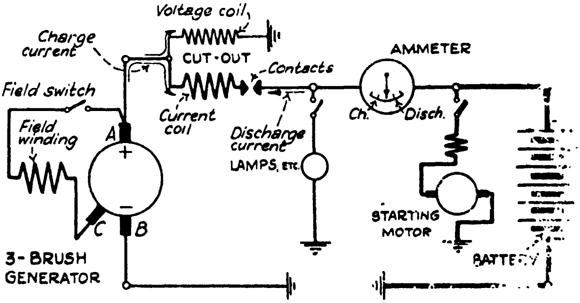


FIG. 31.—The charging circuit.

When, however, the current in the series coil reverses owing to a discharge current flowing from the battery, which takes place when the induced electromotive force of the generator falls below the battery voltage, the magnetic effect due to this coil also reverses in direction. Though the magnetic pull due to the voltage coil tends to keep the contacts closed, the current coil now allows the spring to bring them apart.

The action of the cut-out is entirely automatic, and its function is to switch the generator in and out of circuit according to the speed of the engine. Generally speaking, when the relay is once correctly set, it should not need further attention.

On commercial vehicles, owing to the large current to be controlled, cut-outs are often provided with auxiliary as well as with main contacts. The auxiliary contacts close first and open last, thereby relieving the main contacts of much of the harmful effect of sparking.

CHARGING DYNAMOS

For cars, the standard design has two poles and a cylindrical welded-steel shell. The dynamo rating may be as low as 70 watts for small cars and over 200 watts for larger cars. For motor coaches, where the output may exceed 1,000 watts, four poles may be used, the armature being wave wound so that two brush holders only are needed.

It is important to provide proper cooling for the dynamo, and it should not be allowed to receive heat from the engine. If the temperature of the frame rises above 65° C. (150° F.), there is a danger of soldered joints softening and of the insulation charring. Dynamos are now ventilated. The improved cooling permits a bigger output to be obtained ; a useful result in view of the extra accessories on modern cars. A well-cooled dynamo may have an overload capacity of 50 per cent. Even so, in constant-voltage systems, the voltage regulator has to be compensated to prevent the dynamo being overloaded when the battery is discharged.

Equally important with the mounting is the driving of the dynamo. In this respect the designer objects to the restrictions imposed by a common drive for dynamo and magneto, or for dynamo and coil distributer. The belt-drive commends itself as giving most freedom in arranging for lubrication, ventilation, flexibility and choice of speed. If desired, the fan and pump can be driven off the same belt. The maximum speed is limited by mechanical and commutation difficulties, but dynamo speeds of 4,000 to 4,500 r.p.m., corresponding to engine cruising speeds of about 3,000 r.p.m., are not uncommon. At the other extreme, the dynamo speed in heavy traffic conditions should be above the cutting-in speed.

With the belt-driven dynamo, the driving pulley is made to act as a fan by fitting radial blades on the inner face. These blades form an extractor fan, air being drawn in at the commutator end, through the machine, and expelled at the driving end. Since the amount of cooling air in the ventilated machine increases as the speed rises, the temperature-rise remains fairly steady as the iron and mechanical losses increase, thus permitting the rated output to be obtained over a wide speed range. Even so, commutator temperature-rises of 70° to 80° C. (126° to 144° F.) are reached in ventilated machines compared with 100° C. (180° F.) for enclosed machines. Box-type brush-holders are now used. From time to time the belt should be checked for tightness, especially when new. Many cases of discharged batteries can be traced to slack driving belts.

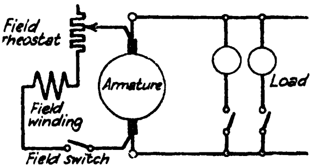


FIG. 32.—Shunt generator.

THE THREE-BRUSH GENERATOR

Since the three-brush machine is a modification of the ordinary shunt generator, the latter will first be considered.

The Shunt Generator.—In the common shunt generator the field winding is in parallel with the armature winding and the load, that is, the field winding is *shunted* across the armature (Fig. 32). By placing a regulating resistance (field rheostat) in series with the field winding the exciting current can be varied at will. Ignoring secondary effects, if the exciting current and the speed are kept constant, the induced electromotive force will remain constant at all loads.

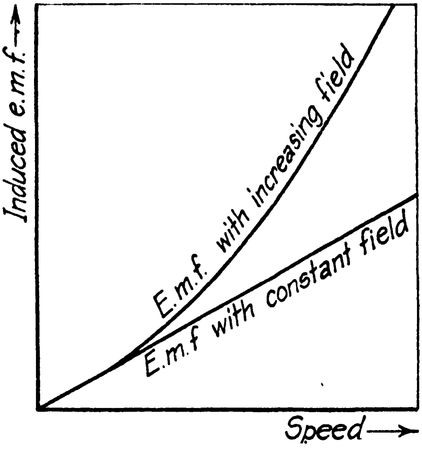


FIG. 33.—Effect of speed on electromotive force induced in shunt generator.

Effect of Varying Speed of Shunt Generator.—If the exciting current is kept constant (either by adjusting the field regulator or by exciting from an external source) while the speed is varied, the induced electromotive force is then directly proportional to the speed (*see* curve, "constant field," in Fig. 33). If, however, the resistance in the exciting circuit remains constant and the terminals are connected to the armature brushes, then, so long as the magnetic field is directly proportional to the exciting current, the voltage will vary as the square of the speed. Beyond this the rate of increase of terminal voltage will be less rapid, and when the magnetic circuit becomes saturated the voltage again becomes directly proportional to the speed. This is shown by the curve "increasing field" in Fig. 33. It is at once clear that neither of the above arrangements is suitable for the automobile. Thus a simple shunt machine alone will not solve the problem.

We need some device whereby the field falls off as the speed rises, and conversely. In order to understand the solution we must examine certain properties of direct-current machines.

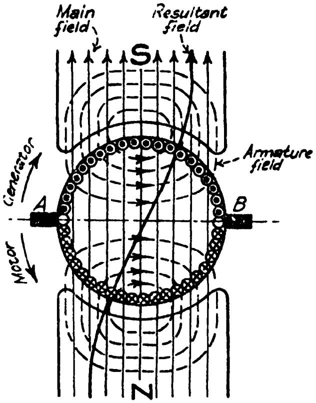


FIG. 34.—Magnetic fields in a direct-current machine.

Armature Reaction in a Direct-current Machine.—Whenever a current flows through a winding a magnetic field is produced. The exciting current, flowing through the exciting winding, produces what is known as the main field. Similarly the armature current, flowing in the armature winding, produces the armature field. These are represented in the cross-section of a bipolar machine shown in Fig. 34, and in the developed diagrams in Fig. 35. With the brushes *AB* fixed in the geometrical neutral axis, as shown, the axes of these two fields are at right angles to one another.

Now two magnetic fields cannot have a separate existence in the same space at the same time; consequently they combine to form a resultant field, also shown in Fig. 35. It is thus seen that at no-load (armature current = zero) the distribution of the field in the air-gap is symmetrical, but on load it is distorted by the armature field (*see* Fig. 35). This effect is known as ***armature reaction.***

Potential Curve of Commutator.—We have now to consider how the voltage depends on the brush position. Suppose a brush *C* to be moved from the brush *A*, fixed in the geometrical neutral axis, to the brush *B*, also fixed in geometrical neutral axis, with a voltmeter connected between *A* and *C*. The voltage will then gradually increase in proportion to the shaded area in Fig. 36, which is drawn for the no-load condition. Thus as the brush *C* moves from *A* to *B* the voltage between *A* and *C* increases from zero to its maxi-

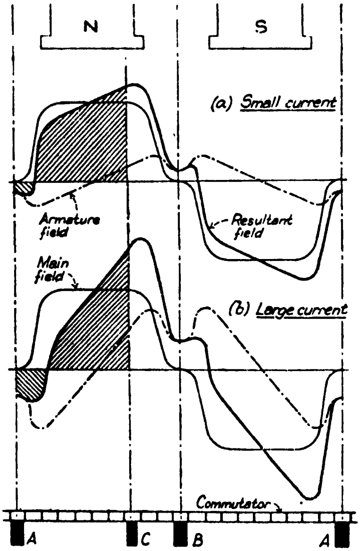


FIG. 35.—Magnetic field distribution in a direct-current machine.

mum value, and is equal to V in the position shown. The voltage curve thus traced out is known as the *potential curve of the commutator*, since it represents the distribution of the voltage or potential over the commutator.

Thus the voltage between two brushes placed anywhere on the commutator is represented by the vertical distance between the two respective points on the potential curve.

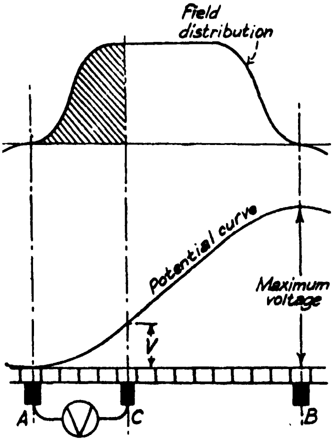


FIG. 36.—Potential curve of commutator at no-load (constant speed assumed).

The same applies to the machine when loaded, except that the potential curve is obtained from the resultant field distribution. Corresponding to every load there will thus be a definite potential curve. In Fig. 37 the potential curves are shown for the cases of the two values of armature current in Fig. 35. The brushes A and B, fixed in the geometrical neutral axis, are called the *main* brushes, and the voltage between them is shown in Fig. 37 as main volts between *A* and *B*.

Effect of a Third Brush.—In addition to the main brushes *A* and *B*, let a third brush, *C*, be placed on the commutator, as shown in Fig. 37. The *voltage* between the brushes *A* and *C* is then *proportional to the shaded areas* in Fig. 35. The exciting winding is connected to the brushes *A* and *C*. An inspection of Fig. 37 shows that with speed and main field constant the voltage across the exciting winding falls off rapidly as the current increases. The explanation is that armature reaction makes itself felt much more between the exciting brushes *A* and *C* than between the main brushes *A* and *B*. By utilizing armature reaction to vary the field, we get a partial solution of the problem of obtaining a constant voltage at a varying speed.

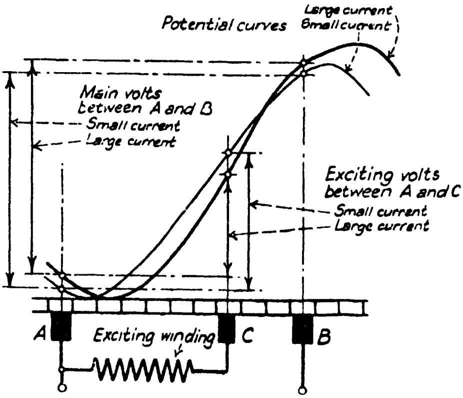


FIG. 37.—Potential curves of commutator at the two loads in Fig. 35 (constant speed assumed).

The Three-Brush Generator.—This is merely a shunt machine with the addition of a third brush; that is, in addition to the main brushes, there is a third or exciting brush (Fig. 38). The load—lamps, etc.—is placed across the main brushes, and the field winding is connected to the exciting brush and a main brush. The shunt regulator is dispensed with. If the generator is run at a constant speed and the load gradually increased, we get the falling voltage characteristic marked "generator characteristic" in Fig 39.* Though this is a considerable step in the right direction, the voltage will not remain sufficiently constant as the engine speed rises and falls. To control the voltage, a storage battery is needed.

Action of Three-Brush Generator and Battery in Parallel.—The generator and battery are joined in parallel as shown in Fig. 38, and the load is placed across the common bus-bars or terminals. In Fig. 39 the loaded generator characteristic is shown to the right of the vertical axis, while the battery characteristic, that is, the battery voltage at different charge and discharge currents, crosses this axis. Linked up in this way, the generator voltage is anchored to the battery voltage. Not only have the generator and the battery always a common terminal voltage, but this common voltage is mainly determined by the battery independently of the engine speed. Taking the constant-speed characteristic in Fig. 39, let us examine the action. It will be seen that any current measured between the vertical axis and the generator characteristic will denote the current given by the generator;

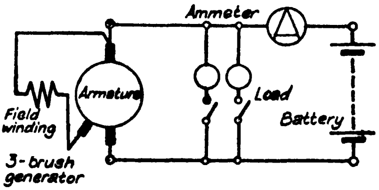


FIG. 38.—Connexions of three-brush generator and battery.

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* This curve was taken on a 3-brush car dynamo, and includes the effect of the exciting current on the armature reaction.

while any current measured between the vertical axis and the battery characteristic will denote the battery current—a charging current being to the right and a discharging current to the left. The horizontal distance between the two characteristics represents the external load current, e.g., lamps.

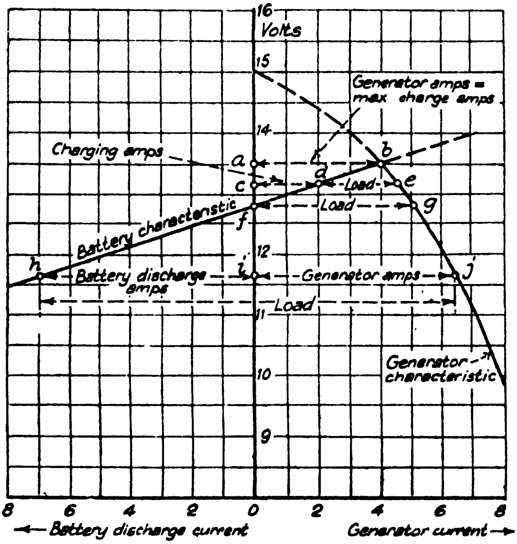
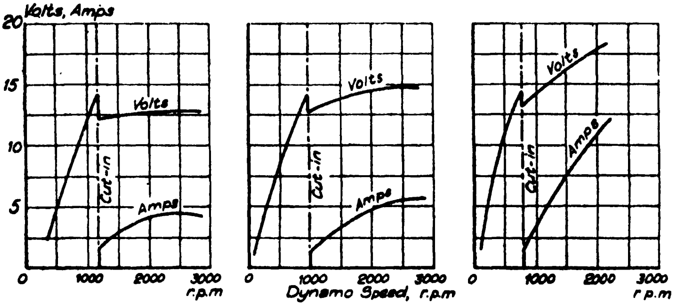


FIG. 39.—Parallel working of three-brush generator and battery (constant speed assumed).

At *a* the voltage is 13·5, the external load is zero, and the whole generator current *ab* is the charging current of the battery. At *c*, where the generator current is *ce*, the voltage has fallen to 13·2 due to a load *de*, the part *cd* representing the battery-charging current. When the load is further increased to *fg*, the voltage falls to 12·8 where the battery characteristic crosses the axis. The whole generator current *fg* is now taken by the load. In this case the battery merely "floats" on the bus-bars.

Increasing the load still further to *hj*, the voltage now becomes 11·7. Part of the load *ij* is supplied by the generator, and part *hi* by the battery, which is now being discharged.

It is thus seen that with a combination of battery and generator, the battery controls the voltage and the three-brush dynamo controls the current. This system has the merit of utilizing and charging the battery which has become indispensable on a modern vehicle. For satisfactory operation, a battery of ample capacity (low internal resistance) is needed ; this too is advantageous for the electric starter. Actually, the battery size is frequently cut to a minimum to reduce cost.



BACKWARD NORMAL FORWARD

FIG. 40—Effect of third-brush setting.

Factors Influencing Output of Three-Brush Generator.—If the three-brush dynamo were adjusted to meet maximum requirements, its output would be excessive, resulting in severe overcharging of the battery. It is impracticable to rely on the driver to switch off the dynamo at discretion, and other means of regulating the output are necessary.

(*a*) *Setting of Third Brush.*—By varying the position of the third or exciting brush it is possible to obtain a certain amount of regulation of the generator current without affecting the voltage very appreciably. For example, a 12-volt generator may be designed to give 8 amperes with an exciting voltage of 9 volts. By rocking the third brush back by about a commutator segment, the current can be halved; while by shifting it forward somewhat, the current can be increased

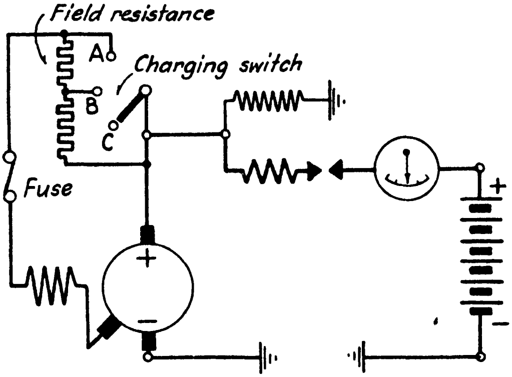


FIG. 41.—Connexions of three-brush generator with three-rate charging switch.

Provided the brush is not rocked too far forward, both voltage and current remain fairly constant for each setting over the whole speed range. These effects are illustrated in Fig. 40.

(*b*) *Three-Brush Generator with Additional Field Resistance.*—The third brush is usually set to give the required maximum output, which is reduced when desired by inserting resistance in the field circuit. When used in this country, the practice is to have two or three charging rates, as desired. The connexions are shown in Fig. 41 for 3-rate charging, and the corresponding regulation curves are shown in Fig. 42. (Some makers do not have the field fuse in circuit when the charging switch is in position *A*.) As seen, insertion of resistance in the exciting circuit raises the cutting-in speed, which is undesirable where the vehicle is used mainly for low speeds with frequent starting. The provision of the 2- or 3-rate charging switch does much to help the driver to keep his battery well charged, especially when the resistance in the field circuit is cut in or out by means of the lighting-control switch.

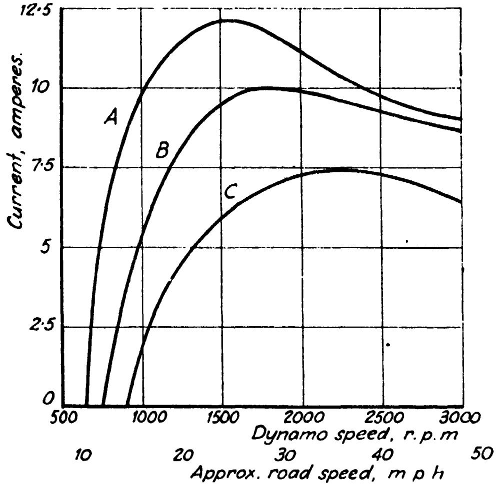


FIG. 42.—Regulation curves of three-brush generator. Curves *A*, *B* and *C* correspond with positions *A*, *B* and *C* in Fig. 41.

(*c*) *Effect of Battery Voltage.*—An acid cell varies from about 1·8 volts when supplying current to 2·7 volts just before charging is completed. Thus to complete the charge of a 12-volt battery, 2·7 × 6 = 16·2 volts will be needed. For this reason the lamps must be able to withstand a certain voltage variation.

The effect of the state of charge on the voltage and charging current taken from the three-brush dynamo is shown in Figs. 43 and 44. It is seen that the current is higher when the battery is charged than when it is discharged. This is the opposite to what is required, but it must be accepted as part of the compromise entailed by this method of control.

(*d*) *Effect of Resistance in Charging Circuit.*—When a generator works in parallel with a battery the charging voltage depends on the resistance of the leads and battery. An increase in resistance by 0·1 ohm due to a bad connexion or a sulphated battery may raise the voltage and current enough to endanger battery, dynamo and lamps. For sulphated batteries, which need a small charging current, this condition is bad; for in such batteries a large charging current dislodges active material and causes active gassing. These facts serve to explain why so many batteries are ruined by overcharging and why the three-brush dynamo is the cause.

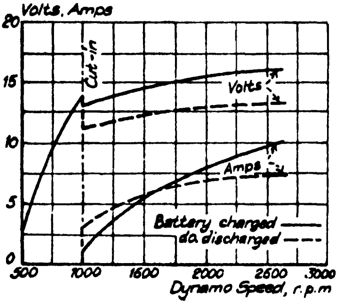


FIG. 43.—Effect of state of battery charge on terminal voltage.

(*e*) *Effect of Speed.*—In the three-brush dynamo the current rises to a maximum as the speed is increased, and then falls as the speed is further increased (*see* Figs. 42 and 44). At high speeds, therefore, the dynamo current may fall below that required by the lamps, and part of the load be thrown on the battery.

The lower the state of the battery charge, the more likely is this to occur.

Put briefly, the dynamo voltage is fixed by the battery voltage—hence the higher the battery charge, the higher the charging current. Also, while the dynamo limits the current, it does not keep it constant.

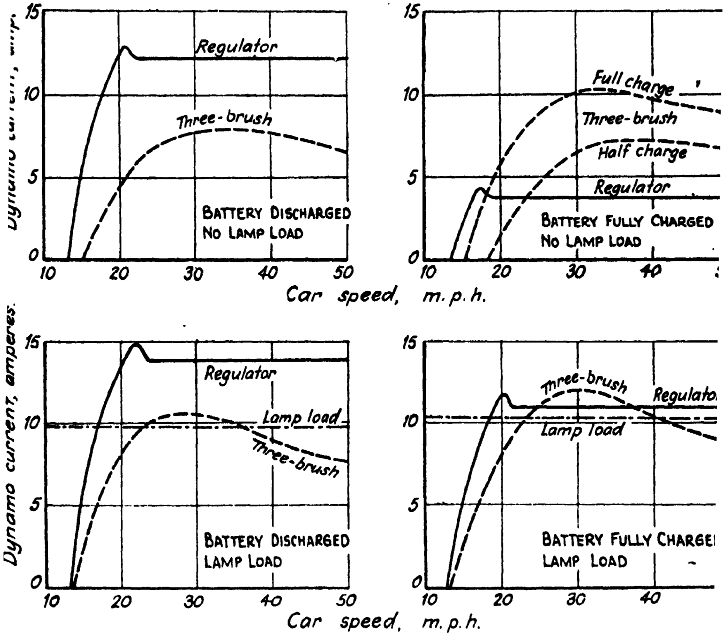


FIG. 44.—Comparison between three-brush and regulator-controlled generators under different conditions.

(*f*) *Dependence on Battery.*—With the three-brush dynamo the battery fixes the voltage; consequently it is not permissible to use the generator without the battery. If the battery is disconnected, the dynamo voltage will rise to an excessive value and endanger both lamps and field winding. It follows that there must not be any switch in the circuit which would isolate the battery from the bus-bars.

Commutator Brushes for Generators.—The brushes for automobile generators are worked at densities from 45 to 75 amperes per square inch, the average being about 60 amperes per square inch. For these rather high densities, also for silent running, it is found that electrographitic brushes are suitable, but commercial considerations often lead to the use of graphitic carbon despite some sacrifice in brush life. Six-volt dynamos often use copper-graphite brushes, of a medium metallic content for the main brushes, on account of their greater collecting capacity and lower contact-voltage drop. The possibility of using a harder brush on the 12-volt than on the 6-volt dynamo is a distinct advantage, giving longer life and a cleaner commutator.

The third or control brush must be made of suitable material such as graphitic carbon, otherwise bad sparking will ensue owing to the position of this brush in the field. Since the exciting current is small, the brush can be made thin, and this helps to reduce sparking and heating.

Twenty-four-volt systems employ almost exclusively electrographitic brushes, like the better-class 12-volt systems.

Rapid brush wear, leading to disintegration of the carbons, results from vicious sparking or burning, and may be due either to electrical causes, e.g., open-circuit in winding, or to mechanical causes, e.g., high bars or micas. Excessive oiling or greasing may cause lubricant to get on the brushgear, where it collects copper and carbon dust and may lead to short-circuits. A large brush pressure—5 to 9 lb. per square inch—is employed to prevent the brush leaving the commutator and to reduce the contact voltage drop, which is about 0·8 to 0·9 volt per brush. The smaller electric heating under the brush thus obtained, however, is largely offset by the enhanced heating due to friction. Care must be taken to bed the brushes properly, and to see that they work smoothly in their holders. Loose contacts must be avoided, and the flexibles must be kept clear of earthed metal. (*See* also p. 64.) Box-type brushes are becoming universal. With them contact is better, and the tendency to squeak is reduced.

Bedding of Brushes.—It is important that all brushes are properly bedded. Perfect bedding of the third brush is particularly necessary, as this largely influences the output of the machine. If contact is made at the toe only, the output is raised; if at the heel only, it is lowered. Similarly, trouble may be experienced with the starting motor if the brushes are improperly bedded. (*See* p. 64.)

A simple way to bed a brush is to press it down on to a wood bobbin of the same diameter as the commutator, while a strip of glass-paper or carborundum cloth (but not emery) placed between is worked to and fro. The process may be completed by holding a bedding stone of suitable quality against the commutator while the machine is running. The dust which comes off the stone passes beneath the brushes and rapidly completes the bedding process. Perfect bedding may be expected only after running in.

Care must be taken when undercutting the commutator micas not to leave thin flakes standing. Such flakes not only prevent proper bedding of the brushes, but when the machine is running they lift the carbons off the commutator, and so cause sparking and abnormal brushwear. The universal practice of recessing commutator micas has been a great benefit to the general brush performance.

Power taken by Three-Brush Generator.—In order to gain an idea of the power taken to drive the dynamo, we can consider a 12-volt machine giving a charging current of 8 amperes. Taking 15 volts as the terminal voltage towards the end of charge, the useful output $=15\times8=120$ watts. The efficiency can be taken as 50 per cent., so that the input will be $120/0{\cdot}5=240$ watts $=\frac{1}{3}$ h.p.

An omnibus dynamo giving 40 amperes at 27 volts $=1{,}080$ watts with an efficiency of 0·63 has an input of $1{,}080/0{\cdot}63=1{,}715$ watts or $1{,}715/746=2{\cdot}3$ h.p.

The chief drawback of the low efficiency of the dynamo is the heating due to the losses. The iron and excitation losses do not increase greatly with the speed because, for constant voltage, the flux falls as the speed rises. Brush loss rises rapidly as the speed rises. In these small highly-rated machines, the improvement in cooling as the speed rises is less than the increase in loss, in consequence of which the temperature tends to become excessive at high speeds. For this reason there is now extensive use of ventilated dynamos.

GENERATOR WITH AUTOMATIC VOLTAGE REGULATOR

The Constant-voltage System.—This system is usually exemplified in the combination of a plain shunt-wound generator and an automatic regulator which controls the exciting current. The regulator is of the quick-acting, vibrating-armature type, and works on the same principle as the Tirrill regulator employed in electricity generating stations for controlling the voltage of turbo-alternators.

When a voltage is applied to a circuit, the current rises (*see* Fig. 104); when the voltage is removed, the current falls. If the circuit is highly inductive, like the shunt or exciting winding, the rise or fall is so slow that the phenomenon can be interrupted at any point by the opening of contacts. Thus, by switching in or out of circuit either the exciting winding, or a resistance in the exciting circuit of the generator, it is possible to maintain at any speed the voltage required. The effect is shown in Fig. 45. Switching in and out is effected in a simple manner by means of a relay

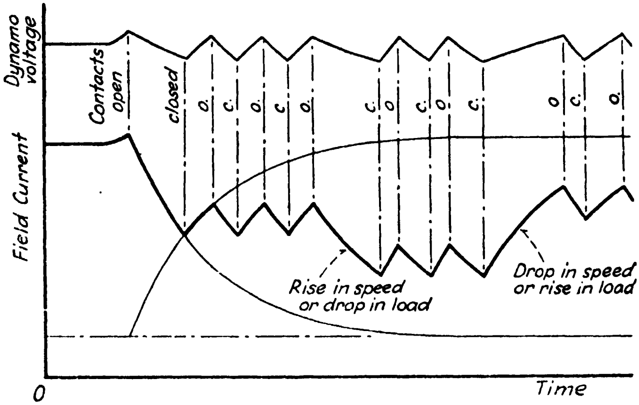


FIG. 45.—Showing rise and fall of generator voltage as exciting current rises (cp. Fig. 104) and falls when contacts close and open.

excited off the dynamo voltage. The construction of such a relay or automatic voltage regulator is shown diagrammatically in Fig. 46.

As in other systems, an automatic cut-out has to be used in conjunction with the voltage regulator (*see* Fig. 47).

Action of Constant-voltage Regulator.—The action of the vibrating-armature regulator may be followed from the diagram in Fig. 46. An iron bar, capable of vibrating, is controlled by the spring *Sp* and the electromagnet *V*. The spring tends to keep the contacts k_1 and k_2 together, while the electromagnet when excited tends to draw them apart. When k_1 and k_2 are in contact, the field rheostat *R* is short-circuited; when apart, *R* is in circuit. As the speed and voltage of the dynamo rise, the exciting current in the coil of the electromagnet increases until eventually the iron bar is pulled towards the magnet and the contacts k_1 and k_2 are separated, inserting the rheostat *R* in the exciting circuit. This causes the exciting current in *V* to fall and enables the spring again to close k_1 and k_2 and short-circuit *R*. The cycle then recommences and the contacts are opened and closed by the to and fro motion of the iron bar as the exciting current rises or falls. The contacts vibrate at 30 to 70 times a second, or even more rapidly in some cases. As the speed of the machine increases, the amplitude of the vibration increases and the period of interruption becomes

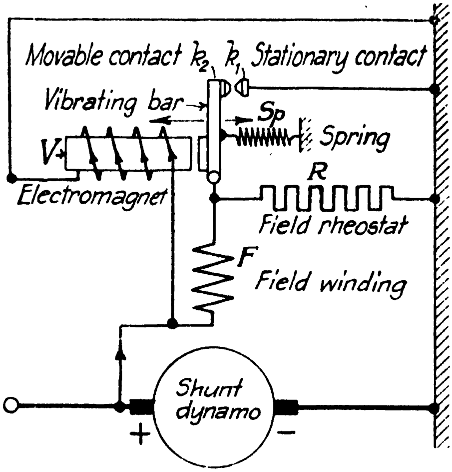


FIG. 46.—Elements of automatic voltage regulator.

longer. By suitably proportioning the parts, the duration of the insertion of the rheostat adjusts itself automatically to keep the mean voltage constant at the desired value independently of load and speed. It is possible to use an alternative arrangement that dispenses with the resistance *R*, and relies solely

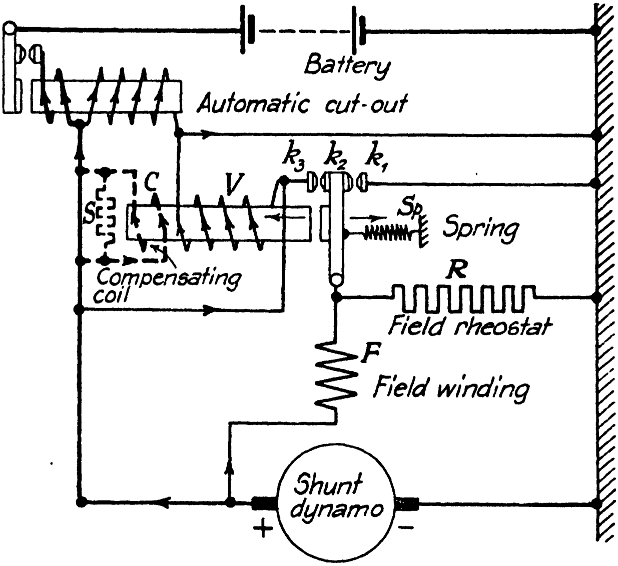


Fig. 47.—Automatic double-contact voltage regulator with compensating winding *C* and adjustable shunt *S*.

on inserting and short-circuiting the field winding *F*. It will be noted that the action of the regulator is independent of the battery, so that in case of the latter failing for any cause, the dynamo and regulator alone—at any speed above the cutting-in speed—can supply the requisite current for coil ignition or lighting.

A modification of the single-contact regulator illustrated in Fig. 46 is shown in Fig. 47, in which a second pair of contacts k_2 and k_3 is employed. When the electromagnet is strong enough to close k_2 and k_3 the field winding F is short-circuited. With this arrangement the first pair of contacts k_1 and k_2 operates as already described and controls the voltage when the speed is low or the load is heavy. When the speed rises considerably, or the load becomes very light, k_1 and k_2 remain permanently apart, while the second pair, k_2 and k_3, opens and closes. When the first pair is operating, therefore, the rheostat R is put in and out of circuit; when the second pair is operating, the field winding F is put in and out of circuit. When k_2 and k_3 touch, the resistance R is placed in parallel with the load; when they are not in contact, R is in series with the field winding, so long as k_1 and k_2 are separated. The construction of the double-contact regulator is shown in Fig. 48.

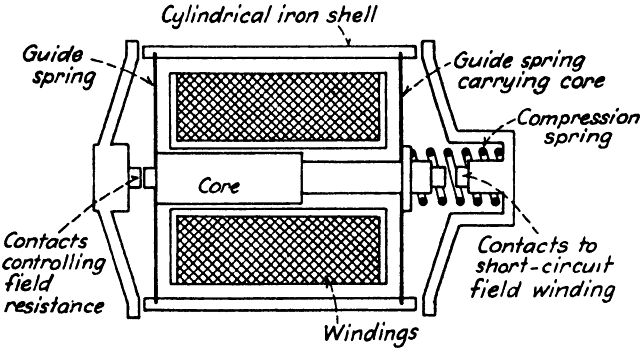


FIG. 48.—Double-contact voltage regulator.

The double-contact regulator leaves the designer more freedom in proportioning the parts, and makes it possible to deal with a larger field current and to use a smaller series resistance. On the other hand, it is more complicated and needs more careful adjustment than the single-contact regulator. Although the latter entails heavier duty on the contacts, it is being widely used, when the field current can be suitably reduced, on account of its simplicity.

A constant-voltage regulator will operate at a predetermined voltage, and under these conditions the empty battery will receive a high-charging current which will gradually fall off as the battery voltage rises, until when the battery is full it receives a trickle charge sufficient to keep it in good condition. Further, when lamps, etc., are switched on, the fall in battery voltage will cause the dynamo to give an increased output to meet the extra demand. This simple form of voltage control is impracticable, because the demands made by a discharged battery are too severe—causing over-heating of the dynamo and the battery. For this reason the compensated-voltage regulator is employed on automobiles.

The Compensated-voltage Regulator.—According to the state of charge of a cell, the voltage required may vary from 1·8 to 2·7 volts, so that if the regulator were set to maintain a constant voltage of 16·2 volts for a 6-cell battery, it is obvious that with a discharged battery and the lamps in circuit the dynamo would be called on to give a very large current. Consequently, it is the invariable practice to provide compensation on the regulator to give a falling voltage characteristic. This is obtained by means of a compensating or series winding. The extra current coil *C* needed for this purpose is shown dotted in Fig. 47. This current coil *C* assists the voltage coil *V*, and by varying the current in the shunt *S* the amount of compensation can be adjusted to meet the required conditions. It is common practice to adjust the regulator to give 15 to 16 volts at no-load, i.e., the voltage of the battery when fully charged. The shunt *S* is then adjusted to reduce the voltage on load so that when charging the empty battery at the rated output current of the dynamo the voltage is about 13·5. By suitable design any combination of battery load can be met both for acid and alkaline batteries.

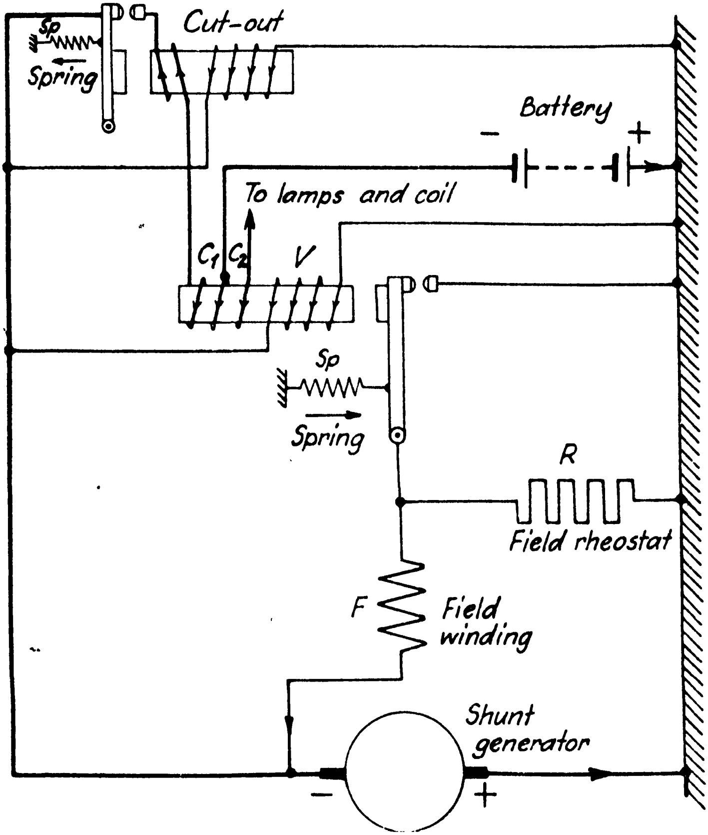


Fig. 49.—Automatic single-contact voltage regulator with divided compensating winding. (In some cases, *R* is on live side and *F* is connected to positive pole)

An alternative arrangement is to sub-divide the compensation as in Fig. 49, one portion C_1 being placed in the external circuit of the main dynamo, the other C_2 in the lead from the battery to the lamps, etc. The coils C_1, C_2 and V assist each other in energizing the magnet system and affecting the movement of the armature. This arrangement permits a more rapid charge to be given to the battery when the lamps are not in circuit, and so enables a discharged battery to be brought up more quickly.

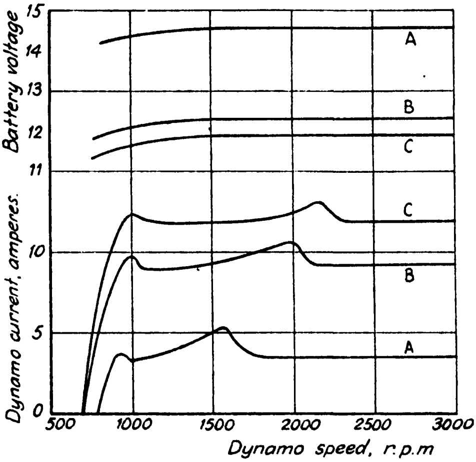


FIG. 50.—Regulation curves of compensated-voltage regulator.

