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CHAPTER ONE

1.0 CHARGING SYSTEM

1.1 INTRODUCTION

Automobile charging system uses generators to produce electrical energy. Most of the electrical power used by motor vehicles is supplied by an electric generator. An electrical generator is a machine that converts mechanical energy in to electrical energy. This energy conversion is based on the principle of electromagnetic induction. Electrical generators vary greatly in size depending upon the load to which they supply power. Regardless of size, all electrical generators, whether direct current or alternating current, depend upon the principle of magnetic induction. An emf is induced in a coil as a result of a coil cutting through a magnetic field, or a magnetic field cutting through a coil. As long as there is relative motion between a conductor and a magnetic field, a voltage will be induced in the conductor.

1.2 PURPOSE OF THE CHARGING SYSTEM

The main purposes of the charging system are:

- To put back in to the battery the current used to start the engine
- To handle the load of the lights, ignition, radio and other electrical and electronic equipment's while the engine is running

Automobile charging system uses generators to produce electrical energy.

1.2.1 Electrical Generator

All electrical generators use the principle of electromagnetic induction to generate electrical power from mechanical power. Electromagnetic induction involves the generation of an electrical current in a conductor when the conductor is moved through a magnetic field. Hence the basic essential parts of an electrical generator are:

- A magnetic field
- Conductors which can move so as cut the flux.

The amount of current generated can be increased by the following factors:

- Increasing the speed of the conductor through the magnetic field
- Increasing the number of conductors passing through the magnetic field
- Increasing the strength of the magnetic field

There are two types of electrical generators used in motor vehicle;

- Direct current (DC) generators
- Alternating current (AC) generators

A Direct current generator makes the output by rectifying the alternating current made in armature coil using the commutator and brush, whereas the AC generators gets the alternating current output from the stator coil and this alternating current is converted into the direct current by rectifying through silicon diodes.

1.3 DIRECT CURRENT (DC) GENERATOR

1.3.1 Types of Direct Current Generators

There are a number of different types of generators. Generators can be distinguished by their method of excitation (the method that is used to start the generator running):

- Separately excited field generators (they require a separate power source during the starting of the generator)
- Self-excited generators (generators use the generators own leftover (residual) magnetism in place of that power source)

a) Separately Excited Field Generator

A separately-excited generator uses a separate source of voltage to excite the generator field winding. The field windings can be connected to a separate, or independent, source of dc voltage, Figure 2-3. With the speed constant, the output may be varied by controlling the exciting voltage of the dc source. This is done by inserting resistance in series with the source and field windings.

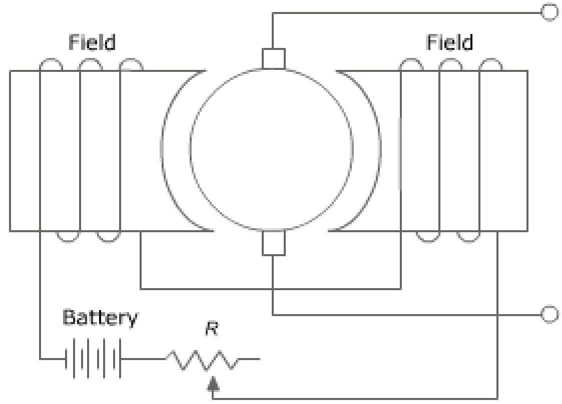


Figure 2-3. A separately excited field generator

Generator output is determined by the strength of the magnetic field and the speed of rotation. Field strength is measured in ampere-turns. So, an increase in current in the field windings will increase the times the speed of rotation. Therefore, most output regulating devices depend on varying the current in the field.

b) Self Excited Generator

A self-excited generator uses no separate source of voltage to excite the generator field winding. The self-excited generator produces a small voltage when the armature windings cut across a weak magnetic field.

This weak magnetic field is caused by magnetism left over in the pole shoes or field coil cores after the voltage and current have ceased to flow. The magnetism left in a magnet after the magnetizing force has been removed is called residual magnetism.
The connection between armature windings and the field coil of a self excited generator can be of the following:

- Shunt
- Series
- Compound.

Look ahead to the diagram of the shunt generator shown in figure 2-4. A residual magnetic field will cause a small voltage to be produced as the armature conductors rotate past the field poles. The small voltage produced will, in turn, cause the current to increase through the field poles. An increase in field pole magnetism will cause a further increase in output voltage. The relationship of the current produced by the armature directly increasing the amount of magnetism in the field poles is how the self-excited generator works. The magnetism produced by the armature voltage will increase until the field poles reach saturation, the point where the poles cannot contain any more magnetic lines of force.

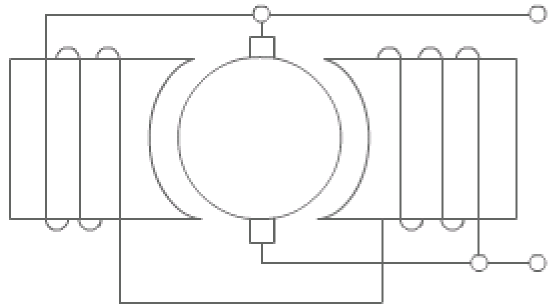


Figure 2-4. A shunt generator

i) Shunt generator

The shunt generator derives its name from the way the field pole coils are connected in parallel to the armature, **Figure 2-4**. Another way of saying parallel is the term shunt. The field windings consist of many turns of small wire. They use only a small part of the generated current produce the magnetic field in the pole's windings. The total current delivered to the load. Thus, the output current can be thought of as varying according to the applied load. The field flux does not vary to a great extent. Therefore, the terminal voltage remains constant under varying load conditions. This type of generator is considered a constant voltage machine.

All machines are designed to do a certain amount of work. If overloaded their lives are shortened. As with any machine, the life of a generator can be shortened by an overload condition. When overloaded, the shunt generator terminal voltage drops rapidly. Excessive current causes the armature windings to heat up. The heat can cause the generator to fail by destroying the thin coat of insulation covering the armature wires.

b) Series generator

The series generator is so named because its field windings are wired in series with the armature and the load. Such a generator is sketched in Figure 2-5. A series winding by itself will provide a fluctuating voltage to the generator load.
As the current increases or decreases through the load, the voltage at the generator output terminals will greatly increase or decrease. Because of the wide difference in output voltage, it is not a very practical generator to use if the load varies.

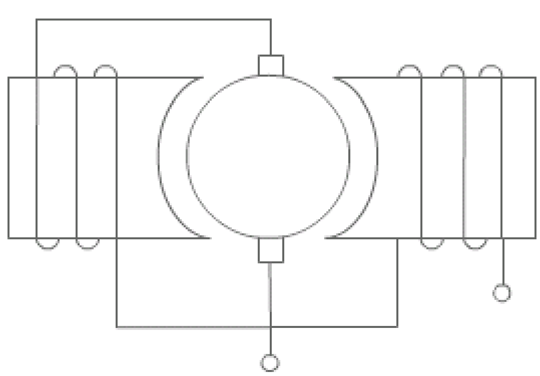


Figure 2-5. A series wound generator

c) Compound generator

The compound generator uses both series and shunt windings in the field. The series windings are often a few turns of large wire. The wire size of the series windings is usually the same size as the armature conductors.

These windings must carry the same amount of current as the armature since they are in series with each other. The series windings are mounted on the same poles with the shunt windings. Both windings add to the field strength of the generator field poles. If both act in the same direction or polarity, an increase in load causes an increase of current in the series coils. This increase in current would increase the magnetic field and the terminal voltage of the output. The field are said to be additive. The resulting field would be the sum of both coils. However, the current through the series winding can produce magnetic saturation of the core. This saturation results in a decrease of voltage as the load increases.

The way terminal voltage behaves depends on the degree of compounding. A compound generator, which maintains the same voltage either at no-load or full-load conditions, is said to be a flat-compounded generator. An over compounded generator will have a decreased voltage at full-load current.

A variable load may be placed in parallel with the series winding to adjust the degree of compounding. Figure 3-15 shows schematic diagrams of the shunt, the series, and the compound generator.

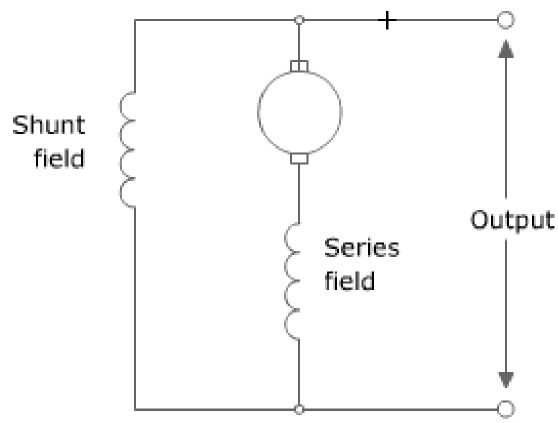


Figure 2-6. A compound wound generator

1.3.2 Main Components of Direct Current generator

a) Armature

The armature is the device for generating a current by rotating in the field. As shown in 2-7, it comprises of armature core, armature coil, and commutator shaft. The armature core is made of multiple of thin silicon steel and wound by coil having insulating cover at the slit of the outer circumference. The winding methods of the armature coil are the wave winding type and the lap winding type. The lap winding type is most used.

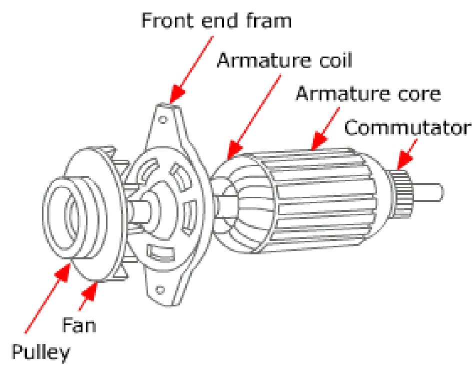


Fig 2-7 Structure of Armature

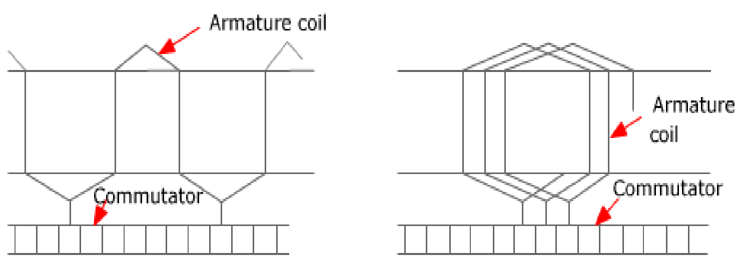


Fig 2-8 Unfold diagram of armature coil

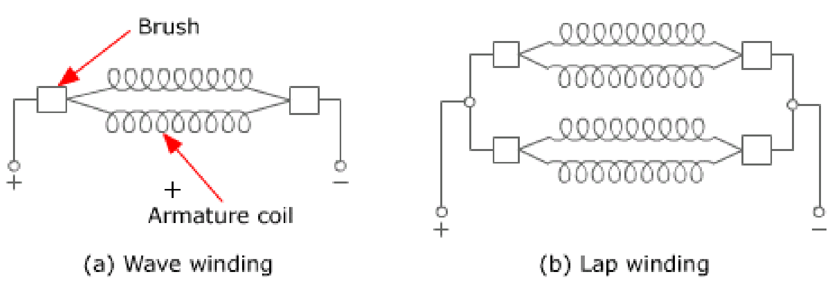


Fig 2-9 Connection between brush and armature coil

By comparing with the armature of the start motor, that of generator has less current, so the coil is made of thinner wire. However, to get large electromotive force, the coil includes a lot of winding number and multiple of wire is inserted in one slit. The both ends of the armature are soldered on the commutator. The alternating current generated at the armature coil is rectified to convert into a direct current by the commutator and the brush sliding on the commutator. As the armature of the DC generator is continuously rotating during the operation of the engine, the both ends should be supported at the end frame by the ball bearing, and at one end, there is a screw for fixing a pulley.

b) Pole core & Field coil

The pole core supporting the field coil in the yoke is installed by screws. The pole core becomes an electromagnet to form N and S pole when a current flows into the field coil. The field coil is the coil wound around the pole core and magnetizes the pole core when a current flow therein.

The DC generator has little residual magnetism at pole core even the current does not flow in the field coil so that the electric generation is started basis on this residual magnetism. The field coil and the armature coil are connected in serial (shunt winding type).

According to the grounding method of the end of these coils, there are internal grounding type and external grounding type.

For the internal grounding type, the start of the coil winding is connected to the voltage regulator of the generator regulator and the end of the coil is connected to the internal space of the pole core. For the external grounding type, the start of the coil is connected to the armature terminal and the end of coil is grounded via generator voltage regulator.

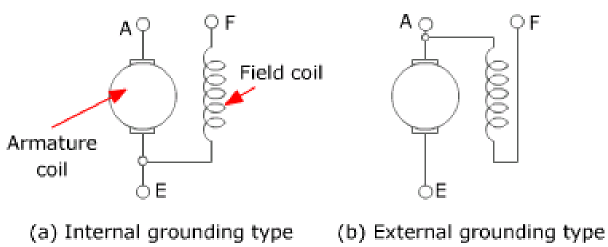


Fig 2-10 Wiring of the direct current generator

c) Brush

The brush of DC generator rectifies the alternating current generated at the armature by connecting with the commutator and sends to out. As the brush is always working with the engine operation and has wide range of rotation speed, it should be made of carbon material having good rectifying performance and less wearing character. Despite that the brush of start motor is contacted to the commutator in perpendicular, the brush of generator is contact is contacted to the commutator with some angle.

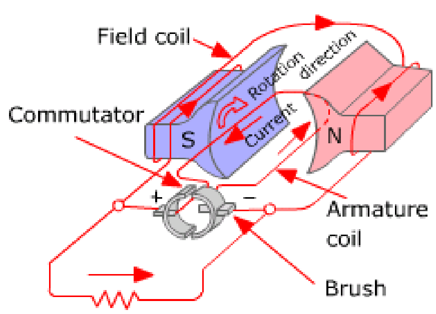
d) Generator regulator

The output of the generator is decided by the winding number of armature (or stator) coil, the strength of field and the number of intermitting the magnetic flux per time (rotation speed). Therefore, as the rpm of engine is increased, the voltage and current made at generator are also increased. Therefore, the generated voltage and current should be controlled to protect the all elector devices and generator. The generator regulator works this role. It can control the generated current by regulating the magnitude of the current flown the field coil using any method.

1.3.3 Principle of the direct current generator

As shown in Fig 2-1, by rotating a conducting wire (armature coil) in the magnetic field (Pole core) of the fixed N and S poles, an electromotive force is induced in the conducting wire by the electromagnetic induction law. At this time, the direction of electromotive force is the same with the arrow in figure according to the Fleming right hand law. The direction of the voltage generated at the rotating armature coil is changed at every 1/2 (180°) turn. When the armature turns in one turn, then the 1 cycle of AC voltage is generated. Therefore, the DC generator is formed by connecting a commutator comprising of half cylindrical pieces of commutator to the terminal of the armature coil in order to be rotated with the armature coil and connecting brushes on the commutator pieces.

At the load connected to the brush, the direct current, as shown in Fig 2-2, will flow. In the actual DC generator, the armature coil is wound by overlapped somewhat with neighbored coil, so the electromotive force of each coil is overlapped; therefore, the output has less microseism.



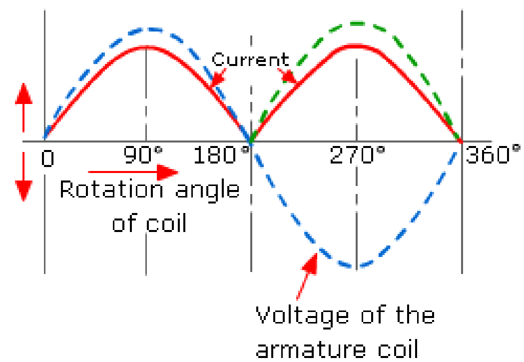


Fig. 2-1 Principle of the direct current

Fig. 2-2 Waveform of rectified output

1.3.4 Direct current generator regulator

The DC generator regulator comprises of the cut out relay, the voltage regulator and the current limiter.

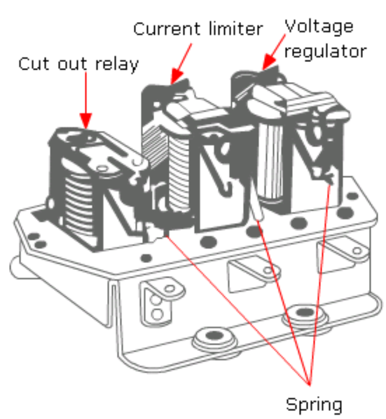


Fig 2-11 Direct current generator regulator

a) Cut out relay

This is one of switch using electromagnetic force. It protects the reverse current from battery to generator when the generator is stopped or the generated voltage is lower than battery voltage. When the current flows to the battery, the contact point should be closed. This action is cut-in and the voltage for this action is cut-in voltage. Generally, the cut-in voltage for 12V battery is 13.8~14.8V.

i) Structure of the cut-out relay

As shown in Fig 3-28, the cut-out relay comprises of the electromagnet having two coils, one is wound with thin wire and the other is wound with thick wire, and the contact point. The thin wire coil is called the voltage coil, and the thick wire coil is called current coil. They are wound in the same direction. The contact point is opened by the armature adjusting spring. When the magnetic force of the electromagnet is stronger than tension of this spring, the contact point is closed.

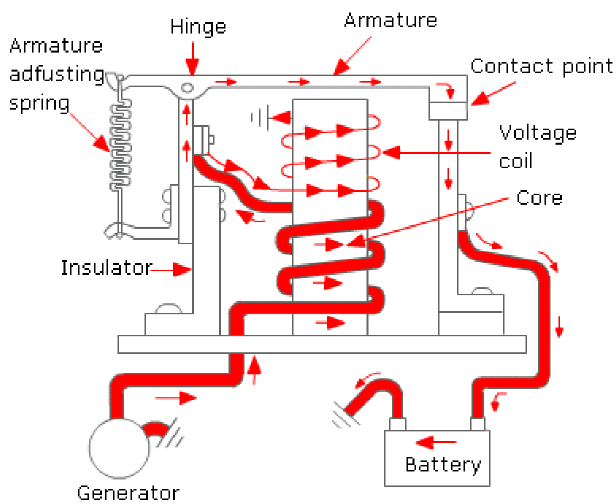


Fig 2-12 Structure of the cut-out relay

ii) Operation of the cut-out relay

If the current generated by rotation of the generator meets to the cut-in voltage (charging voltage), then the core will be magnetized by the magnetic force formed by the voltage coil, and then the contact point will be closed. At this time, the current coil has current, so that the contact point can be completely closed by the magnetic force generated by the two coils. Therefore, the charging current will flow into the battery. So, the contact point will not be separated by any vibration but maintain the contacting condition during driving.

In comparison, when the rotation speed of generator is to be slowed and the voltage of generator is to be lowed, the current will flow through the current coil in opposite direction.

As a result, the magnetic force of the core will be weakened suddenly. At that time, by the tension of the spring, the contact point will be opened and then the charging circuit is also opened. So, the reverse current from the battery to the generator can be protected.

a) Voltage regulator

The voltage regulator is to ensure that the generated voltage maintains a constant value. If the generated voltage is higher than regulated value, the exciting current will be reduced by connecting an additional resistor to the field coil in serial in order to cut down the generated voltage. If the voltage is lower than the regulated value, then some resistor will be disconnected from the field coil to recover the generated voltage.

In the voltage regulator, there are the vibration contacting type, the carbon pile type, the transistor type and the IC type. Nowadays, the IC type is only used. It will be explained in the section of AC generator regulator with the transistor type.

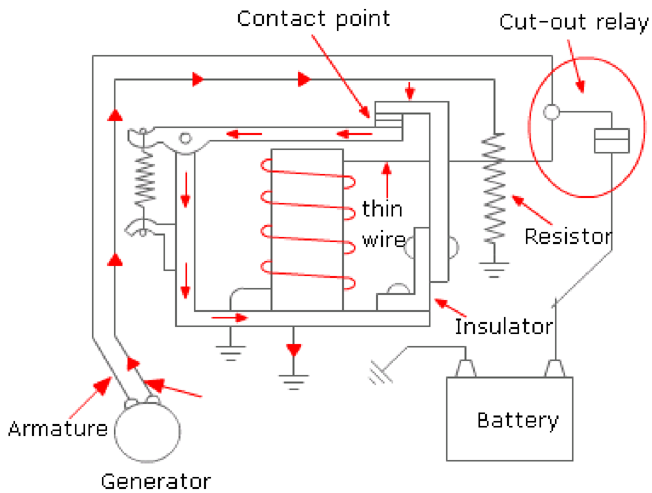


Fig 3-29 Structure of the voltage regulator

b) Current limiter (Current regulator)

The current limiter plays role of protecting the generator from the over current by controlling the current made by the DC generator. That is, the current limiter prevents an electric load higher than the regulated value from being applied to the generator.

a) Structure of a current limiter

Like the voltage regulator, the current limiter comprises of armature, the armature adjusting spring, and the contact point. Only that the electromagnet coil (or current coil) is excited by the charging current is the different thing.

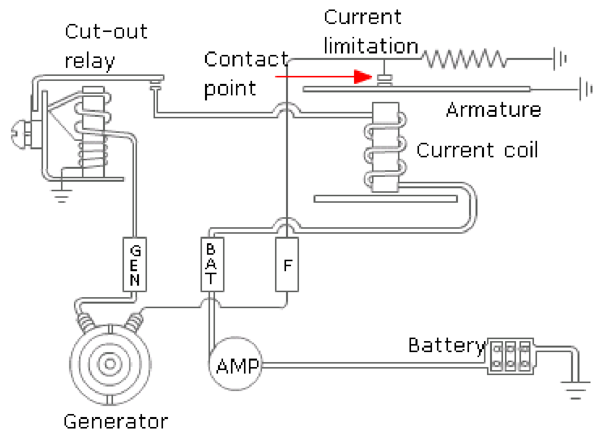


Fig 2-14 Structure of a current limiter

b) Operation of the current limiter

As shown in Fig 2-14, before the output current of the generator meets to the regulated current, the contact point is closed. As the output current of the generator is increasing, if it reaches to the limitation value at last, then the contact point will be opened by the magnetic force of the electromagnet. When the contact point is opened, the serial resistor is connected to the field circuit so that the generated voltage will be decreased. Therefore, the load current is reduced. As the load current is reduced, the pulling force of the electromagnet is reduced so that the contact point will be closed again by the spring.

1.4 ALTERNATING CURRENT (AC) GENERATOR

Most of the electrical power used aboard motor vehicles is ac. As a result, the ac generator is the most important means of producing electrical power. Ac generators, generally called alternators, vary greatly in size depending upon the load to which they supply power. For example, the alternators in use at hydroelectric plants are tremendous in size, generating thousands of kilowatts at very high voltage levels. A typical automobile alternator weighs only a few pounds and produces between 100 and 200 watts of power, usually at a potential of 12 volts.

1.4.1 Advantages of AC Generators

The Advantages of AC generator over DC generators are:

- It has small size and lightweight, it makes output voltage chargeable in low speed.
- Having not commutator in the rotation part, the limit of the permeable rotating speed is very high.
- As it rectifies with silicon diode, it has large electric capacity.
- The lifetime of brush is long.

1.4.2 Single phase Alternating Current

a) Generation of the single phase AC

As shown in Figure 1.4.2a, the DC generator makes the current by rotating a conducting wire in a magnetic field, whereas, the AC generator makes the current by rotating the magnetic field with fixing the conducting wire.

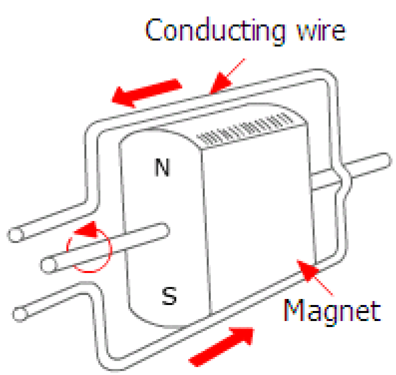


Figure 1.4.2a Generation of the single phase AC.

b) **Relationship between the rotation number and the frequency**

As shown in Figure 1.4.2b, the one cycle is the change of electromotive force from **a** to **a**' and the frequency is the repetition number of this change for one second. In the Fig 2-15, when the magnet rotates one turn during one second, the frequency is one cycle. In the Figure 1.4.2a, if

4-pole magnet is used, then the same change is repeated in every 1/2 turn, so 2-cycle is occurred at every one turn of magnet. As the number of magnetic pole is increased or the rotation speed is increased, the frequency is also increased. This relationship is represented by the following equation:-

$$f = \frac{\frac{p}{2} \times N}{60} = \frac{N \times P}{120}$$

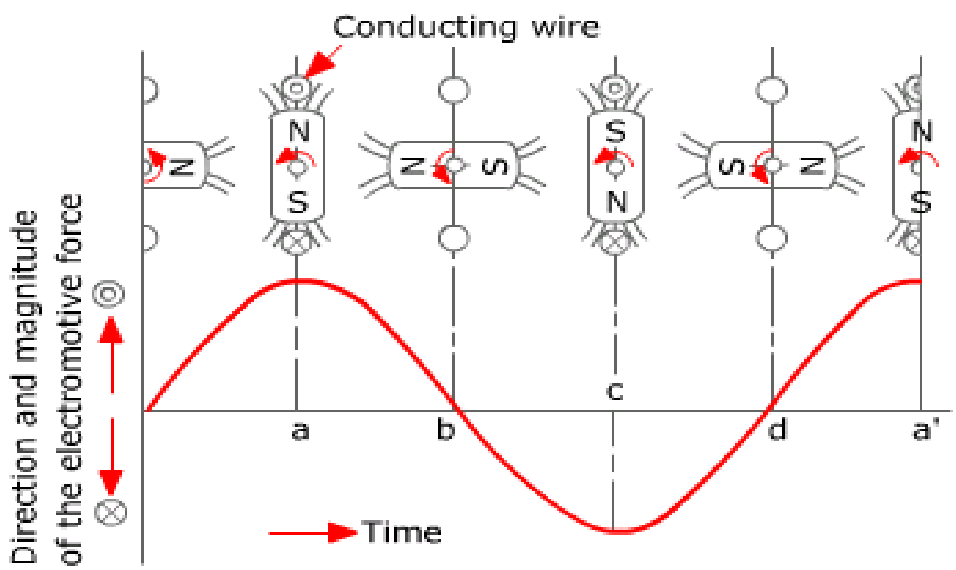


Figure 1.4.2b circle of a single phase AC.

1.4.3 Generation of the 3-phase AC

As shown in Figure 3-3, after the 3 groups of coil having the same windings, A-A', B-B' and C-C', are wound in 120° arraying, when a magnet is rotating within the coil array, then the 3-phase AC voltage is generated as shown in 3-4. The coil B generates the voltage in 120° lag behind the voltage generation at coil A, and the coil C generates the voltage in 120° lag behind the voltage generation at coil C. These AC waveforms generated at the A, B and C groups are called 3-phase AC.

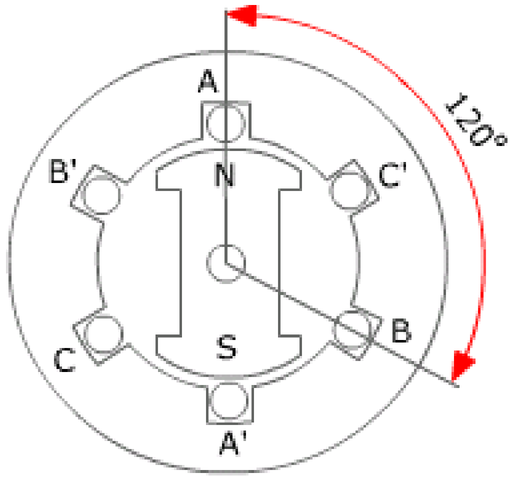


Figure 1.4.3a 3- phase coil

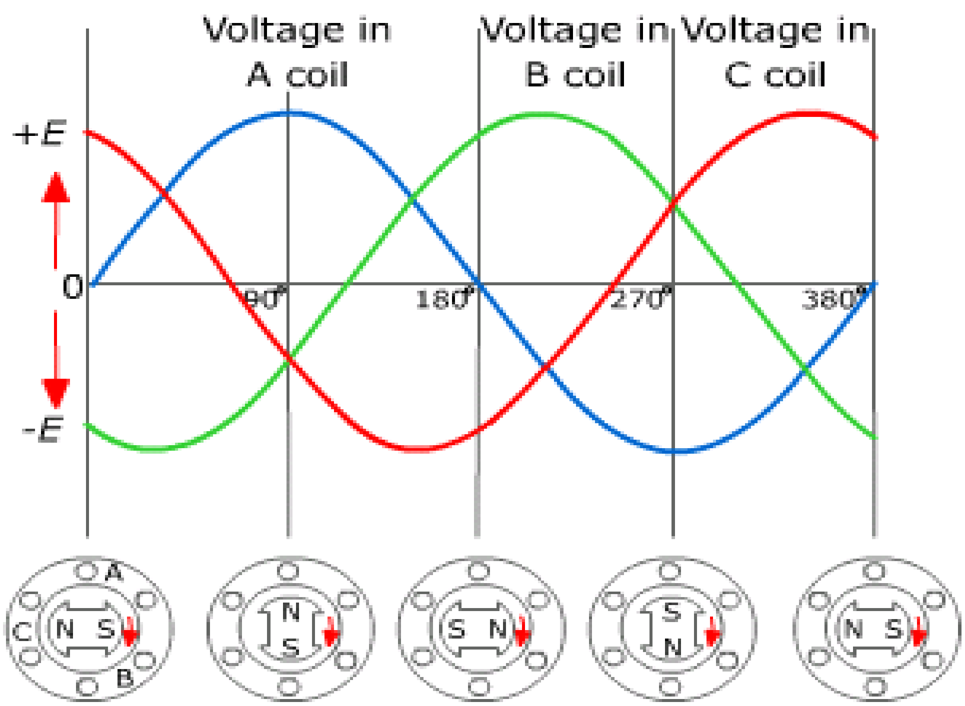


Figure 1.4.3b 3-phase AC voltage

1.4.4 Connecting method of 3-phase coil

In the commercial 3-phase AC generator, the 3 pairs of coil are connected as shown in Fig 3-5. The figure (a) shows the Y-connection (or star connection) in which each one end of A, B and C coil is each outer terminal and the each other end is connected at one point, while, the figure (b) shows the tri angle connection (or delta connection) in which one start point of each coil is connected to other end point of each coil and each connected point is three outer terminals.