Fig. 50 shows typical characteristic curves for a compensated-voltage system. The characteristics are somewhat modified by a change in temperature. The resistance of the regulating coil V—if of copper—increases as the temperature increases, causing the regulator to control at a higher voltage. Means for overcoming temperature effect are discussed on page 115.

(*a*) *Wear of Contacts.*—On commercial vehicles with large dynamos, the field coils are sometimes divided into two parallel circuits, each of which is controlled by a regulator, to reduce the load on the contacts.

Regulators for four-pole dynamos have a heavier load imposed on them than regulators for two-pole dynamos. Decreased wear of the contacts results from absorbing in a shunted resistance part of the field energy released as the contacts separate. This reduces the frequency of vibration of the regulator armature, which is counteracted by an additional coil on the regulator wound in opposition to the main shunt winding, thereby causing the contacts to close more rapidly.

(*b*) *Regulator Setting.*—If a healthy battery be found to be persistently undercharged there is an indication that the regulator setting is too low, and that the voltage should be raised. There are two ways of increasing the charging current. The one is to raise the voltage of the whole system by adjusting the regulator setting. If overdone this gives an excessive charge injurious to the battery. The other—a matter for the designer—is to make the compensation curve less steep, which cannot harm the battery.

(*c*) *Temperature Compensation.*—The action of a voltage regulator is affected by temperature. If the device is adjusted to function correctly when cold, the setting will not be correct when the device is hot. At 20° C. (68° F.) the resistance temperature coefficient of copper is 0·4 per cent. per degree C., that is, for every degree above 20° C., the resistance increases by 0·4 per cent. A rise in temperature from 20° to 100° C. causes the resistance of a coil of copper wire to increase by $0{\cdot}4 \times 80 = 32$ per cent. With a constant exciting voltage, this means a drop of 32 per cent. in the exciting current or ampere-turns.

The reduced magnetic pull on the vibrating armature prevents the regulator operating until a higher voltage is reached, consequently the battery receives a higher charging current with a hot than with a cold regulator, and in summer than in winter.

Since the resistance of the electrolyte falls as the temperature rises, the voltage required to supply a fixed charging current to a battery must vary inversely as the temperature.

In Fig. 51 the effect of temperature is shown. The uncompensated regulator gives the battery larger charging currents in summer than winter.

(*d*) *Application of Bimetal Strip to Regulator.*—This simple device is shown in Fig. 52, and its action is clear from Fig. 53. As the force on the screw, i.e., the couple tending to hold the regulator contacts together, falls as the temperature rises, the voltage setting of the regulator falls. The compensation effected is not enough to make summer voltage setting less than winter voltage setting, but it gives the battery a boost after a stop. This is useful to motorists who make frequent use of the starter.

(*e*) *Use of Temperature-sensitive Windings.*—Here use is made of the fact that the resistance of a conductor depends on the temperature and on the material of which it is made. Two coils A and B are wound on the same core and connected so that their magnetizing ampere-turns oppose. Both A and B are of copper with a resistance temperature coefficient of 0·4 per cent. per degree C. at 20° C. In series with A there is a resistor S of negligible temperature co-efficient, making the combined temperature co-efficient of AS about 0·1 per cent. per degree C. To show the action of such a device, let the ampere-turns on A and B be 300 and 200 respectively at

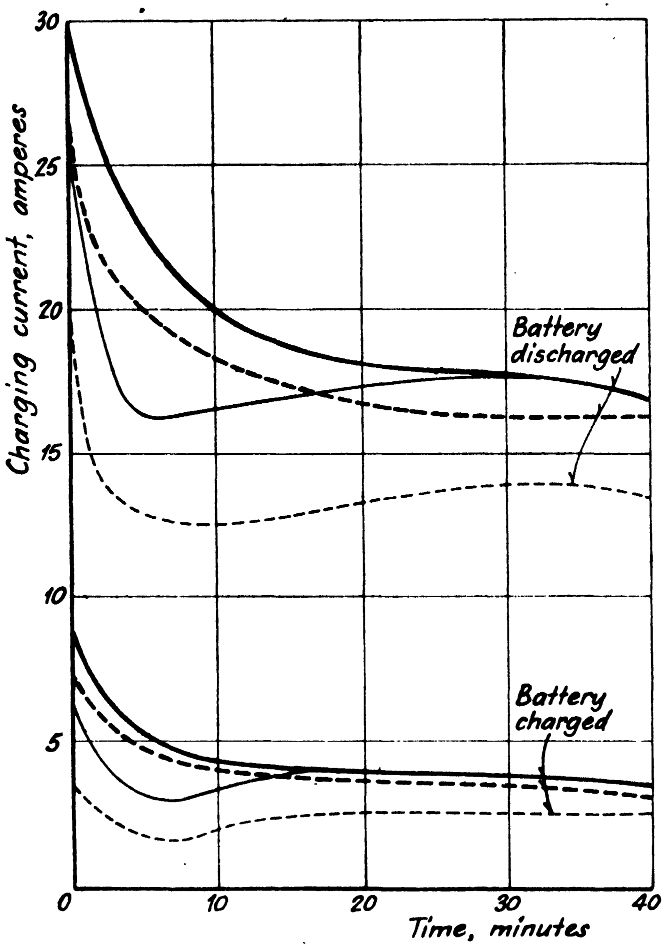


FIG. 51.—Influence of temperature on action of automatic voltage regulator.

———— summer. – – – – – winter.

Two heavy curves in each group—compensation by bimetal strip.

Two light curves in each group—no compensation.

20° C. Since these are in opposition the resultant ampere-turns at 20° C. are 300 − 200 = 100.

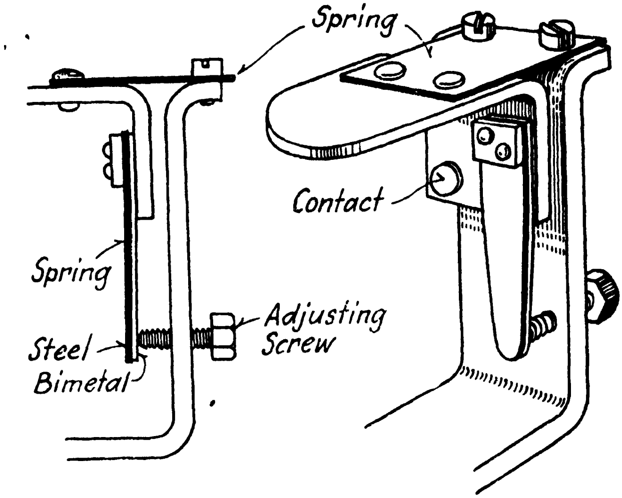


FIG. 52.—Bimetallic temperature-compensating device for voltage regulator.

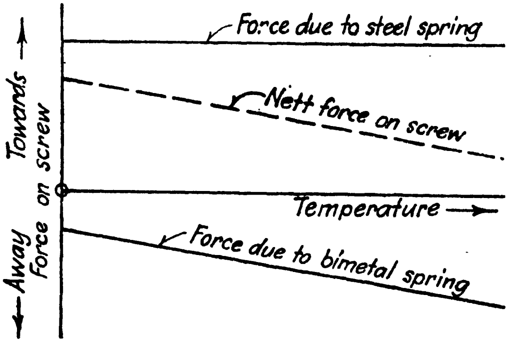


FIG. 53.—Characteristic of bimetallic spring.

At a temperature of 100° C. (80° C. rise) the conditions are as follows. The resistance of *AS* has increased by 80 × 0·1 = 8 per cent., so that the ampere-turns of *A* are reduced by 300 × 0·08 = 24, that is, from 300 to 276. In coil *B* the resistance has risen by 80 × 0·4 = 32 per cent., resulting in a decrease of 200 × 0·32 = 64 ampere-turns, leaving 200 − 64 = 136.

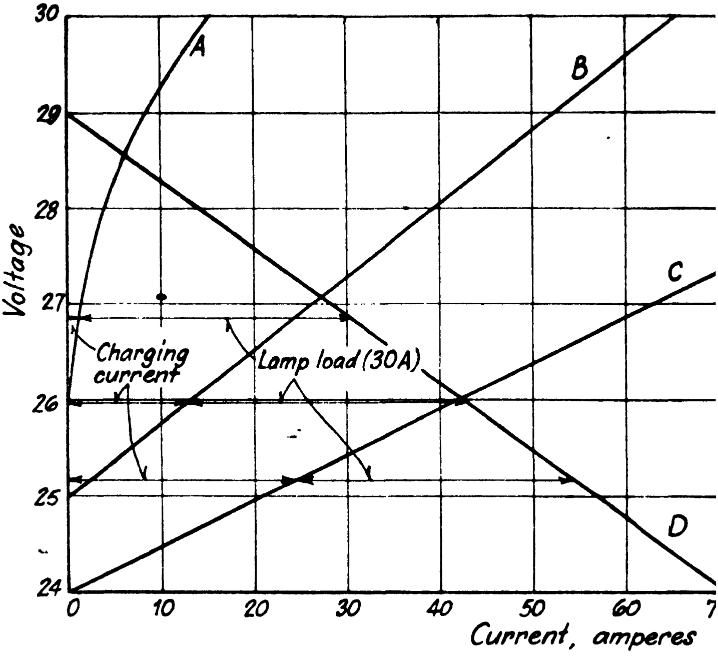


FIG. 54.—Parallel working of compensated-voltage generator and battery (constant speed assumed).
Battery characteristics : *A*, charged ; *B*, partly charged ; *C*, discharged. Generator characteristic : *D*.

Consequently the resultant ampere-turns are now 276 − 136 = 140. In other words, the excitation has risen from 100 to 140 ampere-turns, i.e., by 40 per cent.

A glance at Fig. 46 will show that strengthening the magnet has a similar action on the contacts as weakening the spring.

By suitably designing the temperature-sensitive winding, compensation can be given any desired value; e.g., the temperature compensation winding can be made to raise the winter voltage setting above that for the summer.

Action of Compensated-voltage Generator and Battery in Parallel.—The generator and battery are connected in parallel by means of the cut-out, as in the case of the three-brush generator, and the load is placed across the common bus-bars (Figs. 47 and 49). In Fig. 54 are shown the loaded generator characteristic for a given regulator setting and the characteristics for a charged, partly charged and discharged battery. The generator was rated at 1,600 watts at 1,000 r.p.m. and the 24-volt acid battery had a capacity of 175 ampere-hours.

Suppose a lamp load of 30 amperes is switched on, then the charging and total currents are found as shown by drawing a horizontal line corresponding to 30 amperes between the generator characteristic and the relevant battery characteristic. For the charged, partly-charged and discharged battery the charging current at this load is 1, 13 and 24 amperes respectively, and the generator load is 31, 43 and 54 amperes respectively.

The corresponding voltages are seen to be 26·8, 25·9 and 25·2 volts respectively. If the load is not adjusted to the chosen value of 30 amperes, e.g., if the same lamps are left in circuit, the current will vary because the voltage changes somewhat.

If the lamp current exceeds the generator current, the battery will make up the difference—i.e., the battery will give a discharging current.

Whatever the load conditions, the algebraic sum of the dynamo, battery and load currents is always zero;

while the voltage of the system adjusts itself to satisfy this condition.

Advantages of Voltage Regulator.—The advantages of the compensated-voltage regulator can be summed up as follows: By preventing overcharge, maintenance (topping-up, etc.) of the battery is reduced, while its life is prolonged; the voltage cannot rise above a predetermined value, no matter whether the battery is in circuit or not, thus reducing risk of lamp burn-outs; dynamo and regulator can function independently of the battery; the charging current is greatest when the battery is discharged and falls off gradually as the charge increases; since the battery has not to control the dynamo, its capacity may be fixed by other considerations, such as starting or lighting. Consequently it is often possible to install a smaller battery than with the three-brush dynamo.

Interpretation of Ammeter Readings.—As usually connected, the ammeter indicates the current passing in or out of the battery, and not the dynamo current. Consequently, properly interpreted, the ammeter reading—during charging—gives an indication of the condition of the battery. A low reading indicates a well charged, and a high reading a discharged, battery. With this control it must not be assumed that the charging system is out of order because of a low ammeter reading. Increasing the current under such conditions merely means overcharging a fully-charged battery. Owing to misuse and damage arising from such misinterpretation, there is a growing tendency to replace the ammeter by a red warning light, which goes out whenever a charging current flows.

After starting from cold, particularly when the car has been idle for some time, the ammeter may read high for a shorter or longer time according to circumstances, but as soon as the battery becomes charged the current drops to its trickle value. When the battery warms up the resistance of the electrolyte decreases, and the value of this trickle current may rise appreciably unless the voltage regulator is designed to deal with this effect.

Combined Regulator and Cut-out.—To reduce costs and simplify the equipment, these two items may be built as one unit, as shown in Fig. 55, where a common armature serves both functions. The initial movement of the armature closes the circuit between battery and generator, while a further movement operates the regulator contacts. In another arrangement the regulator and cut-out have separate armatures, but a partly common field system. When the regulator

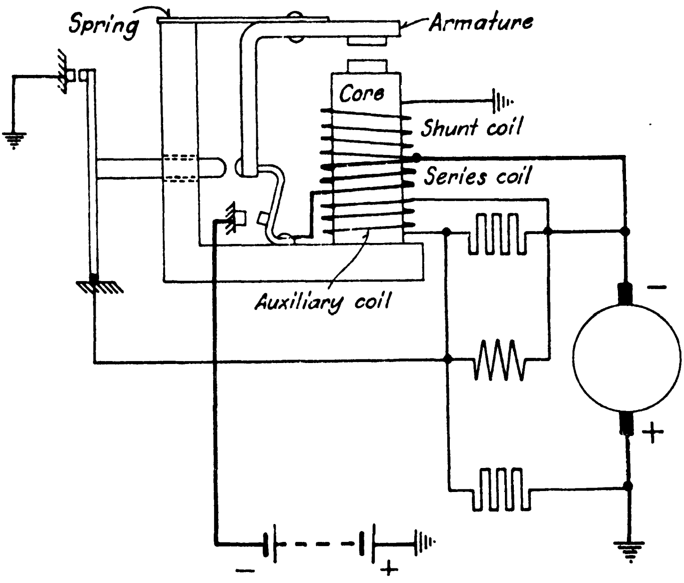


FIG. 55.—Combined voltage regulator and cut-out.

contacts are closed, the auxiliary coil assists the regulator shunt winding to magnetize the core ; when the contacts open, the current in the auxiliary coil reverses and tends to demagnetize the core.

Such a combined unit is commonly used with the single-contact regulator, and being built on a common frame secures compactness. Further compactness is obtained by combining a junction and fuse box with the unit.

Comparison between Three-Brush and Voltage-Regulator Generators.—Although the regulator dynamo has marked advantages over the three-brush dynamo, it must be remembered that as a practical compromise the latter has proved satisfactory, especially for private cars. Its chief merit is simplicity ; its chief demerit is its severity on the battery, by overcharging it when full and starving it when empty With the dynamo controlled by the voltage regulator, the size of the battery on a private car is determined by starting conditions—in the case of a bus or coach it is fixed by the lighting load. With the three-brush dynamo a battery of more ample capacity may have to be installed to lessen the effects of overcharging. This fact may more than offset the extra cost of the regulator.

Though universally employed in Germany, the voltage regulator in this country was first used on commercial vehicles only. It is now widely used on private vehicles. For public passenger-carrying vehicles the three-brush dynamo is out of the question. America, the home of the three-brush dynamo, now uses the voltage regulator on buses and on many cars.

In Fig. 44 typical characteristics of a three-brush generator and a compensated-voltage regulator are given to illustrate what has been said earlier in this chapter.

CHAPTER V

MISCELLANEOUS ELECTRIC EQUIPMENT

THE LIGHTING SYSTEM

ELECTRIC lamps are used on many parts of the motor vehicle. In addition to the headlamps and the legal side and tail lamps, there may be fitted a stop light, fog or pass light, spotlight, reversing light, direction signal lights, dash lights, interior lights, warning lamp, inspection lamp, etc.

When used in the automobile industry, electric lamps are referred to as "bulbs." The carbon filaments of the earliest lamps were too fragile for the then road conditions, and the battery too undeveloped to supply their heavy consumption. Electric lighting of automobiles became feasible with the development of the metal-filament lamp, the provision of a satisfactory method of controlling the voltage of the lighting dynamo, and with the introduction of the automobile battery. Even so, satisfactory working is dependent upon good conditions. Bad lighting often results from poor condition of the battery, traceable either to under- or to over-charging. Similarly a bad connexion or poor voltage regulation may have serious results. With voltage below normal, the candle-power of the bulb falls rapidly, though life is prolonged; over-voltage increases candle-power and efficiency, but reduces life. Mechanical vibration is particularly bad for the life of the bulb—a high-frequency vibration, as from a horn, transmitted to the lamp may destroy the filament.

Vacuum and Gas-filled Bulbs.—The earlier metal-filament lamps were of the vacuum type, and with them it was possible to obtain a consumption of about 1·5 watts per candle-power. The striving after higher efficiency—more light for less consumption—led to the coiled tungsten-filament in a bulb containing an inert gas at about two-thirds atmospheric pressure when cold, and atmospheric pressure when hot (filament about 2,800° C.). The consumption of the gas-filled is about half that of the vacuum type.

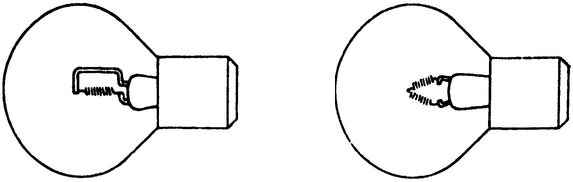
Gas-filled have almost entirely superseded vacuum bulbs for side as well as for head lamps, owing to their superior brilliancy and concentration of light source, and the improved constancy in light-output due to lessened blackening of the larger bulbs.

The latest development—the coiled-coil—is also finding its way into the automobile industry.

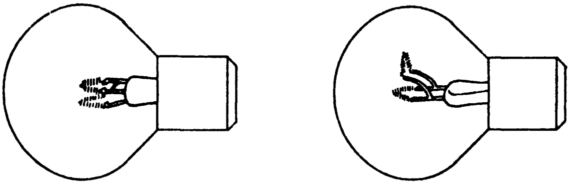
Shape of Bulb Filament.—The low voltage used on automobiles permits of short and thick filaments, sufficiently robust—except in extreme cases—for the rough service demanded of them. The ideal point filament required for accurate adjustment of the light-source at the focus of the parabolic reflector is neither practicable nor desirable. A point source gives a parallel beam of diameter equal to that of the reflector, and as such is suitable for searchlights or spotlights. In order to obtain the illumination needed for headlights, a filament of finite dimensions is required, while such a filament is more easily focussed in service.

Line versus V Filament.—The filaments used in automobile bulbs have different shapes. For sidelights the accepted form is mostly a horseshoe or bow—Fig. 56 (*f*). For headlights there is no such consensus of opinion. Some makers specify the line filament, Fig. 56 (*a*), but more prefer the V filament, Fig. 56 (*b*).

The advantage claimed for the line or axial filament

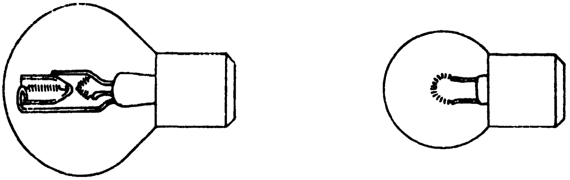


(*a*) Line filament (*b*) V filament



(*c*) Bi-focal filament
Lower for driving; upper for dipping

(*d*) Bi-focal filament
Lower for driving; upper for dipping and slueing



(*e*) Twin filament
V for driving; line for dipping

(*f*) Horse-shoe filament
(Side and rear lights)

FIG. 56.—Electric bulbs for automobiles.

is that, if accurately made and properly placed in an accurately shaped reflector, some portion of the filament must approximately coincide with the focus of the reflector, whence there is freedom from any dark central spot in the beam. The parts of the filament outside the focus provide a certain amount of scattered light, and this combined with a suitable glass cover produces a uniform oval beam giving a suitably spread driving light. The length of the filament, however, makes it practically impossible to confine the beam within a very narrow angle.

The V filament is less easy to dispose relative to the focal point of the reflector to avoid dark spots; but owing to the short length of the filament—from front to back—the beam can be confined within a narrower angle. With this form of filament the distribution of light is less uniform over the sectional area, but with the V parallel to the road and a suitably moulded glass cover the light is diffused into a wide horizontal beam. The ideal is to obtain this transverse spread without increasing the beam vertically.

From the driver's point of view the uniform circular beam is satisfactory, but the shallow beam produced by the V filament is more easily dipped to prevent dazzling oncoming traffic, while its greater width illuminates the verge or kerb more effectively. Probably about 75 per cent of bulbs for headlights have the V filament.

From page 129 it is seen that, for equal ratings, V filaments are less efficient (fewer lumens per watt) than line filaments. This is attributed to the cooling effect of the gas stream on the open turns at the apex of the V, and to the cooling effect of the support at the V, where such exists.

Double-filament Bulbs.—Double-filament bulbs are used in various ways.

(1) *Combined Head and Sidelight, Twin Filament.*—At one time, on small cars, sidelamps were dispensed with, the headlamps being fitted with a double filament. The one filament was of the conventional type

for night driving; the other, an auxiliary filament, the exact position of which was immaterial, was a substitute for the sidelamps, and satisfied statutory requirements for parking and driving without headlights. This type is obsolescent.

(2) *Anti-dazzle, Twin-filament Headlight with Internal Reflector.*—A widely used class is the double filament arranged to provide a normal driving beam and a dipped passing beam. In one type, shown in Fig. 56 (*e*), a V filament is used for driving, and a line filament, in front of the focal point and half shielded by a horizontal cap below it, for passing. This second filament produces a wide-angled conical beam, while the effect of the shield is to cut off the upper-half completely.

(3) *Anti-dazzle, Bi-focal Headlight.*—In the other type there are two V filaments, both unshielded. The one gives the normal driving light, the other is so far offset from the axis of the bulb and the reflector as to bias the resulting beam considerably. The two ways of arranging these filaments are shown in Fig. 56 (*c*) and (*d*). With the two filaments parallel (American type), Fig. 56 (*c*), the auxiliary is above the driving filament. With the plane of the auxiliary filament at right angles to that of the driving filament, Fig. 56 (*d*), the former may have its apex vertically upwards (12 o'clock position), or pointing "north-east" (10.30 o'clock position), to give the dipped beam a bias towards the near side of the road.

The objection urged against the devices in (3) is that there is not so much a complete redirection of the beam, e.g., a dip, as a redistribution of the light in it, leaving possibly a distressing amount of light above the horizontal plane to dazzle the on-comer.

In the Table on page 129 a representative selection of automobile bulbs is given of the types illustrated in Fig. 56 (*a*) to (*e*). All these bulbs are gas-filled. The diameter of the headlight bulb is generally 38 mm., and of the side, tail and dash bulbs 18 mm.

Comparison between 6-volt and 12-volt Bulbs.—For the same efficiency, measured in candle-power or lumens per watt, the brightness of the filament of a given type of lamp depends on the consumption in watts and is the same irrespective of the candle-power or voltage, if secondary considerations are ignored. The actual candle-power is proportional to the surface area of the filament ; also for the same candle-power and efficiency, the consumption in watts is the same for 12 as for 6 volts. From these facts it can be shown that for a given candle-power a 12-volt lamp has a filament 60 per cent. longer than that of a 6-volt lamp, but its diameter is only about 60 per cent. of the diameter of the 6-volt filament. Constructional conditions modify this result.

Considering now the actual bulbs, the one extreme is the 6-volt headlamp, where the filament is relatively short and thick, leading to excessive loss in the supporting wires and reducing the temperature at the ends, resulting in a lower efficiency. For currents over 5 amperes there is also the difficulty of accommodating the leading-in wires with the small bayonet cap used. The other extreme is the 12-volt side lamp, owing to the fact that filaments of less than ⅓ to ½ ampere rating are too fragile. The former extreme limits the 6-volt bulb to 30–36 watts, while the latter gives the smallest 12-volt bulb a 4-watt rating. The effect on the efficiency in lumens per watt is seen in the Table on page 129. One reason for the different values of efficiency is the stipulation that similar 6- and 12-volt bulbs shall have equal life under actual running conditions. For

AUTOMOBILE BULBS (Gas-filled).

I. HEADLIGHTS

Filament		Fig. 56.	Volts.	Watts.	Lumens per Watt.
Single—	line	(*a*)	6	12	14·3
,,	line	(*a*)	6	18	14·7
,,	V	(*b*)	6	18	13·2
,,	line	(*a*)	6	24	15·9
Bifocal—	V, both ...	(*c*)	6	18	14·0
,,	V ,, ...	(*d*)†	6	24	14·5
Twin*	V, driving ...	(*e*)	6	18	12·6
	line, reflected			18	14·2
Single—	line	(*a*)	12	24	16·5
,,	V	(*b*)	12	24	16·2
,,	line	(*a*)	12	36	18·5
,,	V	(*b*)	12	36	17·5
,,	V	(*b*)	12	48	19·2
Bifocal—	V, both ...	(*d*)†	12	24	15·7
,,	V ,, ...	(*d*)†	12	36	17·5
Twin*	V, driving ...	(*e*)	12	36	16·0
	line, reflected			24	15·1
Single—	V Bus type	(*b*)	24	24	10·8‡
,,	V ,, ...	(*b*)	24	36	12·0‡

II. SIDE, TAIL AND DASH LIGHTS

Filament	Fig. 56.	Volts.	Watts.	Lumens per Watt.
Single horseshoe ...	(*f*)	6	3	6·7
,, ,, ...	(*f*)	6	6	9·5
,, ,, ...	(*f*)	12	4	6·5
,, ,, ...	(*f*)	12	6	8·6
,, ,, ...	(*f*)	24	6	7·5‡

*** Graves type (See Fig. 62). † 10.30 o'clock position. ‡ At 28 volts.**
1 mean spherical candle-power=12·6 lumens.

12-volt headlights the rating usually employed is 36 watts. In this connexion, too, it has to be remembered that the longer filament of the 12-volt bulb is what is wanted for the driving beam. Against the 12-volt system, the fact that the lowest bulb-rating is 4 watts, compared with 3 watts with the 6-volt system, is of less consequence than the more fragile filament.

The 6-volt system appears to be standard on most American cars, and on many Continental makes. It is also used on small British cars. To aid cheapness, the bi-focal bulbs (*c*) and (*d*) and the twin-filament bulb (*e*) of Fig. 56 are often used instead of the more expensive dipping reflector. It might also be mentioned that 12-volt lamps for 60 watts are also used, but there is a movement to limit the maximum rating to 36 watts.

For commercial vehicles the 24-volt system has been widely adopted, and makers—rather against their will—have to make 24-volt bulbs. The objection arises from the necessarily fragile filament having to withstand the rough-and-tumble service conditions inseparable from motor vehicles.

HEADLAMPS

The requirements to be satisfied by the headlights are: A powerful beam of light to illuminate objects 200 yards ahead to enable the driver to pull up under such adverse conditions as high speed, slippery road surface, poor braking ability; sufficient dispersion to permit driver to see kerbs, verges, potholes, signposts, etc., and freedom from light and dark spots; prevention of glare to ensure safety to oncoming traffic, yet with ample light for safe driving; good mechanical and weatherproof construction.

Standard practice is to use a parabolic reflector with the filament of the bulb at or near the focal point. The diagram in Fig. 57 shows the cross-section of a parabolic reflector with the bulb at *B*, the filament being considered to be a point source at the focus. The full-line rays represent direct light, and the dotted rays reflected light. As shown, such reflectors have the property of reflecting the rays of a source of light, concentrated at the focus, into a parallel beam. It is seen that the beam consists principally of reflected light, the remainder of the direct rays being dispersed as stray light. Except for the small amount of light cut off by the bulb itself, the beam is strongest along the axis, the illumination falling off towards the edge of the beam to an extent depending on the shape or depth of the reflector. A deep, narrow-angled reflector (Fig. 58 (*a*)) gives a concentrated beam with but little stray light, rendering it

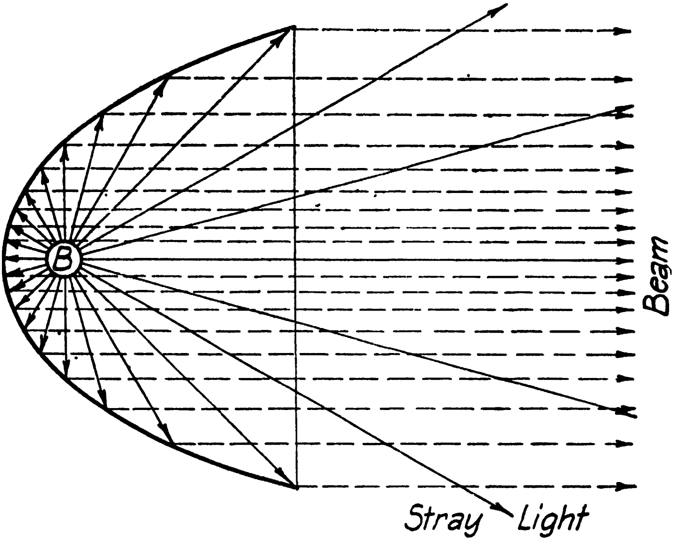


FIG. 57.—Parabolic reflector with bulb at focus.

suitable for spotlights. On the other hand, a shallow wide-angled reflector (Fig. 58 (*b*)) gives much stray light and a less concentrated beam. With a sufficiently large filament such a beam is suitable for headlights, the scattered light being essential for illuminating the sides of the road. For a wide beam the opening angle should be large. (The opening angle is the angle contained between the lines drawn from the edge of the reflector to the focus.)

The exact location of the filament in the reflector is important, as indicated diagrammatically in Fig. 58 (*c*). The full-line ray indicates a filament correctly placed at the focus, the reflected light forming a parallel beam. If the filament is too far back, i.e., too close to the reflector, the beam becomes divergent and less concentrated, as indicated by the dotted ray; if too far forward, the rays (chain dotted) are reflected across the axis at a point a short distance in front of the lamp, and thereafter the beam is divergent with a central dark spot. In either case the lamps will have a poor range and will cause dazzle to approaching traffic.

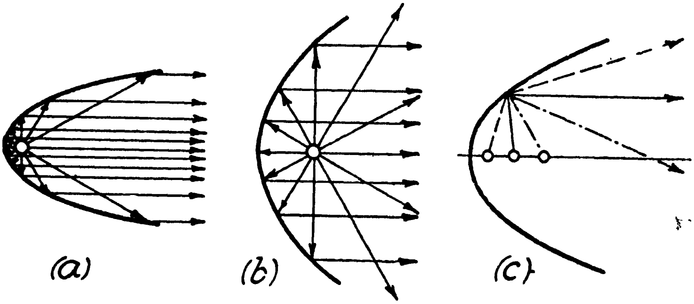


FIG. 58.—(*a*) Narrow-angled reflector—short focal distance.
(*b*) Wide-angled reflector—long focal distance.
(*c*) Effect of position of bulb in reflector.

With a highly concentrated source of light, such as is given by a gas-filled bulb, accuracy of reflector shape is important, otherwise there will be great variation in the beam intensity, giving rise to streaks and patches. A badly focussed bulb not only gives a poor driving light, and dazzles oncomers, but the sharp contrasts of light and dark it produces are dangerous to the driver and fatiguing to the eye. With a view to reducing the amount of adjustment, eliminating focussing devices, and producing a spread beam, a filament of appreciable dimensions becomes necessary.

The headlamps are mounted about one yard above the road surface. If mounted too low, small objects and road inequalities throw exaggerated shadows. The two headlights are adjusted so that their beam axes meet at about 200 yards in front of car. The mountings should be rigid and, preferably, not attached to the wings only. A variation in trim of only 1° in the lamp gives a dip of 5 feet at 100 yards. Vibration should be avoided, as this reduces bulb life. Rubber headlamp mountings are successfully used to minimize vibrations and lengthen life of bulbs.

Correct alignment and focussing are essential for the best results. The two lamps must be aligned so that their beams are directed straight ahead, i.e., parallel with the road and with each other. As shown in Fig. 58 (*c*), for a parallel beam the filament must be as near as possible to the focus of the reflector. Alignment and focussing can be checked so as to conform with the recommendations of the Ministry of Transport by placing the car on level ground not less than 25 feet away from a vertical wall. The front of the car must be square with the wall and the beams from the headlamps must meet the wall at right angles.

In order to obtain as intense a beam as possible, the surface of the reflector is highly polished. Sometimes the polished surface is protected by a thin coat of varnish. This practice may be objected to owing to the falling off of reflecting power in course of time. The lamps should be made weatherproof, to give protection against dust, water and chemical action. In this connexion it is inadvisable to varnish the lamps yellow (against fog), because harmful vapour is thrown on the reflector from the varnish. The reflectors are made of brass, which is cheap and easily adapted to requirements. Though best for reflection, a plating of silver is sensitive to damage when cleaning and to chemical action. Chromium has the advantage of hardness and insensitiveness to chemical action. One drawback to chromium is its selectivity to the blue end of the spectrum, giving the light a bluish tint. When changing bulbs care must be taken not to introduce oil or moisture from the hands, etc.

Glass Cover of Headlights.—Various attempts have been made to diffuse the issuing beam of light by using frosted bulbs or frosted lamp covers or by using stippled glass for the covers, but the resulting improvement was not considerable. With such means the beam was still too concentrated and directed too much in the distance, while too little light was thrown over the road in front of the vehicle. Moreover, the circular beam thus produced was wasteful, because the upper part was useless.

Modern efforts have been directed to producing an oval horizontal beam by means of a properly-designed diffusing glass cover; in other words, by paying due heed to the laws of light.

When light strikes the surface of a medium, it may be reflected, refracted or absorbed. If the ray is thrown back, as from the polished surface *AB* in Fig. 59

it is said to be *reflected*. In this case the angle made by the reflected ray R with the normal ON equals the angle made by the incident ray I with the normal, namely α. *Absorption* occurs when part of the energy of the incident light is not available as such after it strikes the surface. If, however, the incident ray is diverted, as illustrated in Fig 60, where a ray is shown passing from glass into air, it is said to be *refracted*. This occurs when light passes from one medium to another of different density and is shown by the angle α being different from the angle β. Thus lenses can be used to refract the rays to form a convergent or divergent beam. These are theoretical cases. In practice, a beam of light is never totally reflected, refracted, or absorbed; but a combination of these phenomena occurs.

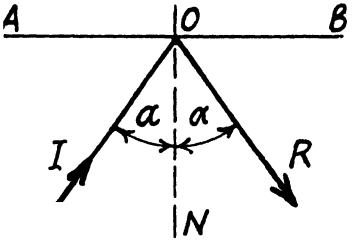


FIG. 59.—Reflected light.

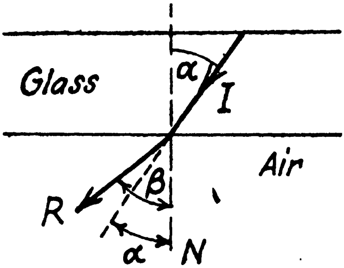


FIG. 60.—Refracted light.

Applying these laws to headlamps, a reflector is used to direct the light and a moulded glass cover to refract or disperse it. The basic principle employed in scattering the light is refraction, and involves the use of prismatic and convex lenses. A prismatic surface deflects the rays to the right or to the left—as in Fig. 61 (*a*)—or downwards or upwards according to the construction. Cylindrical convex lenses refract the rays in either direction—*see* Fig. 61 (*b*). A type of glass cover widely used in this country and in Germany, where it originated, has a centre of horseshoe or U-shaped design, made of prismatic lenses which distribute the light over a wide angle in and below the horizontal plane. The outer annulus is composed of cylindrical convex lenses which give a gradually increasing oval-shaped spread to the main beam. In this way the candle-power is kept as high as possible for distant illumination—for high-speed cars the U-shaped design may be replaced by a clear centre to concentrate the long-range beam—while the graded spread of light illuminates hedges and buildings along the widest road. The loss of light entailed by such covers is negligible, but the rate of falling away of candle power from the oval peak needs careful design to avoid dark spots on the road on the one hand and waste of light on the other. To prevent light from the bulb issuing in an upward direction, a cupped metal bulb shield may be suitably attached.

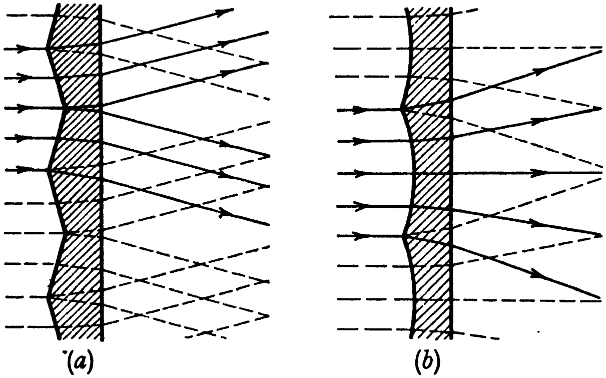

(*a*) (*b*)

FIG. 61.—(*a*) Prismatic lens. (*b*) Cylindrical convex lenses.

It is thus seen that the reflector prepares the light in the most convenient form for distribution, while the front glass effects this distribution by refraction.

Avoidance of Dazzle.—Innumerable patents have been taken out with the object of obtaining adequate driving light with freedom from dazzle to on-coming traffic. Coloured covers or bulbs are not considered advantageous. Some authorities consider that until the use of polarized light is made compulsory any solution must take the form of a compromise.

The conditions require the maintenance of a powerful light in front of the car, while avoiding glare to the on-coming driver. The former condition renders switching off headlights unsatisfactory—indeed dangerous, owing to the inadequacy of the side lamps. When meeting oncoming vehicles the present practice is to depress the driving beam below the horizontal plane; but, even so, glare may not be entirely removed and reflection from a wet road-surface may incommode the driver himself. Nevertheless, the depressed or flat-topped beam system is the most scientific method of approaching the problem which it has been possible to use in practice. The basic idea is that if all light above the eye-level of the approaching driver be removed he cannot be dazzled. The use of such beams enabled vehicles to pass one another without risk at a reasonable speed. Depression of the driving beam can be obtained in various ways, of which two will be mentioned here:

(1) *The Dipping Reflector:* The tilting of the pivoted reflector is usually effected by means of an electromagnet between it and its outside cover, the solenoid being actuated by a switch operated by hand or foot. As the pull to move the reflector is greater than the pull needed to hold it in the tilted position,

the plunger, on reaching the end of its travel, opens a pair of contacts and inserts a high resistance in the circuit, thereby reducing the solenoid current to a fraction of an ampere. When the current is switched off, the reflector is brought back to its normal position by means of a spring. In addition to depressing the beam of the near-side lamp, it is usual to swing it slightly to the left to illuminate the near-side of the road. The reflector is dipped by an angle of 5° to 6° and

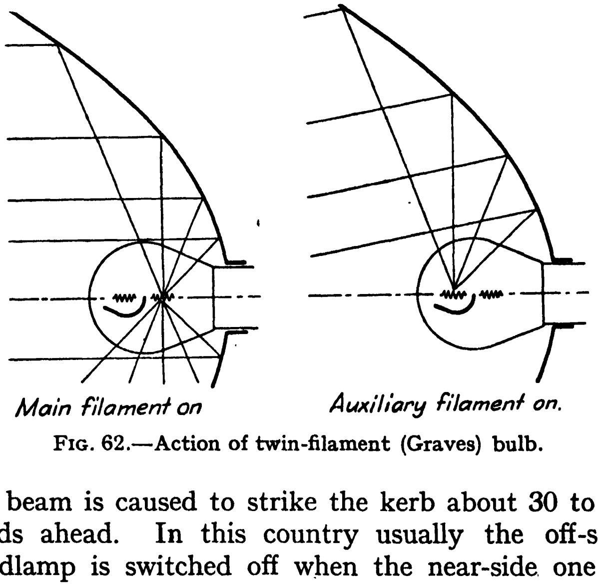


FIG. 62.—Action of twin-filament (Graves) bulb.

the beam is caused to strike the kerb about 30 to 40 yards ahead. In this country usually the off-side headlamp is switched off when the near-side one is depressed. Though this doubtless reduces the road illumination, as an anti-dazzle device it is a good solution, while with the fluted glass cover an adequate lateral driving beam is assured. As a fog lamp, the depressed beam thus obtained is useful, for light is not thrown back into the driver's eyes to the same extent as with the normal beam.

(2) *The Double-filament Lamp:* This is used in the form of the bi-focal bulb, Figs. 56 (*c*) or (*d*), or more usually of the twin-filament bulb, Fig. 56 (*e*). The latter consists of a single bulb with two filaments. The main filament is placed at the focus of the reflector and is used for normal driving; the auxiliary filament above a screen is placed in front of the focus, to give a depressed beam (Fig. 62). The screen or metal cup is employed to intercept the light which would fall on the bottom half of the reflector, so that practically all the light is thrown on the upper side of the reflector and then downwards, giving a bright beam meeting the road about 15 yards ahead. In this, the Graves type, Fig. 62, the auxiliary filament is always placed axially with respect to the reflector, which not only gives a better control of the auxiliary beam as regards light above the horizontal, but provides a greater spread of light in the horizontal plane, thereby throwing ample light on the ground just ahead. The intercepted rays spread out the beam laterally, and thus illuminate the ground close to the car. The maintenance of the full brightness adds to the driver's comfort, and with proper adjustment the beam does not extend above the horizontal plane and is thus non-dazzling. The chief advantage of the double-filament anti-dazzle device is simplicity, though the absence of moving parts is partly offset by the more costly and less efficient bulbs. This device is largely used in Germany and France.

The underlying idea of the bi-focal bulb Fig. 56 (*c*), widely used in American cars, is that by displacing the source from the focal point to just above the focal point, the beam is deflected downwards. Though this and other bi-focal variations give some relief from glare, they are not considered to be as satisfactory as certain other methods.

Whether the dipping reflector or the double-filament bulb is the better is largely a matter of opinion.

Obviously either can be operated by a switch on the steering column.

The Fog or Pass Lamp.—This lamp (where provided) also serves as an alternative to the above, for, having a depressed beam, the fog lamp can be used as a pass lamp when the headlights are switched off. In

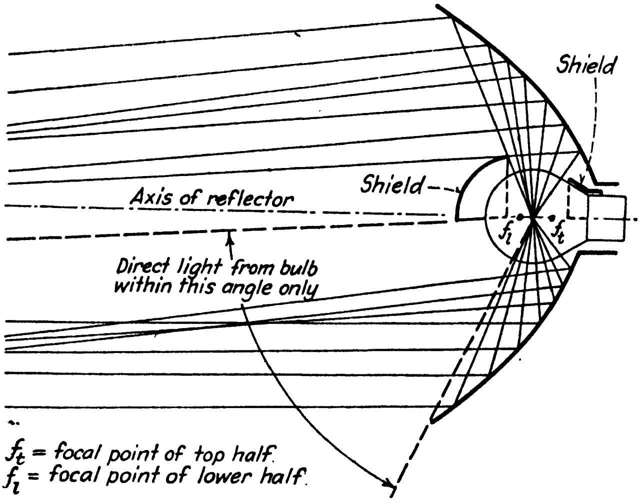


FIG. 63.—Fog (or pass) lamp.

fog part of the light is reflected or refracted, according to the amount of moisture present, rendering headlights less effective. The effect of yellow screens depends on the nature of the fog, which partly explains varying test results. No satisfactory solution has been found for dense fog, though some alleviation against mist or mild fog is obtained by preventing light from being reflected back and dazzling the driver. This is done by avoiding concentration, and spreading the beam as much as possible, and by preventing light from being projected upwards. One attempted solution consists of an extension of the double-filament principle by splitting the reflector in halves, axially displaced with respect to one another. This is shown in Fig. 63. The filament is in front of the focus of the upper half and behind the focus of the lower half. The result is that the light in the horizontal plane is spread sideways and the remainder is deflected downwards, giving a wide beam with a sharp upper cut-off and good downwards distribution. In addition to this strong, flat-topped, long-range beam, a spherical shield in front of the bulb prevents upward glare, and spreads a broad, diffused beam in front of the car. A pilot lamp of this description must be fitted as near the front of the vehicle as possible, and not less than two feet from the ground.

Though the wide beam is generally favoured, in the opinion of some a pencil beam is thought better for penetrating fog. The essential feature of a fog lamp, however, is to cut off all possible light above the driver's eyes.

Side and Tail Lamps.—As made, side lamps are miniature headlamps complete with reflector. Fluted glass covers are often used to give better light distribution and to reduce glare. At one time, on certain small cars, the head and side lamps were combined, two bulbs being arranged for two purposes and controlled by a change-over switch. The main bulb was properly focussed for driving, the auxiliary bulb being used for town work, passing and parking.

The tail lamp has no reflector, and it is usually arranged to illuminate the number plate. A stop or warning lamp is often housed with the tail lamp. This is usually worked by a switch on the brake pedal, which makes the warning signal automatic.

Auxiliary Lamps.—Lamps for warning, panel illumination, signal arms, etc., are often specially shaped, and may be provided with screw-cap type bulbs.

HORNS

Experience shows that the sound emitted by a horn should contain two notes—a low-frequency fundamental of 250 to 500 vibrations per second, and a superimposed high-frequency note of 1,500 to 2,500 vibrations per second. The low-frequency, high-energy note carries a long distance, but is readily drowned in the rumbling noises of traffic. The high-frequency note has a larger effect on the ear for a given amount of energy, and though its energy is but a fraction of that of the lower note, it forms the effective part of the useful sound emitted. The high-frequency note is well above the range of traffic noises, but its carrying distance is limited.

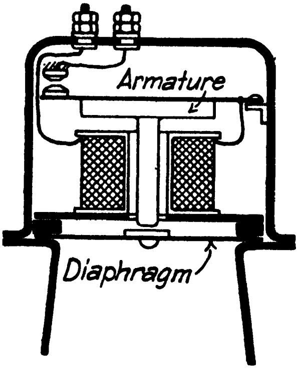


FIG. 64.—Solenoid-operated horn.

Electric horns have practically ousted all others. The electrically produced vibration of the diaphragm of a simple electric buzzer produces a low-frequency note corresponding to the make and break. A much more effective noise results when the armature is allowed to strike the magnet face at the end of its stroke; for at each impact natural high-frequency vibrations are set up in the diaphragm, as when a tuning-fork is struck, in addition to the forced low-frequency waves produced by the movement of the diaphragm as the contacts open and close. Thus arose the impact or high-frequency horn actuated by a solenoid—Fig. 64. The use of a single diaphragm for the dual purpose of producing low- and high-frequency notes, however, is not a success because of superimposed overtones, and something less cacophonous and raucous is demanded.

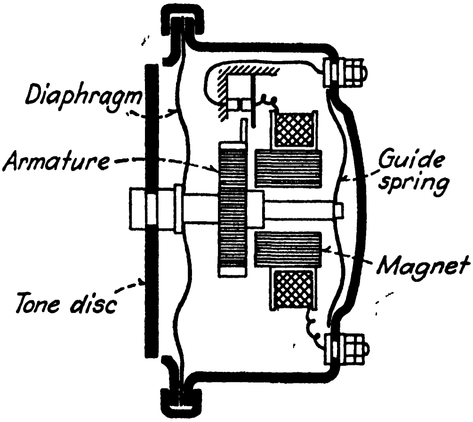


Fig. 65.—Double-diaphragm solenoid-operated horn.

Double-diaphragm High-frequency Horn (Fig. 65).—To separate the two functions, the original diaphragm—secured at the rim—is left to supply the forced deep note of about 300 periods per second; while a tone disc in the form of a second diaphragm, tuned to a lowest natural frequency of about 2,000 periods per second, is provided for the higher notes. The tone disc is a circular plate attached at its centre to the low-frequency diaphragm and to the armature, and it is free at its periphery. The construction is illustrated in Fig. 65. Since the note emitted by a diaphragm depends on its rigidity, dimensions and material, it is possible, by careful tuning, to make the lowest natural period of the tone disc an exact multiple of the forced period of the buzzer. In this way the purer, less unmusical note of the impact buzzer or solenoid-operated horn was evolved. The loudness of the noise emitted by such a high-efficiency horn can be reduced by closing the switch for a shorter interval.

To make a horn more effective the flare or trumpet is made to resonate with the diaphragm. With a battery-fed horn, however, the supply of energy is ample, and the trumpet can be dispensed with. With this delicate part thus removed there is no need to install the horn under the bonnet for protection. For this reason it is mounted free from sound obstruction, on the front of the car, and is made water and dirt proof.

When twin horns are desired for symmetrical appearance, their frequencies may be tuned to approximate a musical interval, and provision made for cutting one out of circuit to reduce the sound, e.g., for town use. The cheaper sets of twin horns are wired in parallel off a single switch. In some designs the horn is operated through a relay, like the starter.

Care must be taken with the mounting of horns employing impact to produce overtones, for the horn itself is set vibrating. The horn should be flexibly mounted; for rigid mounting, though theoretically correct, is not practicable, and imperfect rigidity means energy absorption. With flexible suspension the vibrations are not transmitted to the car. The filaments of the headlamp bulbs are the chief sufferers from high-frequency vibrations.

The Motor-operated Horn (Fig. 66).—Here, too, the sound is produced by impact. A striker, consisting of a hardened steel wheel having serrations cut on its face, is secured to the motor spindle and bears against a hardened steel toe fixed to the middle of the sound-producing diaphragm. Owing to the vibrations set up by the revolving wheel being superimposed on the natural vibration of the diaphragm, the tone of the horn alters with the speed of the motor; consequently varying voltage makes it impossible to maintain resonance between the impressed frequency of the striker and the natural frequency of the diaphragm. The resultant complex nature of the high-frequency notes generated produces a discordant sound; also the changing note as the motor starts and stops is disconcerting. Moreover, there is an inevitable time-lag between the instant of application and the motor attaining its full speed of about 2,000 r.p.m. The loudness is altered by varying the clearance between the striker and the diaphragm.

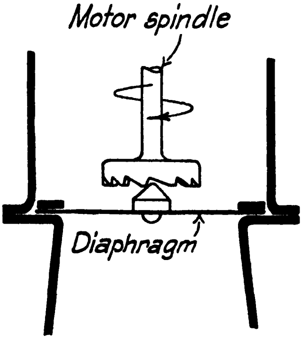


FIG. 66.—Motor-operated horn.

The Wind-tone Horn.—This is a wind instrument like a trumpet or trombone, the sound being produced by the resonance of an air-column in a trumpet flare. In this case, however, the note is caused by the electrically-produced vibrations of a diaphragm, instead of by the lips, as in a bugle, post-horn, trumpet, etc. Oscillograms of sound waves show that the wind-tone horn can imitate fairly well the B-flat trombone. The trumpet length determines the pitch of the note, which is, consequently, unaffected by battery voltage or by adjustment. The horns are supplied in pairs arranged to sound a major third. To vary the strength of the signal a two-way switch is used. In the "soft" position a resistance is inserted in series with the solenoids actuating the diaphragms.

In the high-frequency horn, the sound is caused by the diaphragm and its tone disc being excited to resonance by impact; whereas in the wind-tone horn the sound is produced by the air columb in a flared trumpet being excited at its resonant frequency. Both are actuated by an electromagnet.

The Horn Switch.—The horn switch should be mounted in an easily accessible position on the steering column, preferably so that it can be operated without removing a hand from the steering wheel.

DIRECTION INDICATORS

Various kinds of signalling devices have been tried at one time or another. Light signals only are unsatisfactory in bright sunlight, unless made so brilliant as to dazzle at night. The semaphore type of signal is now becoming general. The semaphore is mounted 4 to 5 feet above the ground, to be about level with the driver's eye. It is an easy matter to illuminate the semaphore to be visible in the dark without causing dazzle. The operating mechanism consists of a long solenoid with an iron core attached to the inside of the semaphore arm. An automatic locking device is employed to prevent the arm swinging from its vertical position due to the motion of the car. The direction indicator, like the windscreen wiper, is becoming a part of the modern vehicle, being built in by the car maker and not merely added as an accessory. In saloon cars the semaphore is usually housed in the central pillar, in order to obtain the necessary room. In this position the arm is not easily visible to the driver, nor is it always possible for him to hear the arm moving into the signalling position. For this reason automatic aids seem to be desirable.

Opinions differ regarding the desirability of automatic direction indicators. Certainly an automatic switching-in device seems to be open to objection, because this can only operate after the turning movement has begun, and is therefore too late. Moreover, the need for an automatic switching-in device is questionable.

The case is different for switching out, for, owing to a variety of causes, the driver may well omit to switch off after completing his turn, and so cause confusion. Various devices are in use for automatically restoring the arm to its off or vertical position. One such device used on the Continent is a spring-operated time relay which restores the arm after 8 to 10 seconds. This is open to the objection that the turn may not be completed before the clockwork time-switch causes the arm to drop, necessitating a further manual operation to switch on again. In this country development follows the lines of automatically cancelling the switch movement by the steering wheel. In this case the arm is not released until the turn has been completed and the steering wheel straightened. The fitting of this device entails co-operation between the makers of the car and of the electrical equipment.

FUEL PUMPS

Mechanically or electrically operated pumps are used where the fuel tank is below the level of the carburettor, and they are rapidly supplanting the vacuum tank.

Bellows Type.—In the arrangement illustrated in Fig. 67, below the actual pump, which comprises a suction and a delivery valve, there is a one-piece hydraulic bellows to which is attached an iron armature hinged at one end and carrying a contact at the other. When the operating switch is closed, the solenoid is energized from the battery and the armature is attracted. This causes the bellows to expand, drawing in petrol through the suction valve, and at the same time the circuit is interrupted by the opening of the contacts. A toggle action ensures sudden opening and closing of the contacts. The armature is thus released and the spring contracts the bellows, closing the inlet valve and forcing some of the trapped petrol past the delivery valve to the carburettor until the contacts again close and the cycle of operations recommences. The action continues till the petrol level in the carburettor reaches its correct height, causing the needle valve to close. When this condition obtains, the operating spring is unable to close the bellows against the back pressure of the petrol, leaving the contacts open. Thus the pump consumes no energy when not in operation. When working it takes about 6 watts, and it has

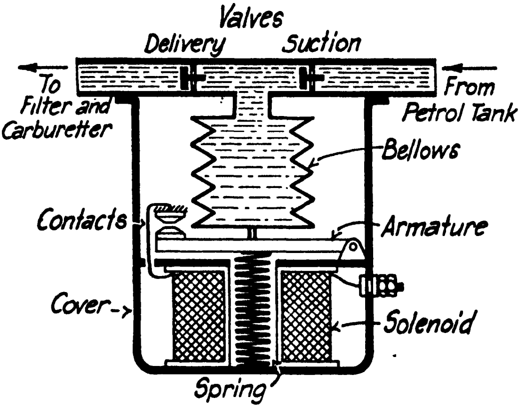


Fig. 67.—Automatic electric fuel pump, bellows type.

delivery up to 7 gallons per hour, making it suitable for engines up to 50 h.p.

Diaphragm Type.—The components of this type are shown diagrammatically in Fig. 68. The action is similar to the bellows type, but the bellows are replaced by a diaphragm, which is flexed by the pull of the solenoid. On the suction stroke the plunger is attracted into the solenoid against the force of the spring, and petrol is drawn into the pumping chamber. The tractive force ceases as soon as the contacts open and interrupt the current. Then follows the return or delivery stroke, actuated by the compressed spring. The contacts are operated by a toggle mechanism to give "snap" make and break. This type is capable of a delivery of 8 gallons per hour through a lift of 4 feet.

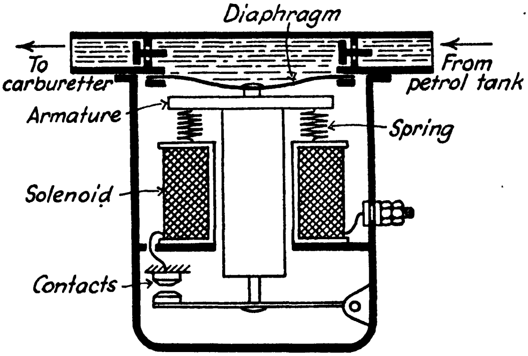


FIG. 68.—Automatic electric fuel pump, diaphragm type.

When fitting an electric fuel pump it is necessary to ensure that the joints are absolutely air-tight. Air leaks may give rise to an air-lock or "buzzing" of the pump, which causes pitting of the contacts. If the pump goes on "heating" without delivering petrol, it is probable that a piece of foreign matter has lodged under one of the valves. Among the advantages of the electric pump it may be mentioned that the rate at which fuel is supplied is independent of the engine speed. It is not necessary to rotate the engine to fill the carburettor float chamber. This self-priming is an advantage which the electric pump possesses over the mechanical pump, where priming has to be done by hand or by the self-starter. If an electrical break-down occurs, such as a run-down battery, or an open- or short-circuit in the pump circuit, the fuel supply is cut off and the engine stops until the fault is rectified.

It will be observed that the solenoid expands the bellows or deflects the diaphragm, and in both types fuel is delivered to the carburettor on the return stroke by the action of a spring. Consequently the pressure under which petrol is delivered is a function of the spring only. This pressure is adjusted to be less than that necessary to lift the needle valve of the carburettor off its seat when the float chamber is full. Thus the fuel supply is independent of battery voltage, and the system is self-regulating, the pump operating only as and when fuel is required.

WINDSCREEN WIPERS

The windscreen wiper can be regarded as an essential part of the equipment of the present-day motor vehicle; for private vehicles the twin wiper is popular. The wiper makes about 30 strokes per minute. It consists of an armature having a semi-rotary motion and carrying a rubber squeegee pressed by means of a spring against the screen. The wiper spindle may be at the top or at the bottom of the screen. When driven from above, the wiper should not sweep over a complete semi-circle, otherwise water may run down over the wiped part. To impart the oscillatory motion to the wiper the spindle is connected to the driving motor through some form of rack and pinion and a speed-reduction gearing, the reciprocating motion of the rack, carrying the wiper arm, being transmitted from an eccentric pin in the last gear.

The driving motor may be of the commutator type, which is self-starting, or of the inductor (or attraction) type, which has no inherent starting torque. When a commutator is used, the construction can be of an elementary type, such as a three-segment commutator, connected to a like number of armature coils wound on large teeth, with a two-pole permanent-magnet field to give a shunt characteristic. In the inductor or attraction type the revolving element carries no winding. The motor runs at about 1,800 r.p.m.

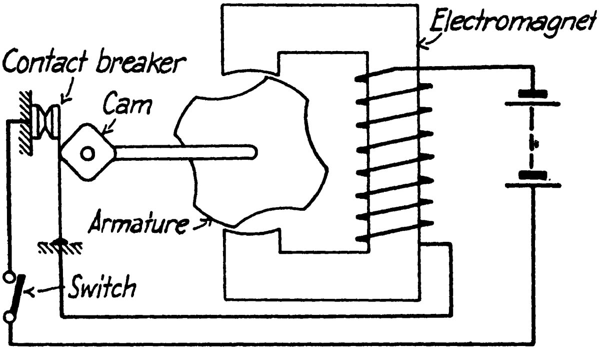


FIG. 69.—Attraction- or inductor-type motor.

The attraction motor is a cheap and simple substitute for a normal machine when small outputs only are required. Though now superseded on automobiles, the action of this motor is of interest. The main features are embodied in diagrammatic form in Fig. 69. The armature comprises an assembly of specially shaped iron laminations mounted on a spindle which also carries an insulated four-lobed cam. The cam opens and closes contacts which periodically energize the field electromagnet in such a way as to keep the armature spinning. The motor is inefficient and relatively larger than the commutator type. It has no inherent starting torque, since there are a number of "dead" points in each revolution. The armature is therefore given an initial twist when switching on.

With twin- or dual-arm wipers a single driving motor is used and the two wiping arms are mechanically connected in such a way that there is not a large unwiped area in the centre of the screen. Three different means of connecting the arms may be mentioned. The first is the plain coupling rod. This does not permit of a complete angle of wipe, because of the stresses set up in the rod at each reversal, and the tendency to lift the blade off the screen. Also, in the "off" or "parking" position, the linked blade does not come to the horizontal position with the other blade. The second is the rack type, in which a rack reciprocated to and fro by the driving mechanism engages with a pinion on each of the wiper spindles. The angle of wipe is about 160°. With this dual wiper the motor can be mounted inside the screen, and by placing the gear and rack mechanism on the outside of the screen the noise made by them is inaudible in the car. The third arrangement comprises a built-in mechanism which can be housed in the scuttle, where there is ample space. The two driving spindles at the bottom of the screen can be connected by a roller or cycle chain, which is rocked to and fro from a motor and gear, the last stage of which imparts the reciprocating motion. The oscillating shaft is connected to the gear box mechanism by a clutch, so that the drive can be disengaged for parking or hand wiping. When parked the wipers lie hidden below the screen,

—the control winding—also fed off the battery. Consequently any change in battery voltage affects the current in both coils, so that the reading is not affected by the state of battery charge. There are different ways of connecting the transmitter, meter and battery.

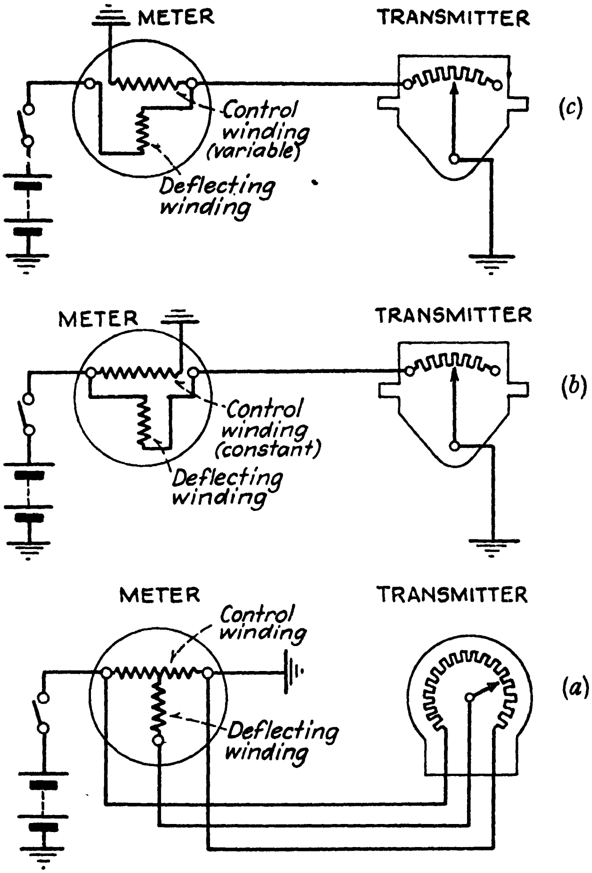


FIG. 71.—Different arrangements of petrol-gauge circuits.

The best arrangement, though needing three wires, is shown in Fig. 71 (*a*). Here the current in the deflecting coil is zero in the middle of the scale and rises to a maximum in the empty and in the full position, thus providing a long scale and fair accuracy. Less wiring is required in the connexions shown in Fig. 71 (*b*) and (*c*), giving constant control and variable control respectively. In these cases, however, the current in the deflecting coil varies from zero to a maximum only. Thus these cheaper and commonly used arrangements are not so accurate as that shown in Fig. 71 (*a*). The current in the deflecting coil rises to about ¼-ampere, and of course varies according to the amount of petrol in the tank.

It should be noted that with these devices no attempt is made to exclude petrol from the transmitter. It is claimed that any sparks produced as the arm passes over the rheostat are not transmitted to the outside petrol, owing to the minute clearance between the spindle and its bearing acting in the same manner as the gauze in the miner's safety lamp.

AMMETERS

The ammeter used on the dashboard is usually a centre-zero instrument, the reading in one direction indicating that the battery is being charged, and in the other direction that it is being discharged. Thus the circuit is arranged so that the ammeter reads the charge or discharge current of the battery. The starting motor is not included in the ammeter circuit, for a meter capable of reading currents of 200 to 300 amperes would be useless for indicating currents from 0–10 amperes, as met with in the other appliances.

The ammeter generally used is the moving-iron type, which is cheaper than the moving-coil type and is good enough for the purpose. This simple type of ammeter has a pivoted soft-iron armature and a permanent-magnet control. For use with the three-brush dynamo no damping is needed, but when a voltage regulator is employed special damping is required to prevent excessive oscillation of the pointer owing to the vibrations of the control mechanism. Fig. 72 represents a moving-iron ammeter fitted with inertia and friction damping. This is obtained by coupling the armature to a balanced rotatable mass by means of a pin in a slot. This arrangement gives a damping effect proportional to the vibrations or movements of the pointer.

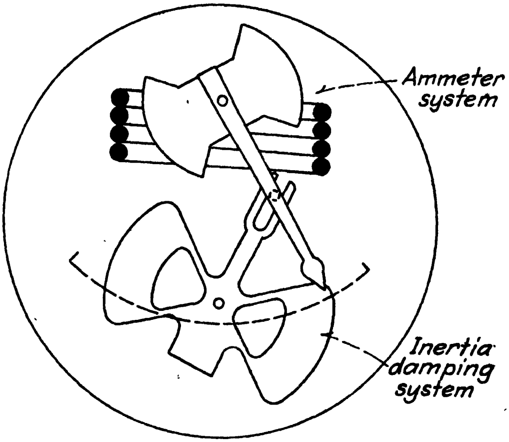


FIG. 72.—Moving-iron ammeter with damping device.

Opinion is divided concerning the desirability of installing an ammeter on the facia board. It can scarcely be regarded as essential, and if a mere indication that the battery is being charged is all that is required, a red lamp would serve the purpose. If attention is paid to the ammeter readings, however, then the meaning of the indications should be understood. Discharge causes no confusion. Ambiguity arising from ignorance can exist regarding the charging current. With the 3-brush dynamo a high charging current would normally denote a well-charged battery. With the voltage regulator a high charging current would indicate a flat or partly discharged battery; whereas a small or trickle charging current would indicate a well-charged battery.

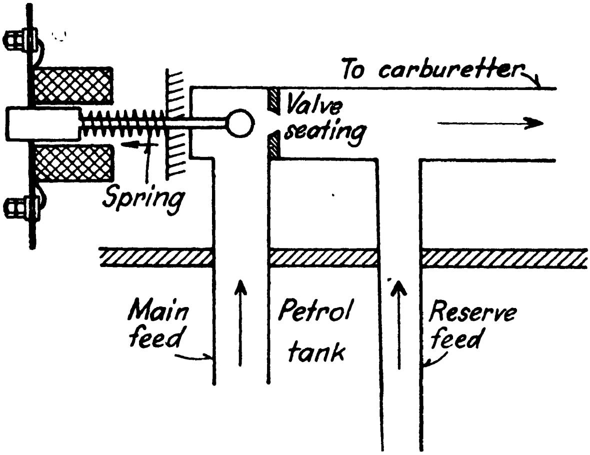


FIG. 73.—Reserve petrol valve.

RESERVE PETROL VALVE

The unit of the electrically-operated reserve petrol valve is mounted at the top of the petrol tank and the operation is controlled by a switch on the instrument board.

Two suction pipes of different lengths project into the tank; both pipes normally deliver petrol until the level of the liquid in the tank falls to the end of the shorter pipe. Air then enters the shorter pipe and petrol ceases to be delivered until this pipe is closed.

This closing is effected by switching on the solenoid which draws the valve on to the valve seating. Ingress of air through the main pipe is thus prevented, and petrol is delivered through the reserve pipe only.

ASSEMBLY OF INSTRUMENTS AND SWITCHES

In modern practice the chassis is wired and important electrical accessories form part of the standard equipment. Instead of placing the instruments and controls haphazard on the dashboard, it is customary to mount the clock, oil gauge, speedometer, ammeter, etc., on a neat facia board, usually of metal and attached to the dashboard, preferably so that wiring, terminals, etc., can be readily examined. Interior illumination is provided. A socket may also be available for a plug to which a hand-lamp, a foot or a rug-warmer may be attached. There is a tendency to place controls used under normal driving conditions in the most convenient position for the driver. Thus the controls for the horn and direction indicator may be placed on or near to the steering wheel. The dimming or dipping device may be foot operated ; the remainder of the controls being fixed on the dashboard. The ignition and throttle controls—if provided—are now often relegated to the dashboard, owing to their decreased importance as a result of engine improvement and the general use of automatic ignition advance mechanism.

CHAPTER VI

WIRING AND INSTALLATION

Earth-return and Insulated-return Systems.—In order that an electric current can flow, there must be a conducting circuit. By insulating the parts of the circuit in a suitable manner the current is constrained to flow in its intended path. There are two ways in which this can be done. In the one case, insulated cables between the sources of energy and the appliances can be used throughout. This is the insulated-return system. In the other case, an insulated cable is used for one pole only—either positive or negative—and the chassis of the vehicle is used for the other pole. This is the earth-return system. Generally speaking, provided the connexions to the chassis are sound and there are good metallic joints throughout, the resistance of the earth (or chassis) part of the circuit is negligible, so that if the same cross-section of cable be used with the same voltage in the two cases, the resistance, voltage drop, and cost of cable are twice as great with the insulated- as with the earth-return. If the same voltage drop in the leads is allowed in the two cases, it follows that the cross-section of the copper in the earth-return system will be half that in the insulated-return system, or the total weight of cable copper will be one-fourth. It is probably this economy in cable, in addition to its simplicity, that has led to the wide adoption of the earth-return system, while its use for ignition circuits is universal. The advantage claimed for the insulated-return system is reliability, but a precise comparison is hard to establish. One difficulty with the earth-return system is that of making and maintaining good earth connexions. On commercial vehicles this is an important consideration where vibration is both severe and prolonged. With the insulated system a single failure to earth does not prevent working; whereas if the insulated cable of the earth-return system breaks down to earth, further working is prevented. On the other hand, it is generally easier to locate wiring faults in the earth-return than in the insulated-return system. Moreover, in the latter system short-circuits between the two cables are always a possible source of trouble. Omnibuses and lorries are often wired with an insulated return, but here the number of accessories may be few, space for double-pole wiring is ample, and reliability is all-important. Past practice has been based on the experience that fewer faults develop on commerical vehicles with insulated return; present practice inclines to earth return on the heavier vehicles. The earth return is used almost exclusively on private cars.

Earthing.—"Earth" is the return path *via* chassis or engine from the appliance to the battery. A bad earth connexion is one of the worst faults possible and it may be difficult to detect or locate. It may upset ignition, starting or lighting. In the earth-return system the question arises: which battery pole shall be earthed, the positive or the negative? The common practice in Great Britain up to about 1937 was to earth the negative terminal, though there was no particular virtue connected with it. On its merits the question is largely a matter of corrosion, which is usually less when the positive terminal is earthed. In a cell it is the positive or anode which is attacked by the liberated gas, etc., and if this be the live part and there be moisture present, leakage currents will flow and corrosion will result.

There are points in connexion with the high-voltage system which bear also on this question. It is found that the positive electrode burns the more rapidly, so that if the high-voltage terminal of the coil is positive, the revolving distributer electrode and the insulated plug electrode burn more rapidly than if the high-voltage terminal is negative. As these are the smaller parts, it is preferable to make the live terminal of the coil negative. Again, the plug voltage depends largely on the temperature of the negative electrode. The hotter this electrode, the lower the voltage. As the central electrode of a plug is hotter than the earthed electrode, a lower plug voltage is needed when the insulated terminal is made negative. Also, plug voltages were found to be more uniform with the high-voltage ignition lead negative, and this was of assistance when weak mixtures began to be used for economy. Thus there were many good reasons for the change in practice, and it is now general to earth the positive terminal.

The arguments in favour of earthing the positive terminal of the battery and of making the central plug electrode negative are satisfied in the auto-transformer connexion in coil ignition, shown in Fig. 103. The advantage of the auto-transformer arrangement is that the primary voltage is added to the secondary voltage, which is more economical than when the respective windings are in opposition or non-cumulative (compare Fig. 102). The auto-transformer connexion entails making the polarity of the high-voltage terminal of the coil the same as that of the live terminal of the battery. In order therefore to obtain these three desired objects—minimum amount of corrosion, negative polarity of central plug electrodes, and economical (auto-transforner) connexion of coil—it is likely that in future the practice of earthing the positive terminal of the battery will be continued.

6-volt and 12-volt Systems.—For the same percentage voltage drop, the amount of copper in the 6-volt system is four times that in the 12-volt system. The relative advantages of the two systems are discussed in the several chapters. On public vehicles the 24-volt system is now finding favour.

The Wiring System.—Despite the low voltage of the lighting and starting circuits, the working conditions are extremely unfavourable. The chassis of an autocar is not only in a state of continual vibration, but there may be relative movement between the several parts. Care must be taken, therefore, to prevent chafing, rubbing or movement of any kind that will tend to destroy the insulation. Where there is relative movement between parts of the chassis sufficient slack in the cable must be provided. In no case must cable press against a sharp edge or corner, and it is essential to bush with insulating material all holes in metal through which cables pass. Flexible metallic tubing, through which the cables are passed, is a good protection where wear and tear are likely to occur. Staples and clamps must be carefully insulated and connexions properly secured. To prevent confusion, cables of different colour are used for the several circuits. Special care must be taken to secure the terminals properly and to ensure that no strain is exerted on the cable. Since most wiring faults are due to bad workmanship or bad material, it can be safely asserted that many wiring faults are avoidable. Cable with inferior insulation should not be used.

The complexity of the electrical system with its many accessories makes a properly installed wiring system essential. As far as possible the wiring should be carried on the chassis alone, and completed before the body is placed on the chassis. Instead of running individual wires from point to point, it is now customary to bunch the wires together in a common covering, the various cables being brought through the covering at appropriate places, securely bound with the conductor ends properly finished. In this "harness" system the several conductors thus braided together form a single wiring unit, so that the whole assembly can be handled and fixed to the chassis as a single component—*see* Fig. 74. This simplifies immensely the wiring of the chassis by reducing the number of points of attachment. The bunching of the wires gives cushioning and reduces risk of fracture. On the other hand, if a wire in the harness system should become defective, it must be cut out and a new external conductor must be run. For identification a colour scheme is adopted. The usual

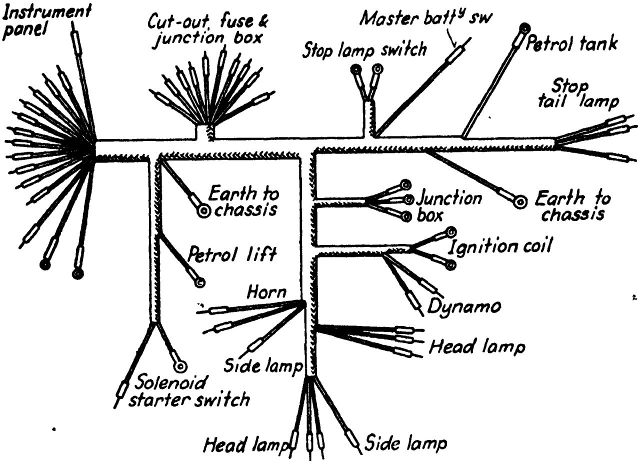


FIG. 74.—Bunching of cables for chassis wiring.

harness is cotton braiding, but an alternative is flexible metallic tubing provided with junction and bifurcating boxes at the necessary points. A combination of the two patterns has advantages, the main run of cable in the chassis being cotton braided, while the individual leads in the unprotected places, such as mud-wings, are run in short lengths of flexible metallic tubing suitably bushed and terminated.

Fusing of Circuits.—Separate fusing of all circuits is impracticable, owing to their number. In some important circuits, such as ignition, fusing is undesirable. Also the headlights, if fused at all, should be fused separately, because of the danger of both lights being extinguished simultaneously. This implies, of course, that particular care must be taken in the wiring of unfused and essential circuits. The auxiliary circuits are fused in groups, as shown in Fig. 76.

In order to avoid intolerable complication when renewing fuses, in many cars one size of fuse only (except for the field circuit) is used throughout the equipment. This size must obviously be rated for the biggest load, e.g., a cigar lighter taking 25 amperes. Fusing all circuits alike has an important consequence. As the fuse must be the weakest part of any circuit, it follows that the rating of the fuse fixes the size of the wiring. Conductors may be larger, but not smaller, than the size corresponding to the fuse.