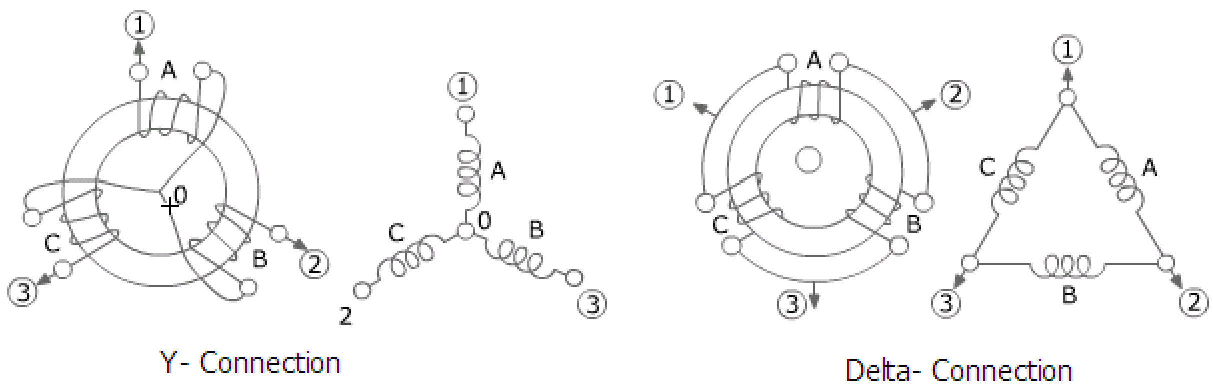


Figure 1.4.4a Connecting method of 3-phase coil

Here, the voltage and current generated at each coil are called the phase voltage and the phase current, respectively. The voltage between the outer terminals and the current flowing at the outer terminal are called the line voltage and the line current, respectively. There are some relationships between Y-connection and Delta connection as followings:

- In the case of Y-connection:- $El = \sqrt{3} \cdot Ep, Il = Ip$
- In the case of Delta connection:- $El = Ep, Il = \sqrt{3} \cdot Ip$

Where, El **= Line voltage,** Ep **= Phase voltage**

Il **= Line current,** Ip **= Phase current**

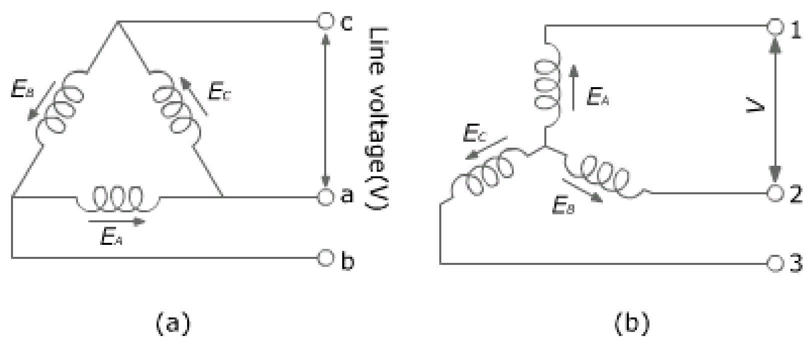


Figure 3-6 Line voltage

In the case of the Y-connection, the line voltage is √3 times of the phase voltage, and in the case of Delta connection, the line current is √3 times of phase current. Therefore, if the coil winding is the same with the generator having same capacity, then the Y-connection can make higher electromotive force than the Delta angle connection. So, AC generator for vehicle can get high voltage in low speed and generally uses the Y-connection, which can utilize middle voltage point. However, for large output, the Delta angle connection is used.

2.4.5 Structure of a Practical Alternator

A practical automobile alternator comprises of stator the fixed part, rotor the rotating part, and end frame supporting the both ends of rotor. The stator coil fixed by the stator generates output current of the generator. The rotor and the rotor coil rotate in the stator to induce the electromotive force at the stator coil.

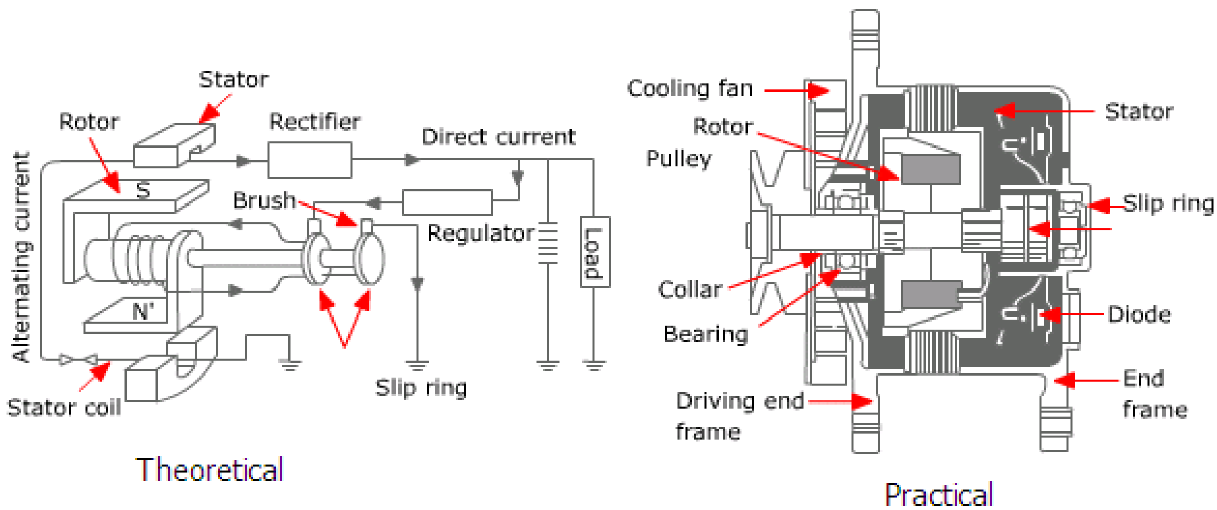


Figure 2.4.4 Structure of an alternator

The alternating current generated in stator coil is rectified by the rectifier (silicon diode) installed at the end frame into direct current and supplied out. The brush is not to get output current but to excite the rotor coil by supplying current to rotor coil from battery. The silicon diode not only rectifies the alternating current generated from the stator coil but also prevents the reverse current from battery to generator. Therefore, it does not need any cut out relay unlike the DC generator. If the generated voltage from the generator is higher than the terminal voltage of battery, then the battery charging will be automatically started.

1.4.6 Main components of an alternator

a) Stator

The stator acts as the armature of the DC generator. As shown in Figure 1.4.5a, separated three coils are individually wound around the steel core consisting of multiple layers. The 3-phase AC will be induced in these coils.

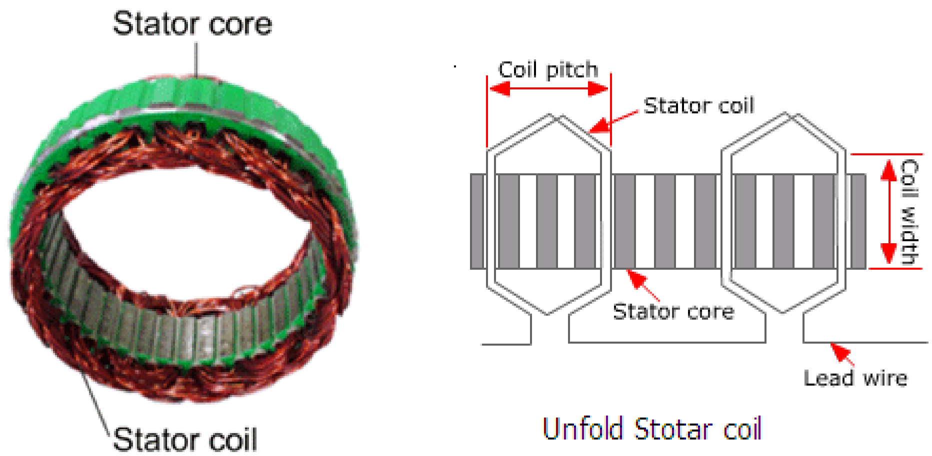


Figure 1.4.5a Stator

To reduce the core loss (phenomena in which the hysteresis loss and the loss of eddy current are occurred because of a lot of changes of magnitude of flux around the steel core), the stator steel core comprises of the lagged thin silicon steel plates, and inside of it there are some slits for installing the stator coil. During operation, it becomes the pathway for the magnetic flux generated from the pole of the rotor.

The one group of stator coil is made by winding the copper wire covered with insulating material into the slit as shown in Fig 3-22. The coil pitch matches to the gap of the pole (pole pitch). The three groups of this coil are arrayed in 120° (2/3 of pole pitch) and formed into 3-phase connection. For the coil connection method, there are the Y-connection and the tri angle connection, as mentioned in former chapter.

b) Rotor

The rotor, like the field coil and the pole core of the DC generator, makes the magnetic flux. It comprises of rotor core, rotor coil, shaft, and slip ring. For the type of rotor, there are the Randle type and the pole type. The pole type has small outer diameter, however, winding method is complicated. This type is used for large capacity generator. For the vehicle AC generator, the Randle type having simple structure and good strength is widely used. As shown in Fig 3-24, the Randle type comprises of combined 4~6 steel cores inserted on shaft from the both ends of cylindrical rotor coil. The winding start and the end of rotor coil are connected to the two slip rings installed on the shaft with being insulated.

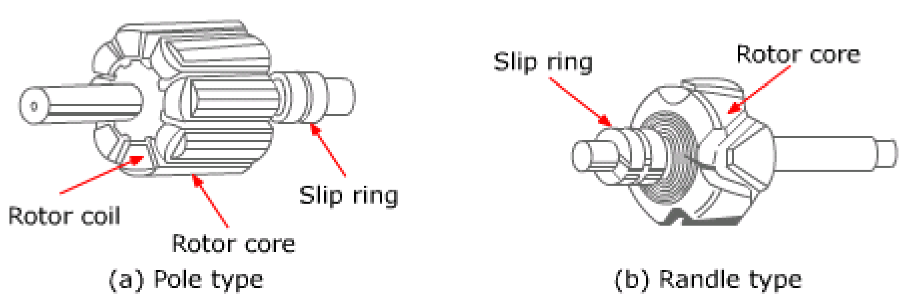


Figure 1.4.5b Types of rotor

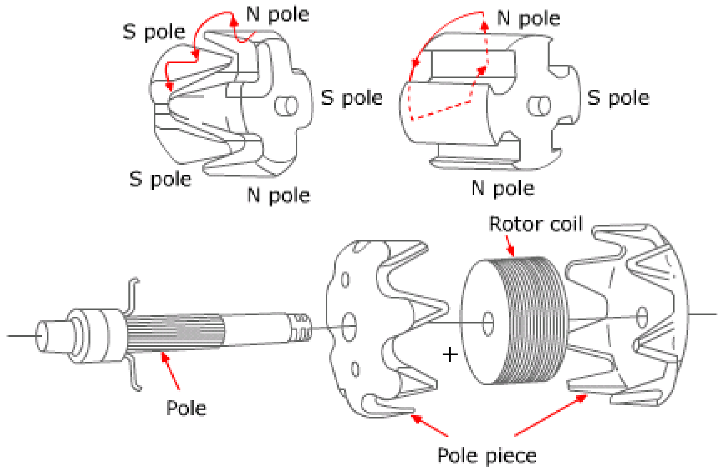


Figure 1.4.5b' Structure of rotor

The operation of the rotor is like that; when the current flows in the rotor coil through the brush contacting to the slip ring, a magnetic flux is formed in the direction of shaft so that one side of core is magnetized into N pole and the other side is magnetized into S pole. Therefore, each pole pieces facing each other is also magnetized and the 8~12 of N poles and S poles are arrayed. The material of rotor core is made by forging or imprinting the low carbon steel. The slip is made of good conducting material such as copper or stainless steel.

c) Brush

The two brushes are inserted into a brush holder fixed on a bracket and contacts to the slip ring by a spring. One brush is connected to the insulated outer terminal, and the other brush is grounded through the brush holder. As the rotor is rotating, the brush sequentially slides and contacts to the slip ring, therefore, it should be made of metal carbon material for good wear resistance and low contact resistance.

d) Rectifier

The rectifier comprises of diode. 6 diodes are installed at the rear part of the end frame to rectify the 3-phase AC generated at the stator coil to convert into the direct current.

When current flows to the diodes, the temperature of diodes is increased, so that they are installed with heat sink (cooling plate). Generally, three diodes of negative side are indented to the back end frame and three diodes of positive side are indented to the heat sink with being insulated. Otherwise, each three diodes of (+) and (-) side are soldered to heat sink, respectively. In other hand, six diodes are installed on the printed board having a heat sink.

i) Connection of diodes

Because a single diode will only block half the the AC voltage. To redirect both the positive and negative polarity signals of the AC voltage to produce DC voltage, two diodes are connected to each stator lead, one positive the other negative.

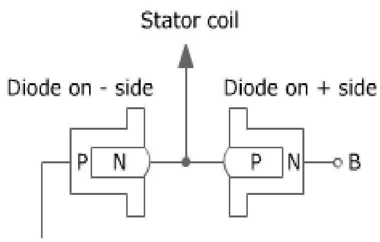


Figure1.4.5d Connection of diodes to stator lead

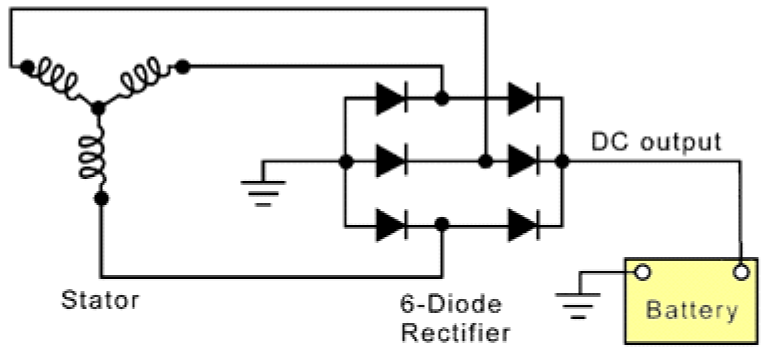


Figure1.4.5eDiodes arrangement in Y-connection stator

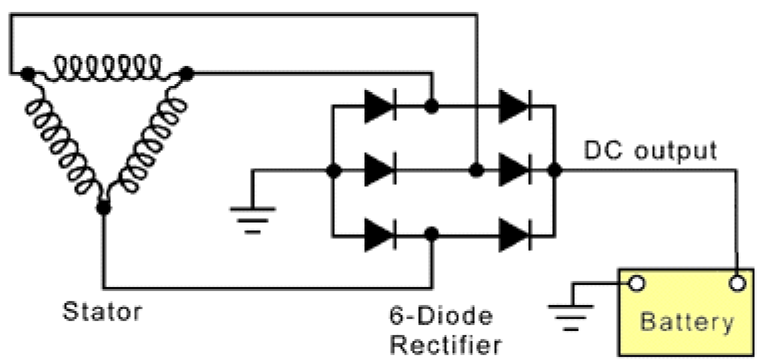
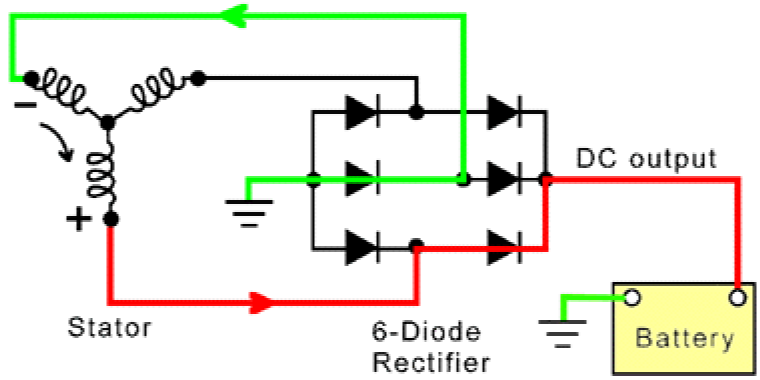


Figure1.4.5f Diodes arrangement in Delta-connection stator

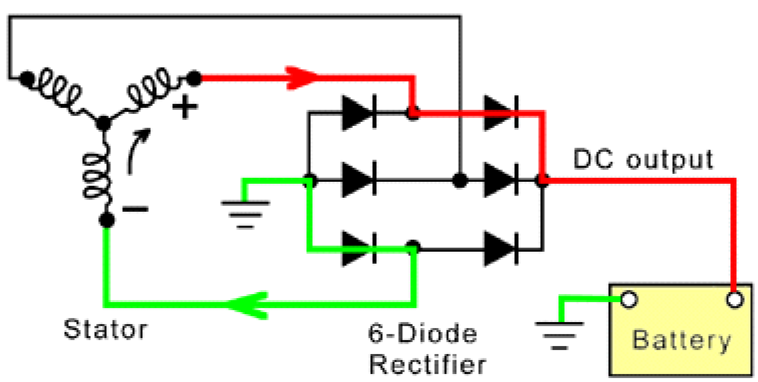
ii) Rectifier Operation

Six or eight diodes are used to rectify the AC stator voltage to DC voltage.

Diodes used in this configuration will redirect both the positive and negative polarity signals of the AC voltage to produce DC voltage. This process is called 'Full - Wave Rectification'



In red you can see B+ current pass through to the rectifier as it goes to the battery.
In green you can see the return path.



Now, in red B+ current passes through to the rectifier however, this time current has the opposite polarity. In green you can see the new return path. Even though it enters the rectifier at a different location, current goes to the battery in the same direction.

1.4.7 Operation of AC generator

Using the Figure 1.4.6, this type will be explained. At first, when the ignition switch is on, current of about 2~3A flows through the path of terminal F → (+) brush → slip ring → rotor coil → slip ring → (-) brush → terminal E (ground). Due to this current, the rotor coil is magnetized to make a magnetic flux.

The AC generator works as a separate excited generator at the beginning of operation. After the engine is cranked, the rotor is rotated by the driving belt, and the stator shut down the magnetic flux of rotor, so that the 3-phase alternating current is generated at the stator coil. This AC voltage is rectified into direct current by the 6 silicon diodes and output via the B terminal.

When the rotation speed of the rotor is 1,000rpm, the voltage of this AC current is higher than the battery terminal voltage. Therefore, the output current is supplied form the B terminal to the each electro device and to the battery as a charging current. Additionally, some amounts of the output current from the B terminal are supplied to the rotor coil. The AC generator now works as the self excited generator.

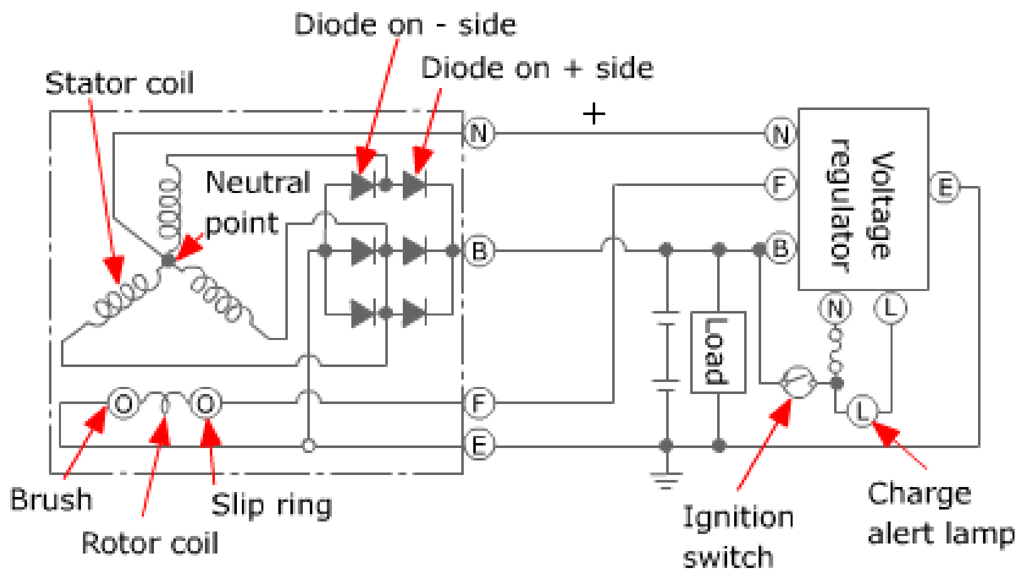


Figure 1.4.6 Operation of AC generator

1.5 ALTERNATING CURRENT REGULATOR

As the AC generator uses silicon diodes as the rectifier, it is not possible for any reverse current to occur. Additionally, it has the current limiting function so there are no worries about over current. Therefore, the AC generator regulator does not need any cut-out relay and current limiter unlike the DC generator. That is, the voltage regulator is the only thing to be required. The charging alert lamp relay shall be connected to the voltage regulator in order to operate the charging lamp.

1.5.1 Types of Alternating current regulator

The regulator limits alternator voltage by controlling the amount of current flowing in the alternator field or the regulator reduces the field current, this prevents excessive voltage. Several types of alternator regulators that are mounted outside and inside the alternator have been used:

- One point type regulator
- Two point type regulator
- Transistor type voltage regulator
- IC Regulator

a) One point type regulator

In this regulator a resistor (R) is connected in series with the field coil (F) of the rotor. This resistance is by passed by the points while the engine is running at low speed. Because the magnetic coil is weak and the points remain closed when the voltage of the alternator is strong the points open and current passed through the resistor and the field coil current is reduced and the voltage of the alternator reduces and points close. In this manner the voltage is stabilized by this type of regulator.

However, one point type regulator is not used very often in present day automobiles be cause of the following disadvantage.

There is great fluctuation of voltage at low speed when the points are opened and closed. A large resistance will cause more sparking when the points are opens resulting shorter life of the points.

b) Two point type regulator

The characteristic of the two-point type regulator is that it has both low speed and high speed operating ranges.

At low speed, the moving point opens and closes the low speed point (P1) in the same manner as the point make and break contact with the high speed point and field current ceases to flow and the voltage out put of alternator decrease as a result the moving point closes with P1 and this cycle is repeated.

But the disadvantage of this type of regulator is the voltage drop due to the hysterics effect when changing from the high-speed side to low speed side. Nevertheless, compared to the one point type, the resistance can be made smaller so there is less sparking so there is a longer life of the points.

1.5.2 Voltage Relay (Charge lamp relay)

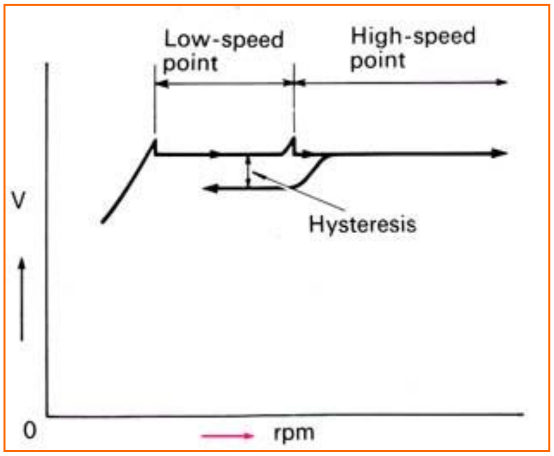
A Charging system employs a two element combination accurate voltage regulation. This is because, the voltage regulator operates in accordance with the voltage generated by the alternator. If there were no voltage relay, there would be a drop in voltage in the magnetic coil because the voltage is applied to a long circuit via the ignition switch. A reduction of voltage would cause a proportionate decrease in magnetic force of magnetic coil so the moving points would not pull sufficiently. As a result alternator voltage would rise to high.

1.5.3 Characteristics of the regulators

For the point type regulators, there are various reasons why voltage fluctuates. But the primary causes are due to its hysterics and temperature characteristics.

a) The hysterics characteristics

The lowering of voltage when the moving point change from high speed side to the low speed point called hysteretic effect causes to remain a residual magnetism from the high speed operation in the coil core and continue to pull the moving point for a short time. This phenomena cause to the alternator out put to decline. There fore no attempt should be made to adjust the regulator when the voltage is dropping due to this effect. A 12 volt system will drop from 0.5 to a volt.



b) The temperature characteristics

The magnetic coil of the voltage regulator employs copper wiring. It temperature of this wire rises, the resistance increased and there will be a reduction of force (electromagnetic force) of the magnetic coil this results a higher alternator out put voltage to prevent such arise in voltage, the regulator utilizes either a resistor or bi-metal element for temperature compensation, but some use both.

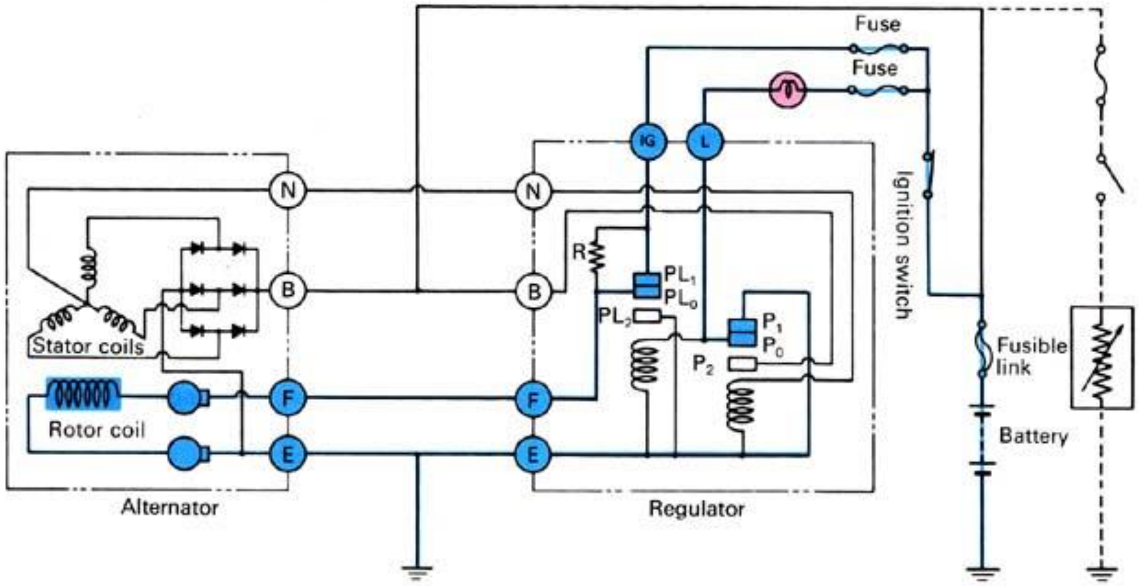
The resistor reduces the over all resistance in accordance with the temperature fluctuation as a result strong electromagnetic force is developed and the contact point will be pulled sufficiently.

The bi-metal element is used together with a spring which supports the moving point. The bi-metal element reduces the spring tension as the temperature rise. There fore the contact point will be easily opened to prevent the raise of alternator out put voltage.

1.5.4 Operation of a regulator with voltage relay

a) When the ignition switch is on engine stepped.

When the ignition switch is turned on field current from the battery flows to the rotor and excites the rotor coil. At the same time, battery current also flows to the charge warning lamp and the lamp comes on.



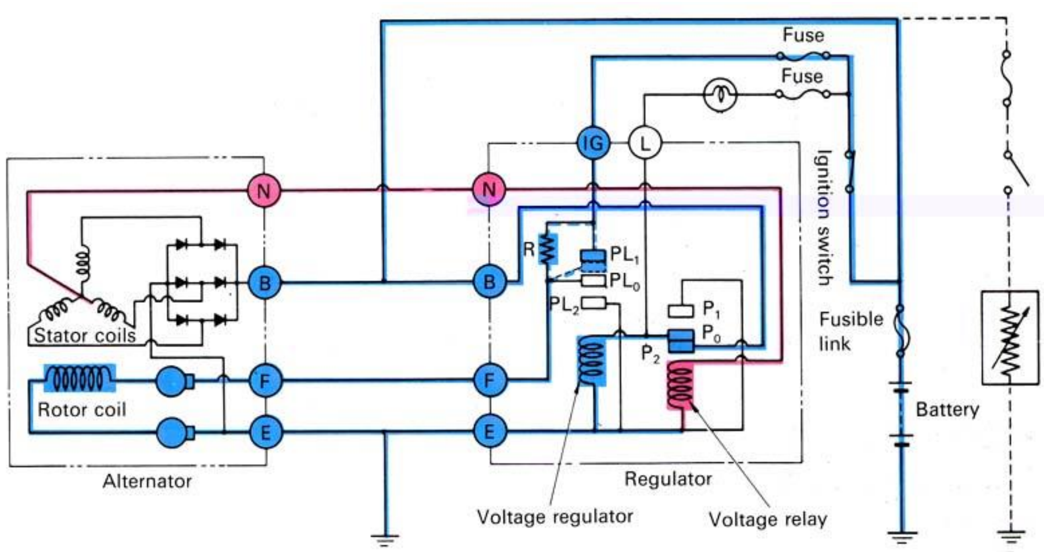
① Battery (+) Terminal → Fusible Link → Ignition Switch → Fuse → Regulator Terminal IG → Points PL_1 → Points PL_0 → Regulator Terminal F → Alternator Terminal F → Brushe → Slip Ring → Rotor Coil → Slip Ring → Brushe → Alternator Terminal E → Ground

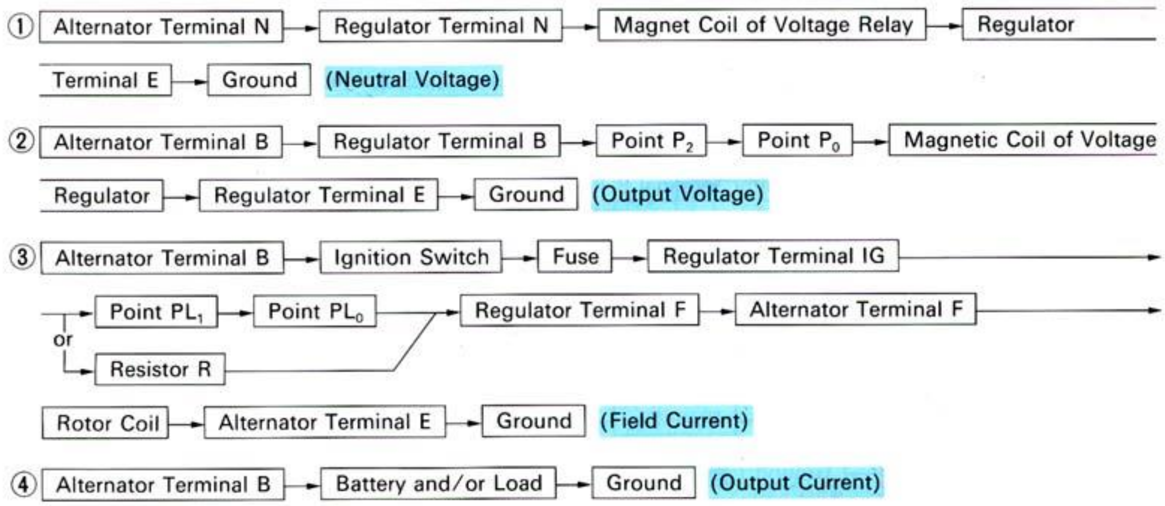
(Field Current)

② Battery (+) Terminal → Fusible Link → Ignition Switch → Fuse → Charge Warning Lamp → Regulator Terminal L → Point P_0 → Point P_1 → Regulator Terminal E → Ground

(Charge Warning Lamp Current)

b) Engine operation- (low speed to middle)

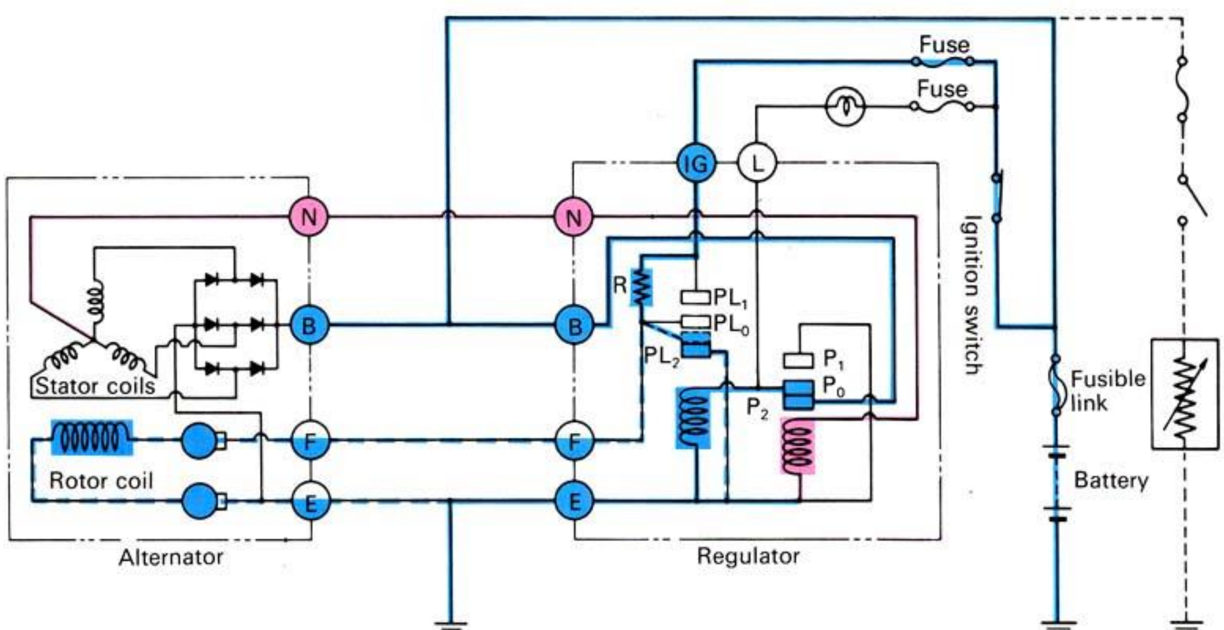


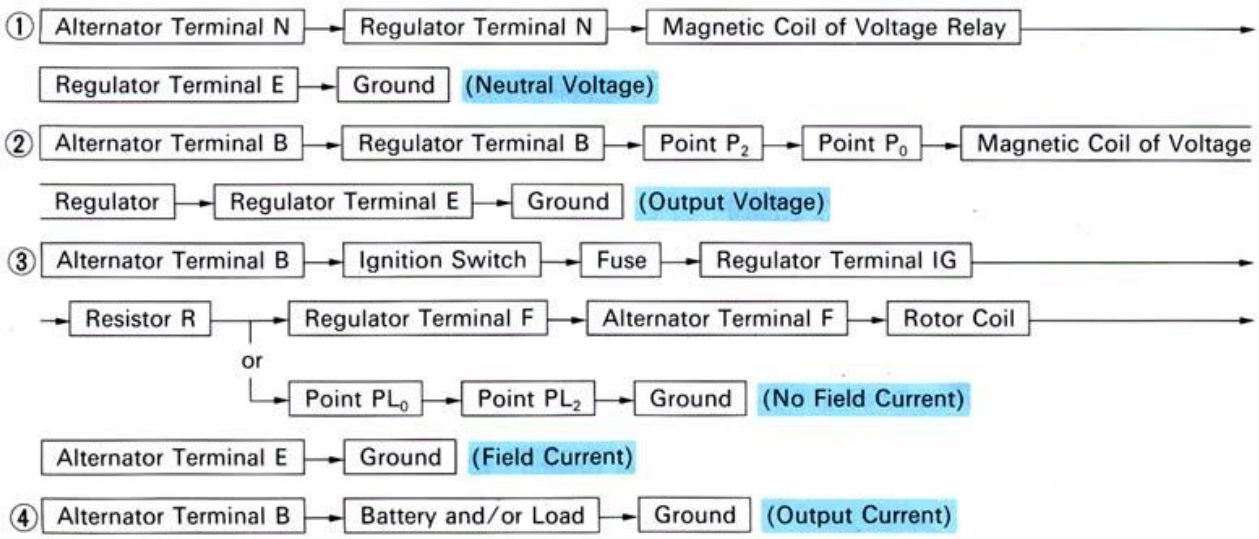


After the engine is started and the rotor is turning. Voltage is generated in the stator coil, and neutral voltage is applied to the voltage relay so the charge warning lamp goes out. At the same time; out put voltage is acting on the voltage regulator. Field current to the rotor is controlled in accordance with the out put voltage acting on the voltage regulator. Thus depending on the condition of point PL_0, the field current either passes through or does not pass through the resistor (R).

c) Engine operating (Middle speed to high speed)

As engine RPM increases, the voltage generated by the stator coil rises and the pulling force of the magnetic coil becomes stronger with a stronger pulling force, field current to the rotor will flow intermittently. In other words moving point PL_0 of the voltage regulator intermittently make contact with point PL_2.