Low-voltage Automobile Cables.—Experience in automobile wiring soon revealed that ordinary protective compounded braiding over the vulcanized rubber, lapped with a varnished cambric tape, was not equal to the severe service demanded. Armouring was one of the means adopted to meet the requirements. Popular practice favours aluminium armouring, although there is a fair demand for brass.

As an alternative to armouring, cellulose or braid and lacquer varnish finish was introduced. The coating presents a smooth polished surface—usually black in colour unless otherwise specified—which will not crack when bent, and will serve as a protection against petrol, oil and water. This finish can be applied to any automobile flexible having an outer braiding of fine cotton.

Some years ago it was found that the tough rubber compound used for tyres (commonly known as Cab Tyre Sheathed, or C.T.S.) formed an admirable covering and protection for insulated electric cables. Such cables resist the action of oil and petrol, and are proof against water, grease and corrosion. They are occasionally used for internal and chassis wiring where reliability rather than price is the ruling factor.

Standard Low-voltage Cables for Automobiles.—The following particulars are extracted from Data Sheet No. 192 (Standard No. 92) issued by the Institution of Automobile Engineers, and from information supplied by cable makers.

The standardized finishes are :—

(*a*) Oil-resisting-cambric taped, braided and varnished.

(*b*) Oil-resisting-cambric taped, braided and treated with weather-resisting composition.

(*c*) Oil-resisting-cambric taped, braided and treated with flame-resisting composition.

(*d*) Oil-resisting-cambric taped and armoured with a close spiral of metal strip of approximately half-round section.

Lighting and Dynamo Cables to be of tinned copper wires, 0·012 or 0·0076 inch in diameter. Each conductor to be insulated with vulcanized india-rubber not less than 0·025 inch thick. The rubber shall be coloured

red for single cables ; one core red and one core black for twin cables ; in a triple cable, white shall be the colour of the third core.

Starter Cables: The thickness of vulcanized rubber dielectric varies with the size of conductor. Rubber-proofed tape lapped over the dielectric to be taped with varnished cambric before applying the outer protection or finish.

Types of Covering: The *braided and compounded* finish consists of a cotton braid impregnated with a weatherproof or fire-resisting compound. The *braided and lacquered* finish consists of a cotton braid coated with a cellulose lacquer or varnish which is flexible and affords protection against petrol, oil and water. Both these types are usually finished black in colour.

Armouring in the form of a close spiral of metal of approximately half-round section not less than 0·015 inch thick is applied direct on the varnished cambric tape.

Particulars of Conductors

Cables for	Nominal Area of Conductor. sq. in.	No. and Dia. of Wires comprising Conductor.	Resistance of Conductor per 1,000 yd.—ohms.
Starter.	0·035	37/·036	0·676
	0·06	61/·036	0·410
	0·09	61/·044	0·275
Lighting Dynamo and Battery.	0·001	23/·0076	25·10
	0·0015	14/·012	16·52
	0·0017	40/·0076	14·40
	0·003	70/·0076	8·26
	0·004	35/·012	6·61

Diagrams of Typical Wiring Systems.—For the sake of illustration we shall show a simple earth-return system, with starter, three-brush dynamo, battery, lighting, etc., and magneto ignition, Fig. 75; and a modern system with voltage-regulator dynamo and coil ignition (Fig. 76) with many appliances. It is usual to find such illustrations in instructional handbooks supplied with automobiles. They are useful for showing the terminals to which the several parts are connected. If the information contained in the diagrammatic representation of the wiring supplied is insufficiently clear or complete, the person interested in the car should make his own diagram. To attempt to trace circuits or faults without a knowledge of the connexions may not only be a useless, but even a risky, undertaking for the uninitiated.

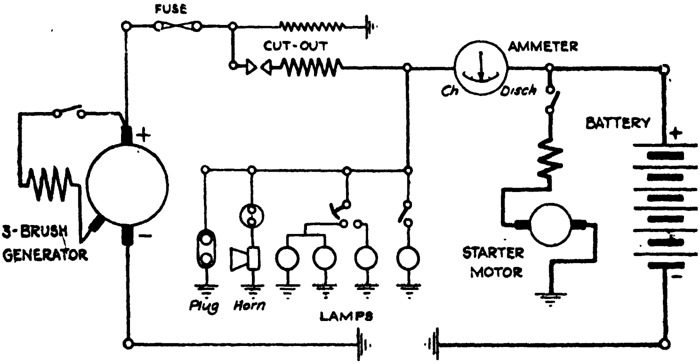


FIG. 75.—Earth-return wiring system with three-brush dynamo and magneto ignition (magneto not shown).

The differences in the numerous diagrams show mainly differences in wiring, switching and other details. If the reader can draw out the scheme of connexions in Fig. 75, he can easily perform a similar exercise for other arrangements. The fundamental principles are the same for all; it is mainly in the arrangement of the parts that differences are introduced.

Most of the details of the diagrams in Figs. 75 and 76 have been discussed elsewhere in the text. The scheme in Fig. 75 is about as simple as is possible to satisfy minimum requirements. The more modern layout in Fig. 76

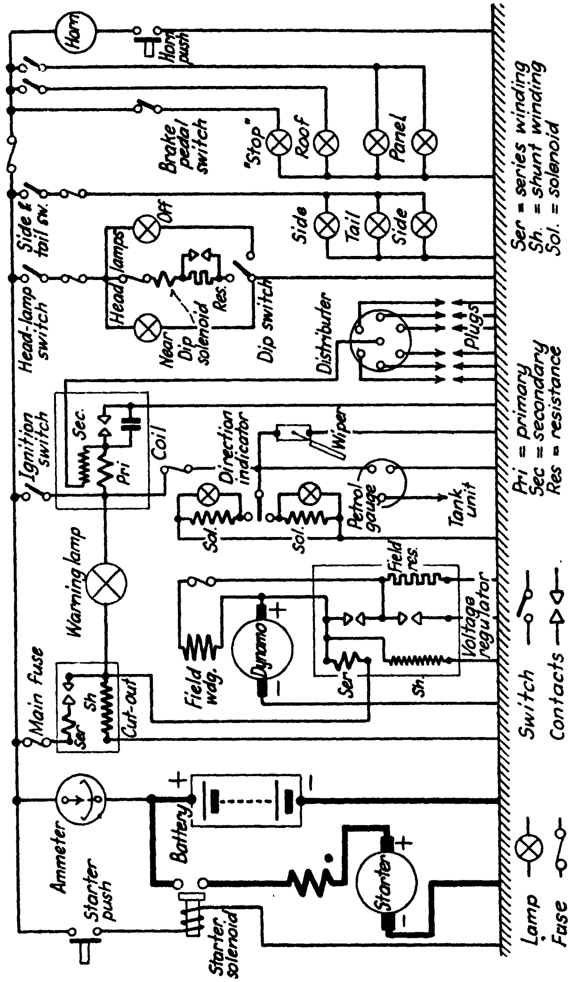


Fig. 76.—Earth-return wiring system with voltage-regulator dynamo, coil ignition and many appliances.

contains many refinements, such as solenoid-operated starting switch ; ignition warning lamp ; dipping headlight reflector ; voltage-regulator control of dynamo voltage. Direction indicators, screen wipers and petrol gauge have become normal parts of modern equipment. The switching and fusing arrangement of the several devices should be particularly noted, and the reason therefor understood.

Master Switches.—The object of a master switch is to enable current to be cut off all circuits in case of emergency, also to provide a safeguard against interference and accidents. The usual practice is to connect the master switch between the battery earthed terminal and earth, so that operation of the master switch isolates all services, including the starter circuit. At the same time the contact-breaker of the ignition system is earthed.

CHAPTER VII

INTERNAL-COMBUSTION ENGINES

Internal-Combustion Engines.—The two main types of internal-combustion engines used on motor vehicles are the petrol engine and the heavy-oil engine. The petrol engine is based on the ignition by a spark of a compressed petrol-air mixture; the heavy-oil or compression-ignition engine, as introduced by Diesel, is based on the self-ignition of a spray of fuel oil as it is injected into highly-compressed and therefore highly-heated air. Nearly all petrol and oil engines used on automobiles work on the four-stroke cycle.

For fuel, petrol engines work on petrol, benzole and alcohol, all of which vaporize readily (50°–200° C. or 122°–392° F.). They can also be adapted for town or suction gas. The fuel for oil engines is gas oil from petroleum or coal-tar oil from coal. Thus liquid fuels for automobiles fall into two classes: light fuel oils and alcohols for engines using a carburettor for atomizing the liquid, as in the petrol engine; heavy fuel oils for engines with atomizing or spraying devices, as in the oil compression-ignition engine.

Ignition is vital in internal-combustion engines. In the Diesel or heavy-oil engine self-ignition occurs by injecting at the correct instant the fuel in the form of spray into the highly-compressed heated air in the combustion chamber; whence the name compression-ignition engine. In the petrol engine a high-voltage spark is used to ignite the fuel in the cylinders—the spark being passed at the correct instant between the electrodes of a sparking plug within the mixture to be fired. There are two ways of producing the spark—by means of a magneto, which is a self-contained unit; or by means of a spark coil, which is operated from a battery or a dynamo. In present practice coil ignition is almost universally used for cars, but the magneto is still employed on certain petrol-driven commercial vehicles and motor omnibuses and on nearly all motor-cycles.

THE PETROL ENGINE

Before discussing ignition there are certain points connected with the working of the petrol engine that should be understood. For this purpose a general outline and typical data only need be given. For precise data on pressures, temperatures, compression-ratios, etc., treatises on internal combustion-engines must be consulted.

The Four-stroke Cycle.—The internal combustion engine, as used on automobiles, completes one cycle in two revolutions of the engine or four strokes of the piston. In the first (downward) or *suction* stroke the explosive mixture is drawn into the cylinder, the inlet valve being open, the exhaust valve closed. During the second (upward) stroke—the *compression* stroke—the mixture is compressed into the combustion chamber at the top of the cylinder, both valves being closed. Towards the end of the second stroke, or at the beginning of the third stroke, the compressed gas is fired, and the succeeding or third (downward) stroke of the piston under the pressure thus created is called the *power* stroke, both valves remaining closed. In the fourth (upward) or *exhaust* stroke, the exhaust valve opens and the burnt gases are expelled from the cylinder. The cycle is thus completed in two revolutions.

These actions are carried out automatically by the aid of valves or ports operated at the correct instants by cams mounted on a shaft which revolves at half the speed of the engine. Thus each cylinder must have an inlet valve and an exhaust valve, and both of these valves remain closed during the compression and power strokes. The settings of the valves in a typical case are shown in Fig. 77. An indicator diagram—Fig. 78—shows whether the adjustments are correct for obtaining good working conditions.

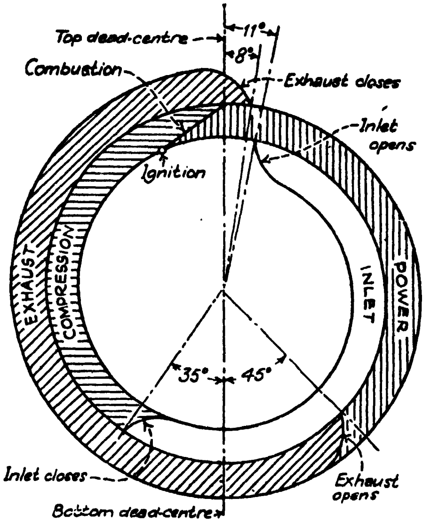
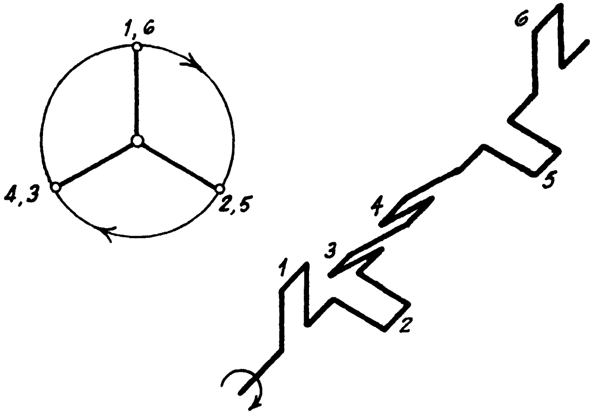


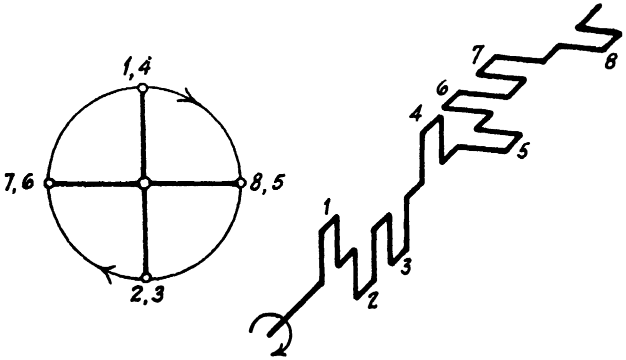
FIG. 77.—Typical four-stroke cycle of petrol engine.

The Indicator Diagram.—In Fig. 78 the diagram of cylinder pressures during a complete cycle is shown. The inlet valve opens when the pressure in the cylinder is at about atmospheric pressure, and the partial vacuum created by the moving piston draws a mixture of petrol and air (or air only in the Diesel engine) into

S. (suction), and *C* (compression), the position of the crankshaft at the commencement of each stroke is



FIGS. 81 and 82.—Crank arrangement and firing order of 6-cylinder engines: 1, 4, 2, 6, 3, 5.



FIGS. 83 and 84.—Crank arrangement and firing order of 8-cylinder engine: 1, 7, 2, 8, 4, 6, 3, 5.

shown in Table I. The relative position of the cranks is shown in Figs. 79 and 80.

TABLE I.—*Strokes in four-cylinder engine when firing order is* 1, 2, 4, 3. (*See* Figs. 79 and 80.)

Angular displacement.	Cylinder number in order of firing.			
	1	2	4	3
0°	**P**	C	S	E
180°	E	**P**	C	S
360°	S	E	**P**	C
540°	C	S	E	**P**
720°	**P**	C	S	E

A six-cylinder engine with cranks arranged as in Figs. 81 and 82, and the direction of rotation shown, can have the order of firing 1, 4, 2, 6, 3, 5, whence we get Table II. The relative position of the cranks is shown in Figs. 81 and 82.

TABLE II.—*Strokes in six-cylinder engine when firing order is* 1, 4, 2, 6, 3, 5. (*See* Figs. 81 and 82.)

Angular displacement.	Cylinder number in order of firing.					
	1	4	2	6	3	5
0°	**P**			S		
60°			C			E
120°		**P**			S	
180°	E			C		
240°			**P**			S
300°		E			C	
360°	S			**P**		
420°			E			C
480°		S			**P**	
540°	C			E		
600°			S			**P**
660°		C			E	
720°	**P**			S		

In a similar way, an eight-cylinder engine can have the order of firing 1, 7, 2, 8, 4, 6, 3, 5, whence follows Table III. The relative position of the cranks is shown in Figs. 83 and 84.

TABLE III.—*Strokes in eight-cylinder engine when firing order is* 1, 7, 2, 8, 4, 6, 3, 5. (*See* Figs. 83 and 84.)

Angular displacement.	Cylinder number in order of firing.							
	1	7	2	8	4	6	3	5
0°	**P**		C		S		E	
90°		**P**		C		S		E
180°	E		**P**		C		S	
270°		E		**P**		C		S
360°	S		E		**P**		C	
450°		S		E		**P**		C
540°	C		S		E		**P**	
630°		C		S		E		**P**
720°	**P**		C		S		E	

Clearly the ignition system must be arranged to correspond with the firing order of the cylinders.

The Compression-ratio.—This ratio has an important bearing on the design of the petrol engine. It may be defined as the ratio of the sum of the stroke and combustion-chamber volumes to the combustion-chamber volume, or, referring to Fig. 78,

$$\text{compression-ratio} = \frac{\text{stroke volume} + \text{clearance volume}}{\text{clearance volume}}$$

$$= \frac{\text{piston-swept volume} + \text{combustion-chamber volume}}{\text{combustion-chamber volume}}$$

In petrol engines this ratio usually lies between 5 : 1 and 6 : 1 for cars and lorries, but for motor cycles the range is wider.

For satisfactory operation, accurate timing and freedom from knocking or pinking are required. To avoid pinking, ignition should be effected by the spark only, and should not be accompanied by self-ignition—*see* page 180. With ordinary petrol, the safe limit for the compression pressure can be taken as about 110 lb. per square inch, which restricts this ratio to about 5 : 1. With an anti-knock fuel permitting a ratio of 6 : 1, the pressure rises to about 150 lb. per square inch with a full charge.

If, with the valves closed, the gases were compressed so slowly as to let the heat due to compression escape, the increase in pressure would be in accordance with the compression-ratio. Owing to the heat of compression, which may raise the temperature just before ignition to over 400° C., the resultant pressure is higher than the value corresponding to the decrease in volume. After combustion, the pressure may reach about 400 lb. per square inch, produced by the burning gases reaching a temperature of 1,200°–1,600° C. and peak temperatures up to 2,000° C.

In a dirty engine the volume of the combustion chamber is reduced, and consequently the compression-ratio is increased. This may well give rise to self-ignition and explains the familiar fact that a dirty engine pinks more readily than a clean one.

Torque and Horse-power.—The mean effective pressure during the power stroke largely depends on the compression-ratio. With a compression-ratio of 5 : 1, the mean effective pressure is about 100 lb. per square inch. On this pressure and the dimensions of the engine in question the turning moment or torque depends, while the power equals the product of the torque and the speed. The effective pressure usually reaches its maximum in the region of 1,000 to 1,500 r.p.m. Speeds much below that giving maximum torque are practically unusable. At standstill, the torque is zero, necessitating auxiliary starting means. At high speeds, restrictions at the valves, carburettor, etc., rapidly reduce the torque. It is sufficient for our purpose to say that on full throttle a petrol engine exerts a constant net torque over a wide range of speed, so that the useful output or brake-horse-power is proportional to the speed. To reduce the power at a given speed, the throttle opening must be reduced.

Self-ignition or Detonation (*leading to Knocking or Pinking*).—An explosive mixture may be fired by an electric spark ; but ignition may also occur without a spark when the temperature exceeds a certain value. This value depends not only on the kind of fuel, but on strength of mixture and other factors. Spontaneous combustion of this kind is known as self-ignition or detonation. Since self-ignition may lead to pinking or knocking, self-ignition temperature becomes one of the limiting factors in design. Commercial petrol has a much lower self-ignition temperature than benzene, consequently a higher compression-ratio can be used with the latter. As thermal efficiency depends on compression-ratio, the designer strives to make this ratio as high as explosions revealed by pinking or knocking will permit.

According to one accepted explanation, the process of combustion seems to be as follows : after ignition a compression wave raises the temperature of the unburnt portion of the mixture. So long as the rate of propagation of the flame is more rapid than the rate of temperature increase, combustion is normal. Should however, the temperature rise more rapidly than the flame spreads, the unburnt mixture may self-ignite before the flame reaches it.

This self-ignition (or detonation), when revealed by audible explosions, is referred to as knocking or pinking. According to this hypothesis, knocking in the petrol engine is caused by a portion of the mixture remote from the spark being raised above the self-ignition temperature by the compression wave and so ignited. Such self-ignition can occur only after the initial firing of a part of the mixture.

ratio is pushed as high as the detonation limit will allow, hence the importance of non-detonating or anti-knock fuels. By suitable blending, fuels are now available permitting a compression-ratio of 7 : 1 with maximum pressure and temperature of the order of 600 lb. per square inch and 2,400° C. In racing engines compression-ratios up to 10 : 1 are met with. With these high performance engines the limits allowable on ignition advance have become closer and closer, by absorbing the fairly wide tolerance in the timing made possible with anti-knock fuels. Such conditions not only intensify the problems of the designer of the ignition apparatus, but they require precise adjustment of the ignition apparatus.

There are various well-known expedients for preventing self-ignition. Thus benzole and alcohol, which have higher permissible compression pressures, when mixed with petrol reduce or eliminate knocking due to detonation. Also various anti-detonating substances, such as lead tetra-ethyl, are available for this purpose. (*See* "Motor Spirit," page 183.)

Pre-ignition.—Pinking arising from self-ignition should not be confused with the dull thumping or knocking caused by premature firing or pre-ignition. Self-ignition occurs *after* ignition by the spark. Pre-ignition may be caused by an over-advanced spark. Other causes are glowing plug points or particles of carbon ; carbonized oil from over lubrication with worn engine, calling for new scraper rings ; or carbon deposit from over-rich mixture, calling for carburettor adjustment. Glowing particles of carbon might be expected in a dirty engine, incandescent plugs might result from over-heating due to a weak mixture or from unsuitable plugs. Such causes of pre-ignition may fire the mixture early in the compression stroke, leading to heavy thuds and irregular running; or late in the suction stroke, accompanied by popping back. (*See* "Sparking Plugs," p. 261). According to conditions, pre-ignition will or will not be accompanied by self-ignition and pinking. The presence of pre-ignition may be checked by driving the engine hard to heat it up and then switching off the ignition with throttle open. Continued irregular running denotes pre-ignition from glowing particles.

From the foregoing it will be seen that a mixture in a petrol engine may be fired wholly or partly in one of three ways: by the sparking device, by a glowing particle, etc., by self-ignition.

Fuel for Petrol Engines.—*Motor Spirit.*—By far the largest amount of motor spirit is used in the form of petrol, a mixture of the more volatile hydrocarbons present in petroleum—an imported product. A certain amount of light spirits is also obtained in this country from shale, while a commencement has already been made to obtain petrol from the distillation of coal by low-temperature carbonization. Also of importance is benzole, produced by the high-temperature carbonization of coal in coke ovens and gasworks; and, lastly, alcohol obtained by fermentation of molasses, residue of beet sugar and of other carbohydrate products.

Petrol.—This spirit is obtained from crude oil by distillation ("straight-run" spirit), and by breaking down the heavier hydrocarbons at high temperatures and pressures ("cracked" spirit). The hydrocarbons present in petrol depend on its source and mode of preparation. The main constituents are known as paraffins, naphthenes, aromatic hydrocarbons and olefines. As the latter two have higher anti-knock values (*see* below) than the former two, the cracking process is directed towards obtaining the desired components at the expense of the others.

Benzole and Alcohol.—These are used for blending with petrol because of the higher compression value at which detonation occurs—a higher compression-ratio means increased thermal efficiency.

Anti-knock Value of Motor Spirit.—The important criterion of motor spirit is its anti-knock value, for on this depends the permissible compression-ratio and consequent thermal efficiency. The anti-knock value of a fuel is determined experimentally by working an engine under definite standard conditions, comparison being made with a standard fuel. Typical anti-knock values expressed as "octane number" with 100 as maximum are: No. 3 spirit (commercial), 65; No. 1 spirit, 70; petrol containing lead tetra-ethyl, 77; aero-engine spirit, 87.

The anti-knock value of a spirit cannot be judged solely by its specific gravity, because there is no definite relation between these two properties. The lower paraffins have a low specific gravity, while the aromatics and naphthenes have relatively high specific gravities, and of these the aromatics have the highest anti-knock value.

The proportion of high-boiling constituents must not be too high, or combustion will be incomplete and the engine oil will be diluted in consequence. There must be a sufficient proportion of low-boiling constituents to ensure ease of starting in cold weather; but the spirit must not be too volatile, or evaporation may be excessive and vapour locks may form in the fuel supply pipes.

In addition to benzole and alcohol, there are some substances like lead tetra-ethyl that, added to petrol in small quantities, increase the resistance to pinking.

Some dopes have a harmful effect on the plugs, valves, etc.

The Explosive Mixture.—This is the name of the fuel-air vapour used for combustion. As an illustration of the combustion of motor spirit which consists of a mixture of hydrocarbons, the prinicpal constituent in petrol may be taken, viz., hexane. During combustion, carbon unites with oxygen of the air to form carbon dioxide, and hydrogen unites with oxygen to form water in the form of vapour. For complete combustion, 1 cubic inch of petrol vapour requires 9·5 cubic inches of oxygen. Since air is a mixture containing 4 parts of nitrogen to 1 of oxygen, it follows that 1 cubic inch of petrol vapour requires $9{\cdot}5 \times 5 = 47{\cdot}5$ cubic inches of air. Thus, by volume, the amount of petrol vapour in an explosive mixture for complete combustion is about 2 per cent. By weight, this is equivalent to 1 lb. of petrol to 15 lb. of air, or about 6 per cent. According to the adjustment of the carburettor the mixture may be richer or weaker in petrol, the limits by weight being somewhat as follows :—

For complete combustion, air : petrol = 15 : 1
Limiting rich mixture, air : petrol = 9 : 1
Limiting weak mixture, air : petrol = 17·5 : 1

An engine with its carburettor can be tuned either for low consumption, i.e., fuel economy, by using a weak mixture (up to 20 per cent more air than is required for complete combustion), or for high power by using a rich mixture (up to 10 per cent. less air than is required for complete combustion). Thus full economy and maximum output demand opposite conditions ; and an engine adjusted for maximum fuel economy will not give peak output on maximum acceleration.

In a mixture that is too rich combustion is incomplete, resulting in a carbon deposit in the cylinder, foul plugs and emission of black smoke from the exhaust, with possibly *backfire* in the silencer. In addition, owing to the scarcity of oxygen, as much as 5 to 6 per cent. of carbon monoxide may be produced—the highly poisonous and odourless gas which renders it so dangerous to start and run an engine in a small garage with the doors closed.

Backfiring may also result from *unburnt* mixture passing into the silencer, e.g., when the ignition is cut off while the engine is running, or when the engine misfires.

A slightly weak mixture may be an advantage when running, but too much air may render burning so feeble and slow as to produce *popping* or *blow-back* in the carburettor, owing to combustion continuing beyond the exhaust stroke and igniting the incoming charge. Weak mixtures may arise from lack of fuel due to blocked jets, sticky or burnt valves. Popping may also occur when combustion takes place while the inlet valve is still open, i.e., from pre-ignition during the suction stroke. Too much weakening may make combustion so slow as to need over-advanced ignition with consequent overheated valves and reduced output. Popping in the carburettor may set it alight, but the occasional pop when warming up—and common in a cold engine—is seldom harmful.

The same carburettor adjustment may be suitable for different grades of fuel, although differeut fuels may affect pinking limits and acceleration. These limits also alter as carbonization increases.

Combustion.—The chemical changes involved in the burning of petrol vapour and oxygen are known as combustion. During this process heat is evolved, raising the burning gases to a high temperature and so increasing the pressure which is utilized in the power stroke of the engine. The process of combustion takes an appreciable time. If the mixture is quiescent, the speed of propagation of the flame may be 2 to 6 metres per sec.; if turbulent, 10 to 20 metres per sec. The conversion of chemical energy into heat should take place as quickly as possible to reduce loss of heat to engine and to cooling water. While rapid burning is desired, the phenomenon variously known as spontaneous combustion, self-ignition, instantaneous explosion or detonation—evidenced by knocking or pinking—is to be avoided (*see* "Pinking" on page 180). The factors on which this depends include compression-ratio, load, grade of fuel, shape of combustion chamber, position of sparking plug, etc.

Since power increases with pressure, the tendency is to raise the latter to the permissible limit, i.e., just when knocking occurs. Apart from details of engine design, knocking may be reduced by obtaining optimum spark setting for each speed and load, by using a non-detonating fuel; by reducing load or throttle opening, and by gear changing.

Other conditions to be satisfied in order to obtain the maximum power from the fuel are: carburation must be good, i.e., the fuel must be thoroughly volatilized before ignition; the explosive mixture must be correctly proportioned; the gases in the combustion chamber must possess a high degree of turbulence to ensure that the flame initiated by the passage of a spark across the plug electrodes is rapidly propagated throughout the mixture.

It is the ignition conditions with which we are concerned. These involve not only the production but also the timing of the requisite spark. Unless these are correct in each cylinder under all conditions of load and speed, the best results cannot be obtained from the engine. (*See* Chapter VIII.)

THE COMPRESSION-IGNITION ENGINE

The type of heavy-oil engine commonly used on commercial and public passenger-carrying vehicles is developed from the Diesel engine. In this engine, the sequence of operations in the four-stroke cycle is the same as in the petrol engine—suction, compression, expansion and exhaust. There is no carburettor. In the suction stroke a full charge of air is drawn into the cylinder. On compression this air is heated to a temperature high enough to ignite spontaneously the fuel injected into the combustion chamber at the end of the compression stroke—in other words the fuel is ignited by the heated air. The carburettor of the petrol engine is replaced by a fuel-injector. Full compression is about 500 lb. per square inch, and, of course, the fuel is injected at a still higher pressure. With airless injection, as used in automobile-type oil engines, the compression-ratio varies from 15 : 1 to 20 : 1, according to the type of combustion chamber ; the average compression-ratio being about three times that in the petrol engine. The indicator diagram for the high-speed Diesel engine is similar in shape to that in Fig. 78 for the petrol engine ; before ignition the pressure is about 500 lb. per square inch, and the temperature about 500° C. After combustion the pressure may reach 800 lb. per square inch, and the temperature may reach 2,500° C. The fuel is usually injected about 12 degrees before top-dead centre, while typical valve settings for commercial-vehicle engines are : inlet opens 10° before T.D.C. and closes 40° after B.D.C.

The exhaust valve opens 40° before B.D.C. and closes 10° after T.D.C. (*compare* Fig. 77).

The accelerator pedal controls the amount of fuel injected, and so the power and speed. The compression pressure is unaffected thereby—a full air charge being admitted at all loads. During combustion the pressure is increased three- to four-fold, as in the petrol engine.

The Fuel-pump Unit.—The fuel used in the oil engine is heavier than petrol and resembles paraffin (*see* below). A mechanical or electrical fuel feed pump is used to convey the oil from the fuel tank to a fuel-pump unit. This pump supplies at regular intervals a minute charge of fuel oil to the injector of each cylinder, the quantity being controlled by the accelerator pedal. Pinking or knocking can be caused much in the same way as in the petrol engine (*see* p. 181). The fuel-pump unit has to be accurately made and adjusted, and the fuel must be carefully filtered. The pump unit is driven at camshaft speed, i.e., at half crankshaft speed. Each cylinder has its own element in the pump terminating in its corresponding injector. All elements are controlled by a common control rod. Timing of ignition in the internal-combustion engine is effected as in a petrol engine, "advance" and "retard" having similar effects.

Fuel for Diesel Engine.—Though Diesel engines will work with crude oil, it is usual to remove by distillation those constituents for which there is a demand. Thus petrol is obtained in the early stages, followed by paraffin. Gas oil, which comes next, is used for Diesel engines. From the residue, lubricating oil and fuel oil for steam raising are obtained. As time goes on and mineral oils become scarce, it seems certain that fuel oil will be obtained from vegetable matter (molasses, sawdust, etc.). From this source also fuels suitable for petrol engines are obtainable which have a higher temperature of spontaneous nigition than petrol, permitting higher compression-ratio and thermal efficiency.

CHAPTER VIII

THE IGNITION SYSTEM

THE modern petrol engine is dependent on electric ignition, the spark which fires the explosive mixture being produced by an electric discharge across the gap between the electrodes of a sparking plug. Before discussing the ignition devices which produce this breakdown, it is desirable to consider the nature or mechanism of the electric discharge. The treatment followed here, though speculative in places, may be said to accord with widely-accepted views; also the reader must bear in mind that it is but an elementary account of the present state of theory and experience.

Complete Breakdown of Spark-gap.—*Disruptive Discharge.*—Normally, for all practical purposes, a gas is an insulator, but it can become a conductor by a process known as *ionization.* According to the electronic theory of matter, an atom consists of a positively-charged nucleus, surrounded by a certain number of negative charges, or *electrons.* These electrons may be supposed to revolve round the nucleus like planets round the sun, while the number and arrangement of the electrons determine the nature or kind of atom. In their neutral state, atoms have equal positive and negative charges. Electrons, however, are also capable of a separate existence, and free electrons may in their wanderings collide with molecules. If the impact between an electron and a molecule is sufficiently violent, a further electron will be liberated, leaving the struck molecule positively charged; but if the colliding electron has insufficient velocity to expel a new electron, it will attach itself to the molecule, leaving it negatively charged. Molecules thus changed from their neutral state are called *ions*—the loss of an electron resulting in a positive ion, and the gain of an electron in a negative ion. Thus ions are particles of matter carrying an electric charge.

We now apply this theory to a gas in the neighbourhood of two electrodes between which an electric field produced by a difference of potential exists. Under the influence of the electric field, any casual electrons or negative ions will be attracted to the positive electrode or anode, while positive ions will be drawn towards the negative electrode or cathode. If the velocity given to these wanderers be sufficient to create further ions in their collisions with neutral molecules, the gas in the gap rapidly becomes ionized. If ultimately the ions bridge the electrodes, a spark passes, and the gap is said to break down, or a disruptive discharge to occur.

Accordingly, for a disruptive discharge, there must be an initial supply of ions, and further a certain critical potential difference between the electrodes of the sparking plug is essential. The former depends on chance conditions, while the requisite voltage depends on gap dimensions, charge density, and electrode temperature.

Effect of Initial Ionization.—Owing to the time taken for ionization to appear and develop between the electrodes, some spark-gaps require much higher breakdown voltages with the impulsive type of discharge produced by ignition systems than with steady voltages. The ratio of these voltages is called the *impulse-ratio* of the gap, and its value is largely affected by the amount of the initial ionization. At starting, ionization is generally small, resulting in high impulse-ratio ; whereas under working conditions, owing to the residual effect of the burnt gases, ionization may be plentiful, consequently the impulse-ratio may be nearly unity.

Owing to the effect of ionization, as expressed in the impulse-ratio, the use of a short gap between two pointed electrodes leads to inconsistent results. This is particularly the case when testing ignition devices and sparking plugs by means of a plug in a closed chamber where the compressed air is moist and quiescent. To ensure ample ionization, either the electrodes can be given relatively large dimensions, as in the annular test gap, or artificial ionization can be produced between the needle points by means of a third point (*see* under "Test Spark-gaps," page 274).

Partial Breakdown.—*Corona Discharge.*—If the voltage is below the critical value required to produce a spark, local ionization may nevertheless occur at the electrode surfaces where the electric stress is greatest. Such a partial breakdown of the gap appears as "brush" discharge or "corona."

Not only may corona discharge be produced at the plug electrodes, but also in other parts of the high-voltage system. Corona may occur at voltages above 6,000 volts, and become excessive above 10,000 volts. Incipient spark discharge or corona effect in air spaces near conductors and live parts of machines is accompanied by chemical action, ozone and oxides of nitrogen being produced. These gases react on metals and insulating materials, causing corrosion and ultimate failure. Likewise, high-voltage cables in metal tubes may break down because ozone rapidly attacks rubber and causes it to perish. It is desirable therefore to work at a plug voltage which is not high enough to produce injurious corona discharge in the ignition device and cables.

In order to reduce corona action in the windings of magnetos and coils, care is taken to exclude air pockets by winding in layers separated by sheets of treated silk and paper and sealing each wire in a layer of varnish. In this respect there is not much to choose between the coil and the magneto with stationary windings. In the revolving-armature magneto, however, corona action may occur at the slip-ring flanges, brush and safety gap, as evidenced by the deposit of fine dust on the insulating surfaces, which also introduces leakage paths—a prolific cause of difficult starting. As regards the distributer, the conditions are the same for the coil as for the magneto. In order to prevent accumulation of the products of brush discharge, it is now the custom to ventilate the parts which might be affected. As the local heating associated with a stationary safety spark-gap greatly reduces the breakdown voltage, a revolving safety spark-gap to reduce corona and to blow out the spark has been introduced.

Factors Influencing Plug Voltage. — With properly adjusted plug electrodes, the normal plug voltage (peak value) usually lies between 4,000 and 8,000 volts, the limit being fixed by the value at which the gap breaks down. It is fortunate that in practice a plug voltage exceeding 8,000 volts is seldom required, thereby minimizing the danger of corona. Briefly, it may be stated that the plug voltage is approximately proportional to the gap length and to the charge density or compression, and inversely proportional to the electrode temperature. The increase of voltage with length of spark-gap shows the harmful effect of setting the electrodes too far apart, or of neglecting gap adjustment to compensate for burning away of electrodes. The effect of charge density arises from the fact that the electric strength of a gas is a function of its density; hence the plug voltage is increased by increasing the gas pressure at a given temperature, and by cooling the gas at a given pressure. When starting a cold engine, therefore, a higher plug voltage is needed than when starting a hot engine with the same compression. As the temperature of the electrodes rises, the requisite plug voltage falls. This may be explained by the electrode being surrounded by a film of heated gas at a density below that of the charge.

Under steady conditions and with a given plug setting, according to the degree of cooling the effect of electrode temperature more or less neutralizes the effect of charge density or compression. Even in supercharged engines the operating voltage is scarcely influenced. If the electrodes are not cooled too effectively, the plug voltage, after a few revolutions of the engine, may be governed almost entirely by the electrode temperature. Cases where the voltage falls from 8,000 to 4,000 volts as the engine warms up are not uncommon. Before conditions have become steady, as at starting or when picking up under fully-opened throttle, the temperature effect cannot exert much influence; consequently, under such transient conditions, the plug voltages may reach high values, possibly exceeding 10,000 volts. In racing engines, with very high compression, much higher values may be reached. Maximum values of 24,000 volts are not unknown.

From what has been said it will be seen that less strain is imposed on the ignition apparatus in an engine in which the plugs have hot electrodes (e.g., where plugs are not exposed to the cooling effect of the incoming charge, or where hard driving is indulged in), than in an engine where the electrodes are cool, owing either to gentle driving or to the position of the plugs in the cylinder.

Other factors influencing sparking voltage are: shape of electrodes—rough or sooty electrodes need a lower voltage than smooth or clean electrodes; steepness of voltage rise—the more rapid the rise, the higher the plug voltage; strength of explosive mixture—a weak mixture may need two to three times the sparking voltage of a rich mixture; temperature of negative electrode—the hotter this electrode, the lower the plug voltage.

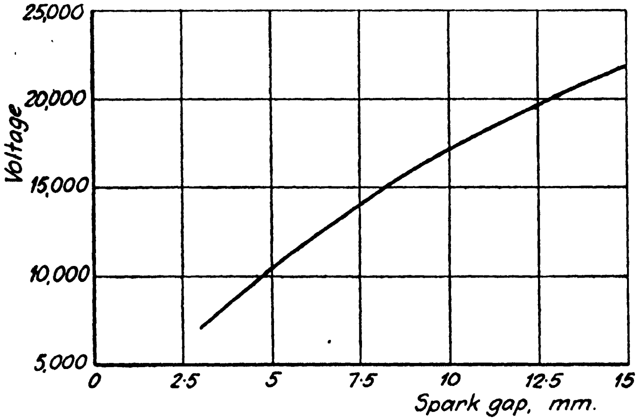


FIG. 85.—Relation between sparking voltage and three-point gap (as shown in Fig. 123).

Measurement of Sparking Voltage.—*Test Spark-gap.*—Owing to the difficulty of measuring the sparking voltage, an ionized spark-gap is used. The construction and properties of such a test spark-gap are explained on page 274. The relation between the sparking voltage in volts and the spark-gap in millimetres under atmospheric pressure is shown in Fig. 85. This spark-gap is not reliable for distances below 3 mm. Ignition devices may be required to spark across test gaps up to 10 or 12 mm. at starting; or a magneto may be specified to give regular sparking with a 6-mm. gap at cranking speed. Characteristics of magneto and coil, showing spark-gap as a function of speed is shown in Fig. 86.

Effect of Plug Fouling.—A plug spark-gap bridged by oil or carbon offers an additional load to the spark-device. Such fouling is equivalent to a resistance shunted across the plug points. According to the value of this resistance, sparking will or will not occur, for the shunt may have any value between infinity and zero. Shunting the spark-gap by a resistance of 200,000 ohms to simulate fouling reduces the spark-gap length to about one-half. Alternatively, such a shunt may halve the secondary voltage (*see* "Testing," p. 274.)

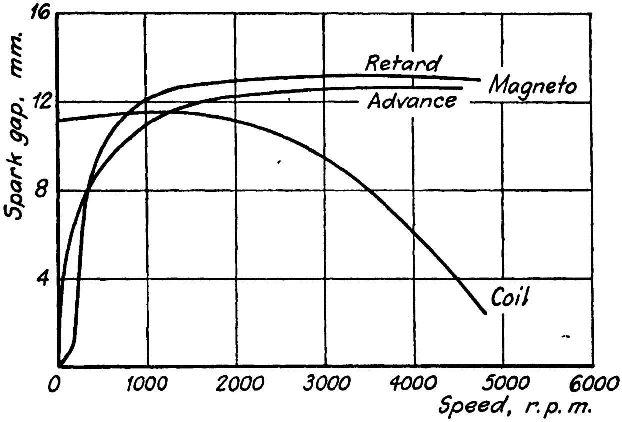


FIG. 86.—Typical characteristics of magneto and coil showing effect of speed on sparking voltage in terms of three-point spark gap (as shown in Fig. 123).

In practice, plug fouling frequently arises from soot being deposited on the insulator surrounding the central electrode, owing to running with too rich a mixture.

Electrode Polarity.—With coil ignition all sparks have the same polarity. In other words, the polarity of the central or insulated electrode is the same for all cylinders. As it is desirable to keep the plug voltage as low as possible, the question of the polarity of the central electrode arises. The sparking voltage is controlled by the temperature of the negative electrode, and the central insulated electrode is usually hotter than the outside earthed electrode. When the engine is cold, the results are apt to be inconsistent. When hot this is not so; when the plugs are thoroughly warmed up, the voltage is usually lower when the central electrode is negative. For this reason it is customary to make the central electrode negative, as shown in the diagram in Fig. 103. (*See* under "Earthing," p. 161.)

Nature of the Secondary Discharge.—When the primary current of the coil or magneto is interrupted by the contact-breaker, the magnetic energy stored in the field is released, and in collapsing induces a voltage in the secondary winding, the value of which is proportional to the rate of change of the magnetic lines of force linked with the winding. Associated with the secondary circuit there is a certain capacitance in the winding, cables, etc., virtually forming a condenser in this circuit in parallel with the spark-gap. As the magnetic field collapses, the rising voltage charges this condenser until the gap breaks down, provided the voltage reached is sufficienly high. An idea of the magnitude of the stored electrostatic energy which is thus suddenly released can be obtained by assuming the breakdown voltage V to be 10,000 volts and the capacitance C to be 50×10^{-12} farad.

The energy released by the initial breakdown is then $\frac{1}{2}CV^2=\frac{1}{2}\times50\times10^{-12}\times10{,}000^2=0{\cdot}0025$ joule. This is called the *capacitance* component of the discharge and it is responsible for breaking down the gap and firing the explosive mixture.

The energy represented by the capacitance component, however, is only a fraction of the inductive energy $\frac{1}{2}LI^2$ stored in the magnetic field, where L is the inductance and I the current. This may reach 0·04 joule in a coil at low speeds, and twice as much in a magneto at high speeds. Usually the energy delivered to the plug points is 0·01 to 0·02 joule per spark. Consequently, after the potential difference has reached a value sufficient to break down the gap, the discharge is maintained until the remaining stored energy is dissipated in losses in the spark or elsewhere in the circuit. This latter and major part of the discharge is called the *inductance* component. Owing to the ionization of the gap, this part of the secondary circuit becomes virtually a short-circuit, so that the value of the current in the spark is a function of the inductance, while its duration is a function of the resistance of the secondary winding of the ignition device. This discharge is usually oscillatory in character.

Function of the Spark Components.—Theoretically, as far as ignition is concerned, the small pilot spark produced by the capacitance component is all that is required, provided the plug is properly situated and clean. The dependence of ignition on the capacitance component also explains why certain ignition devices producing little energy but sudden high voltage are satisfactory. As far as firing a correct mixture is concerned, the inductance component would thus seem to be practically useless. In other words, the idea that a "fat" spark, i.e., a spark with great energy, is essential for satisfactory ignition would appear to be erroneous. On the other hand, it is possible that the inductance component may give a quicker rise in pressure to a weak, turbulent mixture by igniting gas that would otherwise have to wait for the flame to reach it. Also the energy in the inductance component may be serviceable in assisting local volatilization in a cold engine. While therefore a capacitance spark will always ignite a correct mixture of gas and air, a drawn-out spark (i.e., a flame) has a greater chance of firing a weak, stratified mixture, and is also useful where droplets are present.

Apart from the energy required by the spark, reserve energy in the ignition device may be useful. When a plug becomes foul or hot, the insulation resistance may fall to a low value and misfiring may occur with a device having too little energy to maintain a spark across such a plug. In such a case the available energy may be able to maintain regular firing. For this reason ignition devices are tested with shunted plugs (*see* also p. 274). With the coil this reserve energy would be available at low speeds; with the magneto at high speeds. In the latter case there is, however, the disadvantage that the excess energy rapidly burns away the plug points. To prevent this injurious action of the inductance component, some magnetos are fitted with devices for reducing the spark energy at high speeds.

The Safety Spark-gap.—Most ignition devices at certain speeds are capable of producing voltages well in excess of those required, but, providing the high-voltage circuit is in order, the limit is fixed by the value required to produce a spark. Should, for any reason, this limitation be removed, as for example by an accidental break in a high-voltage wire, the voltage in that circuit might be high enough to endanger the winding. With coil ignition it is not usually needful to take precautionary measures, but with magnetos protection is often provided. At one time this took the form of a suitable discharge path in the form of a safety spark-gap, adjusted to operate in case the secondary voltage exceeds a certain predetermined value. This gap was usually about $\frac{5}{16}$ inch or 8 mm. long, with pointed or serrated electrodes, corresponding to a breakdown voltage of about 12,000 to 14,000 volts. The one electrode was earthed, while the other was connected to the high-voltage terminal of the secondary winding. The gap could be stationary, but to prevent harmful corona effects it was frequently made to revolve by attaching the electrodes to the gear wheel on which the distributor arm was fixed. In modern magnetos with stationary armatures this safety gap is often nothing more than a minimum distance between earth and a part of the high-voltage system where insulation cannot be damaged. *See* also under "Testing of Coils and Magnetos."

Driving and Timing of Ignition Devices.—The ignition device must not only be driven by the engine at the correct speed (*see* p. 226), but the spark must be correctly timed with respect to the compression stroke.

Coil.—The drive for the distributer and contact breaker is usually taken from the camshaft. Adjustment of the instant when the contact-breaker points open can be readily obtained by moving the body or housing of the distributer relative to the distributer shaft. To accomplish this relative movement the locking device attached to the body is released—the housing is then turned in the direction of rotation of the distributer shaft to retard the ignition, and against the direction of rotation to advance the ignition. When the desired advance is obtained the locking device is clamped. With some distributers, for small adjustments a vernier arrangement is attached which can be operated without slackening any fixtures of the distributer mounting.

A handy preliminary adjustment is to advance the spark with the engine idling until smooth running is replaced by erratic running. Pinking should just not occur with normal running on load.

Magneto.—A flexible coupling is desirable to reduce vibration on the magneto or distributer spindle. Some form of vernier coupling is often combined to facilitate fine adjustment in the timing. Thus in one coupling there is an intermediate rubber member which has 20 teeth on one side and 19 on the other. With this it is possible to obtain a vernier adjustment of 1/19—1/20= 1/380 of a turn—that is, less than 1 degree—by shifting one side forward and one side backward each one tooth.

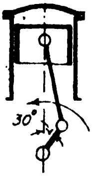


FIG. 87. Position of piston for 30° spark advance.

Generally the position with the timing lever fully advanced for maximum power is given when the crankshaft is about 30 degrees behind the dead-centre position, the piston being on the compression stroke (see Fig. 87)*. The timing can be effected thus: With the timing lever fully retarded† and the contacts just opening, adjust the coupling so that No. 1 piston is just on the dead centre. (On most engines the position of top dead-centre of No. 1 cylinder

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* Compression stroke can be checked by placing finger over sparking-plug hole.

† With automatic spark adjustment the centrifugal device retards the timing when the engine is at rest.

is usually indicated by a mark on the flywheel.) Connect the sparking plug of this cylinder to the distributer segment which is just coming under the revolving arm, and the other plugs to the other segments in their proper sequence. The firing order of the cylinders is usually marked on the engine (*see* p. 175). The point of opening of the contacts can be found by inserting a thin feeler between them and noting when it can be withdrawn.

Accurate and precise timing in all cylinders is important for good working of the engine. For this purpose the contact-breaker, the distributer, the sparking plugs, the cams, camshaft and tappets must all be correctly fitted and adjusted.

Influence of Timing.—Timing of the spark has an important bearing on the working of the petrol engine. Incorrect timing involves not only loss of power, but increased fuel consumption. In Fig. 88 indicator diagrams are given to show the effect of timing. In general it may be said that to obtain maximum power, i.e., maximum area of the indicator diagram, with a given charge, the maximum temperature and pressure should be reached when the piston is 10 to 15 degrees after top dead-centre (T.D.C.). For this to occur, the ignition point is 10 to 40 degrees before the piston reaches T.D.C., depending on the fuel and engine. In the diagram marked (*b*) in Fig. 88, ignition is normal, and occurs at 23° before T.D.C. Pre-ignition occurs when the spark is too early or over-advanced. In Fig. 88 (*a*) a sudden and abnormal rise of the explosive pressure is seen to result in the "over-advanced" diagram—the ignition point here is 48° before T.D.C. Such early ignition causes a sharp rise in the pressure, which may lead to the self-ignition or detonation of the unburnt part of the charge in the cylinder, and, if sufficiently violent, audible knocking or pinking is produced. Pre-ignition may occur even earlier in the upward stroke, owing to a glowing particle of carbon or plug point, and cause the engine to run unsteadily with a heavy thumping noise, accompanied by loss of power.

Lastly, with ignition too late, or over-retarded, the power falls off rapidly. This is illustrated in diagram (*c*) Fig. 88, which is drawn for the ignition point when the piston is at T.D.C. The slow combustion accompanying over-retarted ignition continues throughout the power stroke and produces over-heating, and possibly popping back in the carburettor.

Combustion cannot take place instantaneously, and in order that the maximum temperature and pressure shall occur as the piston reaches the top dead-centre, the spark must be produced before the end of the compression stroke. The requisite amount of spark advance is governed by the conditions prevailing at any given instant. Of the many factors affecting spark advance, it is only necessary here to mention briefly those of greater influence.

Engine speed is important. Under given throttle conditions the advance must obviously be increased as the engine speed rises, if maximum power is to be obtained. Further, at a given engine speed the ignition timing is also a function of the induction-pipe depression. At full throttle, i.e., when the suction in the manifold is low, the engine is running at full load, compression is high, scavenging is good and the explosive mixture is rich—all conditions assisting rapid combustion and requiring small spark advance. On part throttle, i.e., when the suction in the induction-pipe is high, the diluted mixture at the reduced compression takes longer to burn and therefore needs greater spark advance. Thus more advance is required at part than at full throttle, or at high than at low induction-pipe depression (or suction or vacuum). A rich mixture requires less spark advance with high compression and low speed than with low compression and high speed.

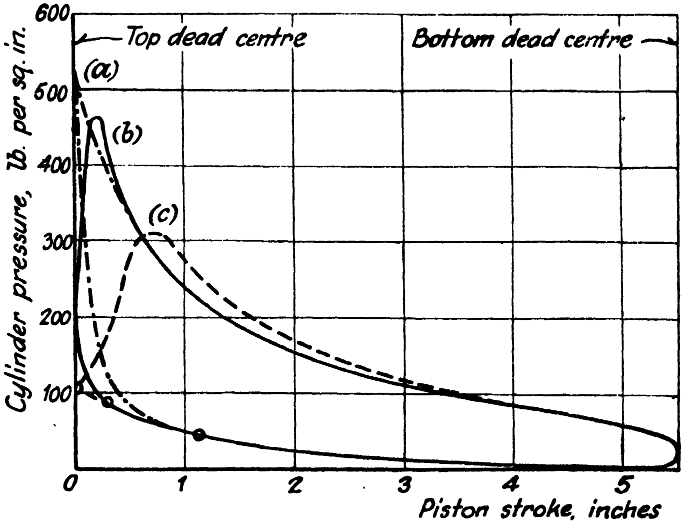
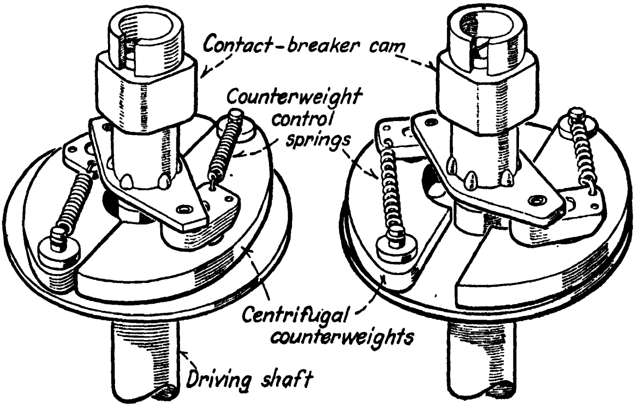


FIG. 88.—Effect of timing of spark on power developed by petrol engine with given throttle and speed.
(*a*) Over-advance (48° advance).
(*b*) Normal (23° advance).
(*c*) Over-retard (0° advance).

To sum up, the correct point of ignition is a function first of engine speed and secondly of inlet-pipe depression; increased advance being required as the speed rises and also as the vacuum in the inlet manifold increases. The former obviously calls for a centrifugally-operated device; the latter for a vacuum-operated piston or an accelerator-pedal-operated device to give maximum advance when throttle is closed.

The amount of advance depends, too, on engine design, especially of the cylinder head or combustion chamber. Thus the requisite spark advance is affected by the turbulence of the explosive mixture : the greater the turbulence, the more rapid the propagation of the flame. If flame propagation were constant, spark advance would follow a simple law. Actual conditions, however, require a specially designed compensating device if correct timing is to be secured.

Automatic Ignition-timing Devices.—Except in the case of slow-speed engines, where the effect of spark adjustment is negligible, or of very small high-speed engines, where the engine accelerates too rapidly to cause trouble, fixed ignition is inconsistent with economical working. Spark adjustment—either manual or automatic—therefore becomes essential. Since automatic devices are both simple and inexpensive, and lead to reduced petrol consumption, less gear changing, improved acceleration and simplified driving, their use is rapidly becoming universal. In many cars it is now the practice to dispense with facilities for manual spark control, provision being made in the automatic device to prevent back-firing at starting. The two factors requiring spark adjustment are change in speed and change in load or throttle-opening. With a given throttle-opening, the higher the speed the greater must be the spark advance; secondly, at a given speed, the greater the throttle opening—or the lower the suction in the manifold—the less must be the spark advance. The characteristics of the automatic timing device or devices must suit the particular type of engine. Modern engines require about 10 to 40 degrees spark adjustment, measured on the crankshaft, the higher compression engines needing the lower values, while the higher values are for commercial-vehicle engines and for engines using non-detonating fuels. If the spark is advanced too slowly, acceleration is reduced; if too quickly, knocking ensues. Where the conditions in the neighbourhood of optimum spark advance are not too sensitive, fairly simple mechanisms can be employed. These, however, require modifications for different types of engine; even with engines of the same type adjustments may be necessary to meet required conditions.



Retarded position for low speeds

Advanced position for high speeds

FIG. 89.—Centrifugally-actuated spark-timing device.

Compensation for Change in Speed.—Automatic timing adjustment for speed variations is now provided on most British cars. Obviously, to correct for speed changes, such devices will be speed-actuated. The common arrangement is a centrifugally-operated mechanism in the form of a flexible coupling interposed between the driving and the driven shaft of the ignition device. A centrifugally-actuated timing device is shown in Fig. 89. With coil ignition the centrifugal advance mechanism is incorporated in the distributer itself—this, of course, does not affect the strength of the spark. Similarly with an automatic device between the magneto and the engine, the magneto is set and remains in the position to give the best spark, any necessary retard being obtained on the device itself. This ensures the optimum condition for the magneto at starting and at all speeds, whatever the timing.

A much lighter mechanism is needed to displace the contact-breaker than to displace the magneto shaft, but rocking the contact-breaker to the retarded position affects the spark conditions of the magneto adversely with retarded spark. For this reason it is usual to place the timing device between the engine and the magneto.

The mechanism should be designed to meet the needs of the particular engine. For each model a power curve has to be taken and a curve of automatic advance suitable for it is obtained by varying the strength of the springs.

Thus the centrifugal device might be adjusted so that from rest until a speed of 200–300 r.p.m. is reached the spark occurs about 5° after the piston has passed T.D.C. The spark might then be advanced rather rapidly up to, say, 500 r.p.m., after which the increase in the advance would be proportional to the speed.

The usual characteristic curve of a petrol engine giving torque as a function of ignition advance shows that, for a given speed and throttle opening, the torque developed rises fairly rapidly to a maximum with increasing advance and then falls off comparatively slowly as the advance is further increased. The point at which detonation occurs depends on the engine design, compression-ratio, grade of fuel, etc. According to circumstances, pinking may occur before, at or after the peak in the torque curve. Obviously with a non-detonating fuel the design of the advance mechanism is much less restricted than when the detonation point coincides with the maximum torque position—the ideal aimed at to meet severe competition. The tendency to increase compression-ratios as anti-knock fuels are improved causes the limits allowable on ignition advance to become closer and closer.

Compensation for Change in Load.—At a given speed an engine requires more advance when working on part than on full load; this correction is thus a function of the throttle pedal movement or of the manifold depression. There are various devices for effecting the required compensation. In one common form, advantage is taken of the fact that at any given engine speed, the intake-manifold suction is roughly inversely proportional to the engine load—at light load the depression in the manifold is high; at full load it is low. This pressure variation is used to actuate a treated-cloth, flexible diaphragm in a metal housing (Fig. 90). The movement thus effected

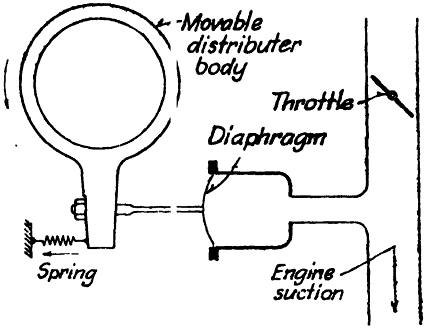


FIG. 90.—Vacuum-operated, spark-timing device.

by the vacuum in the engine induction pipe is made to rotate the distributer head, thereby imposing on the ignition a control additional to that given by the centrifugal mechanism inside the distributer itself. By thus combining the suction device with the centrifugal device, the ignition timing is corrected for load as well as for speed.

The gain obtained by employing a vacuum-operated device to increase the spark advance as the throttle is closed is not large, being about 5 per cent. increase in torque under the most favourable conditions and less than 2 per cent. under normal driving conditions. On the other hand the device is simple and cheap, and it obviates the need of hand control.

Since provision is made when coupling up the centrifugal device to give a retarded spark at starting and so prevent backfiring, there is small justification for fitting additional manual control. In some countries, safety regulations prescribe that spark advance shall be impossible at starting, which renders an automatic device essential. Where a timing lever for manual operation is provided, the range must extend from retard at starting to full advance at top speed. If compensation is desired for change in fuel or state of engine carbonization, a simple micrometer screw can be fitted to the distributer to permit the timing to be adjusted from about 8 degrees retard to 2 degrees advance, with reference to normal setting.

THE INDUCTION COIL

Method of Obtaining a High Voltage.—In order to send a spark across the points of the sparking plug a voltage of 4,000 to 8,000 volts is necessary. To generate this voltage a spark coil or magneto is employed. As already mentioned, the electromotive force induced in a circuit is proportional to the rate of change of the magnetic field linking the circuit. It makes no difference whether the circuit moves and the field remains stationary, or the field itself changes while the circuit remains stationary. Provided there is relative movement between the magnetic field and the electric circuit, an electromotive force will be induced, and its value will be proportional to the rate of change of the linkages of the field with the circuit.

The number of linkages in a circuit is the number of lines of magnetic force multiplied by the number of turns through which they thread, so that for a given magnetic field the linkages are proportional to the turns. Thus, so long as no current circulates, by doubling the number of turns in a circuit the induced electromotive force is doubled for a given change of magnetic field. For this reason, where a high electromotive force is required, a coil with a large number of turns is employed.

Since all modern high-voltage ignition devices involve the principles of the induction coil, the latter will now be explained. The necessary modifications will then be easy to follow.

Principle of the Induction Coil (Fig. 91).—A coil containing a few hundred turns of wire is wound on a core made of iron wires or laminations and connected to a battery. In the circuit are two contacts, one fixed and the other movable. The movable contact is attached to a trembler consisting of iron which can be influenced by the strong magnetic field produced in the iron core when current flows in the coil. When the movable contact is drawn towards the iron core, the circuit is broken and the field collapses. This permits the trembler to jump back again and close the circuit, and so the cycle repeats itself so long as the switch remains closed. The trembler thus rapidly makes and breaks the circuit; with every make the current flows, and with every break it is interrupted. In this way the magnetic field grows and collapses alternately, and while it is being created and destroyed an electromotive force is induced which is proportional to the rate of change of the field linkages. Owing to the fact that the time taken to interrupt the current is much less than the time taken for it to build up, the voltage induced on break is much greater than that produced on make. The sluggishness in the building up of the current is due to the inductance of the circuit, inductance in an electric circuit being analogous to inertia in a machine (cp. Fig. 104). The winding in which this action takes place is called the "primary."

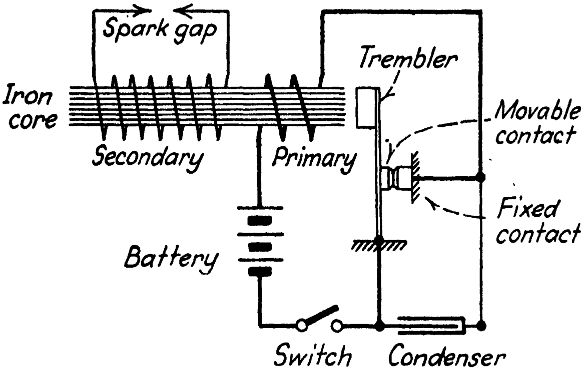


FIG. 91.—Elements of induction coil.

On the same core and linked with the same field is another coil, called the "secondary." This consists of several thousand turns of wire. The electromotive force induced in every turn, whether primary or secondary, is the same, assuming each turn to be linked by the same magnetic field. Provided no discharge occurs at the secondary terminals, that is, so long as no current flows in the secondary winding, the ratio between the primary and the secondary electromotive forces is the ratio of the number of turns in the two coils. In this way an electromotive force of many thousand volts is induced in the secondary every time the current in the primary is broken. The terminals of the secondary coil are arranged to form a spark-gap across which a discharge current flows in the form of a spark every time the primary circuit is broken. This is the spark that is used to fire the charge in the cylinder of the engine.

The Condenser.—Just as energy is released in the secondary circuit every time a spark jumps across the gap, corresponding with the collapse of the magnetic field, so energy is released in the primary circuit owing to the same cause. Hence at the trembler contacts there will be a succession of sparks. This discharge in the primary circuit has a twofold disadvantage: it causes pitting at the contacts and it reduces the energy released across the secondary spark-gap. To reduce sparking in the primary circuit, a condenser is connected across the contacts, as shown in Fig. 91. The condenser consists of two sets of sheets of tinfoil, insulated from one another by sheets of mica; or of strips of tinfoil, separated by strips of paper, oiled, varnished or waxed after winding and made moisture-proof. When a voltage is applied to the terminals of a condenser, a momentary current flows, electric energy is stored, and the condenser becomes charged. The charging current ceases as soon as the voltage ceases to change. The condenser can discharge the stored energy through any circuit provided for it, and this gives rise to a reverse or discharge current.

Referring now to Fig. 91, as soon as the contacts break the circuit, the collapsing field induces in the primary winding a rapidly rising electromotive force which tends to maintain the current in its original direction. The condenser, which shunts the contacts, provides a path for this current and thereby greatly reduces the spark across the opening contacts. The charging current ceases as soon as the voltage ceases to rise, and the condenser immediately discharges itself by sending a reversed current round the closed primary circuit. As a result, the condenser effects more complete and rapid suppression, or even reversal, of the flux, and so produces a higher and more regular voltage at the secondary terminals. Thus, in addition to preventing burning of the contacts, the condenser helps to produce a better spark at the secondary gap.

Thus the condenser forms an integral part of both coil and magneto ignition systems. Without it the ignition device would be impracticable.

In this connexion an interesting experiment may be made with an induction coil by comparing the sparks at the secondary gap and at the primary contacts, with and without the condenser circuit. When the condenser is cut out, vicious sparking occurs at the primary contacts, while at the secondary gap the spark becomes both feeble and irregular. This occurs when the condenser of a coil or magneto is open-circuited.

With the exception of the contact-breaker, which replaces the trembler and ensures precise timing, and the distributer, which provides each cylinder with its spark at the correct instant, we have in the foregoing a description of battery-coil ignition.

As regards magneto ignition, the only difference in principle is the replacing of the battery for providing the primary current by a generator, which is incorporated with the magneto.

In devices in which the contact-breaker revolves, as in the revolving-armature magneto, the condenser must also revolve. In devices in which the contact-breaker is stationary, as in the coil and the revolving-magnet magneto, the condenser is stationary, but as the spark is adjusted the condenser must move round the cam with the contact-breaker.

The manufacture of condensers for automobile work calls for great care. The available space is small, especially where the condenser forms part of the revolving armature of the magneto. Originally the mica and tinfoil laminæ were assembled and riveted into a block, small holes being punched or drilled for the rivets securing the end connexions to the plates. This treatment often resulted in the cracking of the mica sheets, with consequent electrical breakdown. In many present designs the laminæ are securely clamped without any form of riveting. Paper condensers have replaced mica condensers in certain magnetos with stationary windings, and in those used for motor cycles.

With coil ignition paper condensers are mostly used. These condensers consist of rolled tissue paper sandwiched between tinfoils which overhang on opposite sides, giving a tubular construction with terminals at both ends. Low resistance is obtained by feeding the current into the strip from the edge along the whole length. The condenser is vacuum dried, impregnated with wax and sealed into a metal case.

The connexion between the contact-breaker and the condenser must have minimum resistance and inductance ; in other words, the condenser must be as near the contacts as possible. The insulation resistance of the condenser should be high—at least 10 megohms between the plates, and it should be capable of withstanding about 1,000 volts. The capacitance is usually between 0·05 and 0·35 microfarad, a common value being 0·2 microfarad.

Size of Condenser.—When the contacts open, the part of the current that flows across the opening vaporizes the contact surfaces while the remainder charges the condenser. Unless the contacts separate more rapidly than the condenser voltage rises, the condenser may set up an oscillatory discharge across the gap. Consequently the voltage needed to bridge the opening should rise more rapidly than the condenser voltage. From the relation between the velocity of contact opening and the size of condenser, the latter should be chosen so as just to prevent sparking. If a smaller condenser is used, sparking will occur; if a larger, sparking will be avoided, but the rate of current decay will be reduced, and consequently the electromotive force induced on break will also be reduced.

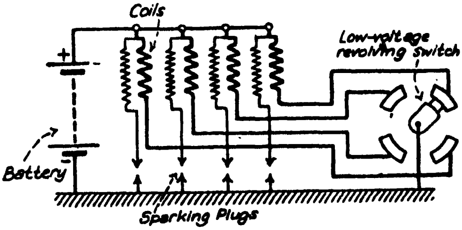


FIG. 92.—Arrangement with a coil for each cylinder and a revolving switch.

THE DISTRIBUTER

It would, of course, be possible to have an induction coil for each cylinder, as shown in Fig. 92, arranged to supply a high-voltage spark at the correct instant by means of a suitable make-and-break device, such as a revolving switch in the low-voltage circuits. Such complication, however, is needless if the revolving switch, or distributer, is placed in the high-voltage circuits and a contact-breaker in the low-voltage circuit as shown diagrammatically in Fig. 93. The later auto-transformer connexions are shown in Fig. 103.

In practice the distributer is arranged in one of two ways: the contact type and the spark-gap type.

Contact-type Distributer.—In this type a number of segments, equal to the number of cylinders and connected to the sparking plugs, are arranged at equal distances in a circle on the distributer head, which is made of moulded material. A carbon brush attached to the end of a revolving arm makes contact with these segments as it passes them one after another. The centre of this arm is joined to the terminal of the secondary coil, so that the current is led to the several sparking plugs in correct sequence. For proper working the brush should take a fine polish and have free movement. With wiping contacts of this kind a certain amount of attention is needful. The track should be inspected periodically and cleaned with an oily rag to prevent leakage currents, sticking or cutting. The contact-type distributer has been largely replaced by the gap-type, which can be made smaller and cheaper, and needs less cleaning.

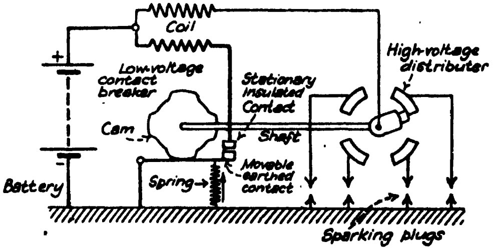


FIG. 93.—Arrangement with a single coil, distributer and contact-breaker.

Gap-type Distributer.—Here there is no brush at the end of the revolving arm, but the end is separated from the distributer segments by a small air-gap, across which the spark jumps. The electrodes are made of nickel or brass, and the gap is 0·01 to 0·015 inch. The actual gap length is not very important and, although it is in series with the sparking-plug gap, its presence makes but little difference to the voltage required. Even if the gap itself needs about 1,500 volts to spark across, the amount to be added directly to the plug voltage is only about 200–300 volts. It is essential to ventilate the distributer head with this type of distributer, especially in magnetos, in order to prevent the accumulation of ozone and nitric acid due to ionization resulting from the sparking. Where ventilation is not feasible the contact-type may have to be used. As dirt may be drawn into the distributer, here again, periodical cleaning is necessary. By isolating the secondary winding in this way the gap-type distributer assists in quenching the spark, should there be a tendency for the same to linger and retard the re-forming of the magnetic flux. The gap-type is mostly used with coil ignition. The distributer is made of synthetic resin. The coil is mounted separately from the distributer.

Speed of Distributer Arm.—It has been seen that in the four-stroke cycle each cylinder needs a spark in every two revolutions of the engine. Consequently the speed of the distributer arm must be half the engine speed, or

$$\text{distributer speed} = \frac{\text{engine speed}}{2} = \text{camshaft speed.}$$

Moulded Insulation Materials.—The moulded insulation materials, which are now employed so widely for ignition appliances, can be divided into rubber-base and synthetic-resin-base materials. The former are composed of rubber and sulphur with a filling material to give body and rigidity to the vulcanized rubber; the latter belong to the synthetic-resin class (e.g., "bakelite"), which is now finding extensive application in electrical and other work.

The most important application of moulded materials in ignition devices is for the cover of the distributer head. Here a composition is needed which will withstand the action of oxides of nitrogen produced by brush discharge and ionization, and will not give rise to surface leakage. Each class of material has its own sphere of application, and by eliminating unsuitable ingredients the earlier troubles have been overcome. For the brush track in the contact type of distributer a rubber-base material is required; elsewhere synthetic-resin-base materials are generally employed. The latter may be said to have revolutionized the cheap and accurate manufacture of insulating parts of ignition apparatus.

THE CONTACT-BREAKER

Construction.—Instead of the trembler used in the induction coil, a device known as a contact-breaker, which is more reliable in its action and precise in its timing of the spark, is employed with coils and magnetos. Of the two contacts, one is movable and the other is stationary with respect to the contact-breaker. The one makes contact with the primary winding and the condenser, and the other is connected to the other terminal of the condenser and the battery. The contacts are opened and closed by means of a cam, the lobes of which press against a bakelised fabric heel fixed to one end of a lever arm. At the other end of the lever arm is the movable contact, while the arm is arranged to rock about a spindle near its centre. A spring presses on this arm to keep the contacts closed except when they are opened by the cam.

As will be seen from Figs. 94 and 95, the cam can be either inside or outside the contact-breaker, according as the primary winding is stationary or revolving. Thus with a coil or a magneto with stationary winding the cam revolves inside the stationary contact-breaker (Fig. 94). With a rotating-armature magneto the contact-breaker revolves inside the cam (Fig. 95). The two contacts must be insulated from each other. The movable contact in a magneto is usually earthed, but with a coil this contact is insulated when the stationary contact is earthed. The stationary contact is attached to

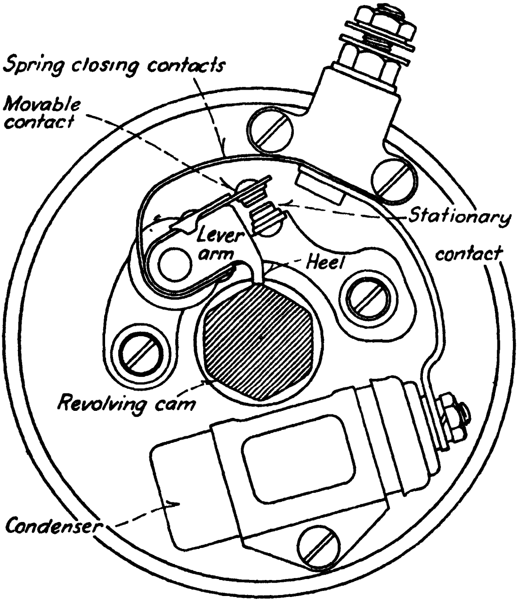


FIG. 94.—Stationary contact-breaker with revolving cam (actual size).

the base by a screw which passes through a slot in the stationary contact support, thus providing a means for adjustment. In the case of the magneto, the insulated contact is connected to the magneto earthing switch to enable the driver to put the magneto out of action.

From a mechanical point of view the stationary contact-breaker is the more satisfactory arrangement. The mechanism can be made much more rigid, as space is not so limited, while considerations of centrifugal force arise at high speed only. Consequently the stationary contact-breaker is likely to need less periodical adjustment than the revolving contact-breaker.

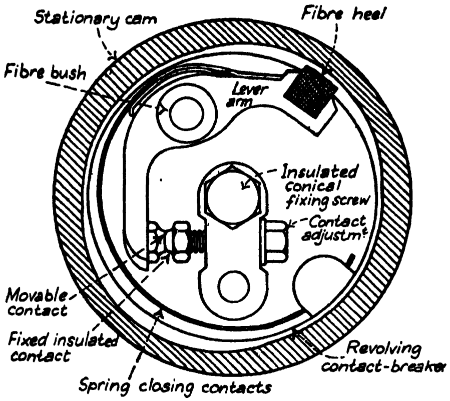


FIG. 95.—Revolving contact-breaker with stationary cam (actual size).

Adverse Conditions at High Speed.—To gain an idea of the rapidity with which the contact-breaker has to work, consider the stationary contact-breaker of a coil for a 6-cylinder engine running at 5,000 r.p.m.—a high, but not uncommon, speed on certain types. Each cylinder requires a spark every second revolution, or 5,000/2=2,500 sparks per minute; hence the 6 cylinders require 6×2,500=15,000 sparks per minute, or 250 sparks per second. For each of these sparks there is a period of 1/250th=0·004 second or 4 milliseconds; and in this brief interval "make" and "break" (or "close" and "open") must be completed. To produce ignition sufficient electric energy must be stored during the time of "make" between sparks, and it is usual to make this time about two-thirds of the period between sparks. In a 6-cylinder engine the cam will have 6 lobes, each occupying 60 degrees, so that the contacts are closed for $\frac{2}{3}\times 60=40$ degrees, or $\frac{1}{9}$th of a revolution. At 5,000 r.p.m. the contacts will then be closed for $\frac{2}{3}\times 4 =2{\cdot}66$ milliseconds. For a satisfactory spark, a modern coil needs a "make" period of 2 milliseconds, corresponding to a speed of 6,700 r.p.m., but the available margin cannot be used if flinging due to centrifugal action occurs.