1.6 IC Regulator

1.6.1 Transistor type voltage regulator

Using a transistor as a switch instead of the contact point in the contacting type regulator, the transistor type voltage regulator changes the average value of the field current to control the generating voltage. In this type, there are the semi-transistor type in which transistors and relays are combined and the full transistor type in which all mechanical parts are removed. Furthermore, the IC regulator includes the full transistor type into the generator body using IC circuit. In the Fig 3-31, the Tr2 is the transistor for intermitting the field current, and the base current of the Tr2 is controlled by the transistor Tr1 and the Zener diode Dz. The generator terminal voltage Et is divided by resistor R1 and R2. To the Zener diode Dz, the voltage E1 represented by following equation is applied in reverse direction.

$$E_1 = Et\frac{R_1}{R_1 + R_2}$$

Here, Et = $E_1 + E_2$.

As the Dz has no current when the Et is low, the Tr1 is OFF and the Tr2 is ON so that the current flow to the yoke. When the E1 is higher than the Zener voltage as the generated voltage is increasing, the current flows through the Zener diode so that Tr1 is ON and the Tr2 is OFF. Therefore, the yoke current will be blocked. That is, the yoke current can be controlled using the operation in which the Tr2 is OFF when the Et is high, and the Tr2 is ON when the Et is low, rapidly.

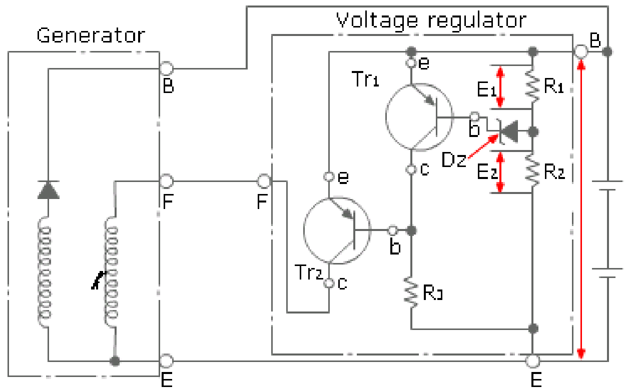


Figure 1.6.1 The basic circuit of the full transistor type regulator

As the transistor regulator has not contact point, there is no spark, which can be a reason of EMI or EMC. As it has not mechanical parts, it has long lifetime and good resistance against vibrations. However, it is weak in high voltage and heat so it should be carefully treated.

1.6.2 IC voltage regulator

a) Purpose of IC voltage regulator

The charging circuit of the IC voltage regulator comprises of the semiconductor circuits to intermit the rotor coil current and then it can regulate the voltage generated at the AC generator. Basically, its operating principle is same with that of transistor type. However, it can be made in tiny size so that it can be embodied into the generator. Therefore, the charging circuit of this type can be made simply and this type many merits like those;

- The wiring will be simple.
- The voltage is not varied by vibration and this type has good endurance.
- The accuracy for controlling the voltage is very high.
- It has high heat resistance and high output.
- It can be minimized in size easily so that it can be installed into the generator.
- The charging performance can be enhanced, and the electric power can be distributed to each electric load properly.

b) Operation of the IC voltage regulator

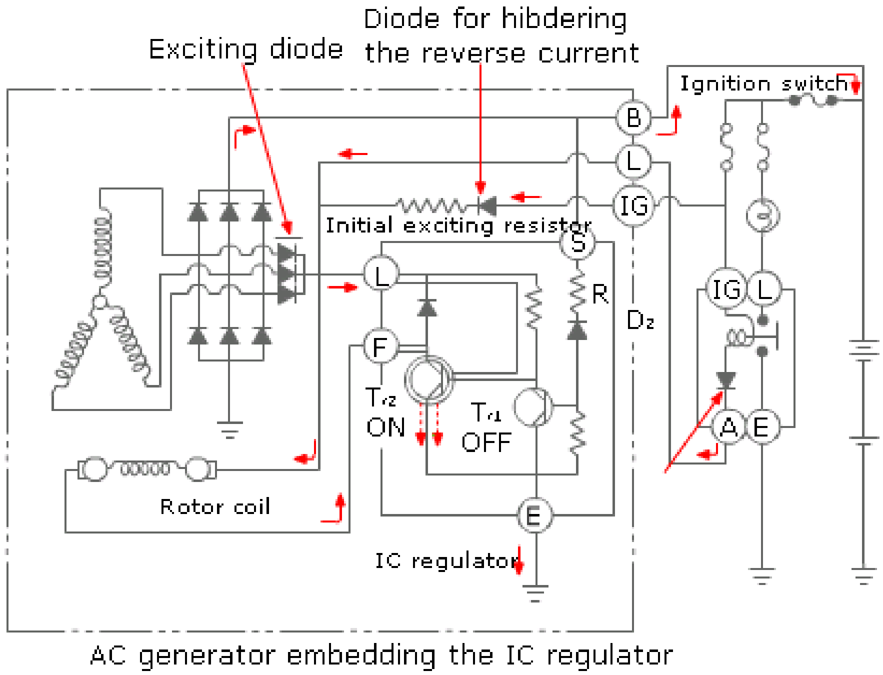


Figure1.6.1a Circuit diagram of IC voltage regulator

i) When the ignition switch is ON during stop state of the engine

When the ignition switch is ON, the current flows from the L terminal of the AC generator to the base of transistor Tr1 through the IG terminal of the AC generator, the charging alert lamp relay IG terminal and terminal A, and then the Tr1 is ON. When the Tr1 is ON, as the battery current (field current) flows from the rotor coil to the Tr1 through the L terminal and the IG terminal of the AC generator, the rotor will be excited. At this time, the current flows to the coil of the charging alert lamp relay to close the contact point by the magnetic force generated at the coil, so that the alter lamp turns ON. As the initial exciting resistor (R4) has high resistance (about 100Ω), the discharge of battery can be protected by controlling the current which flows to the rotor coil when the ignition switch is not OFF.

ii) When the AC generator starts to work after the engine is starting

If the generated voltage of the AC generator is higher than battery terminal voltage (13.8~14.8V), then battery charge will be started from B terminal. At this time, the voltage at the L terminal of the AC generator is increased, and at last it is not different from that of the IG terminal of the charging alter lamp relay. Then current at the charging alter lamp relay coil is cut off so that the contact point is opened. And then the alert lamp is OFF. Due to the diode (D2) for hindering the reverse current, the current flowed through the exciting diode by the voltage of the stator coil flows not to the battery or electric load but to the rotor coil and the L terminal of the regulator.

iii) **When the generated voltage at the AC generator is over the regulated value by high rotation of the engine.**

At that time, as the current flow from the S terminal of the voltage regulator via the resistor R2 and the Zener diode (ZD) to the base of the transistor Tr2, the Tr2 is ON. Here, the voltage at point P is to maintain the voltage for supplying the base current of the transistor Tr1. However, when the Tr2 is ON, the voltage is drop down suddenly and then the base current of the Tr1 is cut off and the Tr1 is OFF. Therefore, as the exciting current of the rotor coil is cut off, the voltage from the AC generator is lowered.

When the voltage from the AC generator is lower than the regulated voltage, the current does not flow to the Zener diode, so that the Tr2 is OFF and the Tr1 is ON again. The voltage generating is restarted. Like this, by repeating the ON and OFF operation of the transistors Tr1 and Tr2 due to the operation of the Zener diode, the exciting current which flow the rotor coil can be intermitted and the voltage from generator can be maintained constantly.

1.7 ALTERNATOR PROBLEM

Alternator may become noisy while the engine is running which is an indication the alternator shaft bearing or bearings are failing. This is a common problem caused by excessive tension on the drive belt on the alternator pulley attached to the alternator shaft. Alternator may, due to excessive moisture, overheating or dirt, develop a short or open in its windings. Alternator diodes may develop a condition known as "short to ground". This results when the automobile alternator was inadvertently sprayed in a car wash as part of the automobile engine cleaning process. Finally the rectifier diode can become damaged, rarely, when the automobile undergoes a process called "resistance welding" during exhaust replacement or auto body sheet metal replacement and the negative auto battery cable was not disconnected.

1.7.1 Alternator Does Not Charge Battery

The electrical output voltage of an automotive alternator, when it is operating, must be above 14 Volts Direct Current (DC) to recharge a standard 12 Volt Direct Current automobile electric starter motor battery. An alternator producing under 14 volts will, in most cases, provide enough voltage and current to meet the electrical requirements of the automobile and automobile accessory after the engine has been started, however it will not charge the electric starter motor battery. Tip: prior to replacing a "dead battery" insure the automotive alternator is developing at least 14 volts Direct Current (DC) by utilizing a DC voltage meter.

1.7.2 No Alternator Voltage Output

No alternator voltage output can be the result of a broken alternator drive belt from the engine crankshaft pulley to the alternator drive shaft pulley. After the Alternating Current (AC) is developed, by the operating alternator, it passes through a rectifier diode to be converted to Direct Current (DC). A shorted rectifier diode or rectifier diodes condition will prevent this process thus no alternator voltage output will result. An open rectifier diode or rectifier diodes condition will also prevent this process. Alternator rectifier diode or alternator rectifier diodes replacements can be purchased individually or as part of an alternator rebuilt kit. Faulty alternator windings, although rare, can also cause no alternator voltage output. After the alternator AC has been converted to DC voltage it is sent to either an internal voltage regulator or external voltage regulator, depending on automobile manufacturer.

1.7.3 Erratic Alternator Voltage Output

Erratic alternator output voltage can be the result of a loose alternator drive belt from the engine crankshaft pulley and alternator drive shaft pulley or faulty alternator voltage regulator. The purpose of the voltage regulator is to constantly maintain the DC voltage and current output developed by the automobile alternator. The alternator voltage regulator provides a means to meet all the electrical demands of the electrical system and recharge the electric starter motor battery. When operating properly the excess alternator voltage output and current are discarded by a path to the automobile chassis ground. This path is also where the negative battery terminal post is connected. The alternator voltage regulator is designed to operate within a specified limit. Exceeding the maximum alternator voltage regulator specified limit, by adding any high current drain electronic accessory, will cause the alternator voltage regulator to stop functioning. Internal alternator voltage regulator and external alternator voltage regulator replacements can be purchased individually or as part of an alternator rebuilt kit.

1.7.4 High Alternator Voltage Output

High alternator voltage output is a problem associated with older model vehicles and vehicles equipped with an external voltage regulator. These external voltage regulators utilize "points" which mechanically open and close to regulate the voltage developed by an alternator which in turn is supplies the the electrical system. When the points open, or disconnect, the voltage developed by the alternator is sent to ground. When the points close, or connect, the alternator voltage is sent to charge the battery and supply electricity to the automobile electrical system. Alternator voltage regulator points at one time were adjustable. This means that by adjusting the air gap between the points one could increase or decrease the alternator voltage output to the automobile electrical system. Alternator voltage regulator points operate like distributor points and experience the same problems of pitting, burning and corrosion. These problems, over time, result in changing the specified air gap settings for the alternator voltage regulator to perform properly. An external voltage regulator is a silver or black *metal* box attached somewhere to the vehicle firewall under the hood with a small visible ground strap. How to locate an external alternator voltage regulator: Locate the vehicle alternator by following the crankshaft drive belt(s). Locate the largest diameter wire connected to the alternator. Follow this large diameter wire from the alternator as it snakes it's way to the alternator voltage regulator. This large alternator wire will only be connected to the alternator voltage regulator.

CHAPTER TWO

2.0 STARTING SYSTEM

2.1 INTRODUCTION

Both Otto cycle and Diesel cycle internal-combustion engines require the pistons to be moving before the ignition phase of the cycle. This means that the engine must be set in motion by an external force before it can power itself.

Originally, a hand crank was used to start engines, but it was inconvenient, difficult, and dangerous to crank-start an engine. Even though cranks had an overrun mechanism, when the engine started, the crank could begin to spin along with the crankshaft and potentially strike the person cranking the engine. Additionally, care had to be taken to retard the spark in order to prevent backfiring; with an advanced spark setting, the engine could *kick back* (run in reverse), pulling the crank with it, because the overrun safety mechanism works in one direction only.

As early as 1899, Clyde J. Coleman applied for U.S. Patent 745,157 for an electric automobile self-starter — inventing one that worked successfully in most conditions did not occur until 1911 when Charles F. Kettering of Dayton Engineering Laboratories Company (DELCO) invented and filed for U.S. Patent 1,150,523 for the first useful electric starter. (Kettering had replaced the hand crank on NCR's cash registers with an electric motor five years earlier.) The starters were first installed by Cadillac on production models in 1912. These starters also worked as generators once the engine was running, a concept that is now being revived in hybrid vehicles. The Model T relied on hand cranks until 1919; by 1920 most manufacturers included self-starters.

The electric starter ensured that anyone could easily start and run an internal combustion engine car, and this made it the design of choice for motor vehicle buyers from that day forward.

The modern electric starter motor is either a permanent-magnet or a series- or series-parallel wound direct current electric motor with a solenoid switch (similar to a relay) mounted on it. When current from the starting battery is applied to the solenoid, usually through a key-operated switch, it pushes out the drive pinion on the starter driveshaft and meshes the pinion with the ring gear on the flywheel of the engine. Before the advent of key-driven starters, most electric starters were actuated by foot-pressing a pedestal located on the floor, generally above the accelerator pedal.

2.2 PURPOSE OF STARTING SYSTEM

The main purpose of the starting system is to crank the engine at a speed sufficient to cause the starting of the engine.

Both Otto cycle and Diesel cycle internal-combustion engines require the pistons to be moving before the ignition phase of the cycle. This means that the engine must be set in motion by an external force before it can power itself. Among the various means available, automobile now use:

- Air (Pneumatic) cranking system
- Hydraulic cranking system
- Electrical cranking system
- Auxiliary starter engine
- Static-start engine

2.3 AIR (PNEUMATIC) CRANKING SYSTEM

Some gas turbine engines and Diesel engines, particularly on trucks, use a pneumatic self-starter. The system consists of a geared turbine, an air compressor and a pressure tank. Compressed air released from the tank is used to spin the turbine, and through a set of reduction gears, engages the ring gear on the flywheel, much like an electric starter. The engine, once running, powers the compressor to recharge the tank.

Another method, for large diesel engines, uses additional valves in cylinder heads. Compressed air is let in the cylinders so that its pressure pushes pistons down when appropriate; at the upward piston movement, air is discharged through normal exhaust valves.

Since large trucks typically use air brakes, the system does double duty, supplying compressed air to the brake system. Pneumatic starters have the

Compared to a gasoline ("petrol") engine, diesel engines have very high compression ratios to provide for reliable and complete ignition of the fuel without spark plugs. An electric starter powerful enough to turn a large diesel engine would itself be so large as to be impractical, thus the need for an alternative system.

An air start system is a power source used to provide the initial rotation to start large diesel and gas turbine engines.

The air cranking motor consists of a five-vaned air motor with gear reduction, which drives the engine to be started through a conventional Bendix-type drive. (See Figure 2.2.1a and 2.2.1b)

An air starting reservoir provides air for the cranking motor only. The connection to the cranking motor is through flexible hose with a quick acting control valve to permit operation of the motor.

Air from the compressor. Which is adjusted to deliver 95 to 120psi maximum pressure, flows through a check valve to the reservoir.

A trailer coupling connection or glad-hand is provided has the reservoir drain connection to permit charging of the reservoir from an external source. Such as another vehicle or from the service shop air supply.

The energy source for an air-starting system is compressed air, which is usually stored in separate receiver tank. The air starter has a rotor that is located eccentrically in a larger diameter bore and usually fitted with five vanes that can slide radially in and out within slots in the rotor. Between the starter and the compressed air tank is a control valve that holds the air in a ready condition. When the valve is opened, the compressor air is released, and the resultant force on the blades causes the rotation of the rotor-much like a paddle wheel.

In an inertia sir-starting system, air is introduced into the air receiver tank by a one way check valve from the air brake system. The compressed air the servo control. When the pushbutton is activated, it sends a servo signal to the main relay valve, which then allow a high-volume air flow to pass on to the starter and crank the engine. Some starters are equipped with a device that is mounted on the inlet of the starter, which automatically injects a measured quantity of lubricant into the air stream so that the moving parts within the starter are adequately lubricated during operation. Also to prevent an extremely loud discharging sound-made by exhaust air-from escaping into the environment, a muffler is used on most starters to bring the overall sound level of the air starting system down near the 80 decibel range.

Today most starting systems used on over the road vehicular applications employ a reengaged cranking motor. A reengaged air starting system is almost identical to the inertia type system except that is utilizes a starter that received a servo signal form the push button whereupon an internal actuator engages the starter pinion with the engine ring gear will the servo signal come out of the starter and on to the relay valve. The life of the engine ring gear has been appreciably extended by the use of the pre-engaged type starters.

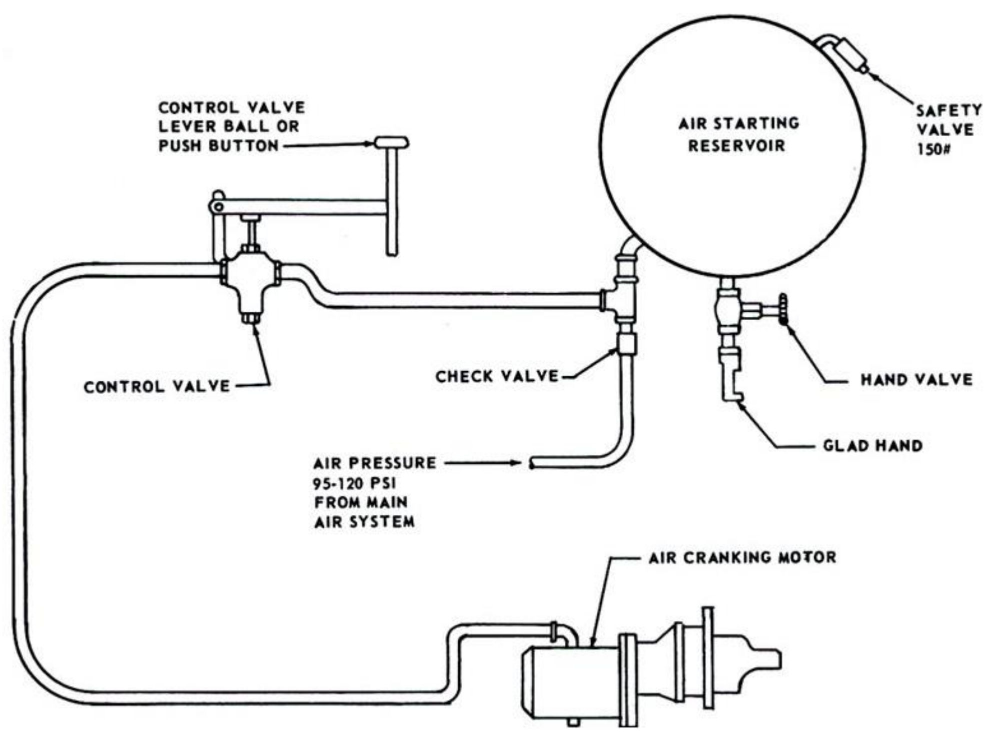


Figure 2.2.1a Pneumatic Starting system

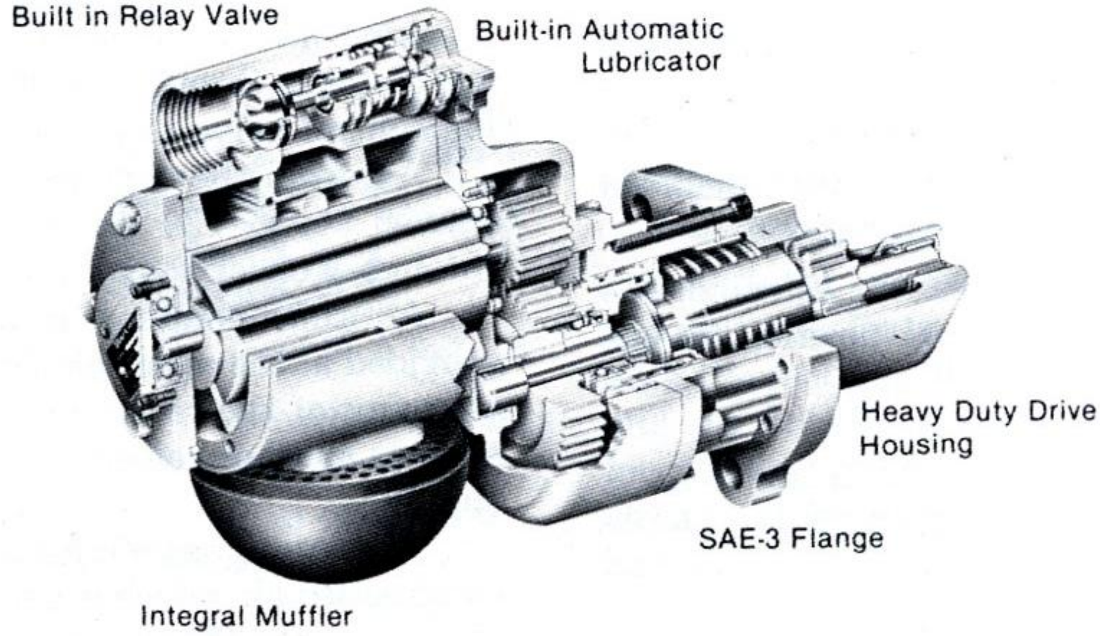


Figure 2.2.1b Cutaway of an air start system.

a) Advantages of Pneumatic starting system

Compared to electric starters, air starters have have the following advantages:

- Higher power-to-weight ratio
- Air starters can be run as long as their air supply lasts, while electric starters and their wiring can become excessively hot if it takes longer than expected to start the engine
- They delivering high torque
- Mechanical simplicity
- Reliability
- They eliminate the need for oversized, heavy storage batteries in prime mover electrical systems.

2.4 HYDRAULIC STARTING SYSTEM

Another method of air starting an internal combustion is by using compressed air or gas to drive a fluid motor in place of an electric motor. They can be used to start engines from 5 to 320 liters in size and if more starting power is necessary two or more motors can be used. Starters of this type are used in place of electric motors because of their lighter weight and higher reliability. They can also out last an electric starter by a factor of three and are easier to rebuild.

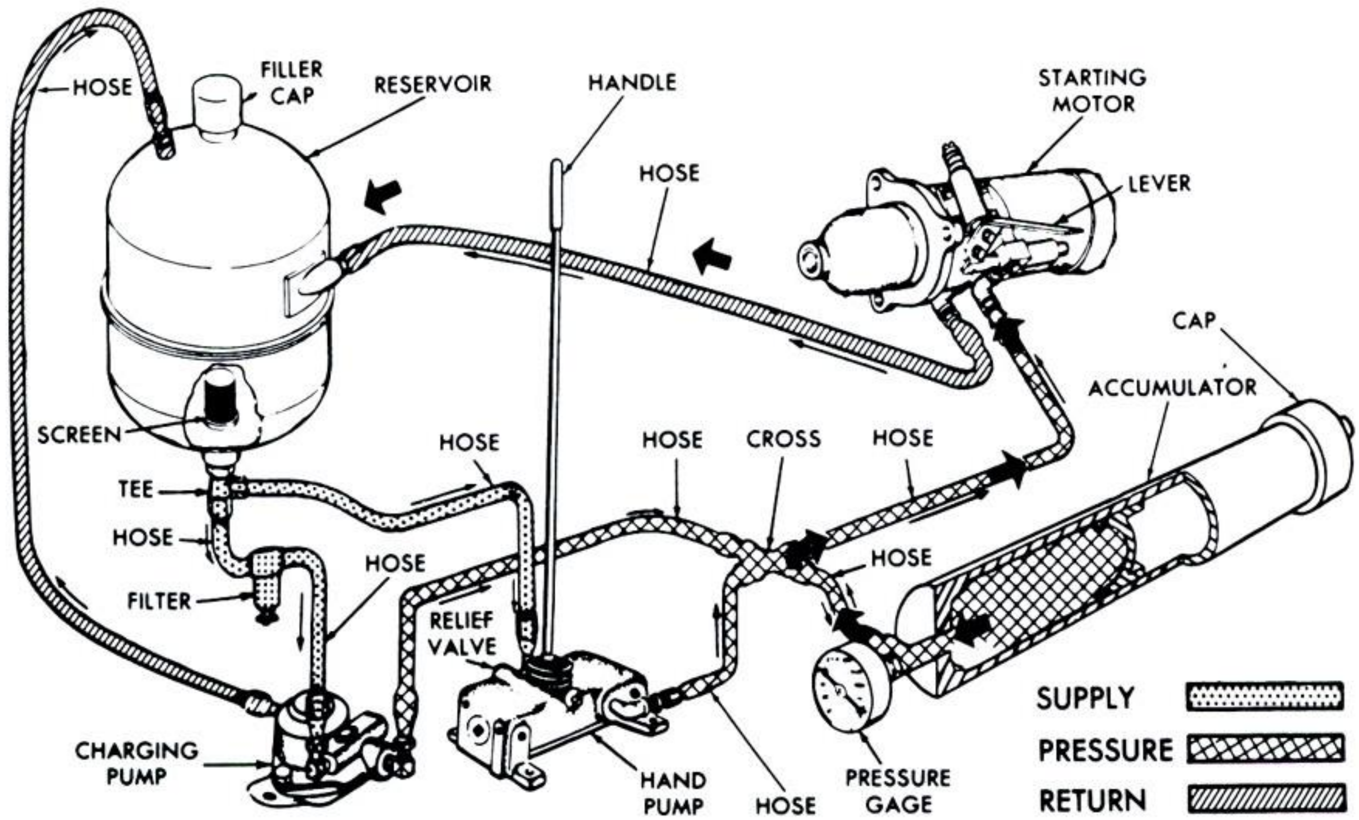


Figure 2.2.2 Hydraulic Starting System

2.5 AUXILIARY STARTER ENGINE

A large, high power Diesel engine, such as those used in off-road heavy equipment, may have a small gasoline-powered engine attached to the side as a starter.

These were also sometimes called pony engines. On some applications, they shared the same cooling system and oil supply. As the pony engine warmed up, it circulated warm coolant and warm oil in the diesel engine. In addition to making it easier to crank, it improved the service life.

2.6 STATIC-START ENGINE

Another way to provide for shutting off a car's engine when it is stopped, then immediately restarting it when it's time to go, is by employing a static-start engine. Such an engine requires no starter motor, but employs sensors to determine the exact position of each piston, then precisely timing the injection and ignition of fuel to *turn over* the engine.

While this concept is elegant in theory, and possibly doable with sensors and precision crankshaft braking to position the piston(s) at the right position(s), obviously this will mean the piston(s) will be required to hold compressed air-fuel mixture for a considerable length of time at position past the TDC (Top Dead Center) for the engine to be turned over with the power stroke(s) when the time comes. However, pistons and piston rings are far from perfect seals in current engine production/design practices, due to costs/manufacturing/metal expansion tolerances considerations. The normal gas blow-by is negligible, due to the very short time the piston is needed to hold the compresses mixture. Air will leak away past the rings and into the crankcase if the pistons are required to hold the compressed mixture for an extended time, not mention problems like moisture condensing as the mixture cools from hundreds of degrees to air temperature. A liter of air holds a significant amount of water, and when it is highly compressed it looses absorbtion capacity.

Unless extremely small clearances in the fit of the pistons and rings with the cylinders are designed into the engine to hold the mixture indefinitely (as in some situations, one can be away for days or weeks before driving the car), eventually all the mixture will leak away in time. Under any realistic notion of engine construction, this would be difficult if not impossible, particularly from a cost and reliability viewpoint. Engines are made of metal, which expands and contracts as it heats and cools. Piston rings are not designed to fit perfectly into a cylinder, but rather have a gap of several thousandths of an inch which is sealed with a thin layer of motor oil when the engine is running. Also, rings have "ring gaps" between each end of the part to allow for expansion under high temperature. There are "gapless" rings, but installation etc. is more difficult for little benefit. Considering the cost of designing such a system with all its extra sensors and tightly fit pieces, as well as the detrimental impact such perfect fittings would have on engine reliability, there seems little need or incentive for either manufacturers nor consumers to pay for such an ambitious and difficult project to replace a component that has worked well for so long. The cost of building a modern gas or diesel engine is high enough without tightening the tolerances twice as much, adjusting sensors, dealing with thermal expansion, redesigning the rings, valves, lubrication systems, and figuring out how to fit a piston tightly enough to hold air when cool, and yet stroke up and down ten times a second while hot. More likely we will see much simpler projects aimed at combining the alternator and starter into one unit, since there are far fewer practical problems created by that attempt, and much more obvious benefits.

Other considerations include maintenance services on the engine, such as changing spark plugs and malfunctions in the pistons positioning system, these will release all the fuel mixture inside the cylinders and render the engine non-startable, unless there is the starter to provide the necessary assistance. For Diesel engines, this concept will require even higher precisions than the extremely high tolerances the Spark Ignition Engines already require; due to their extremely high compression ratios. These ultra-tight tolerances will be detrimental to the free movement of the pistons - if not impossible - once the engine reaches operating temperature, due to metal expansion. Thus, with the current automotive technologies and engine designs, we will probably not see the starter disappear anytime soon.