To avoid misfiring the breaker must act with precision. There must be neither vibration nor flinging of the contact-breaker arm. The moving parts must be light to reduce inertia and the spring pressure must be light to reduce wear. Usually the pressure of the control spring is between 1 and 2 lb. With normal design, flinging of the contact-breaker arm occurs at about 5,000 r.p.m. It is caused by the cam lobes knocking the arm off with such force that the heel does not follow the cam. At the moment of impact with the cam, the arm acquires a sudden velocity, which depends on the speed of rotation of the cam and its profile. The cam is usually of parabolic form. Up to a certain speed the arm will follow the cam. Beyond this speed the initial impact will suffice to fling the arm more or less clear of the cam, so that the period during which the contacts are open rises progressively as the speed increases. Should flinging reduce the "close" period to much less than 2 milliseconds, misfiring results; and it therefore becomes necessary at such speeds—usually beyond 5,000 r.p.m. engine speed—to increase the spring loading or to reduce the weight of the contact-breaker arm. Since the spring pressure has to be increased as the square of the speed, the effect on wear may become pronounced. To obtain lightness the arm may be made of duralumin or bakelized fabric. Beyond these limits resort must be had to a coil distributer with a double contact-breaker, etc. (see p. 236). With revolving contact-breakers for revolving-armature magnetos the design is usually restricted by space consideration.

Pitting of Contact Points.—It is found that, on break, if the potential difference between the points exceeds momentarily 14 volts and there is sufficient current passing, an arc will strike and short-circuit the gap. If the conditions for stability are removed as the separation increases, the arc will be quenched; but if the voltage across the separating points rises above a certain value sparking will occur. Excessive arcing causes vaporization of the contacts and transference of metal from one contact to the other. The resulting pitting may eventually produce misfiring owing to the resistance caused by poor contact due to oxidation.

Formerly contact points for magnetos were made of an alloy of platinum and iridium. These rare metals are costly, and they wear quickly in presence of oil or petrol vapour. Tungsten has practically replaced platinum-iridium for this purpose, good life being obtained if severe arcing and oxidation at the contacts are prevented by keeping the current within permissible limits. With tungsten points, used in conjunction with a condenser of the correct capacitance, the current should not exceed 3·5 amperes, if harmful arcing is to be suppressed. To prevent sparking, the peak voltage should not rise above 300 volts.

Neither platinum nor tungsten is ideal for contacts. What is needed is a material with the non-oxidizing and non-arcing tendency of platinum combined with the mechanical rigidity and high melting point of tungsten.

Attention to Contact Points.—The proper working of the ignition system depends on the correct adjustment of the spark timing and the correct setting of the contacts. The amount of contact opening is important. To reduce vibration and increase the life of the contacts, the opening should be as small as possible, but it is not safe to go below a certain minimum because of the risk of the contacts not opening when the heel becomes worn. In a magneto the opening of the contacts is usually given as 0·012 inch and with coil ignition 0·015 inch—but the maker's figure should be strictly adhered to. Some American coils specify an opening of 0·02 inch.

A certain amount of gap adjustment may be necessary after the first 1,000 or so miles of the car's life, owing to settling down and bedding of the contact-breaker heel. In many cases no further adjustment is called for until a considerable mileage has been covered, if the cam is properly lubricated. Trouble due to wear, pitting or oxidation would usually set in gradually, and would give warning by occasional misfiring. For this reason, apart from adjustment of contact gaps, or cleaning of definitely oily or dirty contacts, interference is not recommended. A slight film of black oxide is quite normal with tungsten points.

The cam lobes, on which the heel presses, are usually of steel, highly polished and hardened. Provided the cam is kept lubricated, the wear of the heel will be negligible. For lubrication, every 3,000 miles put a smear of engine oil on the cam surface, and a drop of oil on the bearing on which the contact-breaker arm is pivoted. Care must be taken to prevent lubricant getting on to the contacts. Owing to the low primary resistance, a film of oxidized oil may reduce the primary current sufficiently to cause misfiring.

The camshaft-speed magneto (*see* p. 256) is a revolving-magnet magneto with as many poles as there are cylinders, and, consequently, the number of sparks produced in one revolution of the magneto is equal to the number of cylinders. The distributer arm is, therefore, coupled direct to the magneto shaft and driven at camshaft speed—hence the name: camshaft-speed magneto.

Speed of Contact-breaker Cam with Coil Ignition.—The speed of the contact-breaker cam will depend on the number of sparks produced by it in one revolution, that is, on the number of lobes on the cam. If, as is usual, there are as many lobes on the cam and as many segments on the distributer as there are cylinders in the engine, then:—

number of sparks produced per revolution of cam
=number of cylinders.

Since half this number of sparks is needed in each revolution of the engine:—

$$\text{speed of cam} = \tfrac{1}{2} \times \text{engine speed}$$
$$= \text{distributer speed.}$$

Consequently with coil ignition the cam and distributer can be mounted on the same shaft, which is made to revolve at half the engine speed, i.e., at the engine camshaft speed.

On engines with six or more cylinders it may be necessary to have two contact-breakers to increase the contact period during "make" (*see* p. 236).

Speed of Magneto.—Since every cylinder needs a spark in every second revolution of a four-stroke-cycle engine, it follows that :—

number of sparks needed per revolution of engine

$$= \tfrac{1}{2} \times \text{number of cylinders};$$

hence, number of sparks needed per minute

$$= \tfrac{1}{2} \times \text{number of cylinders} \times \text{engine speed}.$$

Thus, speed of magneto

$$= \frac{\text{number of sparks needed per minute}}{\text{number of sparks produced per revolution of magneto}}$$

$$= \frac{\text{number of cylinders} \times \text{engine speed}}{2 \times \text{number of sparks produced per revolution of magneto}}.$$

In the following table the magneto speeds obtained from the above general formula are given for four- to twelve-cylinder engines using either two- or four-spark magneto :—

Number of engine cylinders.	Speed of Magneto.	
	With 2 sparks produced per revolution (2-spark magneto).	With 4 sparks produced per revolution (4-spark magneto).
4	engine speed.	½ × engine speed.
6	1½ × engine speed.	¾ × engine speed.
8	2 × engine speed.	engine speed.
12	3 × engine speed.	1½ × engine speed.

Coil Ignition

Construction.—The arrangement of coil ignition is very simple, as seen from the diagram of connexions in Fig. 102. The auto-transformer connexion is commonly used as in Fig. 103. The ignition coil is a small transformer, consisting of a primary and a secondary winding on an insulated iron core. The coil and the condenser are both stationary. The magnetic circuit is never completely closed, but the parts are arranged to decrease the external reluctance of the magnetic path.

The effect of the air-gap in the magnetic circuit is twofold. Assuming a given magnetizing force *H* (Fig. 96) or primary current, it is seen that although

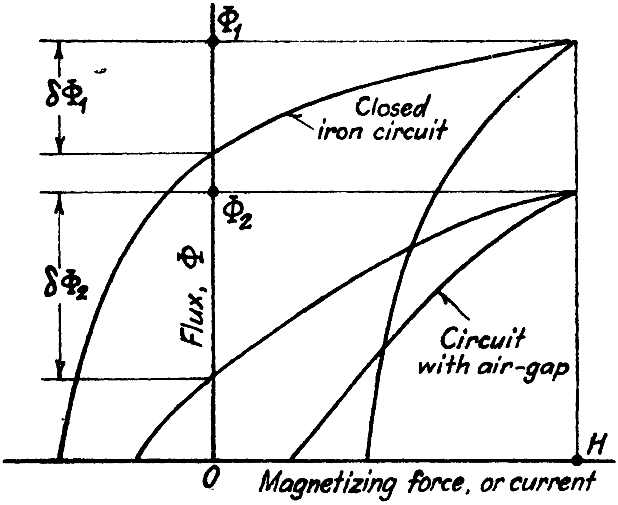


FIG. 96.—Influence of air-gap in magnetic circuit.

the total flux produced is reduced from Φ_1 without gap to Φ_2 with gap, yet when *H* is reduced to zero by interrupting the primary current, the change $\delta\Phi_1$ is much less than the change $\delta\Phi_2$. In other words, the change of flux $\delta\Phi$, on which the induced e.m.f. depends, is much smaller when there is no gap than when a gap is present. A gap or break in the magnetic circuit is therefore included to improve the effectiveness of the device.

Open-core and Closed-core Types.—Two constructions have been developed—the open-core type with long air-gap in Fig. 97, and the closed-core type with short air-gap—Figs. 98, 99 and 100. In each case, the path of the magnetic flux is shown by dotted lines. In general, the closed-core type needs the more iron and the open-core the more copper. As regards functioning, there is little to choose between them.

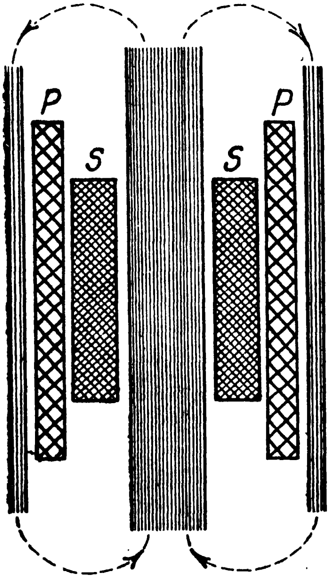


FIG. 97.—Modern construction of open type of coil with long air-gap.

The magnetic properties of the material for the core of a coil are the opposite of those required for a magneto, and are well illustrated in Fig. 107. The soft iron for the magnetic circuit of the coil may be in the form of laminations of 24 or 29 S.W.G. or of annealed iron wire about No. 19 S.W.G., the former insulated by paper or varnish, the latter by varnish, enamel or layer of oxide.

Arrangement of Coil Windings. — The open-type, Fig. 97, commonly used in Great Britain is the one that will be discussed here. Formerly the secondary was placed outside the primary, as in Fig. 101 ; whereas at present the position is reversed, as in Fig. 97. In the earlier arrangement, Fig. 101, it is seen that some of the lines of force, such as *VW*, do not link all the secondary turns, as *XY* do. In Fig. 97 the magnetic coupling is more complete, i.e., the mutual inductance is higher. The coupling in Fig. 97 is further improved by making the axial length of the secondary shorter

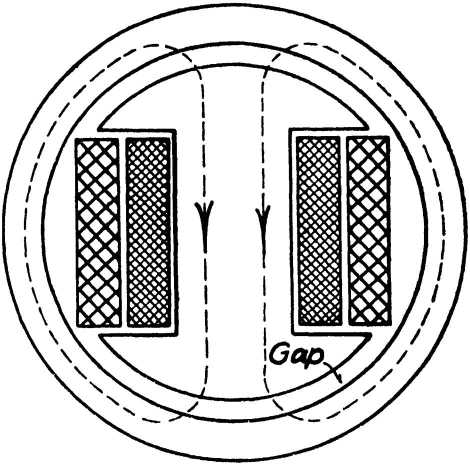


FIG. 98.—Closed-core type of coil with short air-gap.

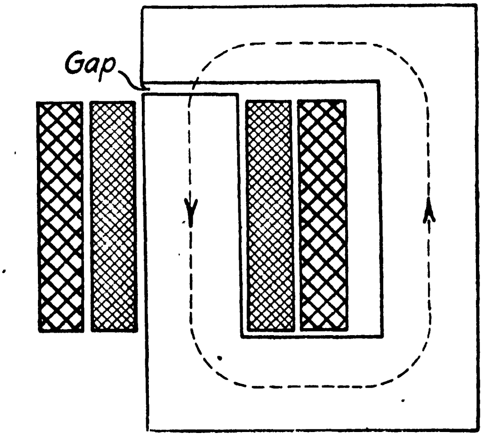


FIG. 99.—Closed-core type of coil with short air-gap.

than that of the primary. To increase the inductance of the open-core type, Fig. 97, and to provide a return path for the flux, a slotted laminated iron sheath is placed outside the coil. Over the iron sheath is placed a metal case for cooling the primary, where the heat is developed, and for protection. With the primary wound over the secondary, the amount of insulation between the outside of the coil and the frame is reduced by insulating the core—to which the secondary winding is connected—from the frame.

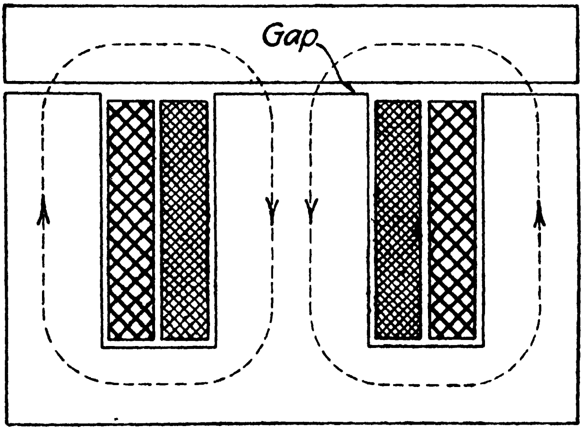


FIG. 100.—Closed-core type of coil with short air-gap.

The primary winding consists of a few hundred turns of enamelled copper wire with a resistance seldom less than 1 ohm. The external primary enables a ballast resistance to be dispensed with. The secondary may have as many as 20,000 turns of wire of Nos. 42 to 44 S.W.G. with a resistance of 2,000 to 4,000 ohms. The load on an ignition device consists of a series of high-frequency surges with each spark. To prevent progressive breakdown from these travelling waves, reinforced insulation of the end layers and careful insulation throughout the winding are needed. The satisfactory coating of wires about 0·004 inch in diameter with a film of enamel 0·0002 inch in thickness has enabled manufacturers to produce satisfactory high-voltage windings occupying a sufficiently small space.

If interspaces in the insulation exist, ionisation may take place in the form of a mild glow discharge; or, if sufficiently concentrated, a spark may be formed. A continuation of severe ionic bombardment causes a gaseous product to be given off and leaves a carbonized conducting path resulting eventually in piercing and breakdown. Likewise, creeping, due to the high-voltage, has to be guarded against. The several layers

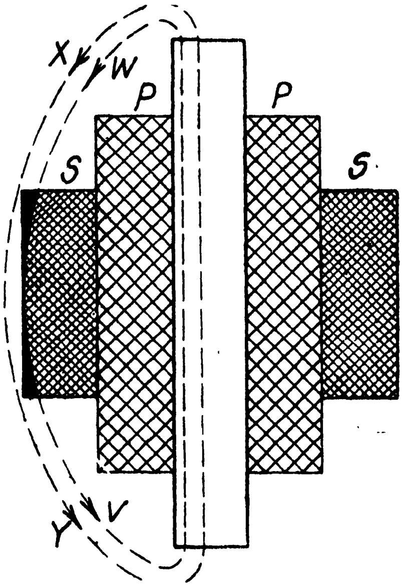


FIG. 101.—Earlier construction of open-core type of coil with long air-gap.

are insulated from one another and from the core by layers of varnished or impregnated paper, cotton or silk. Sometimes untreated paper is used and impregnated with paraffin wax or a resin-wax mixture after winding, to render the coil moisture-proof.

It is common practice to mount the coil separately from the distributer and contact-breaker, but they should be near each other to keep down the length of high-voltage cable. The distributer and cam are on the same spindle, which runs at half engine speed, the contact-breaker and condenser being stationary. By mounting the spindle vertically, or nearly so, access to the contact-points, etc., is made easy. A centrifugal spark-adjuster is usually combined with the distributer head.

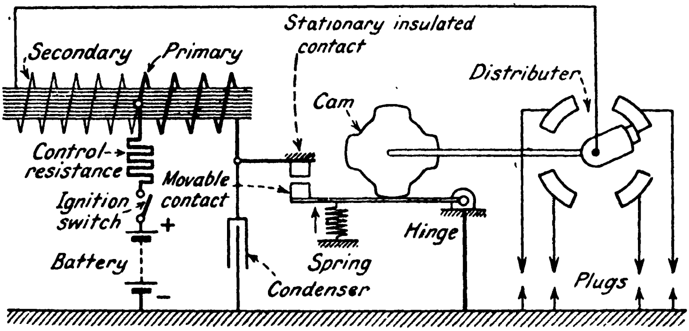


FIG. 102.—Elements of coil ignition.

Coil Circuits.—As shown in Fig. 102, one end of the battery is connected to the junction of the primary and secondary windings, while the earthed end is connected to the movable contact of the contact-breaker and to one terminal of the condenser, either by a wire or through the frame, as shown in the figure. Since the coil is operated with direct current, all the distributer leads have the same polarity, a factor which contributes to precise timing.

A more economical arrangement, shown in Fig 103, is known as the auto-transformer connexion. Here the starting end of the secondary winding is connected to the finishing end of the primary winding. Thus the battery is connected to the free end of the primary, while the junction is taken to the insulated contact and the condenser. The turns and therefore the voltages of the primary and secondary are now additive. The economy obtained with this auto-transformer connexion is greater with the 12-volt system than with the 6-volt system, owing to the larger number of primary turns in the former. In the 6-volt systems, owing to the large turn-ratio, adding or subtracting the primary voltage makes little difference to the coil performance. The reason for earthing the positive battery terminal is explained under "Earthing," on page 161. It will be noticed that no control or ballast resistance is used in Fig. 103.

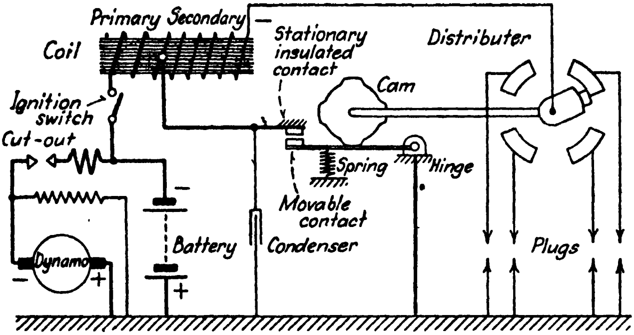


FIG. 103.—Auto-transformer connexion for coil ignition. (Positive pole-earthed to give negative polarity of insulated plug-electrode.)

A switch is placed between the battery and the coil.

A warning lamp may be used to indicate when the switch is "on"; the switch should always be in the "off" position when the engine is not running.

The vulnerable points of coil ignition are dependence on the battery and on the soundness of the car wiring. Owing to the vital importance of the battery, it is essential to keep it in a healthy condition and well charged.

Coil construction is now practically standardized, most parts being made by machinery. A damaged coil is usually replaced, replacement being cheaper than repair.

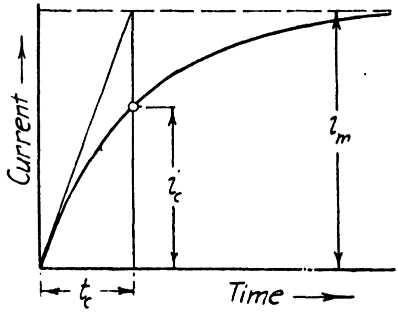


Fig. 104.—Growth of current in an inductive circuit to which a constant voltage is applied.

Growth of Current.—In an inductive circuit, such as exists in the coil, the current does not rise instantaneously to its final steady value, but a certain interval of time is required for this purpose after the contacts are closed. When the speed is low the current attains a higher value than when the speed is high, because then the contacts remain longer closed. This effect is illustrated in Fig. 104, which represents the rate of growth of the current in the primary circuit, when a constant voltage is applied to it. The rate of growth of current in any circuit depends on a factor known as the *time-constant* of the circuit. For any given circuit, the time-constant t_c=(circuit inductance/circuit resistance). t_c seconds after switching on, the current reaches the value i_c, which is 63 per cent. (or nearly two-thirds) of its final maximum value i_m, as shown in Fig. 104. At very low speeds the current has time to rise very nearly to the value i_m=(battery voltage/circuit resistance). As the speed rises, the interval during which the contacts remain closed becomes shorter and shorter, so that ultimately the flux may reach too low a value to produce a spark. From this it follows that the current interrupted at low speeds is larger than that at high speeds, and the strongest sparks are, therefore, produced when the engine is running slowly, though this is partly offset by the action of the ballast resistance, when such is used.

The fact that the coil works best at very low speeds is one of the chief merits of coil ignition. At starting, firing will occur as soon as there is satisfactory carburation, provided that the coil is designed to spark at the low battery voltages which may exist when the starter motor is in circuit. Later it will be seen that the characteristics of the coil in its relation to speed are the reverse of those of the magneto.

Starting.—The above argument on the growth of current is based on the assumption that the voltage applied to the coil is constant. Actually this is not so, because the voltage of the battery, from which the coil is supplied, falls off considerably when the starting motor is switched on. At this instant the voltage may fall to half its nominal value, or even less if the battery is run down. In order that the magnetic energy stored in the coil shall be sufficient to produce a spark when starting under the most adverse conditions, the modern coil is designed to spark at ½ or even ⅓ nominal voltage at low engine speeds. To prevent excessive pitting due to sparking, the maximum current, with tungsten points, must not exceed 3–4 amperes. Refrigerator tests show that carburation and not ignition is now the limiting factor on British cars at low speeds and temperatures.

High Speed.—The problem of producing ignition is simply that of storing sufficient energy in the magnetic circuit of the coil in the time available between sparks. The modern standard coil needs a period of "close" of 2 milliseconds to produce a satisfactory spark. This corresponds to a speed of 6,700 r.p.m. in a 6-cylinder engine. With standard design, however, flinging of the contact-breaker arm occurs at an engine speed of about 5,000 r.p.m., corresponding to a make period of 2·66 milliseconds. In order to take advantage of this margin the mechanical design of the contact-breaker must be modified—the inertia of the lever arm must be reduced and the loading of the spring must be increased. For still higher speeds the electric characteristics of the coil must be modified to reduce the requisite close period below 2 milliseconds. Speeds up to 10,000 r.p.m. in a 6-cylinder engine have been attained in this way.

For higher speeds, or particularly with eight or more cylinders, other solutions must be sought. A limited increase in speed range is obtainable with a double contact-breaker in which each of the contact-breakers is operated alternately by a common cam having half as many lobes as there are cylinders. Beyond these limits the equipment could be divided into two units consisting of separate contact-breakers and coils, each serving half the number of cylinders, with a common distributer head. This arrangement would probably be used on a 6-cylinder engine for speeds of 6,000 r.p.m. and above.

A further aid at high speed is mentioned in the following section on the control resistance.

With regard to the 6- and 12-volt systems, it is found that higher speeds are possible with 12-volt than with 6-volt coils; indeed, the 12-volt system is considered necessary for the high road and engine speeds of British cars.

The Ballast or Control Resistance.—In order that sufficient energy to produce a spark is stored in the coil at high speeds, the current must be allowed to reach a certain minimum value, corresponding to a certain maximum value when the engine is at rest. If the latter current be, say, 3 amperes, the resistance of the primary circuit in a 12-volt system must be $12/3 = 4$ ohms. If the whole of this resistance be in the primary winding, the total heat—corresponding to $12 \times 3 = 36$ watts—in the primary circuit will be generated inside the coil.

Until recent years the primary was wound next to the core and inside the secondary, so that the heat produced in the primary had to pass through the secondary in order to be dissipated.

To reduce this internal heating and the consequent temperature-rise of the coil, it was customary with coils having internal primary to use an external resistance known as a ballast or control resistance. Thus, instead of making the resistance of the primary coil in the above example 4 ohms, it can be made 1 ohm and the remaining 3 ohms placed as a ballast or control resistance outside the coil. In this way the heating in the coil itself is greatly reduced. The ballast resistance is made of a nickel alloy with a high resistance-temperature coefficient, and its functions are important. If the ignition switch is left closed when the engine is not running, and the breaker contacts are closed, the battery will continue to discharge through the primary circuit. Unless some current-limiting device is present, the coil may heat up sufficiently to burn out before the battery is discharged. By using an external control resistance which heats up and reduces the current, the coil is prevented from overheating, and the battery from rapid discharge. Also, if the battery becomes disconnected from the third-brush generator, the control resistance may act as a fuse to the current due to excessive generator voltage and so protect the coil from damage. Owing to the high resistance-temperature coefficient of the ballast resistance, the resistance of the primary circuit is lower when the current is small than when the current is large; consequently the reduction in maximum current at high speeds is less marked. Relatively, therefore, the conditions are better at high speeds with than without such a resistance. When designing a coil, ample margin has to be allowed for voltage drop to compensate for the adverse conditions which exist when starting, especially with the battery partly discharged.

In recent years the ballast resistance has been dispensed with on account of the great variations in cooling conditions in practice, on which its actions so largely depend. If the resistance is too well cooled, the current is too large and the contacts become burnt; if the cooling is too little, the resistance is too high and the current becomes too small. For this reason most firms are doing away with this resistance where, as is usual, the use of the external primary renders this possible.

Advantages and Disadvantages of the Coil.—The coil is cheaper to manufacture than the magneto, owing to the much smaller amount of precision work and the simpler construction. The actual coil is machine wound, while the coil distributer is cheaper than the magneto distributer. The drive for the distributer head at half engine speed is simpler than the drive for a magneto. As the coil is designed to spark when the battery voltage is low, the minimum starting speed is determined by carburation; therefore the self-starter need only be powerful enough to drive the engine at a speed sufficient for effective fuel evaporation, which may be less than the lowest retarded firing speed of a magneto. With coil ignition, adjustment of the spark timing has no effect on its strength. For normal speed ranges the coil satisfies the requirements of high voltage at low speed and low voltage at high speed. Attempts to use weaker mixtures, which need higher plug voltages, are not limited by the coil characteristics.

The coil reaches its limitations at high speeds on account of the current having too little time to attain the value necessary to produce a spark, partly owing to inductance and partly to the flinging of the contact-breaker arm off the cam. For speeds exceeding 5,000 to 5,500 r.p.m., the single distributer head may be unsuitable for engines with more than four cylinders.

The battery and charging generator are indispensable parts of this system of ignition. This multiplicity of essential parts is doubtless a drawback of coil ignition, for both battery and dynamo are liable to breakdown. The wiring also is not so simple as with the magneto. On the other hand, with coil ignition, the ignition switch can be used for controlling other circuits, such as the petrol gauge or petrol pump; also it can be made to break the traffic-indicator circuit.

The almost universal application of the coil on private cars is explained by its low cost and its suitability; while its reliability is considered adequate for such vehicles.

MAGNETO IGNITION

Although almost ousted by the coil on private cars, the magneto is still used on buses, lorries, motor cycles and racing cars. It is favoured where reliability is all-important, and consequent independence of battery and car wiring.

Action of the Magneto.—As in the coil so in the magneto, magnetic energy is stored. Mechanical energy in the magneto is converted into electrical energy either by revolving a winding in a magnetic field (revolving-armature type), or by varying the flux linking a stationary winding (stationary-armature type). The magneto is a self-contained unit. The machine being an alternating-current generator, the primary current in the magneto is produced by the electromotive force induced in the primary coil. The field is provided by a permanent magnet. Thus no battery is needed either for energizing the primary, or for producing the magnetic field; yet at low speeds by providing a constant field a permanent magnet is equivalent to separate excitation of a machine —an advantage not possessed by the self-excited machine. The secondary, condenser, distributer and contact-breaker are incorporated in the magneto. Only high-voltage magnetos, that is, magnetos incorporating a primary and a secondary winding, are discussed here.

We shall first consider what occurs in the secondary winding on open-circuit, that is, when no current flows in it. For this purpose we can suppose that the primary winding and the contact-breaker are removed. Also, for explaining the action of the magneto, we shall assume a machine of the revolving-armature type.

When the magneto is rotated, an electromotive force is induced in its secondary windings by the change in the number of field linkages. A glance at Fig. 105 will show that the number of linkages of the magnetic field with the armature windings is a maximum in the position marked *c*. In positions *a* and *e* there are no linkages between the field and the windings. In intermediate positions *b* and *d* the linkages will vary, as shown by the curve marked "field linkages." Now, the induced electromotive force depends on the rate of change of the field linkages. Hence at *c*, where the number of linkages does not change at all, the induced electromotive force is zero. At *a* and *e* the linkages are zero, but the rate of change in the number of linkages is greatest, and consequently the induced electromotive force reaches its maximum value in these positions.

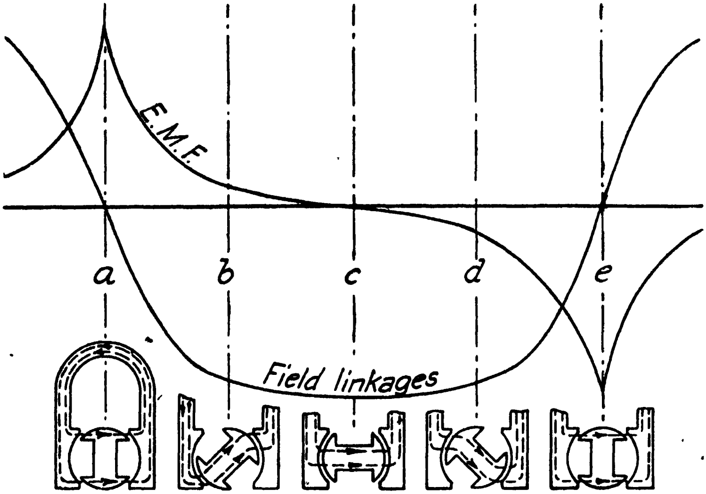


FIG. 105.—Field, linkages and induced electromotive force in two-spark magneto.

Since the direction of the field change at *a* is opposite to that at *e*, the induced electromotive force will be positive in one position and negative in the other. Thus the induced electromotive force in a magneto is alternating, as indicated by the curve marked "E.M.F." in Fig. 105. Although a high voltage can be induced in this way, an abnormally large number of turns would be needed to produce a spark. Moreover, the requirements of ignition demand that the rise in voltage shall be extremely rapid and that it shall occur precisely at a predetermined instant. For this purpose the primary winding with its contact-breaker and condenser is employed. Its function will now be considered.

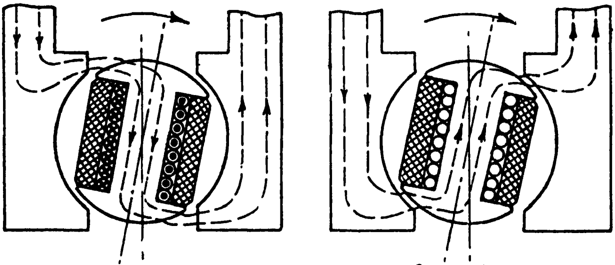

Before "break" *After "break"*

FIG. 106.—Distorting action of primary current on magnetic field. x and ● denote current entering and leaving respectively, O=no current.

The contacts in the primary circuit are arranged to close when the induced electromotive force is zero, that is, at *c*, and to remain closed until the electromotive force reaches a maximum, that is, at *a* and *e*. Whilst the contacts are closed a current flows in the primary winding (*see* Fig. 106), attaining a maximum value of 3 to 5 amperes. Owing to the primary winding being short-circuited and of low resistance, the current induced in it prevents any substantial change in the flux linking the windings. Thus, instead of the flux changes on open-circuit depicted at *d* and *e* in Fig. 105, the lines of force are distorted as shown in Fig. 106. The conditions of Fig. 105 (*d*) now persist while the armature rotates through the position *e*, soon after which the contact-breaker interrupts the primary current and the flux changes very rapidly from the "before break" to the "after break" distribution shown in Fig. 106. This sudden reversal of the distorted field through the primary current being interrupted may be likened to the release of a spring, and results in the rapid induction of a large electromotive force in the windings. In the secondary winding the sudden and large addition to the electromotive force induced in this winding by rotation suffices to send a spark across the plug electrodes. Thus the main function of the primary current in a magneto may be regarded as constraining the flux until the point of break, after which a rapid change of flux takes place. At a magneto speed of 100 revolutions per minute the voltage across the electrodes may be as high as 10,000 volts, producing a discharge current which may easily reach 0·08 ampere.

The instant at which "make" and "break" occur are important. As pointed out, the contacts should close at *c*, Fig. 105, when the induced electromotive force is zero. If "make" occur too early, a current will flow in the opposite direction to that required ; if too late, the current has too little time to reach its maximum value. The cam should be suitably shaped to meet requirements.

A study of Figs. 105 and 106 will indicate that the optimum "break" position will be that at which the induced primary current is at or near its maximum value and when the armature has just passed the position *a* or *e*. It is not possible to obtain one optimum "break" position for all speeds and all positions of the timing lever, if spark adjustment is obtained by rocking the contact-breaker; though it is possible if the adjustment is effected in the driving shaft, as happens with certain automatic timing devices. It is customary to adjust the timing so that optimum break occurs with the timing lever in the fully-advanced position when the magneto is running at low speeds. The effect of spark adjustment is seen in Fig. 86, which shows what occurs when the spark is advanced and retarded. The demands made on the magneto are severe—a large range of spark adjustment with high compression, and a 5–6 mm. spark on a 3-point gap (*see* p. 196) at a speed of 40 to 60 r.p.m. with the timing lever fully retarded. These requirements have been met in the heavy and, therefore, costly magnetos designed to spark at the low speeds common to commercial engines. Also the inclusion of an automatic centrifugal timing device in the driving coupling of the magneto maintains the optimum break condition at all positions of advance and retard, and makes the magneto equivalent to the coil in this respect.

The magneto armature is laminated in the usual way, as are also the pole pieces. The air gap is kept as small as possible—0·1 to 0·2 mm.—and saturation in the magnetic circuit is avoided.

The improvement in magnetos effected by the use of laminated instead of solid pole pieces consists of a greatly increased rapidity in flux changes and a considerable reduction in the loss due to eddy currents in the iron. Extended or skewed poles are now almost universally employed to improve the retarded spark at low speeds.

Properties of Magnetic Steel.—When a current flows through a coil of wire wound on a closed ring of iron, it is possible to measure the magnetic field density produced by a given magnetizing force. The magnetic field density is the number of magnetic lines produced in each square centimetre of the cross-section of the iron. This is denoted by B. The magnetizing force is equal to 1·26 × magnetizing current in amperes × number of turns per centimetre length of the magnetizing coil. This is denoted by H. By gradually increasing the current a curve with B as a function of H is obtained;

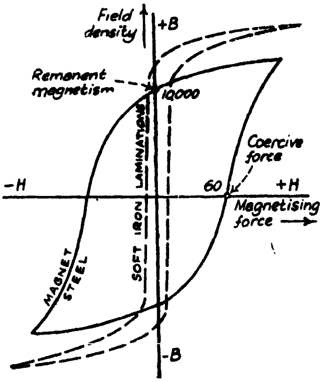


FIG. 107.—Cycles of magnetization of soft-iron and of magnet steel.

such a curve is called the *magnetization* curve. Each specimen of iron has its own magnetization curve.

With both soft iron and steel, if the magnetizing force is gradually reduced from a maximum value to zero, the magnetism does not follow the same law of variation as the exciting current. When the latter is zero it is seen from the curves in Fig. 107 that the magnetism remaining in these specimens is about 10,000 lines per square centimetre. This is called remanent or residual magnetism. Soft iron differs from steel in that it is very easy to demagnetize it completely when the exciting current is switched off. This may be done by a slight mechanical force, or by the application of a small reverse value of the magnetizing current. With steel, however, the material resists demagnetization, even when roughly handled, while a much greater demagnetizing value of *H* is required to reduce its magnetism to zero. A large proportion of the residual or remanent magnetism in steel is retained after the magnetizing force has been removed. This is the permanent magnetism of the steel used in the construction of magnetos. The name given to the demagnetizing value of *H* required to reduce the magnetism to zero is "coercive force." Since permanent magnetism is the essential feature of magneto steel, it follows that high remanence and coercive force are here of prime importance. The feature of modern magnet steels is their high coercive force, i.e., their ability to withstand demagnetizing effect, either by an opposing magnetomotive force or from vibration (*see* p. 248, "Demagnetization").

Magnet Steels.—The output and voltage of a magneto depend on the maximum value of the exciting flux linking the windings. Thus its size will depend on the minimum sparking speed specified and the properties of the magnet steel.

It is clearly advantageous that for a given duty the permanent magnet shall be as small as possible. It can be shown (E. Hughes, *Elec. Review*, p. 410, March, 1933) that a permanent magnet, which has to produce a given value of magnetic field density *B* between the pole-faces of given area and separation has a minimum volume when it is used in the magnetic condition for which the product *BH* is a maximum. Such a curve is shown in Fig 108, which includes an enlarged portion of the magnetization curve for 35 per cent.

cobalt steel in Fig. 107. The construction shows that for this curve $(BH)_{\text{max.}}$ occurs when $H=180$ and $B=5{,}750$. It is thus seen that $(BH)_{\text{max.}}$, denoting the maximum value of the product of field density and demagnetizing force during demagnetization, affords a valuable criterion of the suitability of steels for permanent magnets.

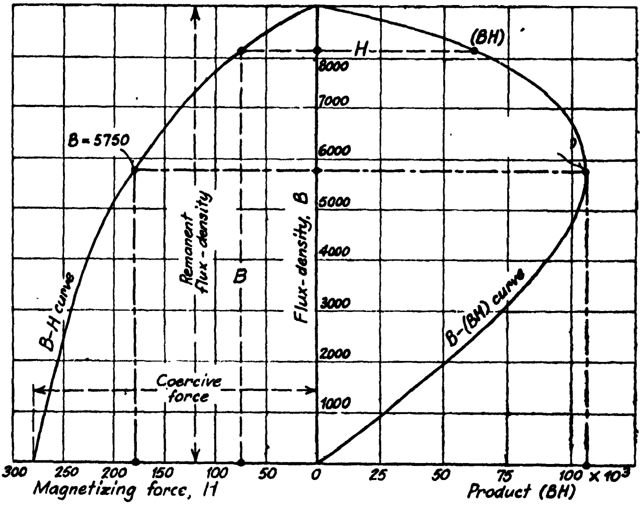


FIG. 108.—Method of finding $(BH)_{\text{max.}}$

Alloy steels are now used exclusively for magneto magnets, because it is found that steel alloyed with the feebly- or non-magnetic metals tungsten, chromium, cobalt, nickel and aluminium show superior magnetic properties. The steels previously used for magnetos were a 5 to 6 per cent. tungsten steel and a 2 per cent. chromium steel, the latter mainly in America. In recent years much work has been done on cobalt-steel and nickel-aluminium alloys. In Fig. 109 and on page 250 details of modern magneto magnet steels are given. Roughly it may be said that the required length and area of a magnet are inversely proportional to the coercive force and the residual induction respectively of the material.

It is the discovery of these alloys that has made the revolving-magnet magneto possible, though the easily-worked chromium and tungsten steels are used where space and weight are not important. Correct hardening of magnet steels is important. The conditions depend on the alloy—a common hardening temperature is about 800° C. with water quenching. Ageing has been almost eliminated during manufacture by boiling after hardening.

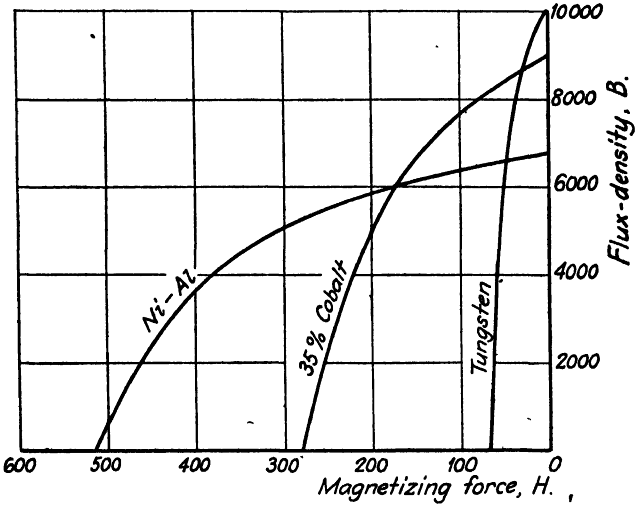


FIG. 109.—Typical B-H curves for various magnet steels. (*Ni-Al*=nickel-aluminium.)

Demagnetization.—Magnets are subjected to a demagnetizing action from various causes. These include mechanical effects (e.g., vibration) and temperature effects (e.g., heating). Also the free poles of a bar or horse-shoe magnet exert a demagnetizing action, which explains why every magnet with age tends to lose its magnetism. In a bar magnet this action depends on the ratio of the length to the cross-section—the smaller the ratio the greater the effect. To reduce demagnetization, a keeper is placed across the poles of a horse-shoe magnet, and a pair of bar magnets is arranged with unlike poles joined by keepers. Wherever it is possible for a magneto to lose magnetism when the rotor is removed, care should be taken to bridge the magnets with soft-iron keepers before dismantling and not to remove the keepers until the rotor has been replaced.

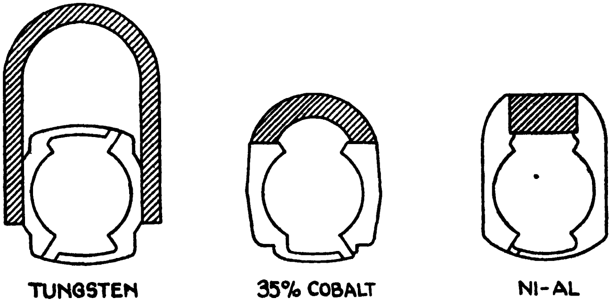


FIG. 110.—Relative amounts of magnet steel (shown shaded) for given duty.

All magnetos are subject to the adverse influence of armature reaction, the worst condition occurring when the closed (short-circuited) primary circuit is carrying a large current and is in a position to react on the main field—as, for example, when the magneto is running at high speed with fully retarded spark. The high coercive force of modern magnet steels is here of great value in resisting this action. Also by extending the (shaped) pole-shoes as shown in Fig. 110, to make the magnetic reluctance less than that of the air-gap between the pole-shoes and armature, i.e., by providing a magnetic shunt, demagnetizing action is largely counteracted.

The improvement in magnet steel and in design is such that a modern magneto can be expected to retain its magnetism indefinitely.

Cobalt Steel.—Since magnetomotive force is the product of magnetizing force and length, the power of a permanent magnet to resist demagnetization is proportional to the product of its length and the coercive force of the material of which it is comprised.

Magnet Steels (Average Values).

Steel.	Coercive force.	Remanent flux density.	$(BH)_{max}$.
2 per cent. chromium	60	9,700	245,000
6 per cent. tungsten	65	10,000	287,000
35 per cent. cobalt	275	9,000	106,000
nickel-aluminium	500	7,000	1,300,000

Hence, if the coercive force be quadrupled, the length can be reduced to one-fourth. This is substantially the case when 6 per cent. tungsten steel is replaced by 35 per cent. cobalt steel. For the same flux the cross-section must be increased inversely as the flux density or remanent magnetism—in this case, 10 : 9. Thus a 35 per cent. cobalt-steel magnet would have about one-fourth the length and an area 10 per cent. greater than a tungsten-steel magnet for a given duty. The drawback of cobalt steel is its high price. Nevertheless this steel practically revolutionized magneto design. Not only was the old horseshoe form unnecessary to provide sufficient length in the revolving-armature magneto, but it became possible to accommodate a revolving magnet in the restricted space. Cobalt steel can be cast or rolled.

Nickel-Aluminium Steel.—This remarkable alloy has made the camshaft-speed magneto possible. The alloy contains iron, nickel and aluminium in varying proportions, the most useful result being obtained with the approximate ratio: iron : nickel : aluminium =60 : 27 : 13. The material can be used as castings only, and it can be worked by grinding only—a limitation not serious for magnetos. Special heat-treatment is required, but this can be combined with the casting operation. It is interesting to compare the nickel-aluminium steel with the tungsten steel in Fig. 109.

For the coercive force :—

Nickel-aluminium steel : tungsten steel
=500 : 65=7·7 : 1.

For the remanent magnetism :—

Nickel-aluminium steel : tungsten steel
=7,000 : 10,000=1 : 1·4.

Hence a nickel-aluminium-steel magnet has about one-eighth the length of a tungsten-steel magnet, and for the same flux about 40 per cent. greater area : or the volume of the nickel-aluminium-steel magnet is about one-fifth of that of the tungsten-steel magnet which it replaces. The density ratio is :—nickel-aluminium-steel : tungsten steel=6·9 : 8, making the weight of the former less than one-fifth of that of the latter.

Fig. 110 is of interest as showing equivalent magnetic circuits for a revolving-armature magneto of given duty, the magnet being shaded in each case.

Types of Magnetos.—The elements involved in magneto ignition are shown in Fig. 111, where for the sake of simplicity the latest development is illustrated—the camshaft-speed magneto. In this case for a 4-

cylinder engine, a 4-pole rotor direct-coupled to the distributer shaft revolves at camshaft speed. The armature is stationary, but the action is identical with that of the revolving-armature magneto—the earliest, and until the advent of cobalt steel, the only practical type of high-voltage magneto.

The development of the revolving-magnet has not only greatly simplified the construction of the magneto by making all the delicate parts—windings, contact-breaker andcondenser—stationary, but it has made it possible to obtain more than two sparks per revolution. The revolving armature, having two poles, the flux changes direction twice per revolution, giving two sparks per revolution. This restriction does not hold with the revolving magnet, where, in each revolution the number of changes in the direction of the flux through the armature is equal to the number of poles. The number of poles can be any even number from two upwards. With the materials now available, the number of poles can be made equal to the number of engine cylinders, if desired.

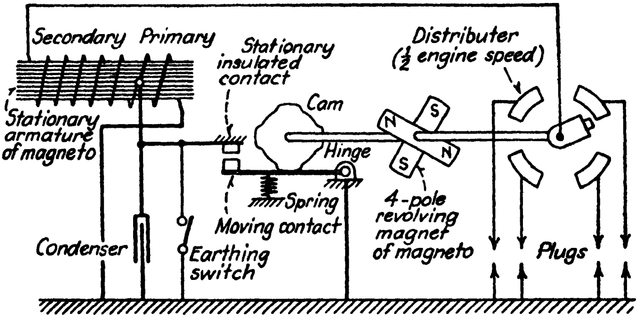


FIG. 111.—Elements of magneto ignition (auto-transformer connexion of windings).

There must be a flexible coupling in the magneto drive, which may be a toothed rubber coupling to permit vernier adjustment of the timing (*see* page 202); also an automatic centrifugally-actuated timing device is desirable. This is not provided on vertical camshaft magnetos, which can be rotated bodily to vary timing. For "speed of magneto," *see* page 226.

According to construction, magnetos may be divided into the revolving-armature types and the stationary-armature types.

(1) *Revolving Armature Types* in which the armature windings, condenser and contact-breaker revolve and the magnet is stationary.

(2) *Stationary-Armature Types* in which the armature windings, condenser and contact-breaker are stationary. A further distinction arises between:—

(*a*) Revolving magnets with any even number of poles up to the number of engine cylinders.

(*b*) Stationary magnets with soft-iron inductors which revolve between them and the stationary armature. Types of this construction are the polar-inductor and the sleeve-inductor types.

Revolving-armature Magneto.—This is the oldest type of magneto, and it was practically the only type before the advent of the modern types which are rapidly ousting it. (See Fig. 112 facing p. 256.) Its magnetic circuit is shown in Fig. 105, and its electric circuit in Fig. 114. The field system consists in the older type of one or more tungsten-steel horse-shoe shaped magnets, as in Fig. 105, and a shuttle or H-type laminated iron armature. In the modern type with cobalt-steel magnets, the latter are short straight bars (Fig. 113), or they form parts of the shell. The primary and secondary windings, together with the condenser, are housed inside the armature. The common terminal of the two windings is connected to the insulated terminal of the condenser, to the insulated conical fixing screw and to the fixed insulated contact. The low-voltage circuit is completed (when the contact-breaker points are closed) through the contact-breaker points to the rocker arm, return spring, base of contact-breaker, tapered boss on base to condenser housing frame, and to the other end of low-voltage winding. An insulated cable is also taken from a brush rubbing on the conical screw to the magneto switch, by means of which the primary winding can be earthed, thereby putting the magneto out of action. The free ends of the primary winding and of the condenser are connected to the metal body of the armature, and a special earthing brush is provided to ensure a good electrical contact between the armature and the frame, engine, etc. If the earthing brush is faulty, current may pass through the ball races in which the armature revolves and cause pitting of the balls.

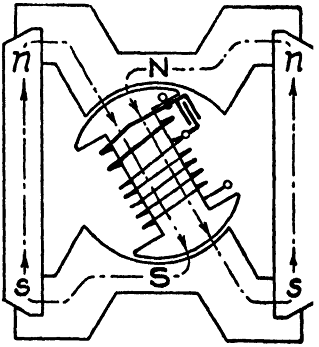


FIG. 113.—Magnetic circuit of revolving-armature magneto (modern type).

The free end of the secondary winding is taken to an insulated slip-ring, which revolves with the armature. The high-voltage current is collected here by means of a slip-ring brush and is conveyed to the revolving distributer brush or electrode by a further brush. It is essential that all parts are kept clean, particularly where carbon dust is likely to accumulate.

In magnetos of this type there may be as many as

50,000 lines in the magnetic field. To enable this field to pass readily from the magnet to the armature, the air-gap is made small. The poles are fitted with laminated pole shoes, which permit the field to change much more rapidly than with cast-iron shoes, because of the reduced eddy-current loss in the former, while extended pole-tips improve the spark at low speeds with the timing lever in the retarded position.

From the nature of their design, revolving-armature magnetos are essentially two-spark magnetos, but by omitting one cam a single spark per revolution can be obtained.

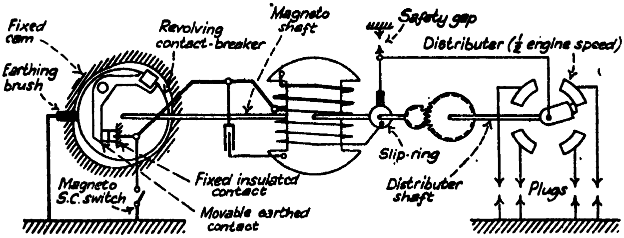


FIG. 114.—Elements of revolving-armature magneto.

Revolving-armature magnetos are well suited for engines having up to four cylinders and for slow-speed six-cylinder engines, but they are being superseded by stationary-armature types, which are essential for high speeds with a large number of cylinders.

Revolving-magnet Magneto.—A section is shown in Fig 115 (opposite p. 256), and the magnetic circuit of this type in Fig. 116. The revolving part consists of a circular magnet or its equivalent, and the field completes its path through a circuit of laminated iron. The stationary windings and condenser are mounted on the detachable part of the magnetic circuit, called the core. The contact-breaker, like the windings, is stationary, the contacts being operated by a revolving two-lobe cam. Thanks to the remarkable properties of modern magnet-steel, the rotating magnet can be accommodated in the available restricted space. The case illustrated is the common one of a two-spark magneto. In the camshaft-speed magneto, the number of poles is made equal to the number of engine cylinders.

The Camshaft-speed Magneto.—The evolution of nickel-aluminium magnet steel has largely overcome space restrictions, and has made possible a revolving magnet with as many poles as there are cylinders. A limitation is introduced by the time taken for a flux reversal, which must be completed before the next cycle begins—for this reason special arrangements may be necessary when there are more than eight flux reversals per revolution of the magneto. Such a magneto can be coupled directly (i.e., without the interposition of gearing) to the distributer arm, and rotated at camshaft speed—hence the name of the magneto. The rotor consists of a circular magnet of nickel-aluminium steel carrying as many laminated soft-iron pole shoes as there are cylinders. Fig. 117 shows a six-pole magneto for a six-cylinder engine. The contact-breaker and distributer are the same as for coil ignition and are usually mounted and driven in the same way through an automatic advance and retard mechanism. Thus, if desired, the camshaft-speed magneto can replace the coil-ignition equipment.

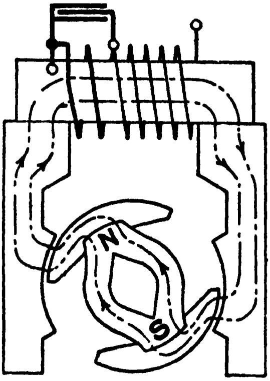


FIG. 116.—Magnetic circuit of revolving-magnet magneto.

The camshaft-speed magneto gives exceptionally

good performance at low speeds, sparking occurring at 25 r.p.m. Speeds in excess of any present-day racing needs can also be obtained.

Comparison between Revolving-magnet and Revolving-armature Magnetos.—In the latter the armature revolves together with its contact-breaker; whereas with the revolving magnet the windings and contact-breaker are stationary. The revolving magnet has many advantages from a mechanical standpoint, but the stationary magnet, with its less restricted space, makes it easier to provide a strong magnetic field. The camshaft-speed magneto is well suited for high-speed engines, and the revolving magnet is becoming a strong competitor of the revolving armature.

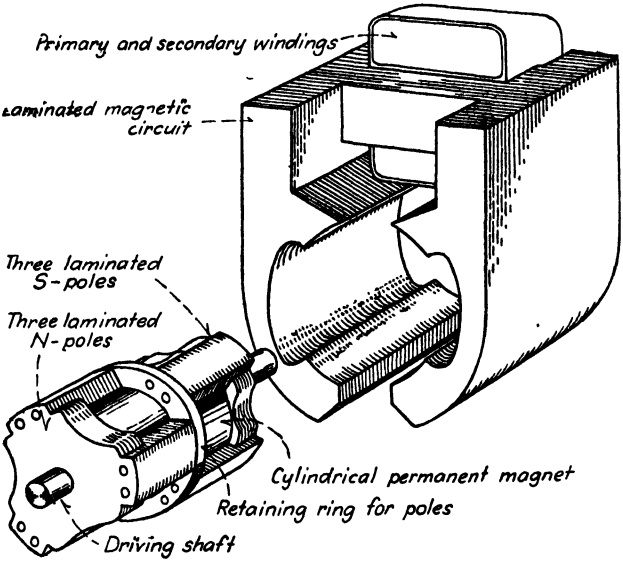


FIG. 117.—Six-pole camshaft-speed magnets for six-cylinder engine.

Polar-inductor Magneto (Fig. 118, facing p. 256).—In the polar-inductor magneto the magnets are stationary, while the field reversals are produced by revolving soft-iron polar projections called inductors. This is illustrated in Figs. 119 and 120. It is a simple matter to obtain a four-spark magneto by means of the four inductors shown in the illustrations. The magnetic path is rather complicated, and the field has to cross four air-gaps. The magnet system consists of two straight cobalt-steel magnets, the ends of which make contact with two laminated iron rings. Thus lines of force from a N-pole leave at one ring and enter a S-pole at the other. These lines induce N- and S-poles in passing through the revolving inductors—shown removed from the magnet system in Fig. 119—and

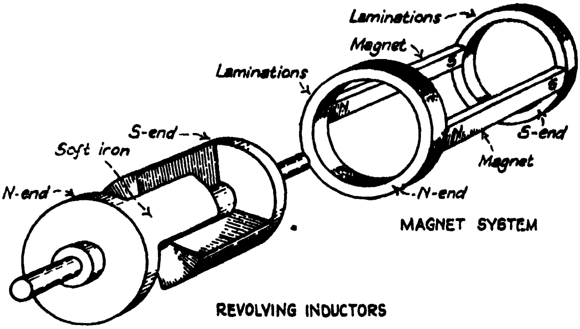


FIG. 119.—Magnets and inductors of polar-inductor magneto.

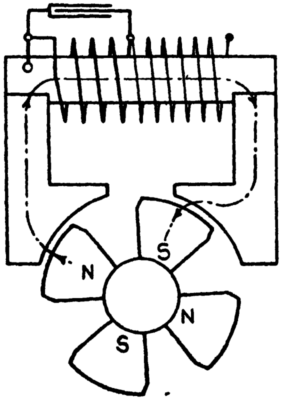


FIG. 120.—Part of magnetic circuit of polar-inductor magneto.

complete their magnetic circuit through the laminations shown in Fig. 120. The total number of magnetic lines through the armature core in this type is about 25,000, and there are four field reversals in every revolution, thus giving a four-spark magneto. The electric circuits are shown in Fig. 121. The windings, condenser and contact-breaker are seen to be stationary, as in the revolving-magnet type.

The four-spark polar-inductor magneto is eminently suitable for high-speed engines and for engines with a large number of cylinders, since its speed is only half that of a two-spark magneto. At the same time, by using a two-lobe cam, it can be run at the same speed as the ordinary magneto, being now made to work as a two-spark machine. This higher speed enables the inductor type to give higher voltages at starting, and, like the coil, to supply all the plugs with sparks of the same polarity (see "Sparking Plugs"). The polar-inductor magneto is found to give a good spark at low speeds, owing to the rapid rise of the secondary voltage.

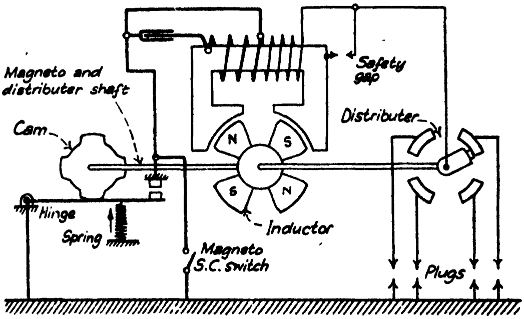


FIG. 121.—Elements of polar-inductor magneto.

Both mechanically and electrically the polar-inductor type, like the revolving-magnet type of magneto, has distinct advantages over the revolving-armature type. Briefly stated, reliability is greater owing to the higher factor of safety. Also in many of these types the spark energy is less than in the revolving-armature magneto, consequently the plug electrodes are not burnt away so rapidly.

The polar-inductor type is but one of the successful magnetos with stationary armature winding. The sleeve-inductor type is another variant; but with the advent of nickel-aluminium steel there is a tendency to develop camshaft-driven magnetos on account of their simplicity, freedom from gearing, ease of mounting, etc.

Advantages and Disadvantages of the Magneto.—The limitations of the magneto have been largely overcome. Even at low speeds improvement in design has left the magneto but little inferior to the coil. At starting, the cranking speed required for carburation can be met by modern magnetos without difficulty. At high speeds the difficulty with the early "two-spark-per-revolution" magneto was first overcome by the development of the "four-spark-per-revolution" magneto, and later by the camshaft-speed magneto producing as many sparks per revolution as there are engine cylinders. It is true that this development has entailed the replacement of the earlier revolving-armature type by stationary-armature types, but this has enhanced reliability through making the more delicate parts—windings, condenser and contact-breaker—stationary. Further, automatic timing of the ignition can be as satisfactorily effected on the magneto as on the coil. Also the powerful spark at high speeds, causing too rapid burning of the plug points, can be satisfactorily overcome by suitable shunts on the magneto. Then, above all, there is the great reliability of the magneto—its independence of the battery and car wiring.

The chief drawback against the magneto is not technical, but economic—in price it cannot compete with the coil, though in fairness to the coil it should be stated that the low-priced coil meets the normal requirements of car engines without difficulty.

The magneto, therefore, finds its use in that limited, though important, field where reliability is more important than cost, such as public passenger-carrying vehicles, and also where it is either a necessity, as in aeroplanes, or desirable, as on motor cycles and racing cars. The replacement of petrol by oil engines on commercial vehicles is further restricting the field for the magneto.

SPARKING PLUGS

Construction.—The sparking plug consists of a steel shell screwed into the cylinder head, thus forming the electrical connexion to the frame, and a rod within an insulating bush of porcelain or mica. The whole plug and its fixing into the cylinder must be thoroughly gas-tight. The electrodes or sparking points are fixed respectively to the earthed steel shell and to the insulated rod. There are many ways of doing this ; moreover, many types of plugs are required to meet the varied conditions of working.

To permit of interchangeability, certain mechanical dimensions of sparking plugs have been standardized, full details of which will be found in B.S. Specification No. 45—1928. The principal dimensions are given in Fig. 122. In order to obtain a smaller boss through the water jacket and better cooling, and to conform with the space restrictions, smaller plugs, with 14, 12 and 10 mm. diameter thread, have been introduced. These plugs give more space for cooling water, and with their smaller heat capacity they soon warm up. Plugs without gland nuts are also made.

Porcelain Plugs.—Ceramic insulators are chiefly used. These are made much in the same way as china is made—from kaolin, with fluorspar as binder, and fired to give a glazed surface. Other ceramic materials are also used, and care has to be taken to choose ingredients capable of fulfilling requirements. Glazing renders porcelain non-porous and helps to

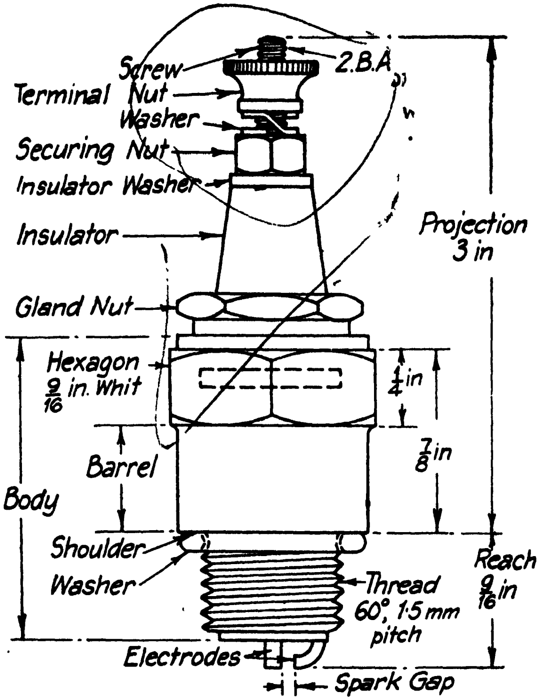


FIG. 122.—B.S. sparking-plug parts and dimensions (18 mm. dia. thread). The central is the insulated, the bent is the earthed electrode.

prevent dirt settling. Consequently, if the glaze is destroyed by excessive temperature or scraping, carbon or oil may be absorbed and ignition vitiated or prevented.

Since the resistance of porcelain decreases rapidly as the temperature increases, adequate cooling of the porcelain part is important; otherwise leakage may be troublesome. In some hot-running engines expansion may make porcelain plugs unsuitable.

Porcelain plugs may easily crack if clamped too tightly. The gland nut should ensure a proper gas-tight fit and yet permit proper expansion.

Mica Plugs.—Mica does not conduct electricity at high temperatures as readily as porcelain, and is, therefore, a good insulator for high-temperature engines, such as air-cooled and racing types.

Mica cracks readily when subjected to sharp bends, and it is common practice, therefore, to make the bush with mica washers pressed tightly between two binding heads; while the central electrode is wrapped closely with several layers of finely-divided mica to form an insulating bushing about 1·5 mm. thick. The mica insulator is highly polished to prevent penetration of oil and petrol. Cooling fins are provided to disperse heat. When cleaning, an abrasive should not be used, and care should be taken not to damage the surface of the mica; otherwise the mica tends to flake off, with consequent danger of pre-ignition and permanent spoiling of the plug. The use of mica plugs under adverse conditions may much reduce their life.

Combined porcelain and mica plugs are also used.

Advantages over porcelain and mica are claimed for other and newer types of insulator material for sparking plugs.

Electrode Construction. — Electrodes must be made of some metal which will withstand oxidation and burning.

The central electrode is cemented or screwed (or both) into the plug insulator and is almost invariably straight. Nickel forms the part projecting into the combustion chamber, being welded on to the steel pin to which the high-voltage cable is attached. The earthed electrode consists of a wire (or wires) fixed to the thread barrel and carried over towards the central electrode, being shaped to prevent rapid burning away (*see* Fig. 122). In recent years, materials other than nickel have been introduced for plug electrodes.

Multiple-pointed Electrodes.—By having two or more points on the earthed electrode, each correctly adjusted, an approach to an annular gap with its lower impulse-ratio is obtained, while less frequent setting is required, as the spark will always take the path of least resistance. On the other hand, multiple-pointed electrodes are more prone to soot up, which may lead to trouble unless conditions are such that carbon deposits are readily burnt off. Owing to the reduced amount of adjustment required by such plugs, their use is desirable in engines where running with them is satisfactory. At the same time gap adjustment should not be ignored, owing to the risk of high voltages in the ignition system, starting troubles and misfiring.

Spark-gap Adjustment.—A gap of 0·02 inch (0·5 mm.) is satisfactory in all normal plugs, but may be reduced to 0·015 inch with large electrodes and high compression. With a gap of 0·03 inch good idling is possible with most ignition devices. The idea that a larger gap is required with coil than with magneto ignition is not well founded. The magnitude of the energy at breakdown, or the capacitance component, is determined by the plug voltage and the capacitance of the plug and cable, and is independent of the source. For a certain voltage in an engine of low compression-ratio, a gap longer than the normal may be needed, and this may account for the idea that the coil commonly used on low-compression American engines needs a longer gap than a magneto. But for the same engine, the plug setting should be the same for the coil as for the magneto. Owing to the lower value of the inductance component of the energy in the spark produced by a coil, the plug electrodes do not burn away so rapidly with coil as with magneto ignition. Consequently, gap adjustment with coil ignition may need less frequent attention. Correct gap adjustment is important, and should be checked by a plug gauge. The smoother running—especially at idling speed—following gap correction well repays attention. Too long a gap may cause trouble at starting, misfiring at high and at low speeds, and danger to the insulation.

To permit the use of weak mixtures with consequent part-throttle fuel economy, claims have been made in favour of wide gaps—of the order of 0·04 inch—with a suitably designed coil.

Plug Polarity.—As burning takes place, metal is transferred from the positive to the negative electrode. The outer or earthed electrode is usually larger than the central or insulated electrode. For this reason it is advisable to make the central electrode negative and the earthed electrode positive. Further, as the central electrode is the hotter, and the plug voltage falls as the temperature of the negative electrode rises, it is advantageous for this reason also to make the central electrode negative. (See also "Earthing," p. 161, and Fig. 103).

These two reasons explain the common practice of making the central electrode of sparking plugs negative in coil ignition, and with those magnetos where all sparks have the same polarity. Though not strictly accurate, this practice is often referred to as working with a negative spark.

With *coil* ignition the polarity of all the plugs is the same. With *magneto* ignition, where the distributer terminals are alternately positive and negative, half the plugs have positive and half have negative polarity. A four-spark magneto fitted with a two-spark cam gives sparks all of the same polarity.

Choice of Sparking Plugs.—When determining the most suitable plug for a given engine—normally a matter for the engine builder—regard must be had to working temperature, compression and suchlike conditions. The one limit for the plug is glowing caused by overheating, leading to pre-ignition; the other limit is fouling caused by overcooling, leading to misfiring. It is found that a temperature of 500° to 600° C. of the part exposed to the burning gases is necessary to keep the plug clean. Below this self-cleaning temperature there is a risk of fouling either from oily plugs, arising from too much oil in the sump, worn scraping rings, or too much upper cylinder lubricant; or from sooty plugs, arising from the carbon deposited by the incomplete combustion of a rich mixture. Fouling on the insulator provides a leakage path to earth for the secondary discharge current. If the resistance of the leakage path be high enough, this shunt may not be serious; but bad fouling causes misfiring. Similarly when the electrodes become short-circuited, due to fouling, the live electrode is practically earthed. To prevent fouling when starting from cold, the sooner the plug gets hot the better.

On the other hand, if the plug in the combustion chamber overheats and reaches a glowing temperature

—over 850° C.—the mixture will be ignited by the glowing plug (pre-ignition). In such cases the engine would run without the spark, and timing would be so upset as to cause knocking, loss of power, popping back, etc. At the same time the plugs should be as hot as permissible, not only to keep them clean, but because the plug voltage falls as the temperature rises.*

The correct choice of sparking plug is thus an important matter. Using a good-cooling plug designed for a high-compression, high-speed racing engine in a normal, medium-compression engine would probably lead to misfiring through fouling from overcooling, owing to the carbon deposit not being burnt off; whereas a poor-cooling plug in a racing engine might be expected to glow and cause pre-ignition due to overheating.

The colour of the plug insulator near the electrode gives a fair indication of its functioning. A brownish discoloration indicates a suitable plug. A white porcelain indicates overheating; a sooted base, overcooling. Overheating a mica plug causes the mica at the base to become flaky and peel off.

Position of Sparking Plugs.—There are several factors which influence the position of the plug on the cylinder. As regards the projection of the plug in the combustion chamber, too long a reach may result in overheating and pre-ignition; whereas if the reach is kept inside the hole, a pocket is formed for burned

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* The resistance of a plug to overheating has been called its "pre-ignition coefficient." A plug with low pre-ignition coefficient is thus suited for good cooling conditions; a plug with high pre-ignition coefficient is needed where cooling conditions are poor. Fouling indicates that a lower pre-ignition coefficient is needed, while pre-ignition indicates a higher pre-ignition coefficient. Thus according to the trouble, the plug with the next lower or next higher coefficient would be chosen. The pre-ignition coefficient depends both on the time taken for the plug to warm up and the final temperature it attains.

gases, or for oil and soot accumulation, which may lead to misfiring or fouling. The position of the plugs relative to the valves is also important. Placed too near the inlet there may be too much cooling for the plug; placed too far away from it, the petrol may have time to condense when the engine is cold and so render starting difficult, also it may make the period of combustion too long. If the plugs are too near the exhaust they may overheat.

The position of the plug is determined by the manufacturer, but the type of the plug can be altered by the user—sometimes wisely, mostly unwisely. Generally speaking, sparking plugs should be replaced by plugs of the same type.

Ageing of Plugs.—Generally speaking only unsound plugs call for replacement. The assertion that a plug should be replaced after a certain mileage is often based more on business than on technical reasons. Nevertheless plugs are subject to wear. The formation of cracks in the surface of the insulator and the embedding of combustion residue therein is but one cause of leakage leading to misfiring and increasing starting difficulties. Such troubles may occur under 10,000 miles, or they may not occur in 50,000 miles—the remedy is new plugs. Ageing is recognizable by roughened insulator surfaces.

Importance of Clean Plugs.—Apart from failures from petrol or oil in mica plugs, or from high internal conductivity of porcelain plugs caused by heat or deposition of carbon, a frequent source of trouble is the partial or complete short-circuiting of the plug by oil or soot between the electrodes, or an excessive deposit of carbon on the upper or lower surface of the insulator. Pure oil is not a conductor, but used oil conducts owing to impurities (carbon due to decomposition, etc.) and so causes misfiring. Plugs thus fouled are leaky and the possibility of misfiring will depend on the resistance of the shunt leakage path thus produced. In some cases, if the ignition device has the necessary rating, a moderately-fouled plug may clear itself, or a spark may be maintained ; in others the plug may have to be removed and cleaned.

To remove oil or soot, a tooth brush and petrol are useful. Scraping with a knife may damage the surface and should be avoided. By removing the gland nut a plug can be thoroughly cleaned, but care is necessary in reassembly. Before removing a plug, remove dirt and grease from the recess. When replacing plug, see that the seating is clean, taking care that no dirt falls into the cylinder. Cleaning should be attended to when the spark gap is adjusted. The plug washers should be renewed occasionally.

According to humidity conditions, moisture due to condensation may be deposited on the plug insulator outside or inside the engine. The leakage path thus formed may render starting difficult.

With upper cylinder lubrication, the oil added to the fuel condenses during combustion, producing a film of oil with a lubricating action. With an over-rich mixture, the plugs may then become oiled up.

SPECIAL IGNITION EQUIPMENT FOR STARTING

In order to start an automobile engine it is necessary to fill one or more of the cylinders with an explosive mixture and to fire this mixture by means of a suitably-timed spark. We have seen that a properly-designed starting motor operated from a battery of adequate capacity can be made to turn the engine at a speed sufficient to draw in the requisite mixture and produce a satisfactory spark from a magneto. Where expense is a secondary consideration, some makers use both coil and magneto ignition, the former being used for starting and the latter for running, or as a reserve. A decided advantage of this dual arrangement is the provision of a reserve source of ignition, for if the coil fails the magneto is available, and vice versa. Where a change-over switch is employed it is possible to use a common contact-breaker, distributer, etc., but all such combined dual-ignition systems lack the simplicity in external wiring peculiar to the magneto.

In all cases up to the present considered there have been battery and starting motor. Some vehicles, however, may have batteries and motors which are not intended to rotate the engine at a speed sufficient to produce sparks from a magneto. The starting problem then resolves itself into the finding of other means of filling the cylinders with an explosive mixture and the production of a suitable spark. Various means are adopted for filling the cylinder or cylinders: the cylinders may be primed; the engine may be cranked by hand or rotated by a motor.

Many devices, too, have been developed for producing the spark needed to fire the mixture. Some of these devices are for use with coil ignition, others with magneto ignition; a great many of them are already things of the past.

Of the various devices used for starting, some rely on the battery for assisting the magneto current or for providing current for the spark, and consequently entail a certain amount of undesirable complication. Others, of a purely mechanical nature, are simpler in character and involve the principle of a hand-operated magneto co-operating with the main magneto—a useful device for starting aeroplane engines. Another well-known device for this purpose is the *impulse* starter. In this device there are two members linked together by a strong spring. One member is fixed to the magneto shaft, and the other to the driving shaft. By means of a pawl or trigger the magneto armature is prevented from revolving, and in consequence a spring is wound up as the engine is cranked. After a certain angle has been traversed the pawl releases the spring, which imparts to the armature a speed equivalent to about 500 r.p.m. for part of a revolution. The spark produced by this rapid movement fires the mixture, thereby starting the engine, while at a low speed the pawl is thrown out of action by centrifugal force and the two members rotate as a single unit. The impulse starter would appear to be suitable for commercial vehicles and tractors, and for aeroplane and marine engines.

A detailed discussion on special aids to starting would carry us beyond the elementary principles of electrical equipment, and, in any case, it is doubtful if their decreasing importance would warrant it.

HIGH-VOLTAGE CABLES

It is invariably the custom to provide an earth return for the high-voltage current. For this purpose the screwed reach of the sparking plug and one end of the high-voltage winding are connected to the engine or chassis, as the case may be. Consequently the cables that connect the distributer of the magneto or coil to the sparking plugs have to withstand a high voltage to earth, that is, to the metal of the engine, chassis, etc. The maximum value of the voltage between the cables and earth may reach 12,000 volts or more under certain conditions. The insulation required to prevent a leakage of current to earth, or an earth fault, by puncturing or surface discharge, therefore, must have a much higher insulating property than in low-voltage systems. Pure rubber with a suitable protective covering should be used for this purpose, and great care should be taken to prevent chafing or damage from heat. If the cables are taken through a metal tube, the holes should be carefully bushed and all sharp edges removed. The use of an earthed metal tube may be disadvantageous as encouraging corona discharge, with consequent perishing of the rubber insulation, while the added capacitance to earth entails a higher voltage, with consequent enhanced risk of breakdown. The metal tube is needed where wireless reception is called for, as on aeroplanes. Heat causes rubber to perish rapidly; it is, therefore, essential to keep the cables away from the exhaust pipe or any other hot part of the engine. Deteriorated or damaged cables must be renewed, not repaired.

To prevent leakage the insulation should not be cut back farther than is necessary; the insulation should be carried close up to the terminal or the connecting eye, as the case may be.

Ignition cables are made of tinned copper wires, stranded and insulated with one or more thicknesses of rubber. The strands are about 0·01 inch in diameter, the number varying up to forty-one. The insulating layer next the conductor is of pure rubber, the whole being vulcanized together to the desired diameter. The overall diameter is made in sizes from 4 to 12 mm., the common size being 7-mm. cable. Since the current is very small the size of the conductor is unimportant, but to obtain the requisite mechanical reliability, stranded cables only should be used here, as elsewhere on the car.

For providing ready identification of the several cables a colour code can be used. This can be carried out by covering the cable with a cotton sleeve and impregnating with a baking varnish of the appropriate colour. The overall diameter of a 7-mm. cable so treated should not exceed 8 mm.

Experience has proved that only materials of the best quality should be used for the electric circuits of automobiles. Some high-voltage cables have very little protection beyond the ordinary insulating rubber. This is to be deprecated, for the heat under the bonnet has an injurious effect. It is preferable to employ high-voltage cable with a suitable protective covering, e.g., of soft rubber. The thicker the covering, the better protected the cable will be, and, therefore, the greater the reliability. As a protection against deterioration from the effects of heat, oil and grease, ignition cables can be braided and thoroughly treated with cellulose varnish. The varnish may be applied in distinctive colours to enable the cylinder connexions to be readily traced. Another suitable covering is cab-tyre sheathing. The tough rubber covering of C.T.S. perishes far less rapidly than ordinary rubber from engine heat.