2.7 ELECTRIC STARTING SYSTEM

Electric starting motor is a low voltage, direct current motor which converts electrical energy from the storage battery into mechanical energy. The starting motor is referred to as a cranking motor by some manufacturers.

2.7.1 Principles and Types of Direct Current Motor

The operation of a dc motor is based on the following principle:

A current-carrying conductor placed in a magnetic field, perpendicular to the lines of flux, tends to move in a direction perpendicular to the magnetic lines of flux. (See Figure 2.7.1a below

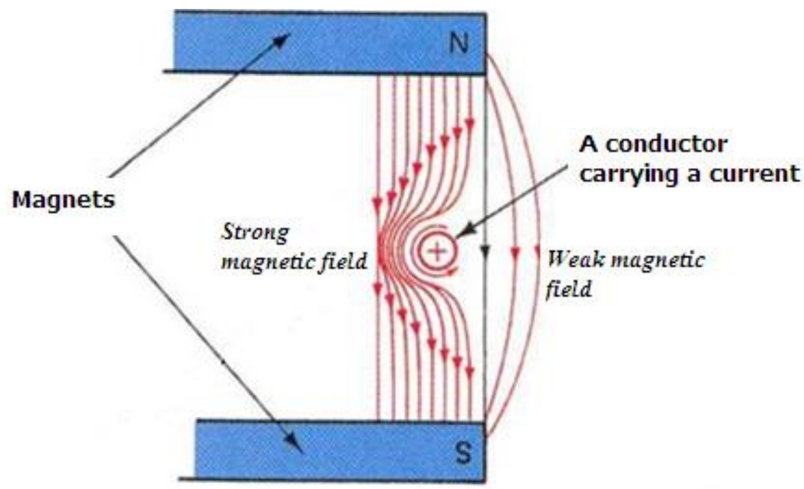


Figure 2.7a Interaction of the magnetic fields surrounding a current carrying conductor placed between two magnets creates a stronger magnetic field on the left side of the conductor, and weak magnetic field right.

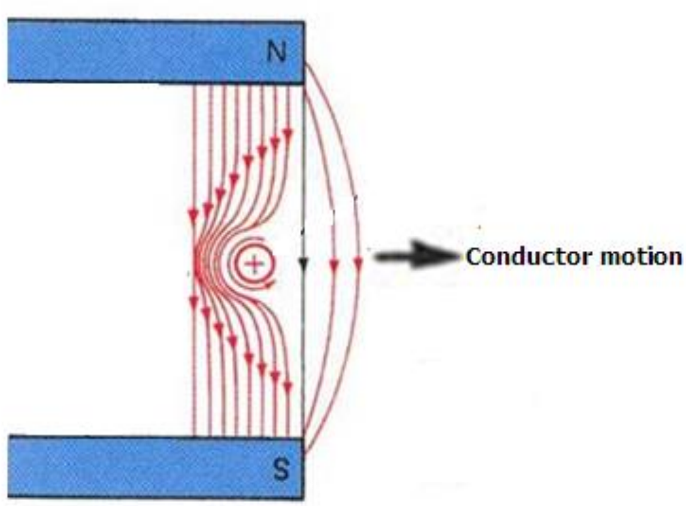


Figure 2.7b A conductor move from a strong magnetic field strength toward a weaker magnetic field strength.

a) Right-hand rule for motors

There is a definite relationship between the direction of the magnetic field, the direction of current in the conductor, and the direction in which the conductor tends to move. This relationship is best explained by using the RIGHT-HAND RULE FOR MOTORS (fig. 2-3).

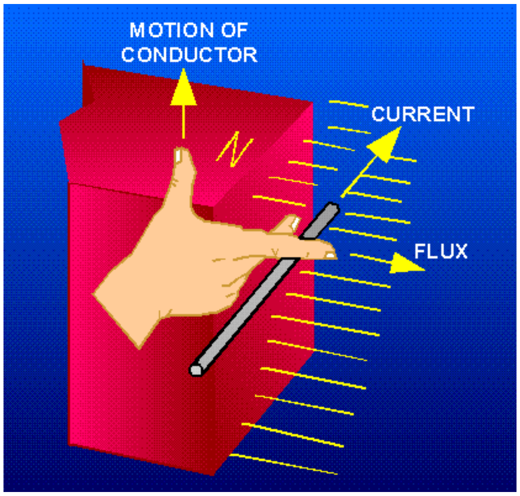


Figure 2-7c Right-hand rule for motors

To find the direction of motion of a conductor, extend the thumb, forefinger, and middle finger of your right hand so they are at right angles to each other.

If the forefinger is pointed in the direction of magnetic flux (north to south) and the middle finger is pointed in the direction of current flow in the conductor, the thumb will point in the direction the conductor will move.

b) The armature loops

A DC motor rotates as a result of two magnetic fields interacting with each other. The armature of DC motor acts like an electromagnet when current flows through its coils. Since the armature is located within the magnetic field of the field poles, these two magnetic fields interact.

Like magnetic poles repel each other, and unlike magnetic poles attract each other. As in the DC generator, the DC motor has field poles that are stationary and an armature that turns on bearings in the space between the field poles.

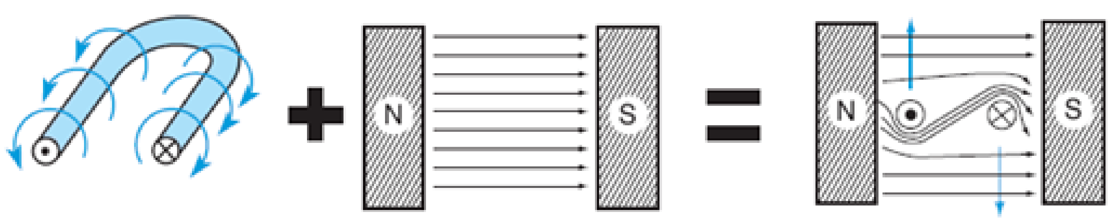


Figure 2-7d The armature loops rotate due to the difference in the strength of the magnetic field. The loops move from a strong magnetic field strength toward a weaker magnetic field strength.

The armature of a DC motor has windings on it just like the armature of a DC generator. These windings are also connected to commutator segments. A DC motor consists of the same components as a DC generator. In fact, most DC generators can be made to act as motors, and vice versa.

Look at the simple DC motor shown in figure 2-7e. It has two field poles, one a North Pole and one a south pole. The magnetic lines of force extend across the opening between the poles from north to south.

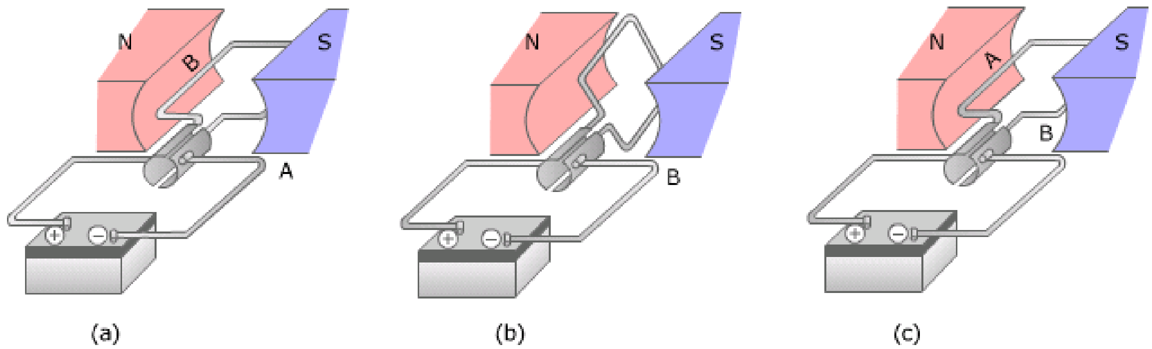


Figure 2-7e One loop DC motor

The DC motor is simply an application of magnetic principles. Motor rotation depends on the interaction of magnetic fields. The construction of a simple DC motor is very similar to a DC generator. In fact, a DC generator and motor are often interchangeable in use. In these cases, they are referred to as **DC machines.**

As with the generators, to make the motor more powerful, permanent field magnets can be replaced by electromagnets called field windings. The field winding is placed over a soft iron pole piece. It consists of many turns of enamel covered copper wire. Like the generator, the field windings can have an independent source of voltage connected to them. Or, the fields windings can be connected in series or parallel with the armature windings to a single voltage source, examine **Figure. 2-7f**

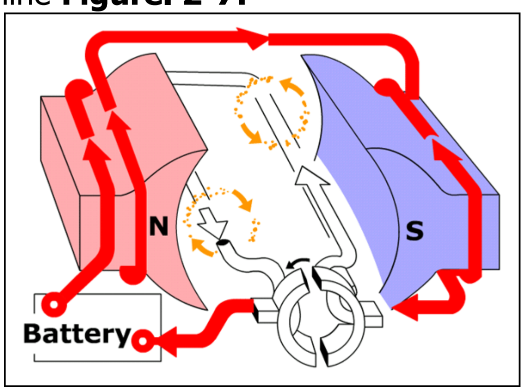


Figure 2.7f. A one loop electromagnetic motor

c) Counter Electromotive Force

When a conductor cuts through a magnetic field, voltage is induced in the moving conductor. And while a motor is meant to convert electrical energy into mechanical energy, when the armature begins to rotate, the motor also becomes a generator. The generated electrical force that opposes the applied emf is called counter electromotive force.

Counter electromotive force is often written as counter emf or cemf. It is a result of the generator action of the motor. If the motor were connected to a prime mover and rotated in the same direction as the DC motor, it would produce a voltage with the opposite polarity. The counter emf magnitude increases as the rotational speed and field strength increase. Therefore:

Counter emf = Speed × Field strength × K, Where **K** equals some constant.

This constant will vary in different motors. It is affected by things such as the number of windings. The actual effective voltage when applied to the windings in the armature must equal:

E source – E counter = E armature

The current flowing in the armature windings at any given instant can be found using Ohm's law when the ohmic resistance of windings is known:

I armature = E armature / R armature

It is important to note that, as rotation of the motor armature slows down, less counter emf is generated. As a result of less counter emf being produced, there will be an increase in the current through the armature circuit. The current will continue to increase until the motor stops rotating as it does when physically overloaded. When the motor stalls, only the resistance of the armature limits maximum current through the armature circuit. This condition results in extremely high current values. A DC motor must be properly protected against overload conditions.

If the load were suddenly removed, the armature would speed up and develop a higher counter emf. This higher counter emf would reduce the current flowing through the field and reduce the field strength. In turn, the motor would increase it speed because:

Speed = Counter emf / Field strength × K

This action builds upon itself and, eventually, the motor would reach a speed where the armature would fly apart because of centrifugal force. Thus, a series motor is never operated without a load. Furthermore, the series motor should be connected directly to a machine or through gears. It is not safe to use a belt drive from a series motor to a machine. If the belt should break or slip off, the motor would "run wild" and likely destroy itself.

2.8 TYPES OF DC MOTOR

According to the connecting method between the armature coil and the field coil:

- Series winding
- Shunt winding
- Compound winding

2.8.1 Series DC Motor

In the series wound motor, the field windings are connected in series with the armature windings, **Figure 2-8**. All the line current must flow through both the field and armature windings. Under loaded conditions, the counter emf opposes the line voltage and keeps the current at a safe level.

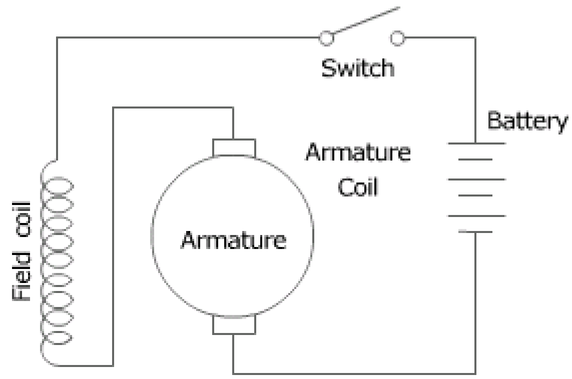


Figure 2-8a Schematic of series motor

A key advantage of the series motor is its ability to develop a high torque under load. Under load conditions, the armature speed is low, and the cemf is low. This condition results in a high armature current and increased torque. Series motors have heavy armature windings to carry these high currents. As the motor increases in speed, the cemf builds up, the line current decreases, and the torque decreases. Series motors are used on electric trains, cranes and hoists, as well as other traction-type equipment.

a) Series DC Motor Characteristic

i) The relationship between the armature current and rotation force

The rotation force of the motor is proportional to the multiplying of the armature current and the strength of the magnetic field. The strength of the magnetic field is decided by the field current and the armature current. The character graph is shown in figure 2-5. As the armature current is high, the rotation force will be increased.

ii) The relationship between the armature current and speed

The armature current is reversely proportional to the reverse electromotive force made by the motor. The reverse electromotive force is proportional to the speed of the motor. Therefore, the armature current is reversely proportional to the speed. The character graph is shown in figure 2-5. As shown in the graph, when the speed is low, that is, the load is high, the rotation force is high because of the increased armature current, and so the series winding DC motor is generally used for starting motor. **Speed = Counter emf / Field strength × K**

2.8.2 Shunt (Parallel) DC Motor

In the shunt motor, the field windings shunt across, or in parallel to, the armature,

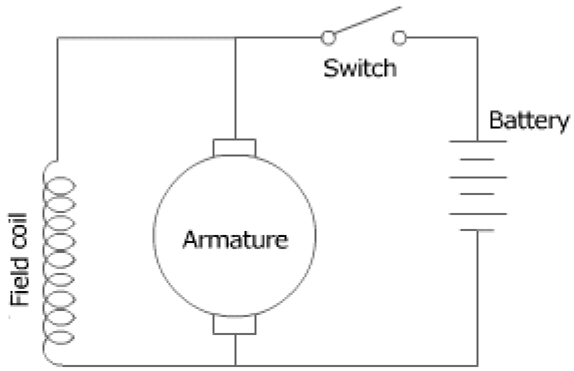


Figure 2.8b Schematic of shunt motor

In the shunt motor, both the field and the armature are connected across the power line. Under no-load conditions, the counter emf is almost equal to the line voltage. Very little armature current flows, and very little torque are developed.

When a load is applied and the armature decreases its speed, the counter emf also decreases. The decreased counter emf increases the armature current and the torque. When the torque matches the load, the motor remains at constant speed, **Table 1**.

No-load	High counter emf Low armature current Low torque
Full-load	Decreased counter emf Increased armature current Increased torque

Table 1. Shunt motor load conditions

The total current used by this motor is the sum of the field and armature currents. The input power may be computed using Watt's law:

Power = Applied voltage × Total current

Note, however, that the output power will be somewhat different because the motor is not one hundred percent efficient.

Shunt DC Motor Characteristics

i) The relationship between the armature current and rotation force

Like the series winding type, the rotation force is proportional to the multiplying of the armature current and the yoke field strength. However, the strength of the magnetic field can not be changed in this type, so the characteristic graph will be as shown in Fig 2-5. That is, as the armature current is large (the load is high), the rotation force is increased, but the increased ratio is less than that of series winding type.

ii) The relationship between the armature current and speed

The rotation speed of the motor is proportional to the voltage and reversely proportional to the field yoke strength. Therefore, when the power source is the battery, the voltage is constant and the yoke field is not changed. Consequently, when the armature current is increased, the voltage is lowered little but the rotation speed is almost constant, as shown in figure 2-5.

The shunt motor is commonly called a constant speed motor. It is used in driving machine tools and other machines that require relatively constant speed under variable loads.

In motor vehicles **Shunt DC Motor are commonly** used for the window washer, cooling fan, power window, and so on

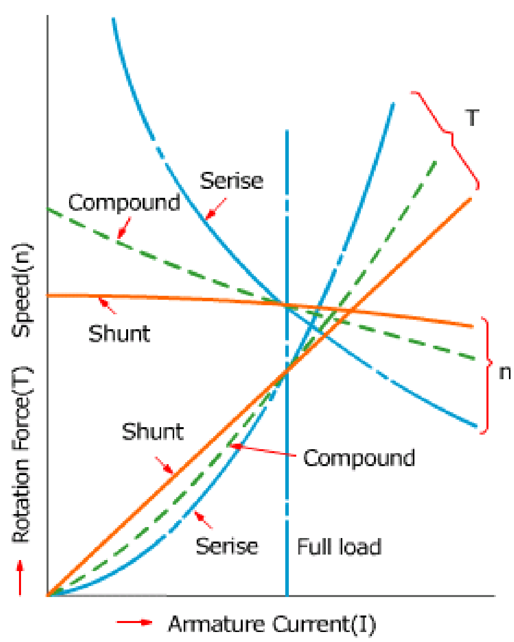


Fig. 2-8c DC Motors Characteristics

2.8.3 Compound DC Motors

The compound motor has both the series winding and a shunt field winding. This motor combines the advantages of each of the other types of motors. The series windings also carry the armature current. The winding consists of a number of heavy turns of wire. The shunt field winding consists of many turns of finer wire. Both windings are wound on the same field poles.

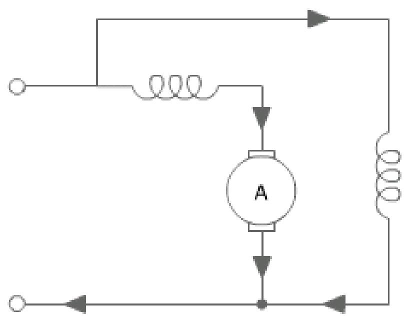


Figure 2-8d. Schematic of compound motor

There are two methods used to connect these windings. If the magnetic field on the series winding reinforces the magnetic field of the shunt winding, the motor is said to be a cumulative compound motor. If the two windings are connected to oppose each other magnetically, the motor is a differential compound motor. A detailed study of compound motors beyond the scope of this text. However, the characteristics of the different types should be noted.

The cumulative compound motor develops high starting torque. It is used where heavy loads are applied and some variance in speeds can be tolerated. The load can be safety removed from this motor. Most compound dc motors encountered will be of the cumulative type. The differential compound motor behaves mush like the shunt motor. The starting torque is low, and it has good speed regulation if loads do not vary greatly. Consequently, this motor is not widely accepted.

a) Compound Dc Motor Characteristic

When the motor is starting, it has large rotating force like the series winding type. After it is started, it has constant rotation speed like the shunt winding type. So, it has more complicated structure than series winding type. This type is used for windshield wiper motor.

2.9 Electrical Starting / cranking motor

Nowadays, most vehicle engine uses the series winding type motor of which source is battery, for the start motor. The series winding type motor generates the low speed and large force with a load. When the load is reduced, the rotating force is decreased but the rotation speed is increased. That is, the rotation speed will be remarkably varied. The start motor should generate the rotation force, which can be against the compressing force of the engine cylinder and the frictional force of all parts, so the rotation force should be large.

The starting motor circuit includes the starting motor, the storage battery, the starter switch, the cables to connect the motor and switch to the battery, and the ground return circuit.

Basic cranking system requirements

- The rotational force for starting should be large.
- It should be small and light as possible and have large output.
- It should be operated with small current capacity.
- It should resist vibrations.
- It should resist mechanical shocks.

2.9.1 Consideration when selecting /designing cranking motors

a) Rotation force for starting

The required rotation force and speed of the start motor for starting of the engine depends on the kind of engine (cylinder volume, compression ratio, and ignition type) or temperature (ambient temperature or lubricant oil temperature). The starting performance is mainly affected by the status of battery, the electrical source. Therefore, when the starting performance is concerned, the requirement for engine, characteristic of the start motor and performance of battery should be included. The rotational resistance of the engine is decided by the forces needed for compressing the air and fuel mixture in the cylinder and the frictional forces of the cylinder, the piston ring, each bearing and gear.

When the engine is starting, the rotation force needed that the start motor rotates the crank shaft against the rotational resistance is called as the starting rotation force. The starting rotation force of start motor can be increased by enlarging the ratio between the flywheel ring gear and the pinion gear (to about 10~15:1). This ratio can be acquired by following equation. This starting rotation force will be large as the cylinder volume or the compression ratio is large as well as it shall be affected by the ambient temperature.

b) Initial rpm for engine starting

To start engine, the rotation speed and force should be larger than those for rotating the crankshaft. If the rotation speed is too low, then the compressed gas between the cylinder and piston will be leaked, so the compression pressure for starting can not be acquired. For gasoline engine, if the voltage supplied to the ignition coil is too low, then the ignition shall be failed. For diesel engine, if the adiabatic compression is not sufficiently performed, then the temperature for igniting the fuel shall not be acquired. The lowest limitation value of speed of rotation for engine starting is called the minimum starting rotation speed.

This rotation speed of diesel engine is little larger than that of gasoline engine. Generally, the minimum rotation speed will be large as the temperature is high. It is also varied according to the cylinder number, cycle number, shape of combustion chamber, ignition type and so on.

For the 2-cylce engine, the minimum starting rotation speed is about 150~200 rpm at $-15°C$ For the 4-cycle engine, it is more than 100rpm for the gasoline engine, or 180 rpm for the diesel engine.

$$\text{Rotating force} = \frac{\text{(Rotation Resistance of engine)} \times \text{(Tooth number of pinion gear)}}{\text{(Tooth number of flywheel ring gear)}}$$

c) Starting performance of the engine

The output of the start motor is varied by the capacity of the battery and the difference of the temperature.

When

2.9.2 Types of electric starter motors

Most engines require a cranking speed of about 200 rpm. There are two major types of electrical starter motor used on motor vehicles, which are:

- Conventional
- Reduction type starter motors

The conventional starting motor is used on most older-model vehicles while the reduction type starter motor is used on most current Vehicle. A heavy-duty magnetic switch, or solenoid, turns the motor on and off. It is part of both the motor circuit and the control circuit. Both systems are controlled by the ignition switch and protected by a fusible link. On some models, a starter relay is used in the starter control circuit. On models with automatic transmission, a neutral start switch prevents starting with the transmission in gear. On models with manual transmission, a clutch switch prevents starting unless the clutch is fully depressed. On Toyota 4WD Truck and 4-Runner models, a safety cancel switch allows starting on hills without the clutch depressed. It does so by establishing an alternate path to ground. Both systems have two separate electrical circuits:

- A control circuit
- A motor circuit

2.9.3 Over-running clutch

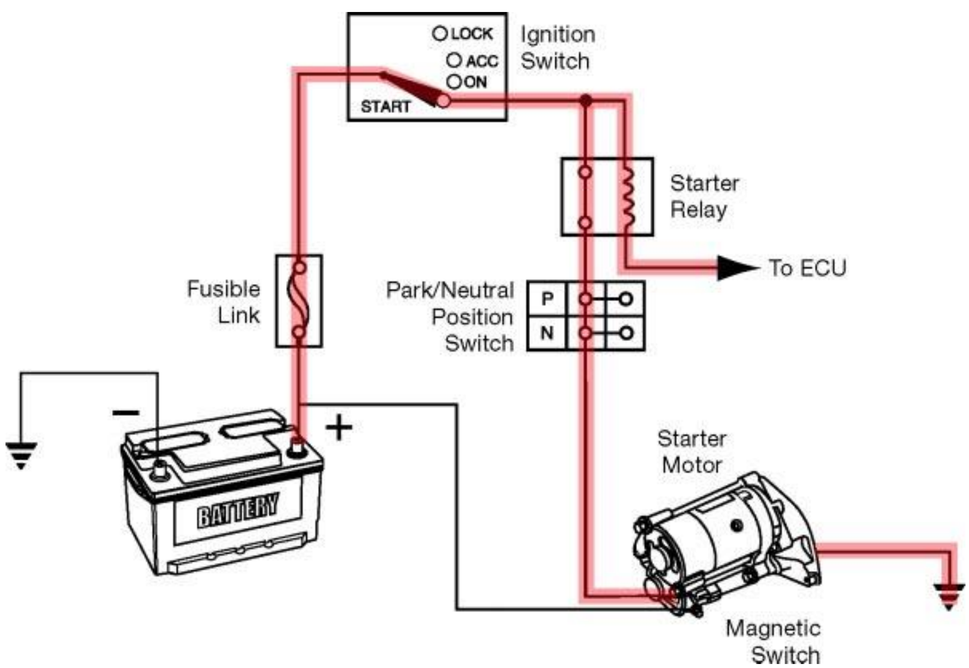
Both conventional and gear reduction starter motors are fitted with a Clutch one−way, over−running clutch. This clutch prevents damage to the starter motor once the engine has been started. It does so, by disengaging its housing (which rotates with the motor armature) from an inner race which is combined with the pinion gear. Spring loaded wedged rollers are used. Without an over-running clutch, the starter motor would be quickly destroyed if engine torque was transferred through the pinion gear to the armature.

During engine start, the starter pinion gear drives the engine's flywheel ring gear.

Once the engine fires, the ring gear almost instantly begins to turn faster than the starter pinion gear. Over−speeding would damage the starter motor if it were not immediately disengaged from the pinion gear.
The clutch uses its wedged rollers and springs to disengage the pinion shaft from the clutch housing (which turns with the motor armature). This happens any time the pinion shaft tries to turn faster than the clutch housing.

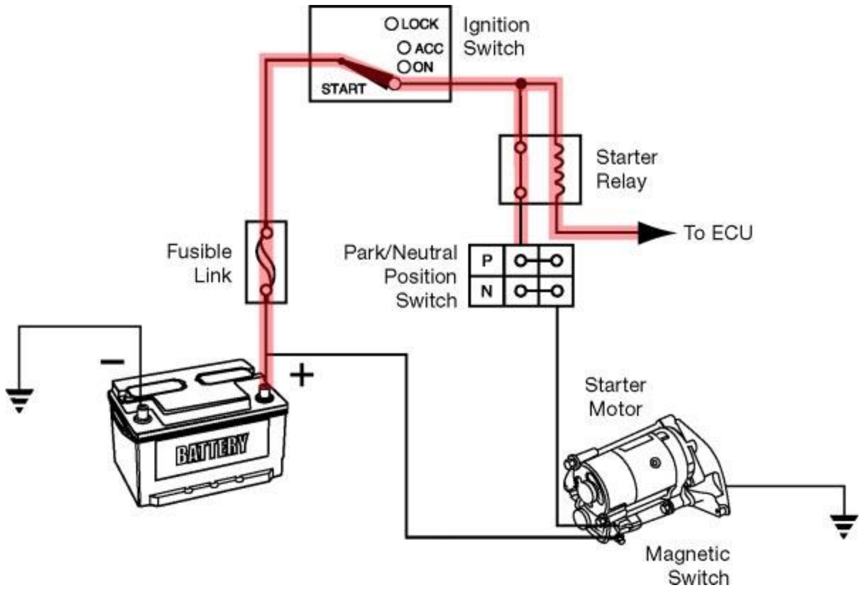
2.9.4 Ignition Switch

The ignition switch incorporates contacts to provide B+ to the starter. The relay energizes the starter magnetic switch when the driver turns the ignition key to the START position.



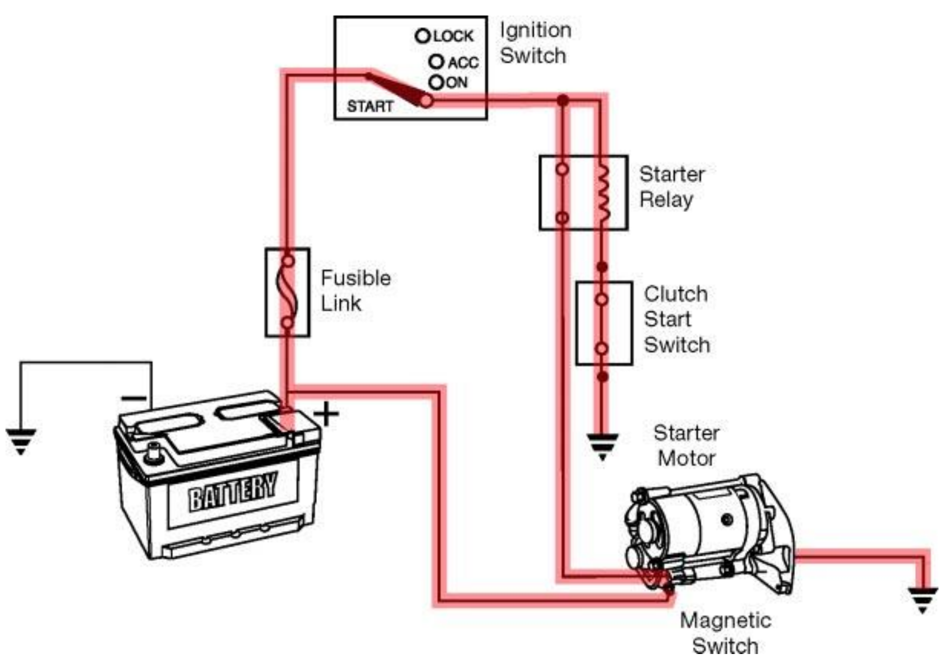
2.9.5 Park/Neutral Position Switch (Automatic Transmission)

The park/neutral position switch prevents operation of the starter motor unless the shift lever is in Park or Neutral. The switch contacts are in series with the starter control circuit. The switch closes with the shift lever in Park or Neutral.



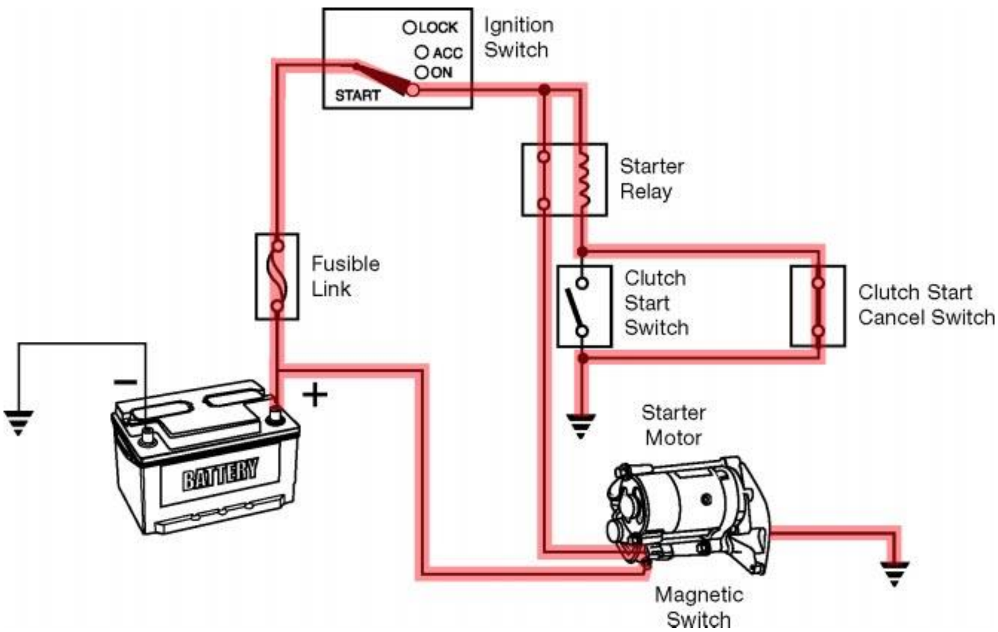
2.9.6 Clutch Start Switch (Manual Transmission)

For manual transmissions the clutch start switch performs the same function as the park/neutral position switch. The clutch start switch opens the starter control circuit unless the clutch is engaged.



2.9.7 Cancel Switch Clutch Start

In some off−road situations it is advantageous to start a manual transmission vehicle while in gear with the clutch engaged. The driver− controlled safety cancel switch allows the driver to bypass the clutch start switch to make this possible. This feature is only available some models.



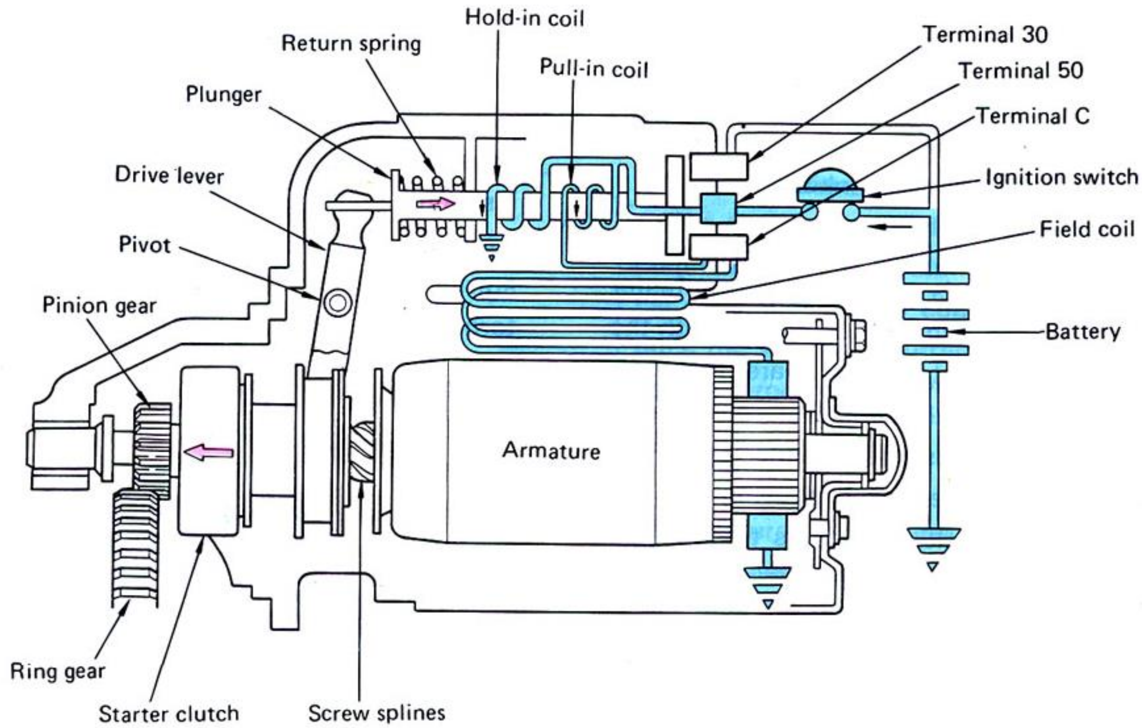
2.10 CONVENTIONAL STARTER MOTORS

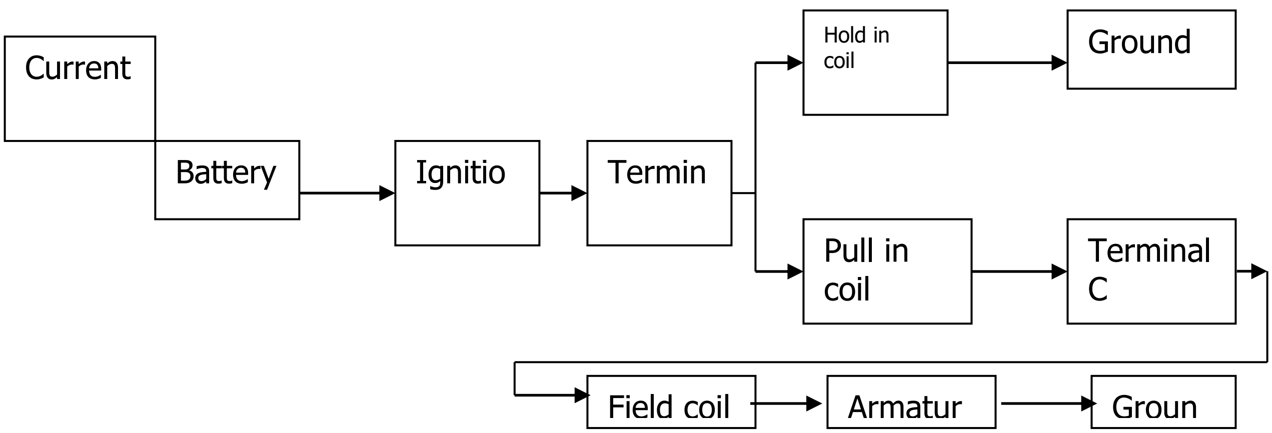
A conventional starter motor starter drives the pinion gear directly. The pinion gear turns at the same speed as the motor shaft. These starters are heavier and draw more current than gear reduction type starters.

2.10.1 Conventional Starting Motor Operation

a) Ignition switch in "ST"

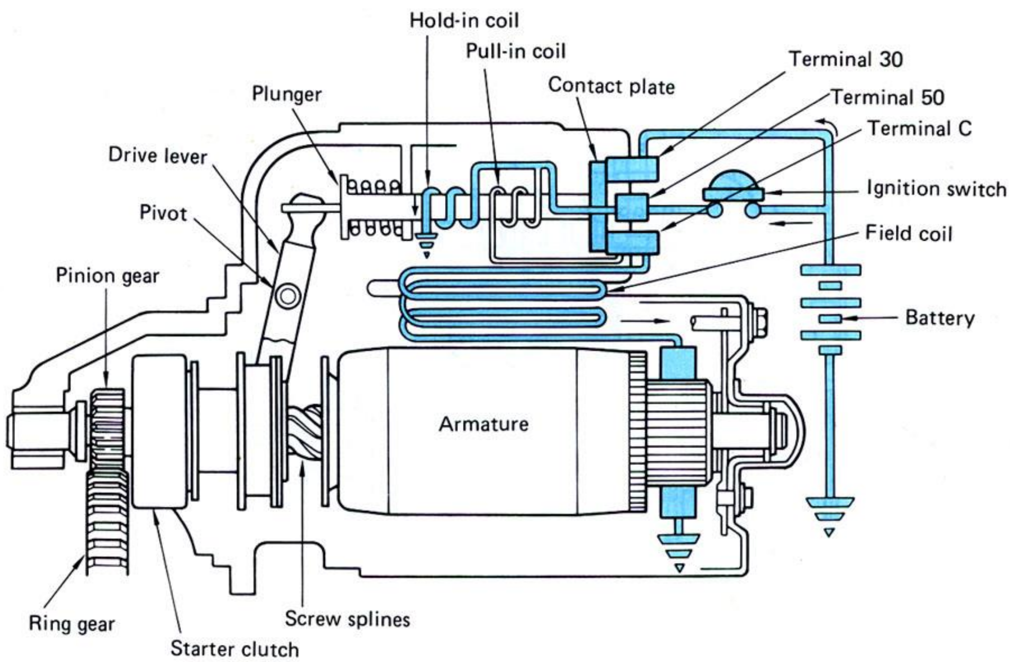
Current flows from the battery through terminal "50" to the hold-in and pull-in coils.
Then, from the pull-in coil, current flows through terminal "C" to the field coils and armature coils.
Voltage drop across the pull-in coil limits the current to the motor, keeping its speed low.
The solenoid plunger pulls the drive lever to mesh the pinion gear with the ring gear.
The screw spline and low motor speed help the gears mesh smoothly.

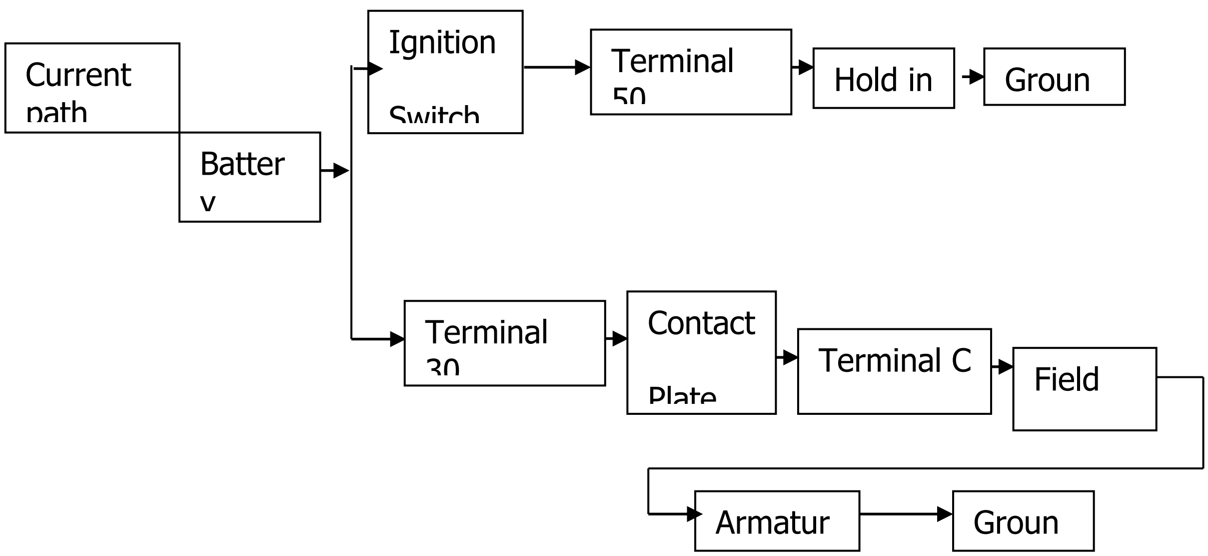




a) Pinion and ring gears engaged

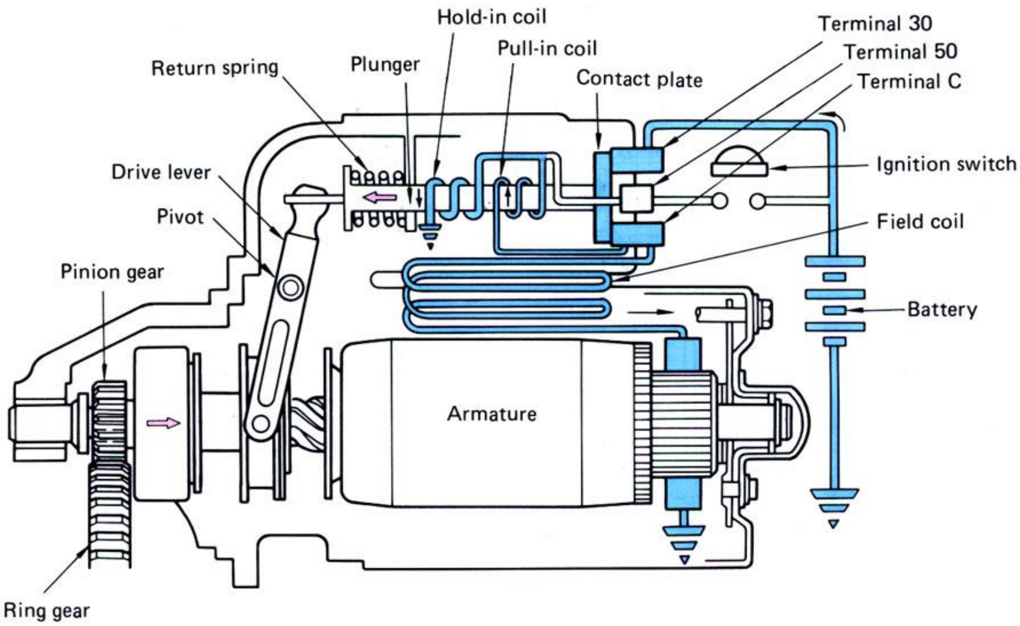
When the gears are meshed, the contact plate on the plunger turns on the main switch by closing the connection between terminals "30" and "C."
More current goes to the motor and it rotates with greater torque (cranking power).
Current no longer flows in the pull-in coil. The plunger is held in position by the hold-in coil's magnetic force.

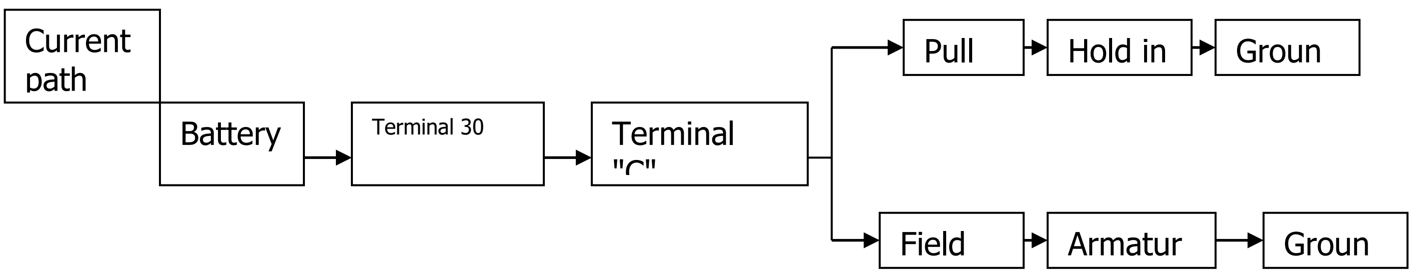




b) Ignition switch in "on"

Current no longer flows to terminal "50," but the main switch remains closed to allow current flow from terminal "C" through the pull-in coil to the hold-in coil.
The magnetic fields in the two coils cancel each other, and the plunger is pulled back by the return spring.
The high current to the motor is cut off and the pinion gear disengages from the ring gear.
A spring-loaded brake stops the armature.





2.10.2 Gear-Reduction Starter

The motor shaft has integrally-cut gear teeth forming a drive gear which mesh with a larger adjacent driven gear to provide a gear reduction ratio of 1/4 to 1/3. This permits the use of a higher-speed, lower-current, lighter and more compact motor assembly while increasing cranking torque.

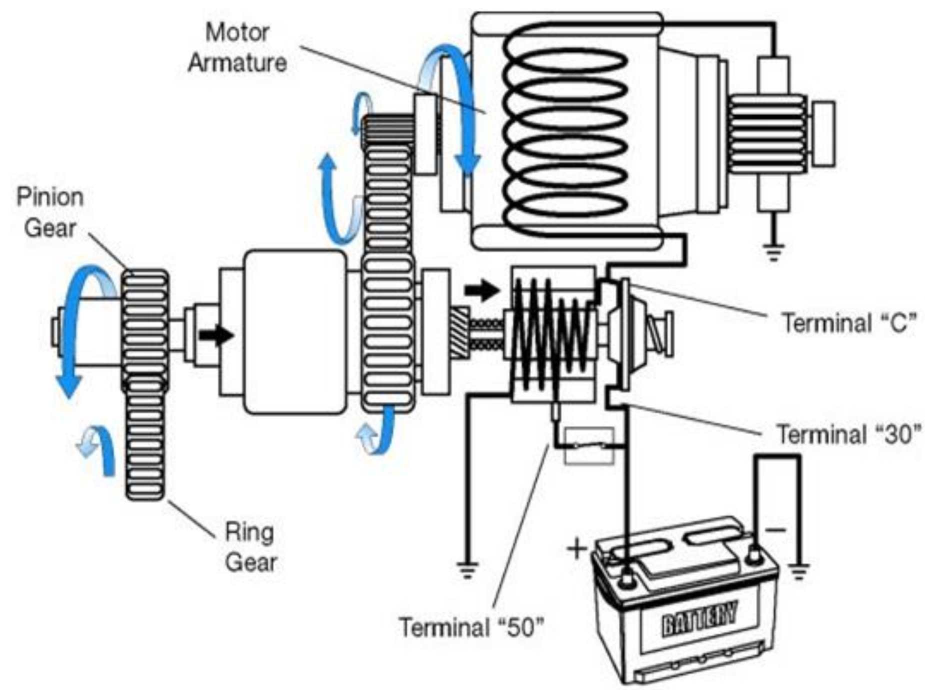
The reduction gear is mounted on the same shaft as the pinion gear. Unlike the conventional starter, the magnetic switch plunger acts directly on the pinion gear (not through a drive lever) to push the gear into mesh with the ring gear. The gear−reduction starter is the replacement starter for most conventional starters.

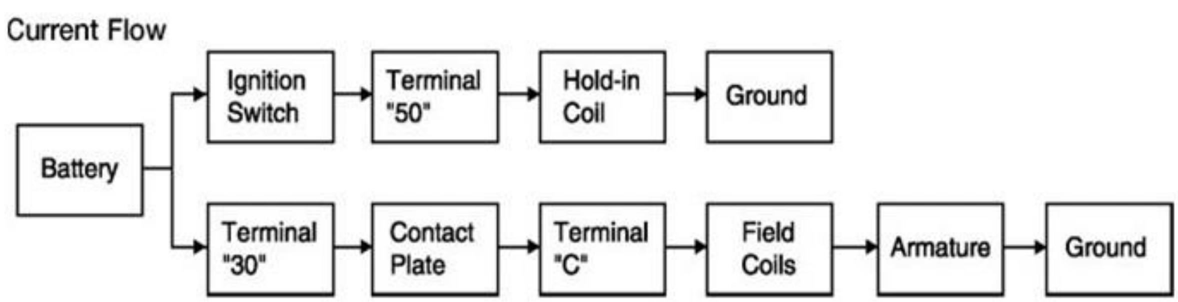
a) Ignition switch in ST

- Current travels from the battery through terminal 50" to the hold−in and pull−in coils. Then, from the pull−in coil, current continues through terminal C" to the field coils and armature coils.
- Voltage drop across the pull−in coil limits the current to the motor, keeping its speed low.
- The magnetic switch plunger pushes the pinion gear to mesh with the ring gear.
- The screw spline and low motor speed help the gears mesh smoothly.

b) Ignition Switch to ST

The plunger pulls the drive lever, which moves the pinion gear into engagement with the ring gear. The magnetic switch closes and current from the battery drives the starter motor directly.

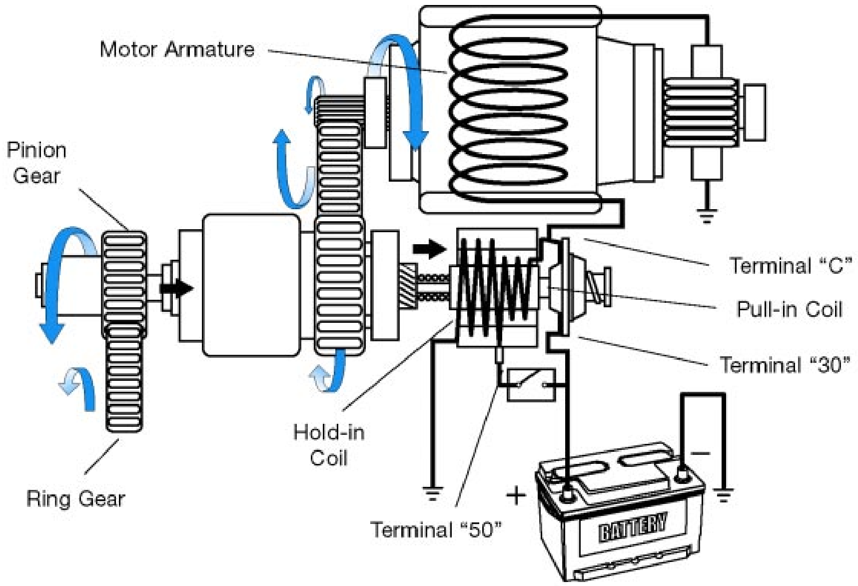


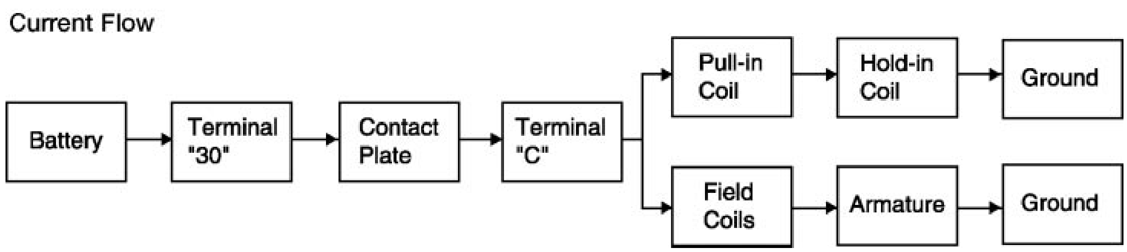


c)**Pinion and ring gears engaged**

When the gears are meshed, the contact plate on the plunger turns on the main switch by closing the connection between terminals 30" and C."
More current goes to the motor and it rotates with greater torque.

Current no longer flows in the pull−in coil. The plunger is held in position by the hold−in coil’s magnetic force.





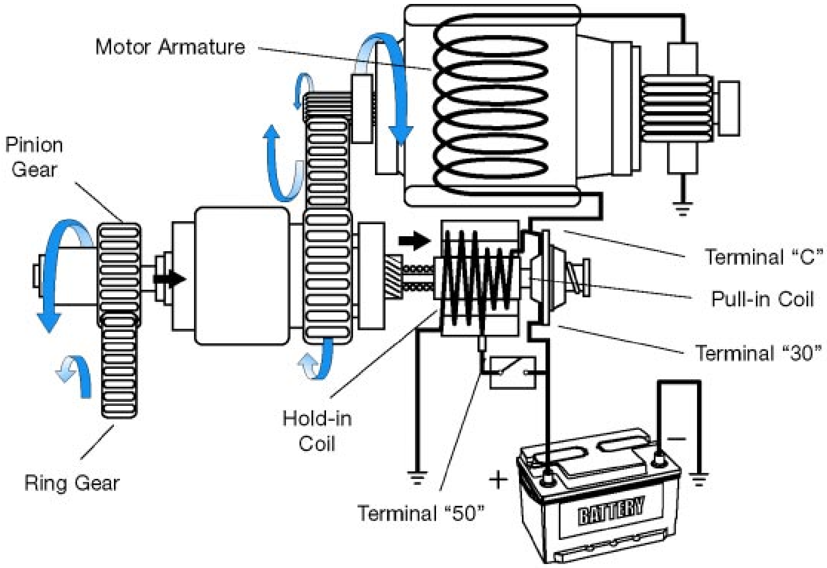
d) Ignition switch in ON

Current no longer present at terminal 50," but the main switch remains closed to allow current from terminal C" through the pull−in coil to the hold−in coil.
The magnetic fields in the two coils cancel each other, and the plunger is pulled back by the return spring.

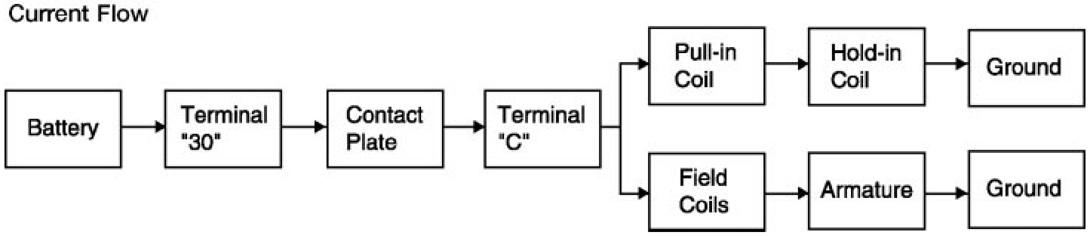
The high current to the motor is cut off and the pinion gear disengages from the ring gear.
The armature has less inertia than the one in a conventional starter. Friction stops it, so a brake is not needed.

e) Ignition Switch ON

Current through the starter relay stops. The pinion gear disengages from the ring gear, and the magnetic switch opens.



Current Flow



CHAPTER THREE

3.0 IGNITION SYSTEM

3.1 INTRODUCTION

One of the requirements for an efficient engine is the correct amount of heat shock, delivered at the right time. This requirement is the responsibility of the ignition system. The ignition system supplies properly timed high voltage surges to the spark plugs. These voltage surges cause combustion inside the cylinder.

The ignition system must create a spark or current flow across each pair of spark plug electrodes at the proper instant, under all engine operating conditions. This may sound relatively simple, but when one considers the number of spark plug firings required and the extreme variation in engine operating conditions, it is easy to understand why ignition systems are so complex.

If a six-cylinder engine is running at 4,000 revolutions per minute (rpm), the ignition system must supply 12,000 sparks per minute because the ignition system must fire 3 spark plugs per revolution. These plug firings must also occur at the correct time and generate the correct amount of heat. If the ignition system fails to do these things, fuel economy, engine performance, and emission levels will be adversely affected.

3.2 THE BASIC FUNCTION OF THE IGNITION SYSTEM

The basic function of the ignition system is to generate sparks that can ignite the air and fuel mixture in the cylinders. This implies that, the automotive ignition system must control the spark and timing of the spark plug firing to match varying engine requirements and also increase battery voltage to a point where it will overcome the resistance offered by the spark plug gap and fire the plug.

3.3 BASIC REQUIREMENTS OF THE IGNITION SYSTEM

The basic function of the ignition system is to generate sparks that can ignite the air and fuel mixture in the cylinders. Hence it must satisfy the following conditions:

- A strong spark
- Proper ignition timing
- Sufficient durability

3.3.1 A strong spark

The voltage that is supplied to the plugs must be high enough to ensure the generation of the powerful spark across the spark plug gaps. This is because the compressed air fuel mixture has electrical resistance.

3.3.2 Proper ignition timing

To obtain optimal combustion of the air there must be means of varying ignition timing in accordance with the engine RPM and load, therefore ignition system must provide proper ignition timing at all times to accommodate the changes in engine speed and load.

3.3.3 Sufficient durability

The ignition must have sufficient reliability to endure vibration heat of combustion and high voltage of the ignition system itself.

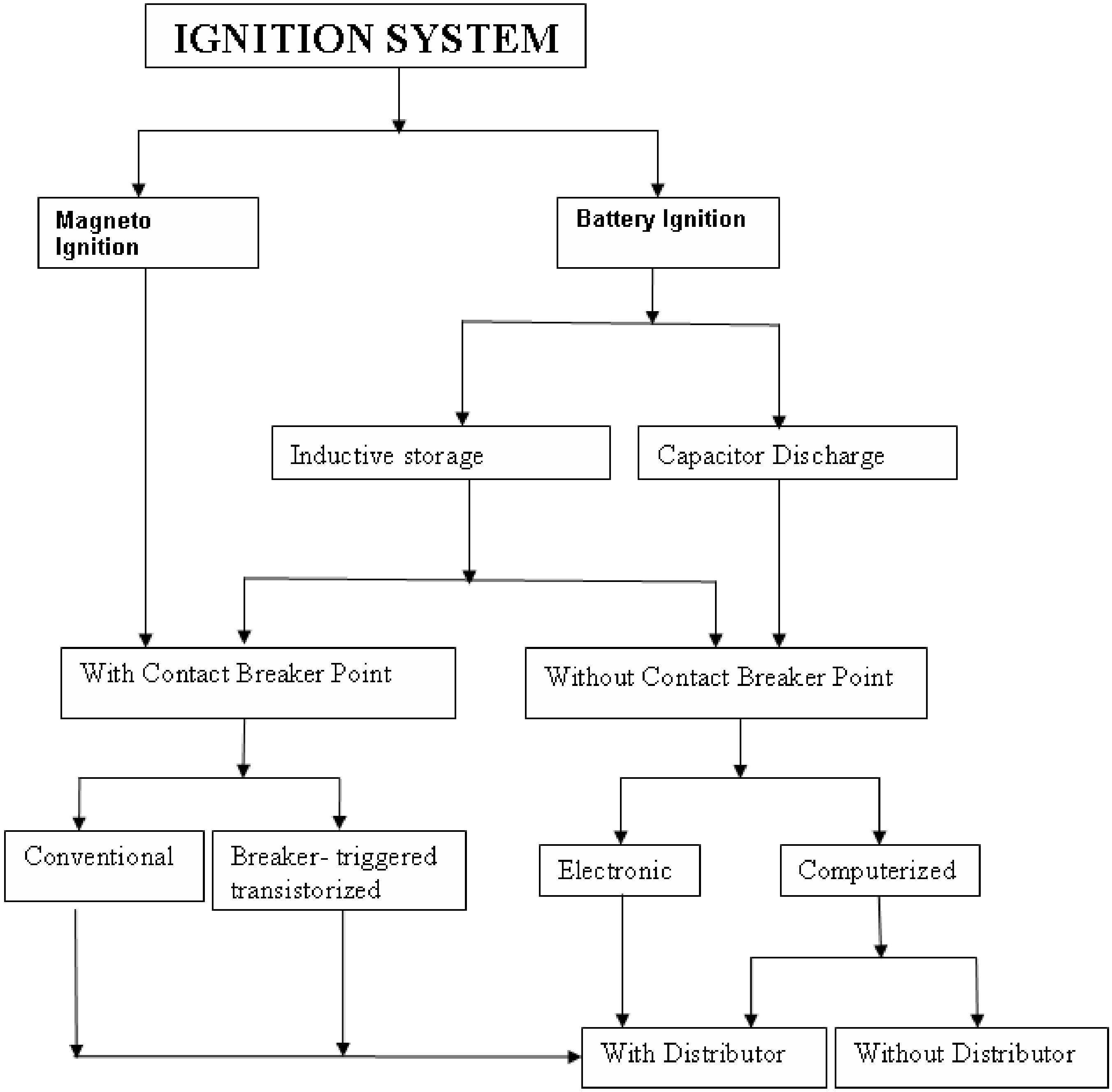
3.4 TYPES OF IGNITION SYSTEMS

There are many different types of ignition systems. Most of these systems can be placed into one of two main groups:

a) Magneto ignition system
b) Battery Ignition system;

- Capacitor discharge ignition system
- Inductive Storage-Type Ignition System;
    - With contact breaker point;
        - ➢ Conventional
        - ➢ Breaker point – transistorized
    - Without contact breaker point;
        - ➢ Electronic
        - ➢ Computerized;
            - ✓ With distributor
            - ✓ Distributorless

3.4.1 Tree diagram of ignition systems


IGNITION SYSTEM
Magneto Ignition
Battery Ignition
Inductive storage
Capacitor Discharge
With Contact Breaker Point
Without Contact Breaker Point
Conventional
Breaker- triggered transistorized
Electronic
Computerized
With Distributor
Without Distributor

3.5 BATTERY IGNITION SYSTEM

With the universal adaptation of electrical starting for automobiles, and the concomitant availability of a large battery to provide a constant source of electricity, magneto systems were abandoned for systems which interrupted current at battery voltage, used an ignition coil to step the voltage up to the needs of the ignition, and a distributor to route the ensuing pulse to the correct spark plug at the correct time. Therefore, the system is called battery ignition because it uses storage battery power to run it.

3.6 INDUCTIVE STORAGE IGNITION SYSTEM

This is called an inductive system because the coil is used as a power storage (an "inductor") device for the spark. Remember, the coil is powered up, stores near 45,000 volts, and unleashes it when the coil collapses (power supply cutoff). A feature of induction ignition is the slightly longer spark duration while the coil collapses. This is an advantage when starting and for igniting lean/high compression mixtures at high RPM. These type of systems require coils meant for "induction" ignitions (they have a higher resistance typically than CDI coils). Induction ignitions are simpler in design (cheaper) and used often on less sophisticated motors.