If the cables are good and are correctly used, the amount of leakage current from them may be negligible. In some cases it is possible to draw sparks from the cables as capacitance effect. Also, when the cables are taken through a metal tube, the return current may pass along the tube and spark over a short distance to earth.

To insure good ignition, leakage should be prevented in any part of the high-voltage system.

It is worth repeating that, with good material and good workmanship, most electrical failures in either the high- or low-voltage circuits can be eliminated.

TEST SPARK-GAPS

In order to test ignition devices—coils, magnetos or sparking plugs—on the bench it is necessary to simulate as nearly as possible the actual conditions in an engine cylinder (*see* also pp. 196 and 277). For this purpose it is not satisfactory to load the coil or magneto by an ordinary sparking plug in air, because at atmospheric pressure a relatively low voltage suffices to send a spark across the normal gap of 0·02 inch. Alternatively the normal sparking voltage at normal air pressure might produce a ¼ to ½ inch spark. Owing to the sudden or impulse nature of the voltage, its measurement by means of a valve voltmeter is too complicated for everyday use. Consequently to simulate actual conditions in a simple way, a test spark-gap is used not only to indicate the sparking voltage of a coil or magneto, but to load the device simultaneously. The biggest distance over which a breakdown occurs is then a measure of the voltage which the device can produce on load (*see* Fig. 85). To simulate the effect of plug fouling, the spark-gap is shunted by a suitable resistance (200,000 to 500,000 ohms). Although it may at first sight appear to be a simple matter to arrange such a spark-gap, there are one or two points which must not be lost sight of, if anomalous and apparently contradictory results are to be avoided.

As explained on p. 192, sparking plugs in a pressure chamber, under what may be termed "static conditions," should not be employed for testing ignition devices. Such plugs have all the disadvantages inherent from lack of ionization and their behaviour is always most erratic. The behaviour of a plug under conditions of steady pressure is no criterion whatever of its behaviour in an engine where ionization is always abundant, except at starting. Similarly the two-point gap at atmospheric pressure is seldom employed nowadays for ignition work on account of its high impulse-ratio, high operating voltage and inconsistent results.

As will have been gathered from the explanation given of the action of a spark-gap, it is essential that there shall be sufficient ionization present in order to provide the mechanism by which the spark is propagated. An ionized gap may be obtained in two ways, either by making the electrodes of fairly large dimensions, so that there is always the probability of the necessary ions being present in the neighbourhood at the moment when their presence is required, or, as an alternative, by providing artificial ionization of the gap. The former type of gap is represented by the annular or concentric gap, the latter by the three-point gap. (*See* Fig. 123.)

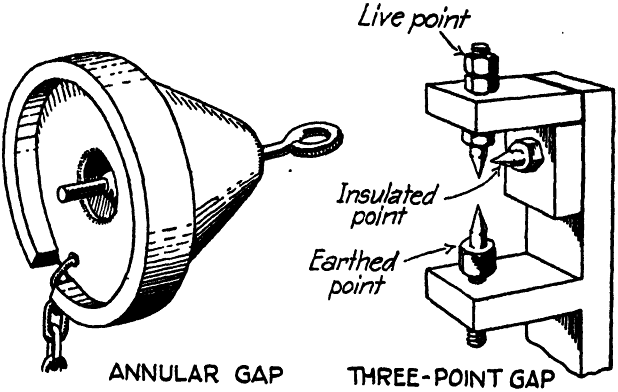

FIG. 123.—Spark gaps for testing magnetos, coils and sparking plugs (For curves with 3-point gap—see Figs. 85 and 86.)

Both of these gaps are used in practice. The annular gap is in more general use for duration testing, as it burns away less rapidly: the three-point gap is the more accurate, and is generally employed for comparative measurements.

The Annular Test Gap.—The annular gap is shown in Fig. 123. It merely consists of a round wire arranged concentrically in a hole in a plate. The edges of the hole are rounded off and the thickness of the plate should be about equal to the diameter of the wire. The diameter of the hole should be approximately five times the diameter of the wire. A convenient gap for general testing consists of an 18-gauge wire working in conjunction with 6-mm. or $\frac{1}{4}$-inch diameter hole. Such a gap will spark regularly at about 8,000 volts and will be independent of polarity. As this represents the upper limit of the working voltage desirable in any normal ignition system, the gap may be used for checking the consistency of operation of an ignition device, whether magneto or coil. If it is desired to test up to about 10,000 volts in order to have a safe margin, a 16-gauge wire in an $\frac{11}{32}$-inch hole may be used.

The Three-point Test Gap.—The three-point gap is shown in Fig. 123. It consists of two sharp-pointed electrodes—one earthed, the other connected to the ignition device. Behind the live point is arranged a third completely insulated point which is separated from it by a gap of a few thousandths of an inch. It is important that this point shall stand slightly behind the main point (say about $\frac{1}{64}$-inch), and not in front of it. Owing to the capacitance of the third point a minute spark occurs between this and the main point slightly before the voltage rises to its maximum value. This spark apparently serves to effect ionization of the main gap, and ensures regular sparking at a voltage much lower than with the two-point gap.

The three-point gap is usually set to 5–6 mm., which corresponds to 8,000–10,000 volts for regular sparking. Since the impulse-ratio is not unity, the discharge voltage of the three-point gap varies with the voltage wave form. Hence, as the wave form steepens in a magneto at high speeds, voltages over 10,000 may easily be attained (*see* also p. 195).

Testing of Coil or Magneto.—To measure the sparking voltage of a coil or magneto over a range of conditions the adjustable three-point gap is used. Results of tests are shown in Fig. 86. The relation between spark-gap and voltage for the three-point gap is shown in Fig. 85. A spark–gap of 5-6 mm. is satisfactory for most purposes, but where plug fouling has to be allowed for the gap must be shunted by a resistance of $\frac{1}{5}$ to $\frac{1}{2}$ megohm. If used continuously, especially on heavy discharges, the points—even when made of nickel—burn away rather rapidly and get out of adjustment. For endurance testing the annular gap is more suitable. For this purpose the fact that an annular gap is set for one voltage only is no disadvantage.

Generally speaking it may be said that where an ignition device gives regular sparking, either on the annular gap or on the three-point gap, it will give satisfactory service on any normal type of engine. Only when the spark-gap test fails should the ignition device be blamed for faulty running.

Testing of Sparking Plugs.—The voltage required to break down a gap at atmospheric pressure is much lower than that required under actual running conditions (pp. 192 and 274). Where the amount of plug testing to be done is considerable, the static pressure test is often employed, but, owing to the high impulse-ratio and the lack of initial ionization, a relatively high voltage is needed to break down the plug gap in compressed air in a quiescent state ; consequently the chief value of the static test is to make sure that the plug insulation is sound. Where possible the plug should be tested in an engine (*see* p. 296).

CHAPTER IX

FAULTS AND THEIR LOCATION

Breakdowns.—The electrical equipment of a motor vehicle consists of several systems, more or less independent. A breakdown may be due to various causes: an insulation failure leading to a short-circuit or to an earth; a melted fuse or a conductor fracture leading to an open-circuit; a battery failure, due to under- or over-charging; a faulty connexion introducing resistance.

Necessity of Locating Cause of Breakdown.—Many faults are manifested by their effects. In these cases, not only must the effect be remedied, but it is also necessary to locate and remedy the cause. For example, a fuse may fail from wear and tear, e.g., fracture due to mechanical vibration, or gradual volatilization due to heat, in which case the fuse merely needs to be replaced. Alternatively, a fault in the protected circuit may cause the fuse to melt—in such a case the fault must be located and remedied. Similarly a machine winding may burn out owing to an external fault. Unless the fault be remedied, the fuse will melt as often as it is replaced, or the winding will burn out as often as it is renewed. Put briefly, to prevent the effect the cause must be traced and removed.

Bad or Loose Contacts.—These may be very troublesome owing to the resistance they introduce into circuits, or the intermittent faults they give rise to. The effect of increased resistance is most pronounced in the starter circuit. Suppose that a poor contact at a terminal or to the chassis increases the resistance of the circuit by 1/200th ohm and the current in consequence falls to 200 amperes. The voltage drop at the contact is then 1 volt and the loss at the contact 200 watts. The former may suffice to prevent initial breakaawy on switching in, while the latter may produce dangerous local heating.

Replacements and Renewals.—Although it may be possible to repair minor faults, it must be recognized that in many cases a repair is out of the question. A breakdown in a machine winding, coil, cut-out, voltage regulator, high-voltage cable, harnessed conductor, etc., is generally remedied by a replacement. In this respect the user or garage mechanic is no worse off than the maker—indeed, the latter is less likely to attempt a repair than the former. As in the case of a lamp failure, the user must be contented with locating the fault and paying for a replacement.

Deterioration of Insulating Materials.—Insulating materials are made from cotton, paper, fibre, rubber, oil, spirit, gum or synthetic-resin varnish, mica, shellac, enamel and paint. Failure may result from overheating, moisture, fracture, chemical action, or coating with dirt, dust, petrol, water, oil, grease, carbon and copper particles. Cotton and paper being hygroscopic, they are protected by varnish—such materials lose their insulating properties at 140°–160° C. At these temperatures fibre shrinks and rubber softens. Shellac and enamel retain insulating properties at higher temperatures, but deteriorate.

For high-voltage wiring the only suitable insulation is rubber, silk and enamel. In electric fields of high intensity rubber undergoes physical and chemical changes, and so gradually deteriorates. Petrol and oil also lower the insulating properties of rubber, particularly at high temperatures.

In cases of breakdown, repairs are often out of the question—cables must be replaced in the same way as accessories.

BATTERY FAULTS

A battery that exhibits a persistently discharged state indicates the existence of a fault, either in the battery itself or in the outside circuit. In this section the battery only will be considered, outside faults being discussed elsewhere. Beyond the satisfaction of locating a battery fault, there is little to be gained from the investigation, for the remedy of such faults is usually a matter for the battery maker.

Before attempting any tests a visual inspection should be made for anything so obvious as dirt, water, loose wires, etc. For the tests a hydrometer and a 3-volt voltmeter are needed. To determine the condition of a battery that has failed, the cells should first be tested by means of the high-discharge apparatus referred to on page 27 (3), which enables local faults to be detected without first submitting the battery to prolonged charging.

If no local fault is present, the plates in each cell should be washed out with water, refilled with water, and the battery given prolonged charging at a rate not exceeding 1/20th of the nominal 10-hour capacity rate.

Defective cells are indicated when near end of charge by:—

(*a*) *Low Voltage.*—This may be due to internal short-circuit, and should be checked by taking specific gravity, which will also be lower than the other cells. Short-circuit may be due to collection of sludge; if so, wash cells out with dilute acid.

(*b*) *Voltage much higher than the other cells.*—Probably due to large internal resistance caused by sulphating, broken plates or connexion to lugs. Excessive gassing may indicate this condition.

On discharging, a defective cell will be revealed by its lower voltage measured while current is flowing.

Battery Earthed.—When cells are in position on the car, *test for earth* by removing connexions and testing between each terminal and earth with voltmeter. A reading on voltmeter indicates an earth or leakage fault which may account for the run-down condition of the battery. If possible test each cell independently.

Rough Test for Faults.—Disconnect battery wire and touch the battery terminal lightly with it when all switches are off. A spark indicates a fault, which may be an earth or short-circuit in wiring or an earth in battery.

STARTING TROUBLES

Some of the chief troubles connected with battery-motor starting systems and their possible causes are summarized below :—

TROUBLE	POSSIBLE CAUSE
Motor will not run or not run fast enough.	Discharged battery. Bad connexions at battery, switch or motor, or to earth. Brushes wrongly adjusted. Brushes sticking in box. Internal layer of brush dust. Presence of fuel oil. Engine locked.
Pinion does not engage.	Screw shaft dirty or bent. Thick oil on shaft.

TROUBLE	POSSIBLE CAUSE
Pinion does not disengage after engine fires.	Screw shaft dirty or bent. Pull-back spring too weak. Pinion sticking due to wear in keys or threads.
Bad sparking at brushes.	Spring pressure too low. Brushes sticking in holders, or held up by flexible. Worn brushes. Dirty commutator. High micas in commutator. Presence of fuel oil. Bent screw shaft.
Motor takes large current and only crawls.	Short-circuit fault in field coils, or earth fault. Armature coils burnt out.
Motor takes only small current.	Bad or broken connexions of armature coils to commutator, or in circuit. Brush flexible loose in brush.

GENERATOR TROUBLES

Some of the chief generator troubles and their possible causes are summarized below :—

TROUBLE	POSSIBLE CAUSE
Charging current too small.	Brush pressure too feeble. Brush sticking in holder. Brush badly worn. Flexible damaged. Commutator dirty or oily. Fault in field winding.
Sparking at the brushes	Brush pressure too small.

GENERATOR TROUBLES

Trouble	Possible Cause
Sparking at the brushes.	Faulty brush contact.
	Worn brushes.
	Dirty commutator.
	Commutator eccentric, or with high micas, or with high bars.
Refusal to excite.	Faulty brush contact.
	Brush spring weak.
	Dirty commutator.
	Glazed commutator.
	Field winding broken.
	Field winding earthed or short-circuited.
Refusal to excite.	Armature winding broken.
	Armature winding earthed.
Large current pulsations (violent swinging of ammeter needle).	Dirty commutator.
	High commutator bars, or high micas.
	Faulty brush contact.
	Faulty brush flexible.
	Dynamo belt slipping.
	Loose contacts in outside circuit.
	Short-circuit beyond cut-out. (This reduces voltage to zero and opens cut-out. Generator then excites again and closes cut-out. This goes on repeating itself.)
Exciting winding or lamps burn out.	Battery disconnected from three-brush dynamo.
	Regulator contacts welded together (rare).

CIRCUIT FAULTS

Here it will be convenient to consider wiring and machines separately.

In an *earth*-return (or one-wire) system a wiring fault may be an *earth* (due to an insulation breakdown to earth) or an *open-circuit* (due to a melted fuse, burnt-out lamp, broken wire or cable, loose connexion, faulty switch, etc.).

In an *insulated*-return (or two-wire) system, in addition to an earth or an open-circuit, a *short-circuit* may arise from the failure of the insulation between the conductors.

In many instances faults can be detected by careful inspection without the aid of instruments, e.g., melted fuse or broken filament. On the other hand, a fault may be *intermittent* in character ; that is to say, it may occur under certain conditions only. As these conditions in many cases cannot be repeated while a test is being made for the fault, it is often difficult to trace such faults. Thus a broken wire with undamaged insulation may give rise to an intermittent fault which is troublesome to detect.

General Tests for Faults.—Tests for an *open-circuit.* If fault is not revealed after inspecting fuse or lamp, place an ammeter and a cell in the circuit to be tested and close switch (if any). A lamp or other resistance may be inserted in the circuit to safeguard ammeter. In the ammeter indicates zero, the fault is probably an open-circuit, traceable to a loose connexion, broken or disconnected wire or cable, poor earth connexion, faulty switch, or joints in chassis not making metallic contact.

Test for an *earth.* Isolate the circuit by disconnecting the car battery and intentional earth connexions (by removing lamps, etc., in an earth-return system) and connect the negative of a cell to the wiring, and the positive of the cell to the positive of a 3-volt voltmeter, the other pole of which is earthed. A reading on the voltmeter indicates an earth. If a switch is part of the wiring, the test should first be made with the switch open and then with the switch closed, with a view to locating the position of the earth fault.

Test for a *short-circuit.* This fault is possible in the wiring of an insulated-return system. Carry out test as for open-circuit, but with the lamps removed, or any other piece of apparatus disconnected. A reading on the ammeter indicates either a fault to earth on both positive and negative leads, or a short-circuit between these conductors. To determine whether the fault is an earth or a short-circuit, carry out the test for an earth.

Location of Wiring Faults

Open-Circuit.*	Earth.*	Short-Circuit.†
If fuse and lamp are sound, connect ammeter (or lamp) and cell in faulty circuit. Close switch. *No reading* (or no light) indicates open-circuit. Look for: Loose connexion; broken or disconnected cable; faulty switch; poor earth connexion; chassis joints not making metallic contact.	Isolate circuit by disconnecting battery and intentional earths, removing lamps, etc. Connect cell negative to wiring. Connect cell positive to positive terminal of 3-volt voltmeter. Connect negative of voltmeter to chassis. *A reading* indicates an earth. Test first with switch open and then with switch closed to locate position of fault.	Test as for open-circuit, but with lamps removed and apparatus disconnected. *A reading* indicates either earth fault on both leads or short-circuit between leads. Apply test for earth. *No reading* on earth-test voltmeter indicates a short-circuit.

* Possible with earth- or insulated-return.
† Possible with insulated-return.

No reading on the voltmeter indicates that the fault is a short-circuit.

If no suitable meters are available, a lamp, rated for the voltage of the test cell (or battery) employed, may be used for making any of the above tests. One or more cells of the car battery, if isolated, can be used for this purpose.

To assist methodical procedure the above tests are set out in tabular form on page 285.

Faults in Starting-motor Circuit.—When the motor will not move on switching on, an indication of the nature of the fault may be obtained from the headlights as follows : If on closing the starting switch the lights do not become dim, an open-circuit is indicated. If the lights do become dim, a short-circuit or an earth is indicated. To locate the fault connect a suitable voltmeter to the motor terminals and press the starting switch just long enough to observe the instrument. *No* reading indicates an *open*-circuit in the starting switch or in the wiring to the battery. If a *very low* reading is obtained, look for loose connexions at the battery, switch or motor, for an earth or a short-circuit in the wiring, or for a short-circuit in the motor (see under "Location of Faults in Machine Windings"). In this case the motor may crawl. A reading *equal* to the battery voltage indicates an *open*-circuit at a brush or in a winding of the motor (see under "Location of Faults in Machine Windings").

Faults in Generator Circuit.—These are generally made evident by the absence of the normal indication of the charging current. If a brief examination of the cut-out (by tapping, etc.) and of the brushes fails to rectify the fault, connect a suitable voltmeter (range 0 to 30 volts) across the generator terminals, remove the leads from the battery, and open all switches except the dynamo field switch (if one be provided). Run the engine and dynamo, taking care to bring up the speed slowly and watch the voltmeter, owing to the possibility of a high voltage. If the voltmeter now shows a reading in excess of 6 or 12 volts, as the case may be, with the battery thus isolated, the generator is in order and the trouble must be sought in the wiring or accessories beyond the switches, or in the refusal of the cut-out to act. If only a low voltage or no voltage at all is obtained, disconnect the main leads from the generator, keeping the field circuit closed. If a high reading is now obtained, look for an earth or short-circuit fault in the disconnected leads or cut-out; if disconnecting the leads makes no difference, the fault is most likely in the generator windings or brushes (see under "Location of Faults in Machine Windings").

A fault beyond the cut-out may cause violent current oscillations through the circuit being closed by the cut-out as the generator voltage rises, and then being opened as the voltage drops to zero, owing to the rush of current into the fault. Since in the nature of things this excessive current, once the fault exists, goes on repeating itself, bad pitting at the cut-out contacts inevitably ensues.

Loose connexions, a dirty commutator, or brush faults may also cause the ammeter needle to oscillate.

Faults in Lighting, Horn, and other Branch Circuits.—If only one lamp fails, examine for a burnt-out lamp by trying a lamp known to be in order. Should this lamp not light, examine the faulty circuit for open-circuit, earth, or short-circuit, as explained on page 285. If all the lights fail when all switches are closed, see if opening or closing any of the lamp switches makes a difference. If it does, a faulty branch circuit is indicated. If not, a fault in the circuit between battery and distribution board is indicated. Having located the faulty circuit, carry out the tests described on page 285 for open-circuit, earth or short-circuit.

Faults in Cut-out.—In addition to the electrical faults already referred to, there is always a possibility of the contacts refusing to open or to close. A smart tap may often suffice to make the cut-out operate, but the contacts may need attention from time to time. It is well to cultivate the habit of observing the ammeter needle in the same way as the oil gauge, particularly when the engine is stopped, to ensure that the battery is not left to discharge through the generator armature because the cut-out has failed to open the circuit, nor through the coil in a coil-ignition system because the ignition switch has not been opened.

Faults in Automatic-voltage Regulator.—The same faults may occur here as in the cut-out—open-circuit due to broken wire, short-circuit due to insulation breakdown, burnt contacts due to wear. Most faults in these devices require expert attention, often by the makers. As in many other parts of automobile equipment, the only remedy for many faults in cut-outs and voltage regulators is replacement of the damaged parts.

LOCATION OF FAULTS IN MACHINE WINDINGS

Field-winding Faults.—Discontinuity and earth faults in the field circuit of a machine can both be traced by isolating the coils and applying tests similar to those described for the wiring system. A short-circuit between adjacent turns in a coil causes the resistance between its terminals to be lower than that of a healthy coil. If two or more such coils are, therefore, connected in series with a testing battery, and the voltage across each coil be compared, the voltage measured across the coil with some of its turns short-circuited will be lower than that across a healthy but otherwise similar coil; while no reading on the voltmeter is indicative of a complete short-circuit. A reading equal to the voltage of the testing circuit would show that there is an open-circuit in this coil. To locate a coil which is earthed, proceed exactly as directed for an earth fault in the wiring.

Brush and Commutator Faults.—After removing the cover (if any), make a careful examination to ensure that all brushes are bedding properly. Trouble may arise from a worn brush, brush sticking in holder, defective spring, insufficient spring tension, or earthed brush-holder or brush flexible.

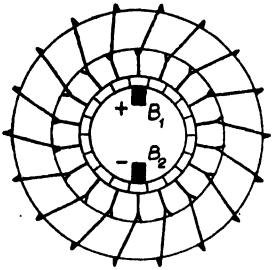

FIG. 124.—Closed-circuit, two-pole ring winding for direct-current armature.

Examine the commutator for carbon deposit or oil, and see that the micas between segments are not short-circuited by carbon or dirt. High micas may prevent a brush from making contact with the segments. It is now common practice to recess the micas.

Armature Faults.—When an armature develops a fault, we may wish to diagnose the fault and locate its exact position, although the repair of most armature faults is generally a job for the makers or for someone with skill and experience of such work. Direct-current armatures have closed-circuit windings, i.e., the end of the one coil is joined to the beginning of the next, and so on throughout, to form a closed circuit. This can be represented diagrammatically by the two-pole ring armature shown in Fig. 124. Connexions to the commutator are tapped on to the coils ; it will be seen that there are two paths in parallel between the positive and negative brushes B_1 and B_2. In an actual machine the wire is wound into coils, which are carefully insulated and placed in slots round the circumference of the cylindrical or drum-shaped armature core. Fig. 125 shows two coils of such a drum armature with the connexions to the commutator. Only one turn per coil is shown, but on a small armature there are many turns in a coil between adjacent commutator segments. The connexions shown in Figs. 126 and 131 and the following notes refer to a two-pole armature in which there are two paths in parallel between brushes placed 180 degrees apart, but the principles may be applied to machines with any number of pairs of poles and armature paths.

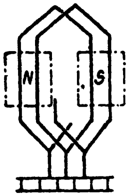

FIG. 125. Coils of a drum-wound armature with connexions to commutator (lap connexion).

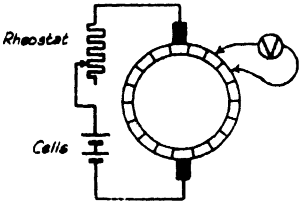

FIG. 126.—Connexions for locating an open-circuit in an armature coil.

(1) *Open-circuit (or Break) in an Armature Coil.*—Make the connexions as in Fig. 126, in which a 6- or 12-volt battery with regulating resistance is shown connected in circuit with the faulty armature. A low-reading voltmeter is

attached to as pairof leads so that the voltage between adjacent segment all round the commutator can be read. It will be found that, *if the armature is kept stationary relative to the brushes,* no reading of the voltmeter will be obtained between any pair of adjacent segments in that section of the armature included between the two brushes in which the fault lies, *except* between the segments connected to the faulty coil. This is explained by the diagram in Fig. 127.

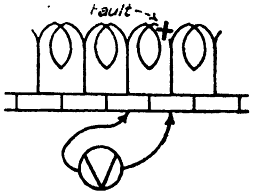

FIG. 127.—Location of open-circuited coil in Fig. 126 by indication on voltmeter across fault.

If there should be more than one break, then this test will givea negative result and the connexions shown in Fig. 128 must be made. The voltmeter leads should be kept fixed while the armature is moved slowly. As soon as a faulty coil enters the section between the voltmeter connexion and the right-hand brush, the reading will fall to zero. The coil should be repaired, or the segments to which it is connected should be temporarily bridged across and the test continued in the same way to locate other open-circuited coils. Finally, the connexions in Fig. 126 should be made and the voltage drop test in Fig. 127 employed to locate the last of the broken coils.

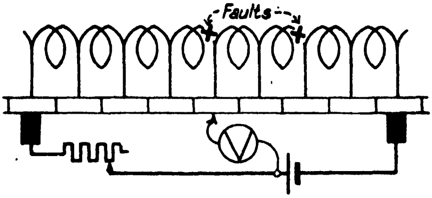

FIG. 128.—Test connections when more than one coil is open-circuited.

(2) *Open-circuit (or Break) between a Coil and Commutator Segment.*—This is a very common fault in small armatures. Connect as in diagram in Fig. 126 and proceed as before to measure the voltage between commutator segments. In Fig. 129 the disconnexion is shown in the lead connecting a pair of coils to segment *b*. It will be found that the testing voltmeter gives the same reading when connected between any pair of adjacent segments, except between bars *a* and *b*, and again between *b* and *c*, where no reading is obtained. Between bars *a* and *c* about twice the normal voltage between segments will be observed.

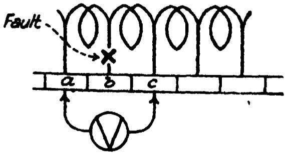

FIG. 129.—Location of open-circuit between coil and commutator segment. Between *a* and *b* or *b* and *c* reading is zero. Between *a* and *c* reading is doubled.

In an armature that has failed faults (1) and (2) may both be present, in which case fault (1) will manifest itself in the first instance.

(3) *Short-circuited Coil.*—This condition is shown in Fig. 130. Connect as in Fig. 126 and measure voltage between segments. A reduced voltage between a pair of segments indicates a short-circuit or a partial short-circuit. A voltmeter range of 0 to 0·1 volt may be required for this test, and care must be taken to obtain good contact between the voltmeter leads and the commutator bars.

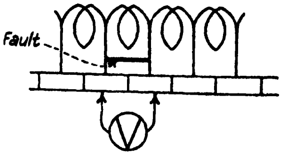

FIG. 130.—Location of short-circuited coil, indicated by reduced voltage between segments.

(4) *Earth Fault.*—Before testing the armature winding the brush-holders should be carefully

examined and tested for a possible earth fault. The test for an earthed brush-holder may be conveniently carried out as directed for the wiring system (p. 285), a piece of paper being inserted between each brush and the commutator to insulate the armature from the brushes and brush-holders.

To locate the faulty coil when an earth has been traced to the armature winding, connect the testing battery and regulating resistance to the armature

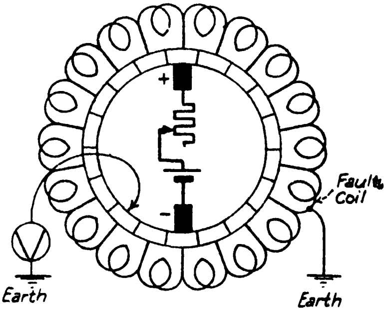

FIG. 131.—Location of earth fault, showing test connexions and voltmeter.

terminals, one terminal of the testing voltmeter to earth and the other voltmeter terminal to a lead which can be connected to every commutator bar in turn, as in Fig. 131. Take readings of the voltage between each segment and earth. On passing from bar to bar, if there is an earthed coil, the voltmeter reading will decrease as a certain segment (or pair of segments) is approached, and will be zero or reach a minimum value at this place. The voltage will rise again when this segment is passed, but now it will be in the opposite direction. Since an armature has more than one circuit, the earthed coil may or may not be connected to the segment thus located. When such a segment is found, therefore, the voltmeter connexion should be kept in contact and the armature rotated relatively to the brushes. If this movement of the armature does not alter the voltmeter reading, then this segment is earthed or is the one nearest in contact to the earthed coil. If movement of the armature changes the voltmeter reading, this segment is not earthed, and the test must be continued until a segment is found on which the minimum voltage to earth is independent of its position relative to a brush.

A clue to the position of a fault is often obtained by inspection of a commutator. Flashing takes place between a brush and a segment associated with a disconnexion fault (open-circuit). With an earth-return system, an earthed coil causes a short-circuit when the segment to which it is connected passes under a brush joined to the insulated side of the system. Consequent sparking causes burning of the brush and the segment, the latter often becoming covered with a deposit of carbon.

In a dynamo and in a motor a short-circuited coil usually burns out because of the heavy induced current in the short-circuited turns. The appearance of the burnt and damaged insulation is often a guide to the faulty section.

IGNITION FAULTS

Apart from the battery, the most likely seats of breakdown are the high-voltage wiring and winding and the sparking plugs. Here it is intended to discuss engine trouble arising from ignition faults only.

In the case of an engine stoppage on the road, experience will often indicate the cause of the trouble by the manner in which the stoppage occurs. It is, of course, necessary to make sure that the breakdown is not due to fuel starvation or mechanical failure.

Ignition faults may cause misfiring or they may prevent the engine running at all.

Misfiring.—Failure of the charge to ignite or to ignite at the correct instant often occurs when the engine is cold, owing to sticking valves, incorrect fuel either in quality or quantity, foul plugs, plugs with gap too large or too small ; chafing or other damage of a high-voltage cable, faulty contact-breaker or incorrect gap, faulty condenser, incorrect timing, wet insulator. Misfiring in one or more cylinders may be due to faults in a section of the ignition system.

Stoppage of the Engine may be caused by earthing of magneto switch cable, sticking of rocker arm with contacts open, loose lock nuts or central screw of contact-breaker, breakdown of magneto or coil to earth, disconnected or discharged battery with coil ignition, dampness, oil, dirt, etc.

Pre-ignition may result from glowing particles of carbon, especially on low speed, high gear, and heavy load with dirty cylinders. *Backfiring* in the silencer may be due to an over-rich mixture, while too weak a mixture may cause *popping-back* in the carburettor (*see* pp. 186 *et seq.*).

Sparking-plug Faults.—In case of *misfiring* in one or more cylinders, evidenced by engine vibration or loss of power, it is well to suspect plug fouling in the first instance. This breakdown to earth is caused by a deposit of soot or oil on the plug, or even condensation when starting cold. If the fouling is merely a bridge across the plug electrodes, the trouble may clear itself, or the spark energy may clear it—with magneto ignition by racing the engine, and with coil ignition by letting the engine idle. At starting, irregular firing is common, but this may go off as the engine warms up. If misfiring is persistent, the faulty plug must be located either by feeling which plug is comparatively cool, or by running the engine and finding which plug, when short-circuited, makes no difference in the running. This can be done by earthing successive plugs by means of a short length of insulated cable or a screwdriver with a wooden handle. In all cases be careful to press one end of the cable or screwdriver firmly against the engine before touching the plug terminal with the other end, and to keep the hand insulated ; otherwise a bad shock may result. Removing then the high-voltage wire from the terminal of the suspected plug and holding the wire first about ¼ inch first from earth (e.g., cylinder head) and then from the suspected plug terminal, compare the sparks as the engine is turned by hand. The passage of a strong spark to the cylinder and a weak spark to the plug generally indicates that the plug is at fault. Alternatively, replace the suspected plug by a plug known to be sound. If the running is now regular, the old plug is at fault. The fault may be due to fouling, too-large gap, or failure of plug insulation. To remove fouling, clean thoroughly, dismantling the plug at the gland nut, if necessary. The gap can be tested either by a gauge, or, with the plug in position, by an annular test-gap set for about 8,000 volts. (Fig. 123.) This test is made by attaching one electrode to the plug terminal and the other to the engine. If, on running the engine, a spark jumps the gap, the voltage is too high and the distance between the points must be reduced to the prescribed value. This is a common fault. If the plug still will not work when cleaned and adjusted a cracked porcelain or leaky mica is probably the cause of the trouble, and the remedy is a new plug.

Coil (or Magneto) Circuit Faults.—If no spark passes from a removed high-voltage wire to the engine frame, the low-voltage and primary circuit being in order, some fault in the high-voltage wire, or in the magneto or coil, is indicated. Test the high-voltage cable by trying a new cable. If the new cable does not remove the trouble, look for cracked or leaky distributer or faulty breaker, as explained below. A fault, such as a broken wire, may be intermittent and hard to locate. If cable is suspected, try a new one.

If the engine will not run at all, and neither a preliminary examination of the ignition device (distributer, contact-breaker, etc.) nor any test for misfiring reveals the fault : With *magneto* ignition, if switch cable proves to be in order (by attempting to start engine with switch cable removed), remove the distributer, and test for spark by noting the safety spark-gap or spark from slip-ring. For this test it may be necessary to take off the magneto. With *coil* ignition, remove the high-voltage lead from distributer, switch on with contacts closed, and test for spark to frame when the contacts are separated by hand.

(*a*) If good sparking occurs, then magneto or coil, whichever is used, is in order, and distributer must be examined as the probable source of fault.

The possibility of a break in the high-voltage wire from coil to distributer, or a terminal fault, however, must not be overlooked.

Distributer. — Examine distributer insulation to detect any evidence of burning, puncturing, cracking or loose holding nuts. Carbon-brush distributer : see that the track is clean ; the brass segments are smooth, clean, and flush with the insulation ; the brush is moving freely in the holder and making good contact.

The brush should exhibit a glazed surface and should be examined periodically. With spark-gap type distributer, see that all surfaces are clean. With this type ventilation is essential to prevent formation of nitric acid.

(*b*) If sparking is poor or if none occurs, there is probably a fault in the magneto or in the circuit including coil, distributer and battery. The several parts must be examined in detail.

Battery Circuit.—Test circuit between battery, coil and distributer by noting ammeter reading, applying tests for wiring faults, etc.

Contact-Breaker.—Examine rocker arm to see if it is sticking owing to swollen fibre bush; examine also spring tension. Examine contacts to see if they are smooth and free from oil; see also if all screw connexions of cables and condensers are clean (free from oil) and secure. Examine lock-nut and central screw for tightness. Check each contact gap opening. Poor running at low speeds may be caused by dirty or pitted contacts, or by too small contact gap.

Collector Insulator and Slip-Ring (magneto with revolving armature).—Examine insulator to discover any evidence of burning or puncturing. See that carbon brush makes proper contact. Remove all traces of carbon deposit from insulators. Examine brush connecting conductor in collector insulator with conductor in distributer rotor.

Faulty Condenser.—An open-circuit or break in the condenser causes vicious arcing at the contact-breaker points. A short-circuit in the condenser puts the coil or magneto out of action.

Faults in Windings.—If all the above details are found to be in order, winding faults may be discovered by removing distributer cables and connecting distributer terminals together by a thin wire, the end of which isheld about $\frac{1}{32}$ inch from frame. A feeble spark or no spark points to short-circuit or earth in the winding, slip-ring or condenser. The repair may need expert attention or renewal of faulty part.

Dampness, which causes leakage, may be removed by drying out. If ignition trouble is experienced after a car has been washed, dampness should be suspected.

Weakening of Magnets, which causes weak sparks, may necessitate remagnetization.

Location of Ignition Faults

Misfiring.		**Engine stoppage.**	
Run engine and locate faulty cylinder. Remove high-voltage wire from plug in faulty circuit and hold it $\frac{1}{4}$ in. from frame, or use annular test gap.		If fault is not revealed by inspection, misfiring or magneto-switch-cable tests: With magneto ignition, remove distributer head, and test for spark from safety gap or slip-ring. With coil ignition, switch on with contacts closed, hold high-voltage wire to frame and open contacts by hand.	
Spark.	**No spark.**	**Spark.**	**Poor or no spark.**
Indicates plug fault. (1) See plug faults. (2) If fault is intermittent try under "No spark."	Indicates fault in wire, magneto or coil. (1) Try new cable. (2) Examine (*a*) distributer; (*b*) breaker; (*c*) slip-ring, etc.	Indicates faulty distributer. See distributer faults.	Indicates fault in breaker, magneto, coil, or battery circuit. (1) Examine (*a*) breaker; (*b*) slip-ring, collector insulator; (*c*) battery and coil circuit; (*d*) test for faulty condenser or winding. (2) Test for dampness.

FAULTS :—

Plug :

Soot or oil on electrodes.
Deposit of carbon or water.
Gap too large.
Porcelain cracked.
Mica leaky.

Distributer :

Burning.
Punctured.
Cracked.
Loose nuts.
Carbon or dirt deposit.
Dampness.
Faulty segment.
Faulty brush.

Condenser and Windings :

Short-circuit distributer terminals and hold wire $\frac{1}{32}$ in. from engine. Feeble or no spark indicates broken-down winding, condenser or slip-ring.

Cable :

Disconnexion.
Broken wire.
Insulation.

Contact-breaker :

Dampness (rocker arm sticking).
Broken or weak spring.
Dirty or pitted contacts.
Wrong gap opening (unequal cams, etc.).
Loose lock nut.
Loose central screw.
Sheared key.

Slip-ring, Collector Insulator :

Burning (smell of burnt ebonite).
Puncture.
Carbon deposit.

Brushes :

Faulty slip-ring, earthing, or collector-rotor brush.

Weak magnets.
Worn bearings, etc.

Safety Spark-Gap.—See that distance is correct ($\frac{5}{16}$ inch or 8 mm.).

The above tests are tabulated on page 299 for reference.

Methodical Procedure.—Faults should be located in a methodical manner ; much time may be wasted by haphazard methods.

If all apparatus becomes inoperative the continuity of the circuits should be checked *from* the source of supply outwards towards the junction boxes and hence to the individual circuits. On the other hand, if a sub-circuit proves faulty, then it can be readily ascertained whether other sub-circuits are in order (e.g., switch on another lamp circuit or windscreen wiper, etc.) and the sequence of testing should then be from the revealed fault inwards *to* the junction boxes and switches.

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