- The conventional breaker point type ignition systems (in use since the early 1900s)
- The electronic ignition systems (popular since the mid 70s)
- The Computerized ignition system (introduced in the mid 80s)

3.6.1 Comparison of Inductive Storage Ignition System

	FUNCTIONS	TYPES OF IGNITION SYSTEM			
		Conventional	Electronic	Computerized	
				With Distributor	Distributorless
1	**Ignition triggering**	Mechanical	Electronic	Electronic	Electronic
2	**Determining the ignition angle on the basis of the speed and load condition of the engine**	Mechanical	Mechanical	Electronic	Electronic
3	**High tension generator**	Induction	Induction	Induction	Induction
4	**Distribution and assignment of spark to the correct cylinder**	Mechanical	Mechanical	Mechanical	Electronic
5	**Out put Voltage**	10-30kV	30-40kV	30-40kV	30-45kV

3.6.2 Basic Circuitry

All ignition system consists of two interconnected electrical circuits; a primary (low voltage) circuit and a secondary (high voltage) circuit.
Depending on the exact type of ignition system, components in the primary circuit include the following:

- Battery
- Ignition Switch
- Ballast Resistor or resistance wire (in some systems)
- Starting by-pass (in some systems)
- Triggering device
- Switching devices or control module
- Condenser
- Ignition coil primary winding

The Secondary Circuit consists of:

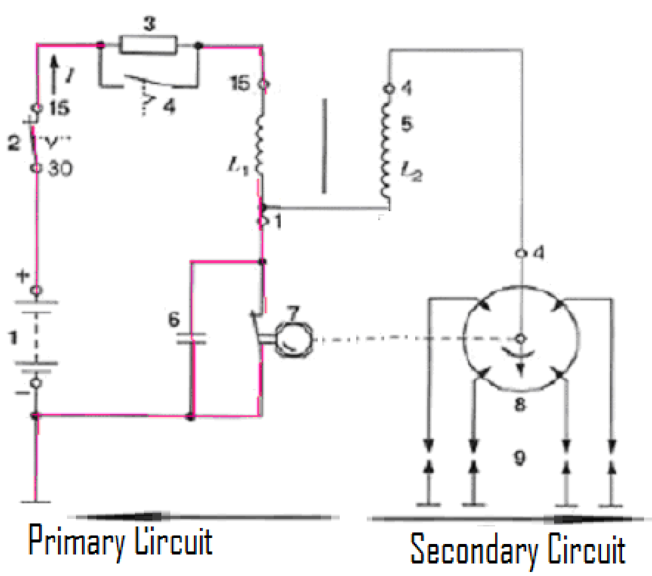
- Ignition coil secondary winding
- Distributor cap and rotor(in some systems)
- Spark plugs
- Ignition (spark plugs) cables

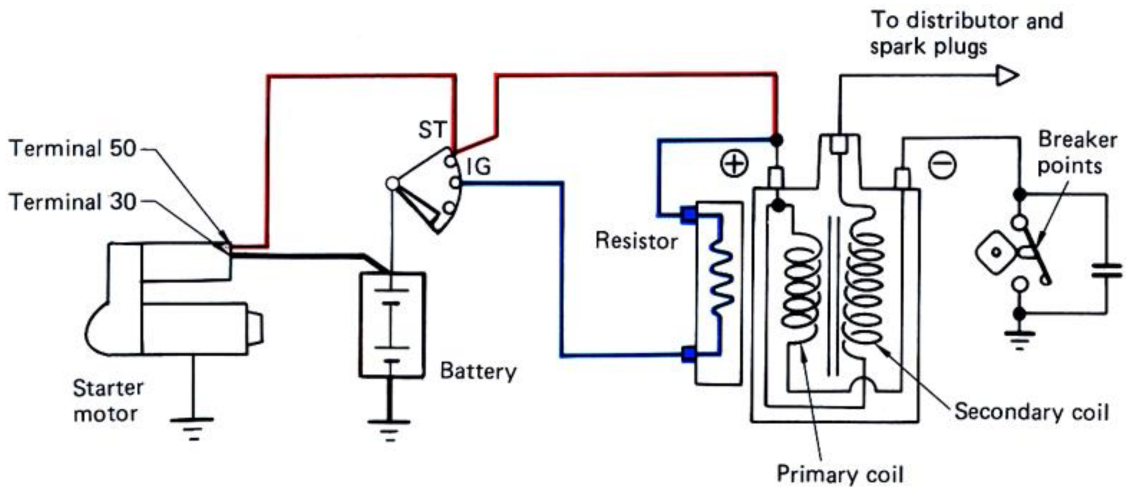
3.7 BATTERY IGNITION SYSTEM WITH CONTACT BREAKER POINT

a) Breaker triggered (conventional) ignition system

This type of ignition system has the following basic construction:

- The primary current and ignition timing are mechanically controlled
- The primary current in the ignition coil flows intermittently through the breaker points
- The governor advancer and the vacuum advancer control the ignition timing
- The distributor distributes the high voltage that is generated by the secondary coil to the spark plugs



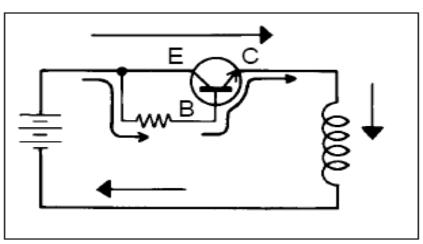


b) Breaker triggered transistorized ignition system (TI-B)

The **(TI-B)** is further development of **Conventional Ignition system.** In the (TI-B) the contact point operate in conjunction with the transistor; the contact no longer needs to switch the primary current but only the control current for the transistorized ignition system.

The transistor is used as the circuit breaker in place of a contact breaker point in the CI and assumes its switching function in the primary circuit of the ignition system.

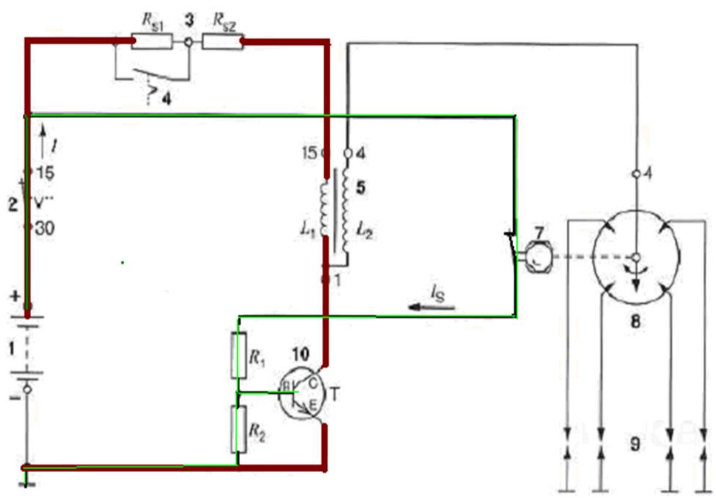
When the base circuit of a transistor is energised, a small amount of current is applied to the transistor collector. Since the emitter is closer to the collector than it is to the base, most of the current is conducted by the emitter- collector section of the transistor. This is caused by the fact that electricity normally follow the path of least resistance



The power transistor acts as an electronic relay - using a small current to switch a bigger current) and the power transistor supplies a normal 12 volts to the coil. But like the electronic it provides faster switching than sparking points can, so coil performance is a little better than Conventional ignition system - still in the 18-20,000 volts range to the plugs though. The points last a long time as they don't spark any more - only small trigger current flows through them. These systems are not very common these days.

By doing so a larger amount of current can flow in the primary circuit, while just a small amount of current flowing through the contact breaker point thus;

Increasing the strength of magnetic line of force
Decreasing the arcing at the contact breaker point



1- Battery, 2-Ignition & starting switch, 3- Ignition trigger box, 4-Ballast resistor, 5-Cable connection to the starter, 6-Ignition coil, 7-Distributor, 8-Spark plug, I-Primary current, Is-Control current

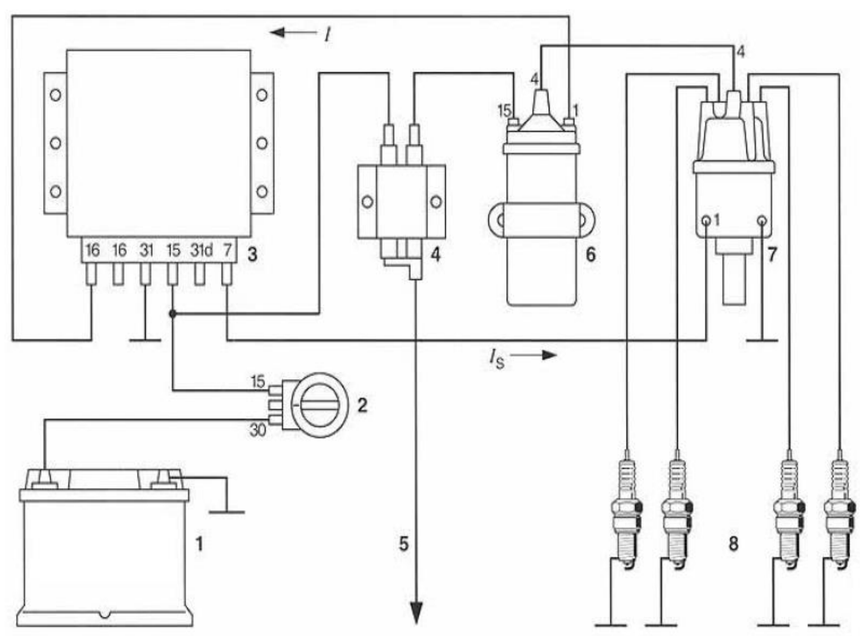


Figure Components and connection diagram of the TI_B

3.8 ELECTRONIC (TRANSISTORIZED OR SOLID-STATE) IGNITION SYSTEM

From the fully mechanical breaker point system, ignition technology progressed to basic electronic or solid-state ignitions. Breaker points were replaced with electronic triggering and switching devices. In this type, the switching devices (transistor) control the primary current so that it flows intermittently in accordance with the electric signals that are generated by the electronic triggering devices. The electronic switching components are normally inside a separate housing known as an electronic control unit (ECU) or control module.

Timing advance is controlled mechanically in the same way as in the breaker point’s type system.

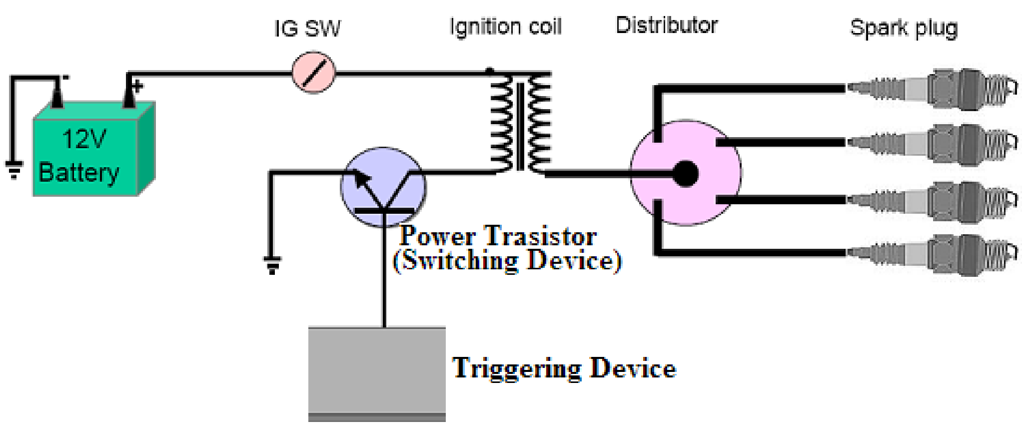


Figure 21-17 Switching and triggering Devices

3.8.1 Switching Systems

Electronic ignition systems control the primary circuit with an NPN transistor. The transistor's emitter is connected to ground. The collector is connected to the negative (-) terminal of the coil. When the triggering device supplies a small amount of current to the base of the switching transistor, the collector and emitter allow current to build up in the coil primary circuit. When the current to the base is interrupted by the switching device, the collector and emitter interrupt the coil primary current. An example of how this works is shown in Figure 21-17, which is a simplified diagram of an electronic ignition system.

3.8.2 Electronic Triggering Devices

The time when the primary circuit must be opened and closed is related to the position of the pistons and the crankshaft. Therefore the position of the crankshaft is used to control the flow of current to the base of the switching transistor.

A number of different types of sensors are used to monitor the position of the crankshaft and control the flow of current to the base of the transistor. These generators serve as triggering devices and include:

- Magnetic pulse generators
- Metal detection sensors
- Hall-effect sensors
- Photoelectric (optical) sensors.

The mounting location of these sensors depends on the design of the ignition system. All four types of sensors can be mounted in the distributor, which is turned by the camshaft.

Magnetic pulse generators and Hall-effect sensors can also be located on the crankshaft. These sensors are also commonly used on Computerized Ignition Systems.

3.8.3 Operating Principles of Electronic Ignition System

The primary circuit of a distributor ignition system is controlled electronically by one of the triggering devices and an electronic control unit (module) that contains some type of switching device.

When the ignition switch is in the ON position, current from the battery flows through the ignition switch and primary circuit resistor to the primary winding of the ignition coil. From there it passes through some type of switching device and back to ground. The switching device is controlled by the triggering device. The current flow in the ignition coil's primary winding creates a magnetic field. The switching device or control module interrupts this current flow at predetermined times. When it does, the magnetic field in the primary winding collapses. This collapse generates a high-voltage surge in the secondary winding of the ignition coil. The secondary circuit of the system begins at this point and as a result the spark plug fires.

Once the park plug stops firing, the transistor closes the primary coil circuit. The length of time the transistor allows the current flow in the primary ignition circuit is determined' by the electronic circuitry in the control module.

Some systems used a dual ballast resistor. The ceramic ballast resistor assembly is mounted on the fire wall and has a ballast resistor [or primary current flow and an auxiliary resistor for the control module. The ballast resistor has a 0.5-ohm resistance that maintains a constant primary current. The auxiliary ballast resistor uses a 5-ohm resistance to limit voltage to the electronic control unit.

Main characteristics of Electronic Ignition System

- The signal generator (triggering Device) generates an ignition signal.
- The igniter (Switching Device) receives the ignition signal and causes the primary current to flow intermittently
- The ignition coil, to which the primary current has been shut off abruptly, generates a high-voltage current.
- The distributor distributes the high voltage current generated by the secondary coil to the spark plugs.

- The spark plugs receive the high voltage current and ignite the air-fuel mixture. The timing advance is controlled through the use of the governor advancer or vacuum advancer.

a) Magnetic Pulse Generator

Basically, a magnetic pulse generator consists of two parts: a timing disc and a pick-up coil. The timing disc may also be called a reluctor, trigger wheel, pulse ring, armature, or timing core. The pick-up coil, which consists of a length of wire wound around a weak permanent magnet, may also be called a stator, sensor, or pole piece. Depending on the type of ignition system used, the timing disc may be mounted on the distributor shaft, at the rear of the crankshaft (Figure 21-18), or on the crankshaft vibration damper (Figure 21-19).

The magnetic pulse or PM generator operates on basic electromagnetic principles. Remember that a voltage can only be induced when a conductor moves through a magnetic field. The magnetic field is provided by the pick-up unit and the rotating timing disc provides the movement through the magnetic field needed to induce voltage.

As the disc teeth approach the pick-up coil, they repel the magnetic field, forcing it to concentrate around the pick-up coil (Figure 21-20A). Once the tooth passes by the pick-up coil, the magnetic field is free to expand or unconcentrate (Figure 21-20B), until the next tooth on the disc approaches. Approaching teeth concentrate the magnetic lines of force, while passing teeth allow them to expand. This pulsation of the magnetic field causes the lines of magnetic force to cut across the winding in the pick-up coil, inducing a small amount of AC voltage that is sent to the switching device in the primary circuit.

When a disc tooth is directly in line with the pick-up coil, the magnetic field is not expanding or contracting.

When a disc tooth is directly in line with the pick-up coil, the magnetic field is not expanding or contracting.

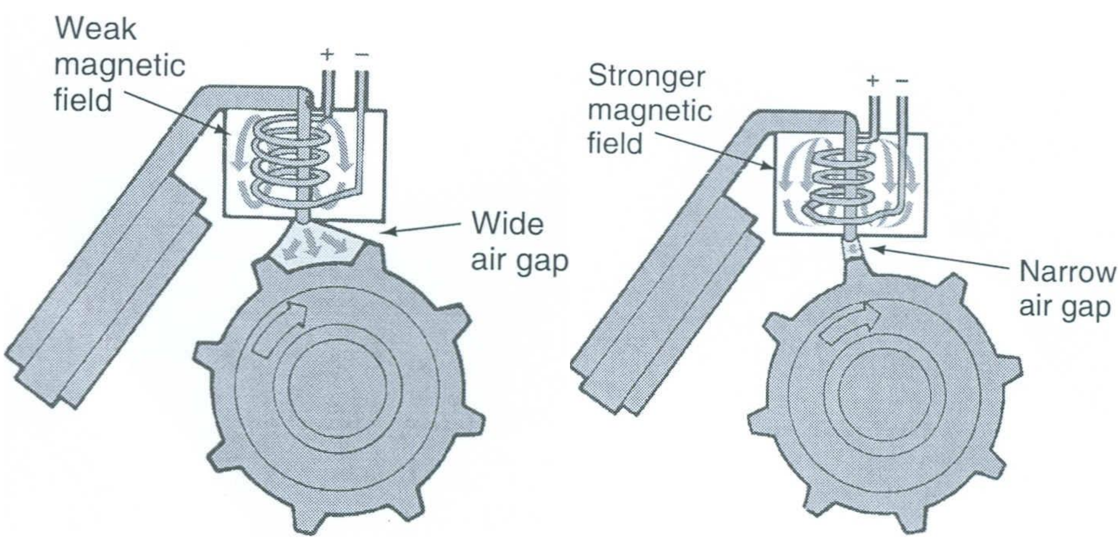
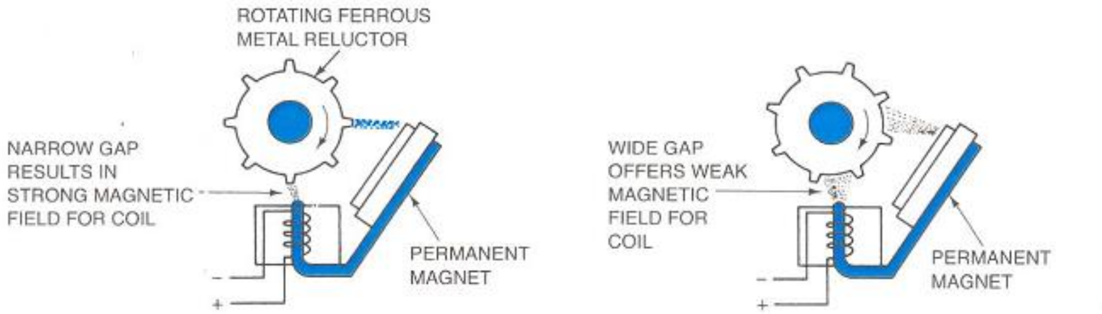
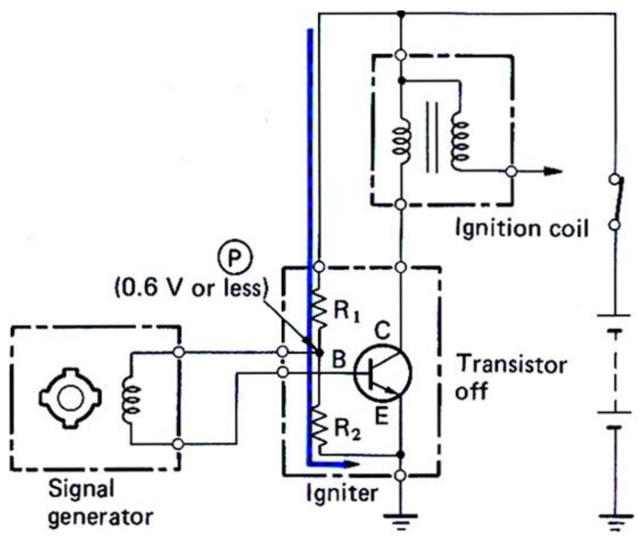


Figure 21-20 Single Pole

(A) Wide gap produces a weak magnetic signal (B) Narrow gap produces a strong magnetic field.

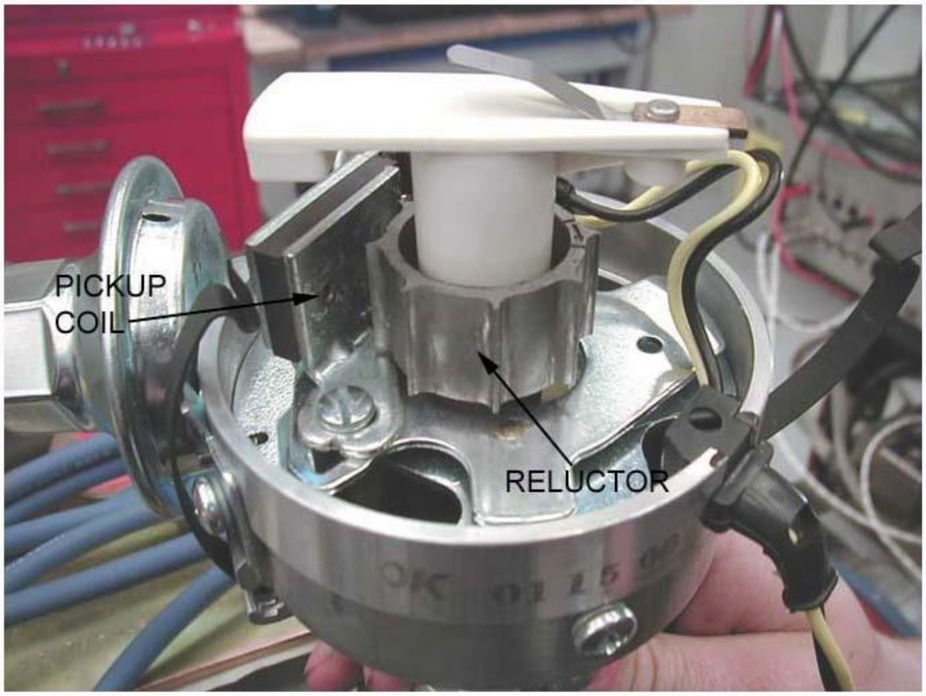




Since there is no movement or change in the field, voltage at this precise moment drops to zero. At this point, the switching device inside the ignition module reacts to the zero voltage signals by turning the ignition's primary circuit Current off. As explained earlier; this forces the magnetic field in the primary coil to collapse, discharging a secondary voltage to the distributor or directly to the spark plug. As soon as the tooth rotates past the pick-up coil, the magnetic field expands again and another voltage signal is induced. The only difference is that tlle polarity of the charge is reversed. Negative becomes positive or positive becomes negative. Upon sensing this change in voltage, the switching device turns the primary circuit back on and the process begins all over.

The slotted disc is mounted on the crankshaft, vibration damper, or distributor shaft in a very precise manner. When the disc teeth align with the pick-up coil this corresponds to the exact time certain pistons are nearing TDC. This means the zero voltage signal needed to trigger the secondary circuit occurs at precisely the correct time.

The pick-up coil might have only one pole as shown as **Figure 21-21.** Other magnetic pulse generators have pick-up coils with two or more poles.



The pulse generator is very popular and still used for many applications today because its a rugged durable design. In addition the sensor is not powered (like in Hall Effect) so it can be used in self powered magneto ignition applications. The problem with magnetic is that at higher RPM the sensor has trouble seeing "teeth" close together on the magnetic rotor. This is a bigger problem with many cylinder engines and/or high RPM applications. Also, you may remember magnets tend to loose their strength with vibration and heat.

Main characteristic of Pickup coil (pulse generator):

- The magnetic pulse generator is installed in the distributor housing.
- The pulse generator consists of a trigger wheel (reluctor) and a pickup coil.
- The pickup coil consists of an iron core wrapped with fine wire, in a coil at one end and attached to a permanent magnet at the other end
- The center of the coil is called the pole piece.
- The pickup coil signal triggers the transistor inside the module and is also used by the computer for piston position information and engine speed (RPM).
- If the distributor has advance mechanisms, the centrifugal advance is sometimes mounted under the pickup plate, and the vacuum advance is positioned on the side of the distributor.

b) Metal Detection Sensors

Metal detection sensors are found on early electronic ignition systems. They work much like a magnetic pulse generator with one major difference.

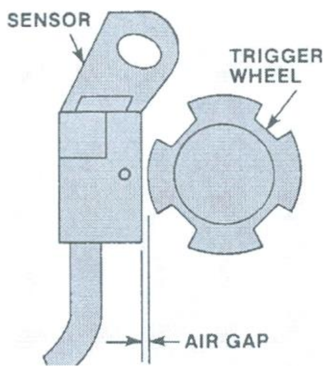


Figure 21-22 In a metal detecting sensor, the revolving trigger wheel teeth alter the magnetic field produced by the electromagnet in the pick-up coil

A trigger wheel is pressed over the distributor shaft and a pick-up coil detects the passing of the trigger teeth as the distributor shaft rotates. However, unlike a magnetic pulse generator, the pick-up coil of a metal detection sensor does not have a permanent magnet. Instead. the pick-up coil is an electromagnet. A low level of current is supplied to the coil by an electronic control unit, inducing a weak magnetic field around the coil. As the reluctor on the distributor shaft rotates, the trigger teeth pass very close to the coil (Figure 21-22). As the teeth pass in and out of the coil's magnetic field, the magnetic field builds and collapses, producing a corresponding change in the coil's voltage. The voltage changes are monitored by the control unit to determine crankshaft position.

c) Hall-Effect Sensor

This is the most widely used type of ignition sensor. The Hall Effect (named after the American physicist Edwin Herbert Hall, 1855-1938) involves the generation of an "electric potential perpendicular to both an electric current flowing along a conducting material and an external magnetic field applied at right angles to the current upon application of the magnetic field".

The Hall-effect sensor or switch is the most commonly used engine position sensor. There are several good reasons for this. Unlike a magnetic pulse generator, the Hall-effect sensor produces an accurate voltage signal throughout the entire rpm range of the engine. Furthermore, a Hall-effect switch produces a square wave signal that is more compatible with the digital signals required by on-board computers.

Functionally, a Hall switch performs the same tasks as a magnetic pulse generator. But the Hall switch's method of generating voltage is quite unique. It is based on the Hall-effect principle, which states: If a current is allowed to flow through a thin conducting material, and that material is exposed to a magnetic field, voltage is produced.

The heart of the Hall generator is a thin semiconductor layer (Hall layer) derived from a gallium arsenate Crystal. Attached to it are two terminals-one positive and the other negative-that are used to provide the source current for the Hall transformation.

Directly across from this semiconductor element is a permanent magnet. It is positioned so that its lines of flux bisect the Hall layer at right angles to the direction of current flow. Two additional terminals located on either side of the Hall layer, form the signal output circuit.

When a moving metallic shutter blocks the magnetic field from reaching the Hall layer or element, the Hall-effect switch produces a voltage signal. When the shutter blade moves and allows the magnetic field to expand and reach the Hall element, the Hall-effect switch does not generate a voltage signal (Figure 21-23

The Hall switch is described as being "on" any time the Hall layer is exposed to a magnetic field and a Hall voltage is being produced (Figure 21-24). However, before this signal voltage can be of any use, it has to be modified. After leaving the Hall layer, the signal is routed to an amplifier where it is strengthened and inverted so the signal reads high when it is actually coming in low and vice versa. Once it has been inverted, the signal goes through a pulse-shaping device called the Schmitt trigger where it is turned into a clean square wave signal. After conditioning, the signal is sent to the base of a switching transistor that is designed to turn on and off in response to the signals generated by the Hall switch assembly.

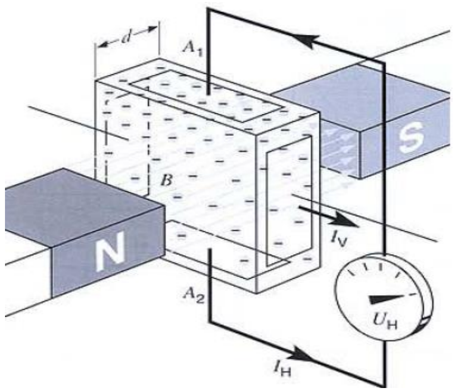
The shutter wheel is the last major component of the Hall switch. The shutter wheel consists of a series of alternating windows and vanes that pass between the Hall layer and magnet. The shutter wheel may be part of air gap, the magnetic field is deflected away from the Hall layer; Hall voltage decreases. When that happens, the modified Hall output signal increases abruptly and turns on the switching transistor. Once the transistor is turned on, the primary circuit closes and the coil's energy storage cycle begins.

Primary current continues to flow as long as the vane is in the air gap. As the vane starts to leave the gap, however, the refon11ing Hall voltage signal prompts a parallel decline in the modified output signal. When the output signal goes low, the bias of the transistor changes. Primary current flow stops.

In summary, the ignition module supplies current to the coil's primary winding as long as the shutter wheel's vane is in the air gap. As soon as the shutter wheel moves away and the Hall voltage is produced, the control unit stops primary circuit current, high secondary voltage is induced, and ignition occurs. In addition to ignition control, a Hall switch can also be used to generate precise rpm signals (by determining the frequency at which the voltage rises and falls) and provide the sync pulse for sequential fuel ignition operation.

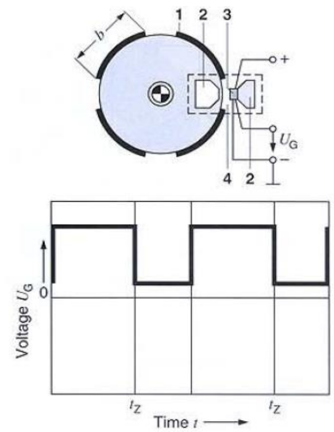
Hall Effect

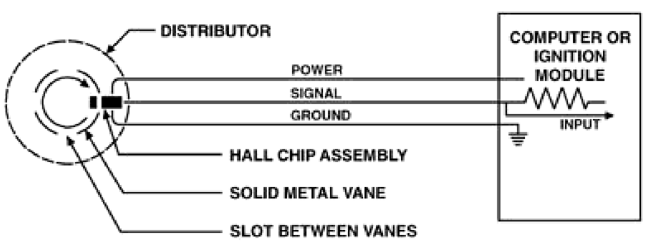
B Flux density of the magnet field, *IH* Hall current, *Iv* Supply current, *UH* Hall voltage, *h* thickness.

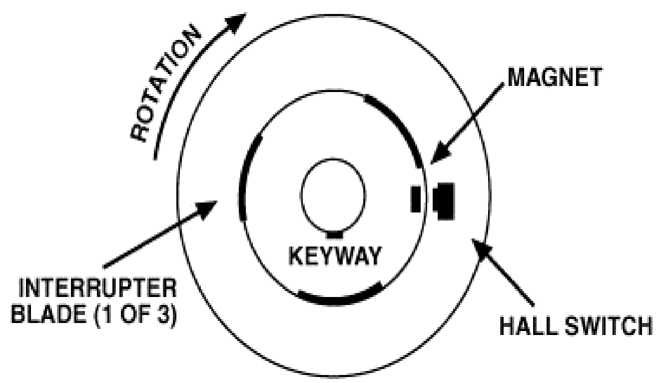


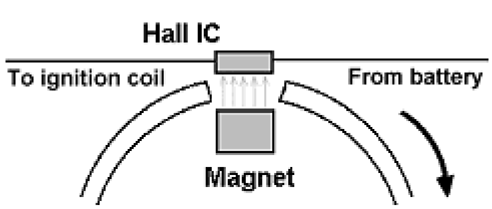
Hall Generator in the Ignition System

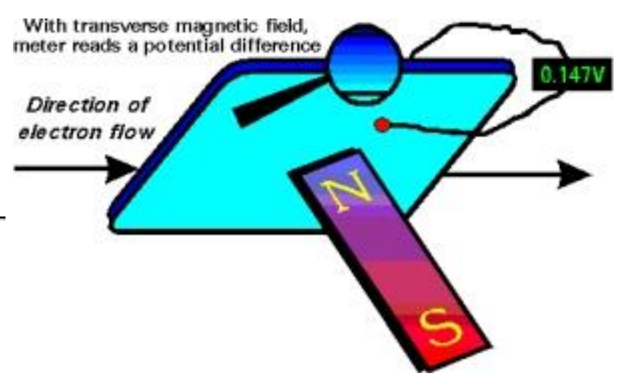
1 Vane with width b, 2 Soft magnetic conductive with permanent magnet, 3 Hall IC, 4 Air gap.







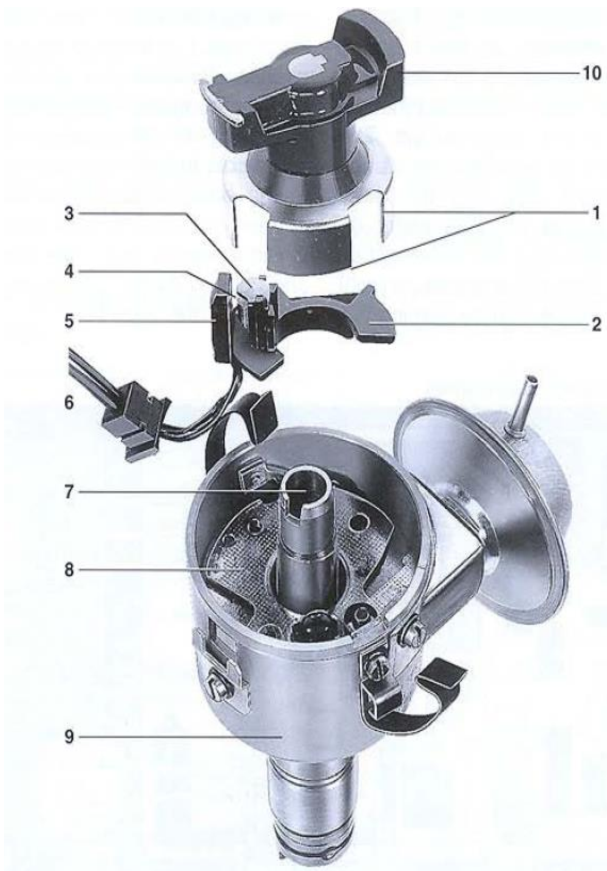




Ignition Distributor with Hall generator

1 Van, 2 Vane switch, 3 Conductive element, 4 Air gap,

5 Hall IC, 6 Three core hall generator lead, 7 Ignition distributor shaft, 8 Carrying plate, 9 distributor housing, 10 rotor.

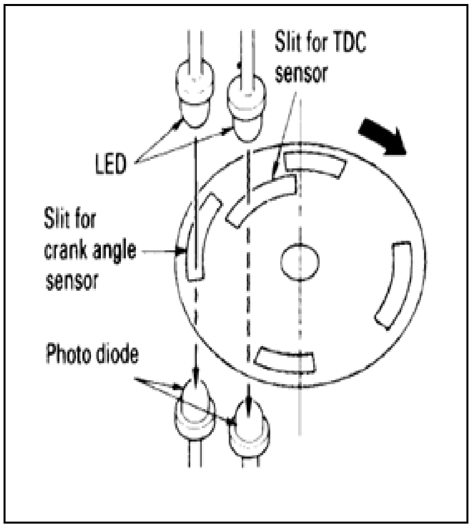


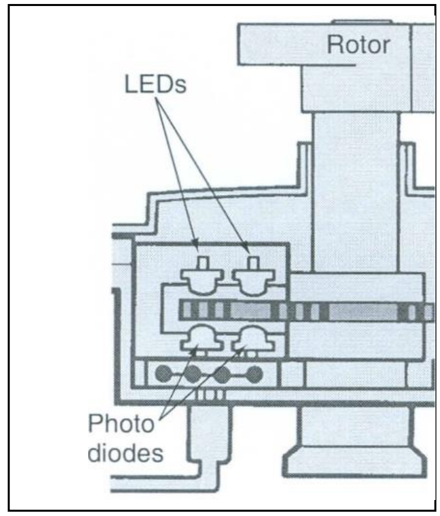
d) Photoelectric Sensor

A fourth type of crankshaft position sensor is the photoelectric sensor. The parts of this sensor include a light emitting diode (LED), a light-sensitive phototransistor (photo cell), and a slotted disc called a light beam interrupter (Figure 21-26). The slotted disc is attached to the distributor shaft.

The LED and the photo cell are situated over and under the disc opposite each other. As the slotted disc rotates between the LED and photo cell, light from the LED shines through the slots. The intermittent flashes of light are translated into voltage pulses by the photo cell. When the voltage signal occurs, the control unit tums on the primary system. When the disc interrupts the light and the voltage signal ceases, the control unit turns the primary system off, causing the magnetic field in the coil to collapse and sending a surge of voltage to a spark plug.

The photoelectric sensor sends a very reliable signal to the control unit, especially at low engine speeds. These units have been primarily used on Chlysler and Mitsubishi engines. Some Nissan and General Motors products have used them as well.





3.9 COMPUTERIZED IGNITION SYSTEMS (CIS)

As technology advanced, many manufacturers expanded the ability of the ignition control modules. For example, by tying a manifold vacuum sensor into the ignition module circuitry, the module could now detect when the engine was under heavy load and retard the timing automatically. Similar add-on sensors and circuits were designed to control spark knock, start-up emissions, and altitude compensation.

Computer-Controlled Ignition Computer-controlled ignition systems offer continuous spark timing control through a network of engine sensors and a central microprocessor. Based on the inputs it receives, the central microprocessor or computer makes decisions regarding spark timing and sends signals to the ignition module to fire the spark plugs according to those inputs and the programs in its memory.

Timing control is selected by the computer's program. During engine starting, computer control is by-passed and the mechanical setting of the distributor controls spark timing. Once the engine is started and running, spark timing is controlled by the computer. This scheme or strategy allows the engine to start regardless of whether the electronic control system is functioning properly or not. The goal of computerized spark timing is to produce maximum engine power, top fuel efficiency, and minimum emissions levels during all types of operating conditions.

The computer does this by continuously adjusting ignition timing. The computer determines the best spark timing based on certain engine operating conditions such as crankshaft position, engine speed, throttle position, engine coolant temperature, and initial and operating manifold or barometric pressure. Once the computer receives input from these and other sensors, it compares the existing operating conditions to information permanently stored or programmed into its memory. The computer matches the existing conditions to a set of conditions stored in its memory, determines proper timing setting, and sends a signal to the ignition module to fire the plugs.

The computer continuously monitors existing conditions, adjusting timing to match what its memory tells it is the ideal setting for those conditions. It can do this very quickly, making thousands of decisions in a single second.

The control computer typically has the following types of information permanently programmed into it;

Speed-related spark advance. As engine speed increases to a particular point, there is a need for more advanced timing. As the engine slows, the timing should be retarded or have less advance. The computer bases speed-related spark advance decisions on engine speed and signals from the TP sensor.

Load-related spark advance. This is used to improve power and fuel economy during acceleration and heavy load conditions. The computer defines the load and the ideal spark advance by processing information from the TP sensor, MAP, and engine speed sensors. Typically, the more load on an engine, the less spark advance is needed.

Wam1-up spark advance. This is used when the engine is cold, because a greater amount of advance is required while the engine warms up.

Special spark advance. This is used to improve fuel economy during steady driving conditions. During constant speed and load conditions, the engine will be more efficient with much advance timing.

Spark advance due to barometric pressure. This is used when barometric pressure exceeds a preset calibrated value.

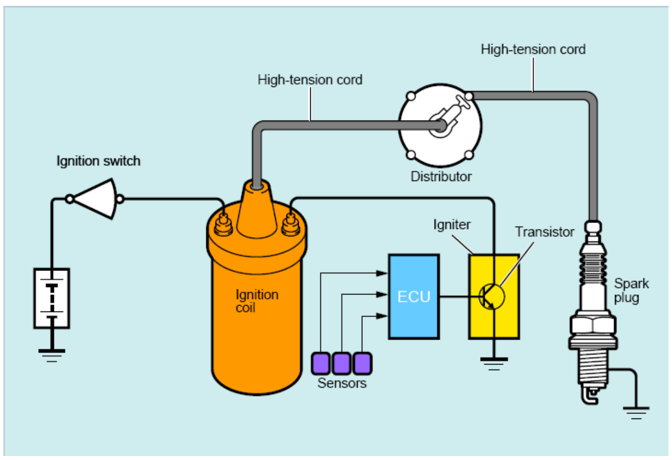
All of this information is looked at by the computer to determine the ideal spark timing for all conditions. The calibrated or programmed information in the computer is contained in what is called software look-up tables.

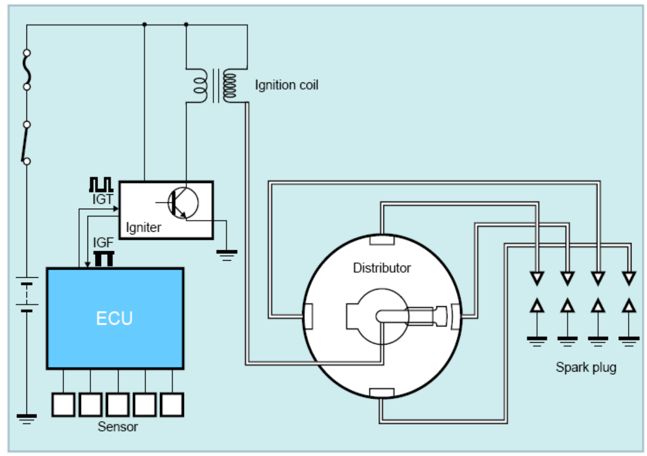
Compared to the mechanical ignition timing control of the conventional system, the control method with the Electronic Spark Advance (ESA) provides higher precision, and the freedom to set the ignition timing. Also

The Electronic Spark Advance can work in conjunction with the electronic fuel control system to provide emission control, optimum fuel economy and improved driveability.

3.9.1 Computerized Ignition Systems with Distributors

The Computerized ignition is very similar in principle to the Electronic ignition, governing the flow of current to the spark plugs. Where the electronic ignition system relies on the pulses signal produced by a rotating reluctor and magnetic-pickup coil to trigger a transistor switch to break the low-voltage a computerized ignition system use a sensor. The use of the mechanical vacuum advancer and the governor advancer has been discontinued in this type. Instead, the Electronic Spark Advance function of the engine ECU controls the ignition timing.





Main Characteristics of a Computerized Ignition with Distributor

The engine ECU receives the signals from various sensors, calculates the optimal ignition timing, and sends an ignition signal to the igniter. (The engine ECU controls the timing advance.)

The igniter receives the ignition signal and causes the primary current to flow intermittently.

The ignition coil, to which the primary current has been shut off abruptly, generates a high-voltage current.

The distributor distributes the high voltage current generated by the secondary coil to the spark plugs.

The spark plugs receive the high voltage current and ignite the air-fuel mixture.

The engine ECU, which receives signals from various sensors, calculates the ignition timing and transmits ignition signals to the igniter. The ignition timing is calculated continuously in accordance with the conditions of the engine, based on the optimal ignition timing values that are stored in the computer in the form of an electronic Spark Advance (ESA) map.

3.9.2 Distributorless Ignition Systems (DIS)

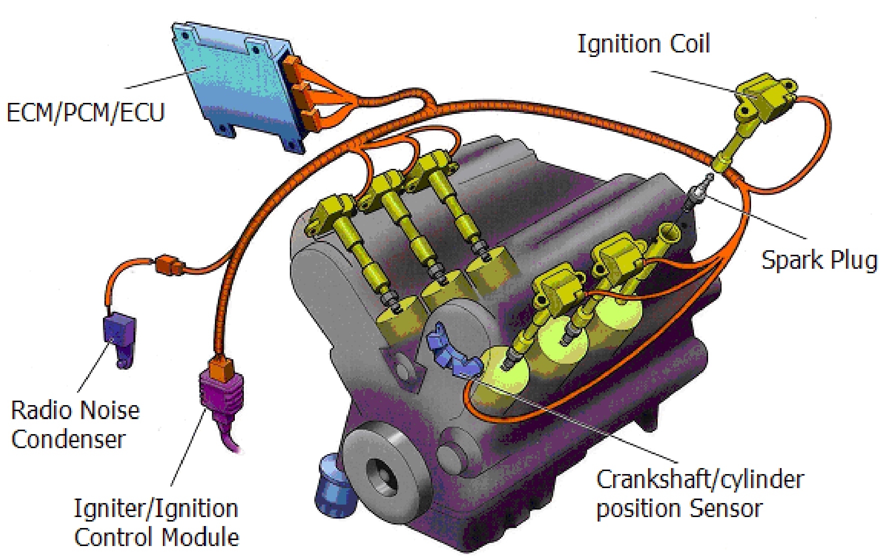
When you eliminate the distributor, you need another system to generate a signal for the engine control unit (ECU) to know when each piston reaches top dead center (TDC). This can be accomplished by taking a signal from a pulse generator attached to either the front pulley on the crankshaft, or the circumference of the flywheel. The ECU can then use this signal to determine the correct ignition timing and advance firing angle for each cylinder, and can switch (trigger) the low voltage primary circuit on and off at the correct moment.

In Computerized Distributorless Ignition Systems each cylinder may have its own ignition coil, or two cylinders may share one coil. The coils are wired directly to the spark plug they control. An ignition control module, tied into the vehicle's computer control system, controls the tiring order and the spark timing and advance.

Since the distributor is eliminated in Computerized Distributorless ignition systems, ignition timing remains more stable over the life of the engine, which means improved economy and performance with reduced emissions.

There are many advantages of a distributorless ignition system over one that uses a distributor. Here are some of the more important ones:

- Fewer moving parts, therefore less friction and wear.
- Flexibility in mounting location. This is important because of today's smaller engine compartments.
- Less required maintenance; there is no rotor or distributor cap to service.
- Reduced radio frequency interference because there is no rotor to cap gap.
- Elimination of a common cause of ignition misfire, the buildup of water and ozone/nitric acid in the distributor
- Elimination of mechanical timing adjustments.
- Places no mechanical load on the engine in order to operate.
- Increased available time for coil saturation.
- Increased time between firings, which allows the coil to cool more.



Distributorless Ignition Systems completely eliminates the need for a distributor and, with it, the distributor cap! The distributor cap is a major problem on high revving race vehicles when you increase the spark plug gap and the secondary ignition voltage. With higher voltages and bigger spark plug gaps, flash over, or cross firing, is more likely, especially between adjacent terminal posts in the distributor cap. And the terminals posts in the distributor are even close together when your engine has eight or more cylinders

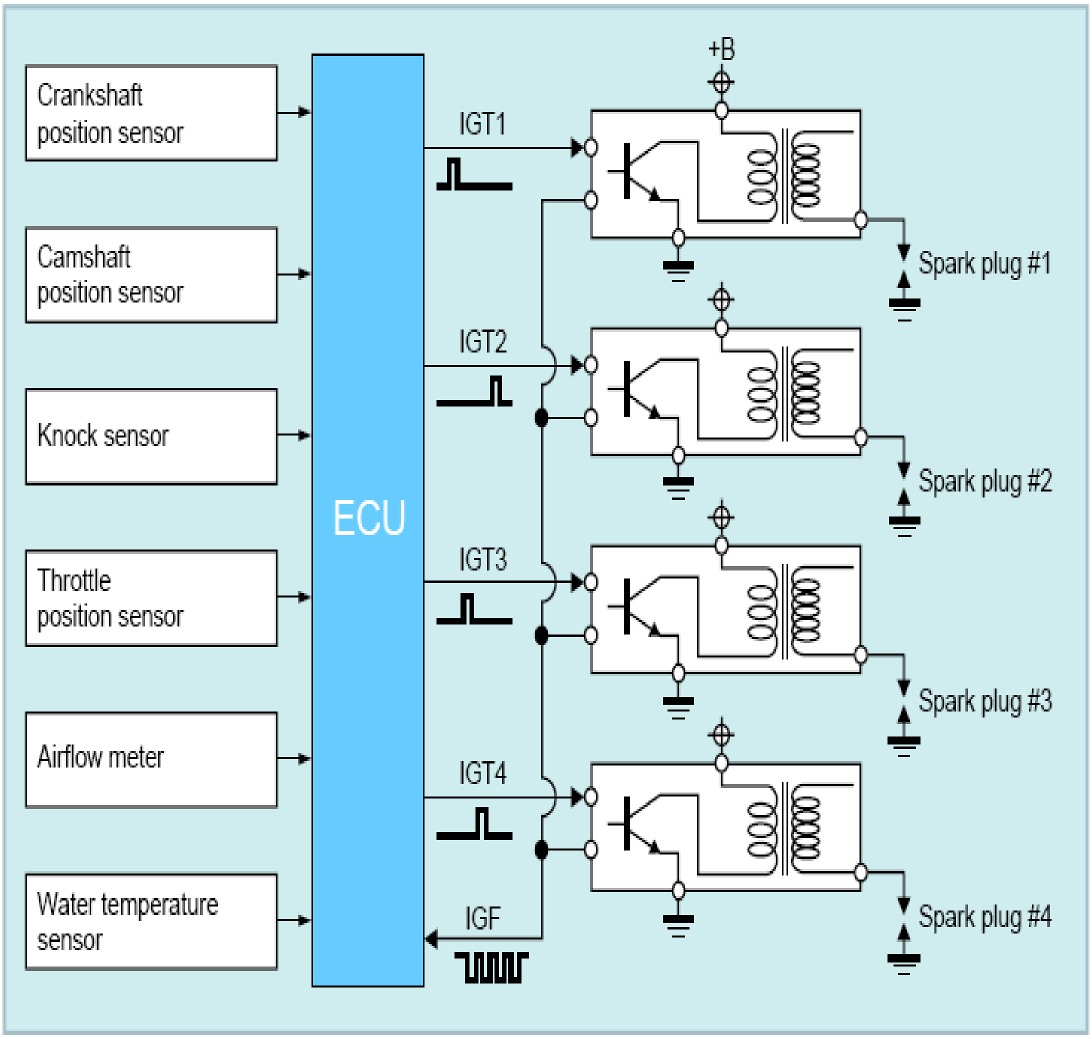
The important thing on a distributorless ignition system is to ensure that the **pulse trigger** is correctly mounted. This actually requires three things you need to check: the **firing pin diameter**, the **firing pin possition**, and the **air gap**.

Basic Components

The Computer/ECU/PCM/ECM. Ignition module (Igniter) and position sensors combine to control spark timing and advance. The Computer collects and processes information to determine the ideal amount of spark advance for the operating conditions. The ignition module uses crank/cam sensor data to control the timing of the primary circuit in the coils (Figure below). Remember that there is more than one coil in a distributorless ignition system. The ignition module synchronizes the coils' firing sequence in relation to crankshaft position and firing order of the engine. Therefore, the ignition module takes the place of the distributor.

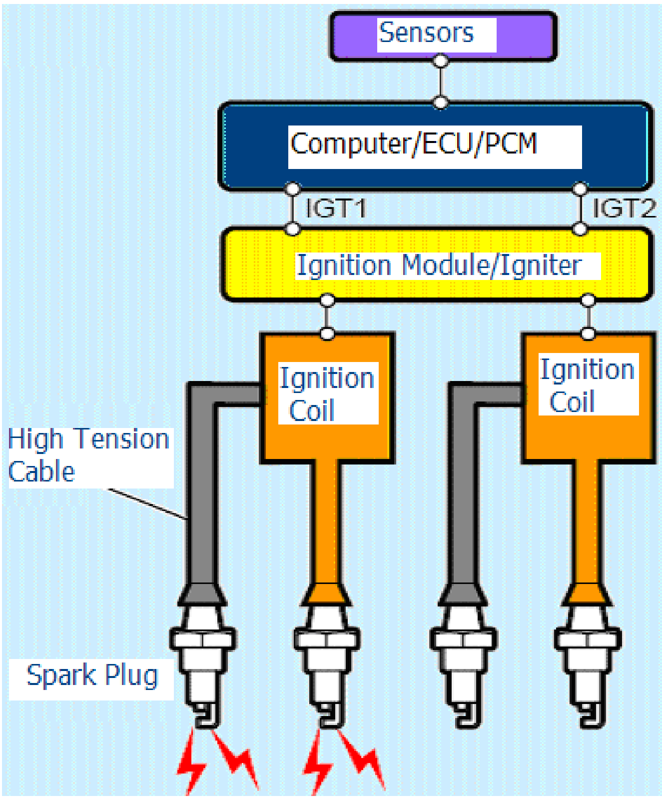
Primary current is controlled by transistors in the control module. There is one switching transistor for each ignition coil in the system. The transistors complete the ground circuit for the primary circuit, thereby allowing for a dwell period. When primary current flow is interrupted, secondary voltage is induced in the coil and the coil's spark plug(s) fire. The timing and sequencing of ignition coil action is determined by the control module and input from sensors (triggering device).

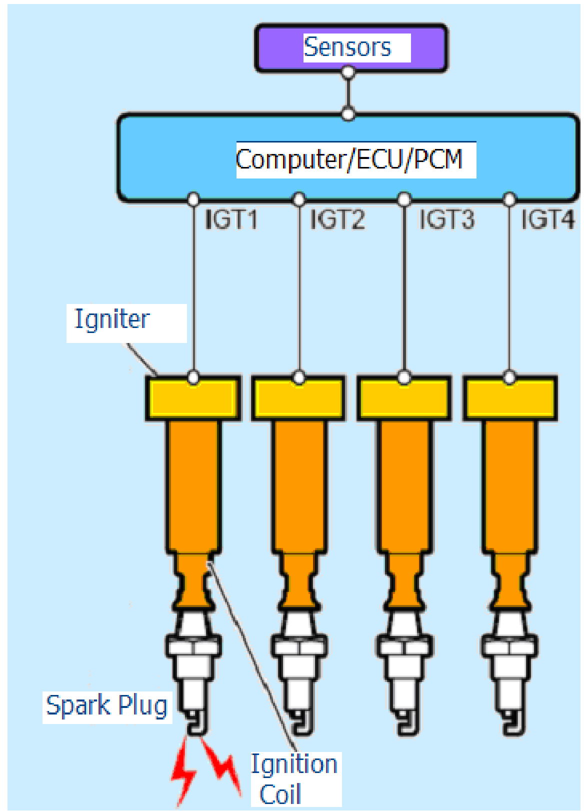
The control module is also responsible for limiting the dwell time. There is time between plug firings to saturate the coil. Achieving maximum current flow through the coil is great if the system needs the high voltage that may be available. However if the high voltage is not needed, the high current is not needed and the heat it produces is not desired. Therefore, the control module is programmed to only allow total coil saturation when the very high voltage is needed or the need for it is anticipated.



The ignition module also adjusts spark timing below 400 rpm (for starting) and when the vehicle's control computer by-pass circuit becomes open or grounded. Depending on the exact DIS system, the ignition coils can be serviced as a complete unit or separately. On those DIS systems that use one coil per spark plug, the electronic ignition module determines when each spark plug should fire and controls the on/off time of each plug's coil.

The systems with a coil for every two spark plugs also use an electronic ignition module, but they use the waste **spark** method of spark distribution. Each end of the coil's secondary winding is attached to a spark plug. Each coil is connected to a pair of spark plugs in cylinders whose pistons rise and fall together. When the field collapses in the coil, voltage is sent to both spark plugs that are attached to the coil. In all V-6s, the paired cylinders are 1 and 4, 2 and 5, and 3 and 6 (or 4 and 1 and 3 and 2 on 4-cylinder engines). With this arrangement, one cylinder of each pair is on its compression stroke while the other is on the exhaust stroke. Both cylinders get spark simultaneously, but only one spark generates power, while the other is wasted out the exhaust. During the next revolution, the roles are reversed. Due to the way the secondary coils are wired, when the induced voltage cuts across the primary and secondary windings of the coil, one plug fires in the n01mal direction-positive center electrode to negative side electrode and the other plug fires just the reverse side to center electrode, both plugs fire simultaneously, completing the series circuit. Each plug always fires the same way on both the exhaust and compression strokes. The coil is able to overcome the increased voltage requirements caused by reversed polarity and still fire two plugs simultaneously because each coil is capable of producing up to 100,000 volts. There is very little resistance across the plug gap on exhaust, so the plug requires very little voltage to fire, thereby providing its mate (the plug that is on compression) with plenty of available voltage





A few DIS systems have one coil per cylinder with two spark plugs per cylinder. During starting only one plug is fired. Once the engine is running the other plug also fires. One spark plug is located on the intake side of the combustion chambers while the other is located on the exhaust side. Two coil packs are used, one for the plugs on the intake side and the other for the plugs on the exhaust side.

These systems are called **dual plug** systems. During dual plug operation, the two coil packs are synchronized so each cylinder's two plugs fire at the same Therefore, on a four-cylinder engine, four spark plugs are fired at a time: two during the compression stroke of the cylinder and two during the exhaust stroke of another cylinder.

Operation of Distributorless Ignition Systems

From a general operating standpoint, most distributorless ignition systems are similar. However, there are variations in the way different distributorless systems obtain a timing reference in regard to crankshaft and camshaft position.

Some engines use separate Hall-effect sensors to monitor crankshaft and camshaft position for the control of ignition and fuel injection firing orders. The crankshaft pulley has interrupter rings that are equal in number to half of the cylinders of the engine (Figure 21-45). The resultant signal informs the PCM as to when to fire the plugs. The camshaft sensor helps the computer determine when the number one piston is at TDC on the compression stroke.

Defining the different types of EI systems used by manufacturers focuses on the location and type of sensors used. There are other differences, such as the construction of the coil pack, wherein some are a sealed assembly and others have individually mounted ignition coils. Some EI systems have a camshaft sensor mounted in the opening where the distributor was mounted. The camshaft sensor ring has one notch and produces a leading edge and trailing edge signal once per camshaft revolution. These systems also use a crankshaft sensor. Both the camshaft and crankshaft sensors are Hall-effect sensors.

Locating the cam sensor in the opening previously occupied by the distributor merely takes advantage of the bore and gear that was already present. Seeing that the distributor was driven at camshaft speed, driving a camshaft position sensor by the same mechanism just made sense (Figure 21-46). This modification really made sense when older engine designs were modified for distributorless ignition.

As the crankshaft rotates and the interrupter passes in and out of the Hall-effect switch, the switch turns the module reference voltage on and off. The three signals are identical and the control module can not distinguish which of these signals to assign to a particular coil. The signal from the cam sensor gives the module the information it needs to assign the signals from the crankshaft sensors to the appropriate coils (Figure 21-47). The camshaft sensor synchronizes the crankshaft sensor signals with the position of the number one cylinder. From there the module can energize the coils according to the firing order of the engine. Once the engine has started, the camshaft signal serves no purpose.

Some systems have the camshaft sensor mounted in the front of the timing chain cover (Figure 21-48). A magnet on the camshaft gear rotates past the inner end of the camshaft sensor and produces a signal for each camshaft revolution. GM's 3.8 L non-turbocharged SFI V-6 engine has a firing order of 1-6-5-4-3-2. Spark plugs 1-4, 6-3, and 5-2 are paired together on the coil assembly. When a trailing edge camshaft sensor signal is received during initial starting, the coil module prepares to fire the coil connected to spark plugs 5-2. After the camshaft sensor signal is received, the next trailing edge crankshaft sensor signal turns on the primary circuit of the 5- 2 coil, and the next leading edge crankshaft sensor signal informs the coil module to open the primary circuit of the 5-2 coil (Figure 21-49). When this coil fires, one of these cylinders is always on the compression stroke and the other cylinder is on the exhaust stroke. After the 5-2 coil firing, the coil module fires the 1-4 coil and the 6- 3 coil in sequence. This firing sequence provides the correct firing order.

On an SFI engine, the PCM grounds each injector individually. The cam sensor signal is also used for injector sequencing. This cam sensor signal is sent from the cam sensor through the coil module to the PCM. The PCM grounds each injector in the intake port when the piston for that cylinder is at 70 degrees before IDC on the intake stroke. When a crankshaft sensor failure occurs, the engine does not start. If the camshaft sensor signal becomes defective with the engine running, the engine continues to run, but the PCM reverts to multiport fuel injection without the camshaft signal information. Under this condition, engine performance and economy decrease and emission levels may increase. When an engine with a defective cam sensor is shut off, it will not restart.

Other systems use a dual crankshaft sensor located behind the crankshaft pulley. When this type of sensor is used, there are two interrupter rings on the back of the pulley **(Figure 21-50)** that rotate through the Hall-effect switches at the dual crankshaft sensor. The inner ring with three equally spaced blades rotate through the inner Hall-effect switch, whereas the outer ring with one opening rotates through the outer Hall-effect. In this dual sensor, the inner sensor provides three leading edge signals and the outer sensor produces one leading edge during one complete revolution of the crankshaft. The outer sensor is the SYNC sensor. This outer sensor is referred to as a synchronizer (SYNC) sensor. The signal from this sensor informs the coil module regarding crankshaft position. The SYNC sensor signal occurs once per crankshaft revolution and this signal is synchronized with the inner crankshaft sensor signal to fire the 6-3 coil. The examples given so far depend on two revolutions of the crankshaft to inform the PCM as to which number cylinder is ready. These systems are referred to as slowstart systems because the engine must crank through two crankshaft revolutions before ignition begins.

The **Fast-Start** electronic ignition system used in GM's Northstar system uses two crankshaft position sensors **(Figure 21-51).** A reluctor ring with 24 evenly spaced notches and 8 unevenly spaced notches is cast onto the center of the crankshaft. When the reluctor ring rotates past the magnetic-type sensors, each sensor produces 32 high- and low-voltage signals per crankshaft revolution. The "A" sensor is positioned in the upper crankcase, and the "B" sensor is positioned in the lower crankcase. Since the A sensor is above the B sensor, the signal from the A sensor occurs 27 degrees before the B sensor signal. The signals from the two sensors are sent to the ignition control module. This module counts the number of signals from one of the sensors that are between the other sensor signals to sequence the ignition coils properly. This allows the ignition system to begin firing the spark plugs within 180 degrees of crankshaft rotation while starting the engine. This system allows for much quicker starting than other EI systems which require the crankshaft to rotate one or two times before the coils are sequenced.

The camshaft position sensor is located in the rear cylinder bank in front of the exhaust camshaft sprocket. A reluctor pin in the sprocket rotates past the sensor, and this sensor produces one high- and one low-voltage signal every camshaft revolution, or every two crankshaft revolutions. The PCM uses the camshaft position sensor signal to sequence the injectors properly.

Another example of a **fast-start** system also uses a dual crankshaft sensor at the front of the crankshaft. The cam sensor is mounted in the timing gear cover. Two Hall-effect switches are located in the dual crankshaft sensor, and two matching interrupter rings are attached to the back of the crankshaft pulley. The inner ring on the crankshaft pulley has three blades of unequal lengths with unequal spaces between the blades. On the outer ring, there are 18 blades of equal length with equal spaces between the blades. The signal from the inner Hall-effect switch is referred to as the 3X signal, while the outer Hall-effect switch is called the 18X signal. These signals are sent from the dual crankshaft sensor to the coil module. The coil module knows which coil to fire from the number of 18X signals received during each 3X window rotation. For example, when two 18X signals are received, the coil module is programmed to sequence coil 3-6 next in the firing sequence. Within 120 degrees of crankshaft rotation, the coil module can identify which coil to sequence, and thus start firing the spark plugs. Therefore, the system fires the spark plugs with less crankshaft rotation during initial starting than the previous slow-start systems. Once the engine is running, the system switches to the EST mode. The PCM uses the 18X signal for crankshaft position and speed information. The 18X signal may be referred to as a high-resolution signal. If the 18X signal is not present, the engine will not start. When the 3X signal fails with the engine running, the engine continues to run, but the engine refuses to restart. In this system, the cam sensor signal is used for injector sequencing, but it is not required for coil sequencing. If the cam sensor signal fails, the PCM logic begins sequencing the injectors after two cranking revolutions. There is a one-in-six chance that the PCM logic will ground the injectors in the normal sequence. When the PCM logic does not ground the injectors in the normal sequence. the engine hesitates on acceleration. Finally, some engines use a magnetic pulse generator.

The timing wheel is cast on the crankshaft and has machined slots on it. If the engine is a six-cylinder, there will be seven slots, six of which are spaced exactly 60 degrees apart. The seventh notch is located 1 0 degrees from the number six notch and is used to synchronize the coil firing sequence in relation to crankshaft position (Figure 21-53). The same triggering wheel can be and is used on four-cylinder engines. The computer only needs to be programmed to interpret the signals differently than on a six-cylinder.

The magnetic sensor, which protrudes into the side of the block, generates a small AC voltage each time one of the machined slots passes by. By counting the time between pulses, the ignition module picks out the unevenly spaced seventh slot, which starts the calculation of the ignition coil sequencing. Once its counting is synchronized with the crankshaft, the module is programmed to accept the AC voltage signals of the select notches for firing purposes.

Ford uses a similar system; however, the reluctor ring has many more slots. The crankshaft sensor for their 4.6 L V-8 engine is a variable reluctance sensor that is triggered by a 36 minus 1 (or 35) tooth trigger wheel located inside the front cover of the engine **(Figure 21-54).** The sensor provides two types of information: crankshaft position and engine speed.

The trigger wheel has a tooth every 10 degrees, with one tooth missing. When the part of the wheel that is missing a tooth passes by the sensor, there is a longer than normal pause between signals from the sensor. The ignition control module recognizes this and is able to identify this long pause as the location of piston # 1.

Chrysler also uses a similar system. However, it uses a different number of teeth on the reluctor, a camshaft sensor, and a camshaft reluctor; therefore, the signals received by the control module are also different. The crankshaft timing sensor is mounted in an opening in the transaxle bell housing. The inner end of this sensor is positioned near a series of notches and slots that are integral with the engine's flywheel.

A group of four slots is located on the flywheel for each pair of engine cylinders. Thus, a total of 12 slots are positioned around the flywheel. When the slots rotate past the crankshaft timing sensor the voltage signal from the sensor changes from 0 V to 5 V. This varying voltage signal informs the PCM regarding crankshaft position and speed. The PCM calculates spark advance from this signal. The PCM also uses the crankshaft timing sensor signal along with other inputs to determine air-fuel ratio. Base timing is determined by the signal from the last slot in each group of slots.

The camshaft reference sensor is mounted in the top of the timing gear cover **(Figure 21-55).** A notched ring on the camshaft gear has two single slots, two double slots, and a triple slot. When a notch rotates past the camshaft reference sensor, the signal from the sensor changes from 0 V to 5 V. The single, double, and triple notches provide different voltage signals. These signals are sent to the PCM. The PCM determines the exact camshaft and crankshaft position from the camshaft reference sensor signals and the PCM uses these signals to sequence the coil primary windings and each pair of injectors at the correct instant.

The development and spreading popularity of Distributorless Ignition System is the result of reduced emissions, improved fuel economy, and increased component reliability brought about by these systems.

Computerized ignition system also offers advantages in production costs and maintenance considerations. By removing the distributor the manufacturers realize substantial savings in ignition parts and related machining costs. Also, by eliminating the distributor, they do away with cracked caps, eroded carbon buttons, burned-through rotors, moisture misfiring, base timing adjustments, and the like.

Since computerized ignition system systems have considerably higher maximum secondary voltage compared to point-type or electronic ignition systems, greater electrical shocks are obtained from Distributorless Ignition System systems. Although such shocks may not be directly harmful to the human body, they may cause you to jump or react suddenly, which could result in personal injury. For example. when you jump suddenly as a result of an Distributorless Ignition System electrical shock. you may hit your head on the vehicle hood or push your hand into a rotating cool-

3.10 TOYOTA COMPUTER CONTROLLED SYSTEM (EFI/TCCS)

3.10.1 Ignition Control

The ignition systems used on today's EFI/TCCS equipped engines are not that much different from the ignition system used on the original 4M-E EFI engine. Primary circuit current flow is controlled by an igniter based on signals generated by a magnetic pickup (pickup coil) located in the distributor. The ignition system has a dual purpose, to distribute a high voltage spark to the correct cylinder and to deliver it at the correct time. Ideal ignition timing will result in maximum combustion pressure at about 10' ATDC.

The most significant difference between TCCS and Conventional EFI ignition systems is the way spark advance angle is managed. The Conventional EFI system uses mechanical advance weights and vacuum diaphragms to accomplish this. Starting with the 5M-GE engine in 1983, the TCCS system controls ignition spark timing electronically and adds an ignition confirmation signal as a fail-safe measure.

There are two versions of electronic spark management used on TCCS equipped engines, the Electronic Spark Advance (ESA) and the Variable Advance Spark Timing (VAST) systems.

3.10.2Conventional EFI Ignition System

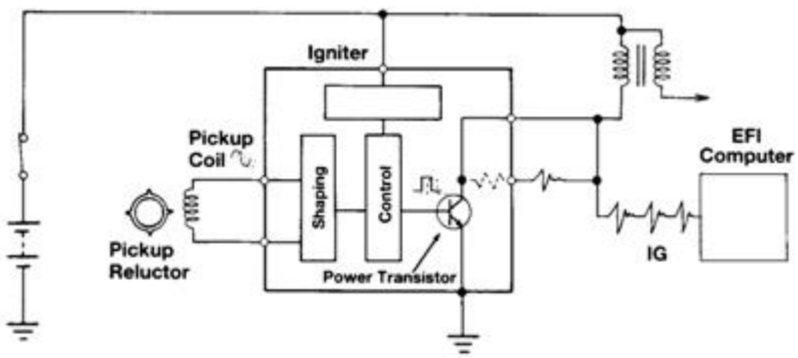
a) Spark Advance Angle Control

In the Conventional EFI system, spark advance angle is determined by the position of the distributor (initial timing), position of the magnetic pickup reluctor teeth (centrifugal advance), and position of the breaker plate and pickup coil winding (vacuum advance). The spark advance curve is determined by the calibration of the centrifugal and vacuum advance springs.

Besides being subject to mechanical wear and mis-calibration, this type of spark advance calibration is very limited and inflexible when variations in coolant temperature and engine detonation characteristics are considered. Mechanical control of a spark curve is, at best, a compromise timing is optimal; in most cases it is not.

b) Engine RPM Signal

Because this system does not use ECU controlled timing, the rpm signal to the ECU advance calibration is very limited and has no impact on spark timing whatsoever. The IG signal is used as an input for fuel injection only.



c) Conventional EFI Ignition System Operation

When the engine is cranked, an alternating current signal is generated by the pickup coil. This signal is shaped in the igniter and then relayed through a control circuit to the base of the primary circuit power transistor.

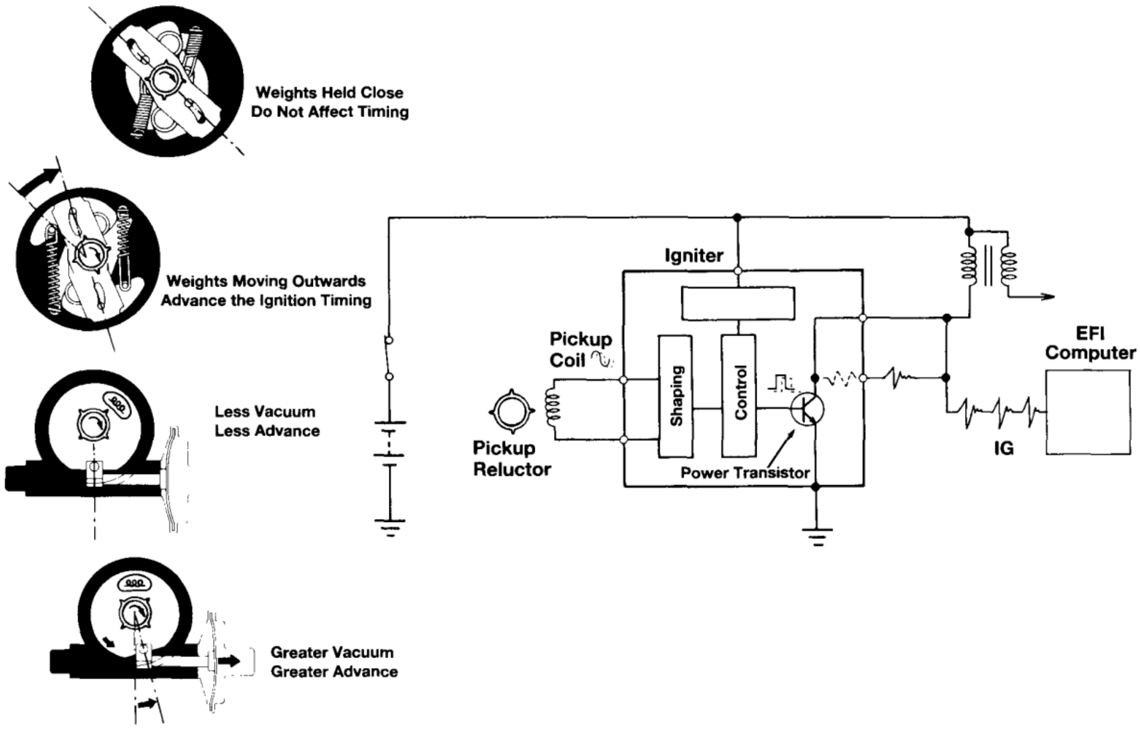
When the voltage at the base of this transistor goes high, current begins to flow through the coil primary windings. When thissignal goes low, coil primary current stops flowing, and a high voltage is induced into the secondary winding. At cranking speed,spark plugs fire at initial timing, a function of distributor position in the engine.

When the engine is running, spark timing is determined by the relative positions of the pickup reluctor (signal rotor) and the pickup coil winding to each other. This relative position is controlled by the centrifugal advance weights and vacuum advance diaphragm positions.

As engine speed increases, the reluctor advances in the same direction as distributor shaft rotation. This is a result of the centrifugal advance operation.

As manifold vacuum applied to the vacuum controller is increased, the pickup coil winding is moved opposite to distributor shaft rotation. Both of these conditions cause the signal from the pick-up coil to occur sooner, advancing timing.

CONVENTIONAL EFI IGNITION SYSTEM



10.3.3 TCCS Ignition Spark

a) Management, Electronic Spark Advance (ESA), and Variable Advance Spark Timing (VAST)

The advent of ECU spark management systems provides more precise control of ignition spark timing. The centrifugal and vacuum advances are eliminated; in their place are the engine sensors which monitor engine load (Vs or PIM) and speed (Ne). Additionally, coolant temperature, detonation, and throttle position are monitored to provide better spark accuracy as these conditions change.

To provide for optimum spark advance under a wide variety of engine operating conditions, a

spark advance map is developed and stored in a look up table in the ECU. This map provides for accurate spark timing during any combination of engine speed, load, coolant temperature, and throttle position while using feedback from a knock sensor to adjust for variations in fuel octane.

TCCS engines use two versions of ECU controlled spark management, Electronic Spark Advance (ESA) and Variable Spark Timing (VAST).

To monitor engine rpm, the TCCS system uses the signal from a magnetic pickup `called the Ne pickup. The Ne pickup is very similar to the magnetic pickup coil used with Conventional EFI. It has either four or 24 reluctor teeth, depending on engine application.

Engines equipped with the ESA system (and the 4A-GE engine with VAST) use a second pickup in the distributor called the G sensor. The G sensor supplies the ECU with crankshaft position information which is used as a reference for ignition and fuel injector timing. Some engines use two G sensors, identified as G1 and G2.

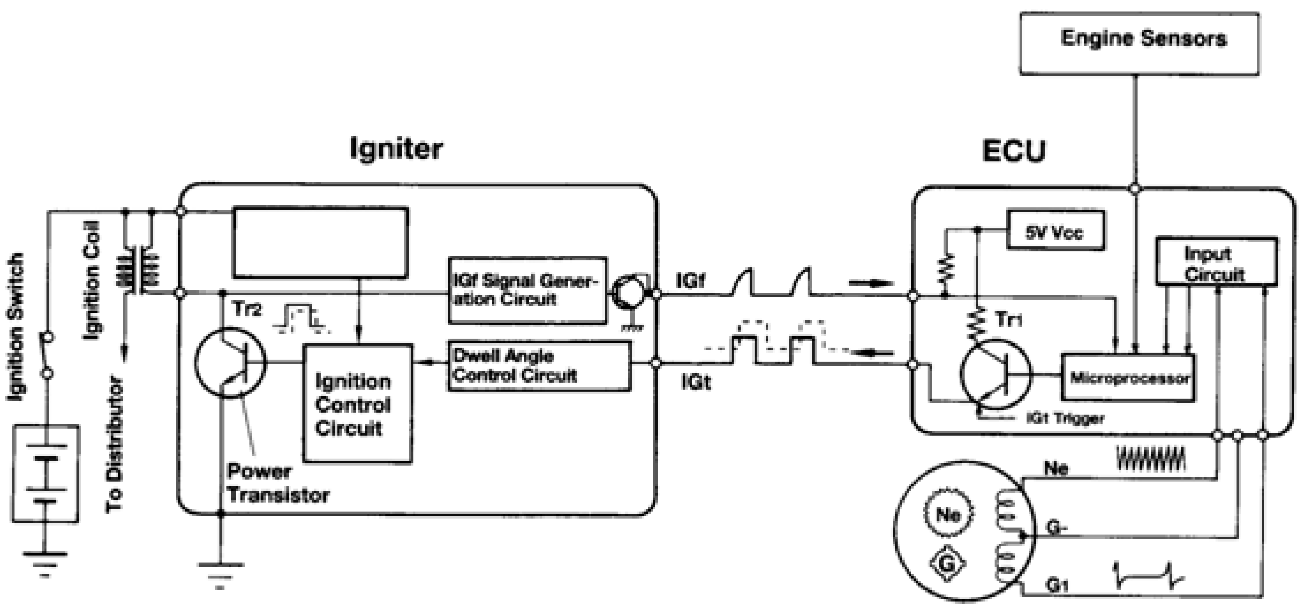
a) ESA Ignition System Operation

In the example above, when the engine is cranked, an alternating current signal is generated by a 24-tooth Ne pickup and a four-tooth G pickup. These signals are sent to the ECU where they are conditioned and relayed to the microprocessor. The microprocessor drives a trigger circuit, referred to as IGt (TR1). The IGt signal is sent to the igniter to switch the primary circuit power transistor on and off.

While cranking, IGt fixes spark timing at a predetermined value. When the engine is running, timing is calculated based on signals from engine speed, load, temperature, throttle position, and detonation sensor The IGt signal is advanced or retarded depending on the final calculated timing. ESA calculated timing is considered the ideal ignition time for a given set of engine conditions.

If the ECU fails to see a Ne or G signal while it is cranking, it will not produce an IGt signal, thus preventing igniter operation.

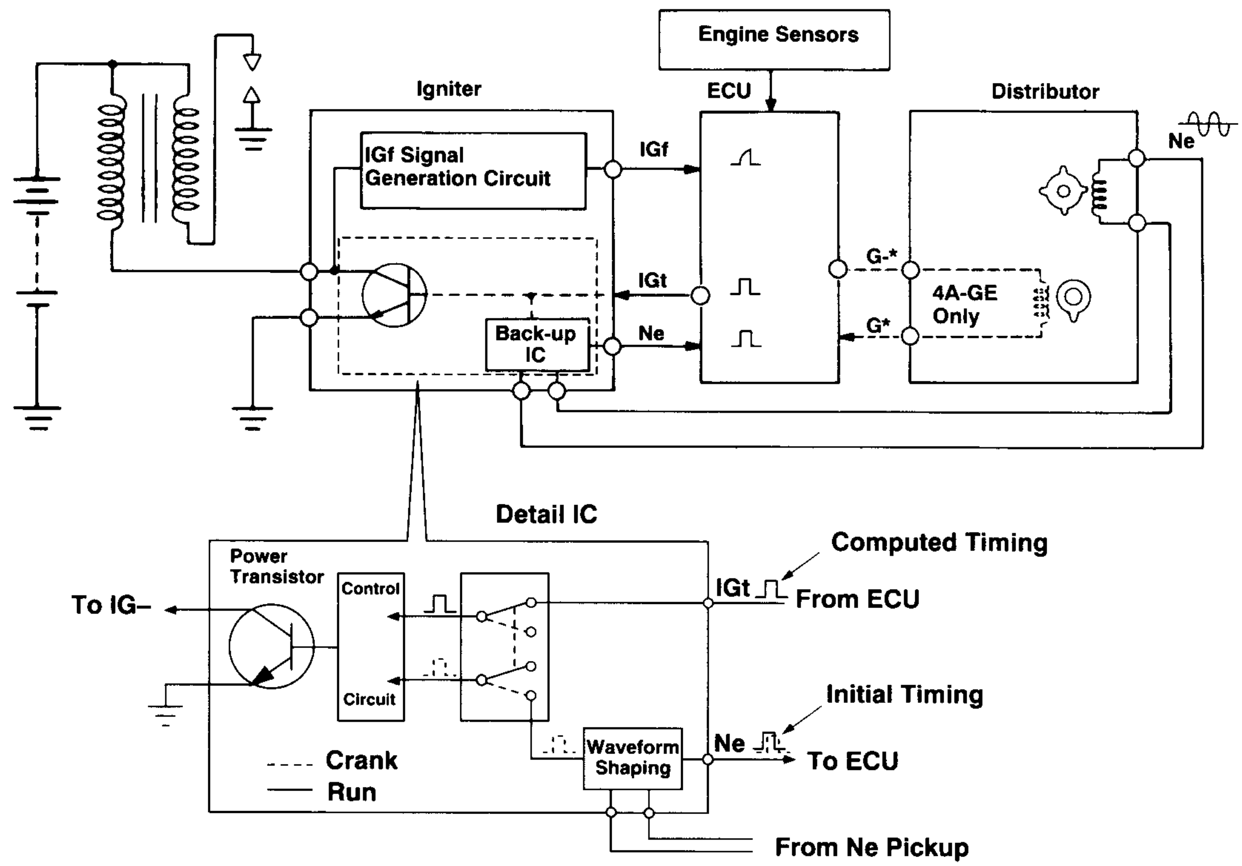
ESA IGNITION SYSTEM



b) VAST System Operation

When the engine is cranked, an alternating current signal is generated by a four-tooth magnetic pickup in the distributor. This alternating current signal is sent directly to the igniter where it is conditioned into a square wave by a waveform shaping circuit.

VAST IGNITION SYSTEM



While cranking, this square wave signal is sent to the ECU on the Ne wire and to the igniter power transistor. The ignition system delivers spark at initial timing under this condition.

When the engine starts and exceeds a predetermined rpm, the ECU begins sending the lGt signal to the igniter. The igniter switches to computed timing mode and uses the IGt signal to operate the power transistor. Timing of IGt is based on information from various engine sensors.

Because the VAST system triggers the igniter directly from the magnetic pickup while cranking, the engine will start even if the IGt circuit to the igniter is open. If IGt signals are not received by the igniter once the engine has started, it will continue to run, defaulted at initial timing, using signals from th e magnetic pickup. The VAST system is only used on the 2S-E, 22R-E, 22R-TE, 4Y-E, and 4A-GE engines.

3.10.4 Igniter Operation

When the IGt signal goes high, the primary circuit power transistor TR2 turns on, allowing cur-rent to flow in the coil primary winding. When the IGt signal goes low, the igniter interrupts primary circuit current flow, causing voltage induction into the coil secondary winding. With the ESA system, the time at which the power transistor in the igniter turns on is further influenced by a dwell control circuit inside the igniter. As engine rpm increases, coil dwell time is increased by turning the transistor on sooner. Therefore, the time at which the transistor is turned on determines dwell while the time the transistor is turned off determines timing. Timing is controlled by the ECU; dwell is controlled by the igniter.

Controlling dwell within the igniter allows the same control over coil saturation time as the ballast resistance does with the Conventional EFI ignition system. It allow s maximum coil saturation at high engine speeds while limiting coil and igniter current, reducing heat, at lower speeds.

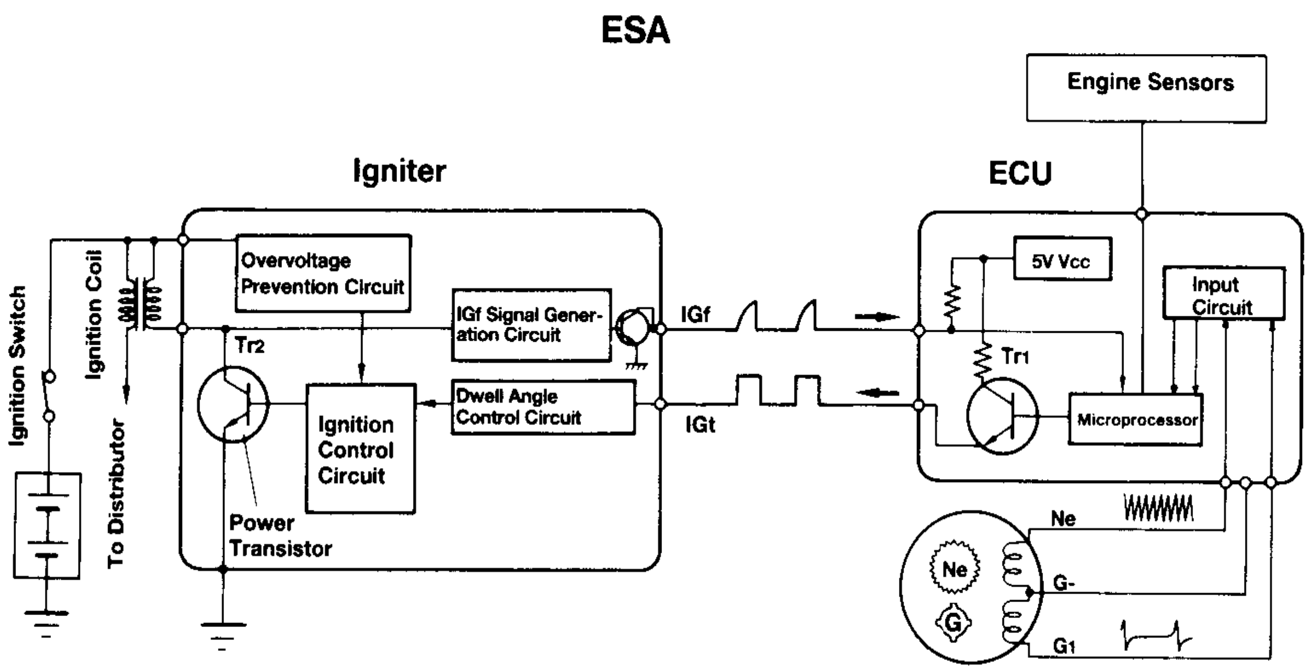
3.10.5 Spark Confirmation IGf

Once a spark event takes place, an ignition confirmation signal called IGf is generated by the igniter and sent to the ECU. The Igf signal tells the ECU that a spark event has actually occurred. In the event of an ignition fault, after approximately eight to eleven IGt signals are sent to the igniter without receiving an IGf confirmation, the ECU will enter a fail-safe mode, shutting down the injectors to prevent potential catalyst overheating.

3.10.6ECU Detection of Crankshaft Angle

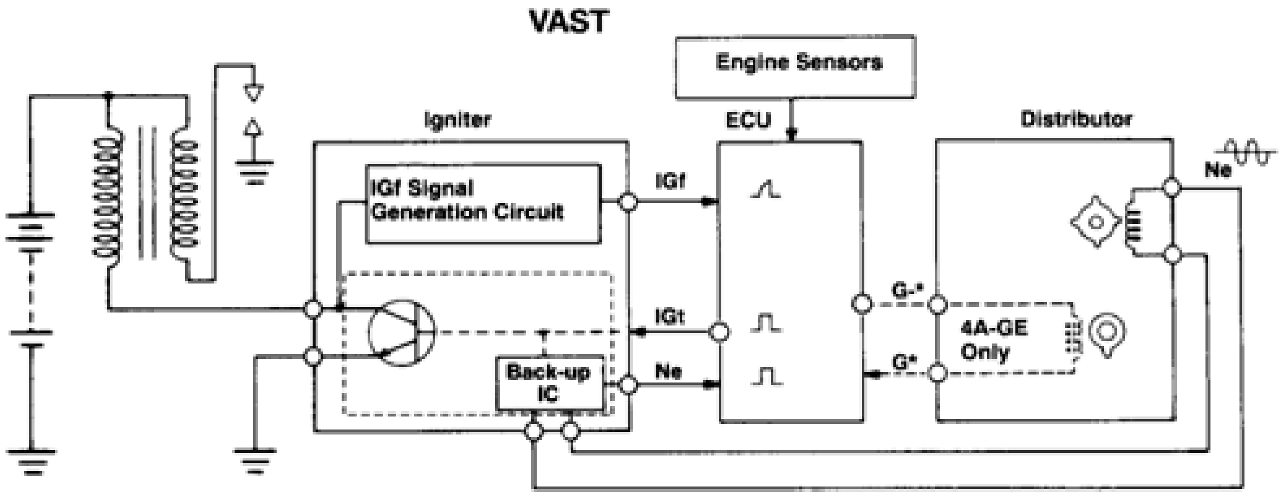
a) ESA System

In order to correctly time spark and injection events, the ECU monitors the relationship between the Ne and G signals. With most engines, the ECU determines the crankshaft has reached 10' BTDC of the compression stroke when it receives the first Ne signal following a G1 (or G2). Initial timing adjustment is critical as all ECU timing calculations assume this initial 10' BTDC as a reference point for the entire spark advance curve.



b) VAST System

Because all engines which use this system have a simultaneous injection pattern (except the 4A-GE), a G signal is not necessary. The four-toothed pickup is designed to produce a pulse once every 180' of crankshaft rotation, signal timing determined by the position of the distributor in the engine. Distributor position determines Ne signal timing and, therefore, initial timing reference. The 4A-GE engine with VAST, because it uses grouped injection, utilizes a G sensor signal indicating camshaft position so the ECU can properly time each injector group.



3.10.6 Ignition Timing Strategy

The ECU determines ignition timing by comparing engine operating parameters with spark advance values stored in its memory. The general formula for ignition timing follows:

Initial timing + Basic advance angle + Corrective advance angle = Total spark advance.

Basic advance angle is computed using signals from crankshaft angle (G1), crankshaft speed (Ne), and engine load (Vs or PIM) sensors. Corrective timing factors include adjustments for coolant temperature (THW) and presence of detonation (KNK).

3.10.7 Distributor-Less Ignition

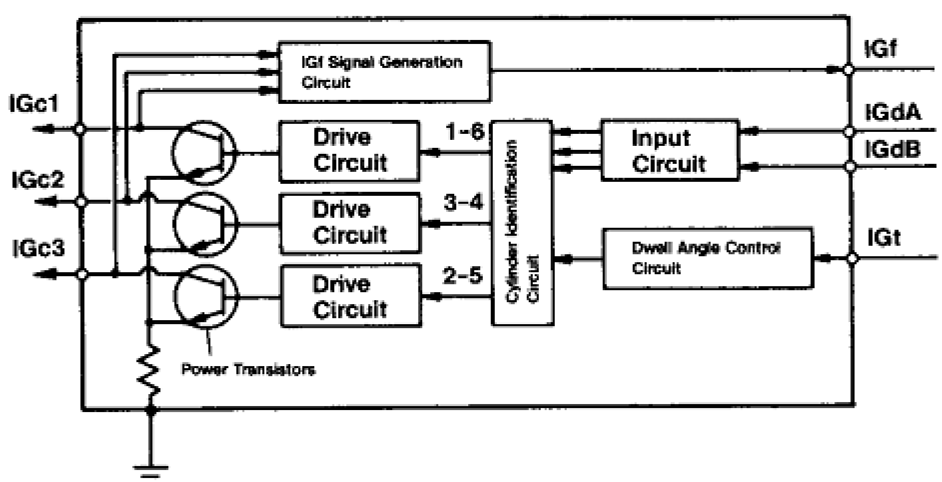
a) Igniter

System (DLI) Used only on the 7M-GTE engine, DLI, as the name implies, is an electronic spark distribution system which supplies secondary current directly from the ignition coils to the spark plugs without the use of a conventional distributor. The DLI system contains the following major components:

- Cam Position Sensor

- Igniter
- Ignition Coils

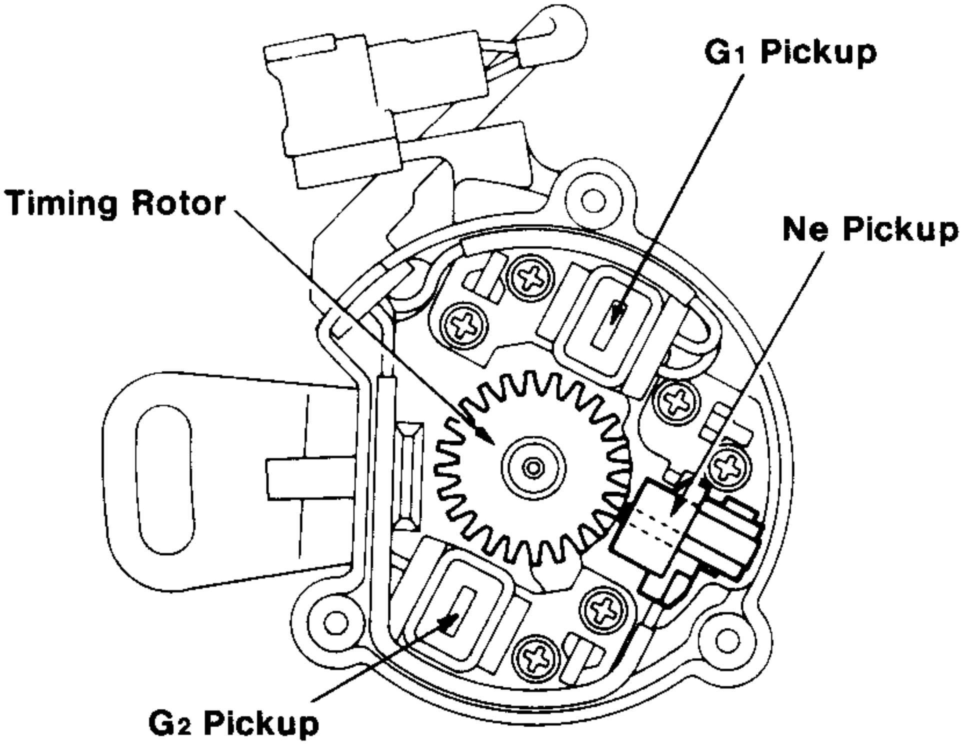
The igniter is similar to those used on distributor type ignition systems but incorporates three separate primary circuits. The igniter determines timing of three primary circuits by the combination of IGdA and IGdB input signals from the ECU. The IGt signal is relayed by the igniter to the proper power transistor circuit to trigger the ignition event at the proper coil. The igniter also sends the standard IGf confirmation signal to the ECU for each ignition event which takes place.



b) Cam Position Sensor

Very similar to the 7M-GE distributor without the secondary distribution system, the cam position sensor houses the Ne, G1, and G2 pickups. The Ne pickup reluctor has 24 teeth, its signal representing crankshaft speed.

The G1 and G2 pickups produce signals near TDC compression stroke for cylinders #6 and #1, respectively. These signals represent standard crankshaft angle and cylinder identification.

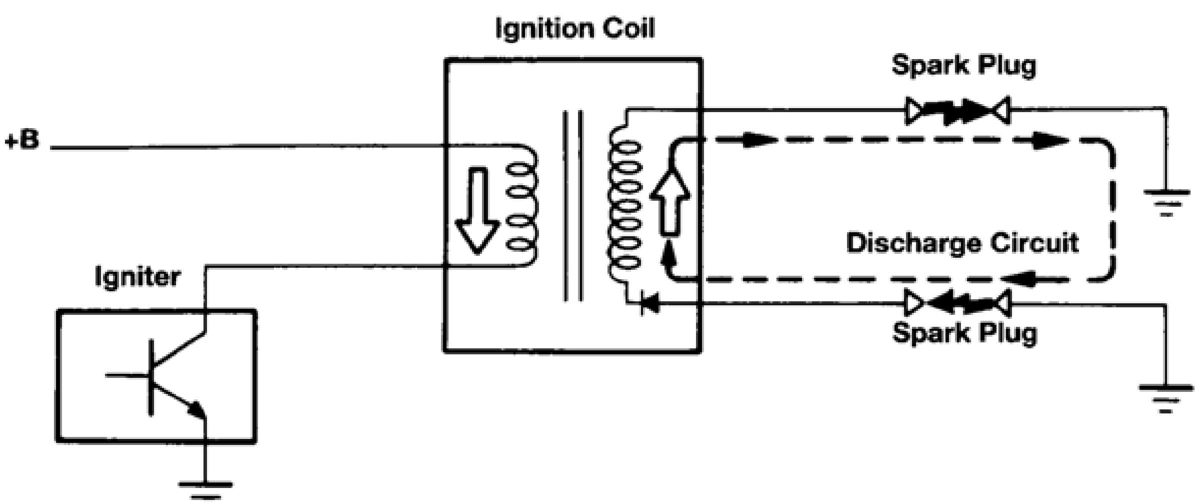


c) Ignition Coils

Each coil is connected in series between spark plugs of companion cylinders. For every engine cycle (720' of crankshaft rotation), ignition is carried out twice at each coil, both spark plugs firing simultaneously.

One plug fires before TDC on the compression stroke while the companion fires at the same position before TDC on the exhaust stroke. This type of secondary distribution is referred to as waste spark.

The three ignition coils are mounted on the top of the engine to the upper section of the head cover. As you face the engine, the coil for the 1-6 cylinder pair is on your left. The coil in the center serves the 3-4 cylinder pair, and the coil to the right serves cylinder pair 2-5.



d) DLI System Operation

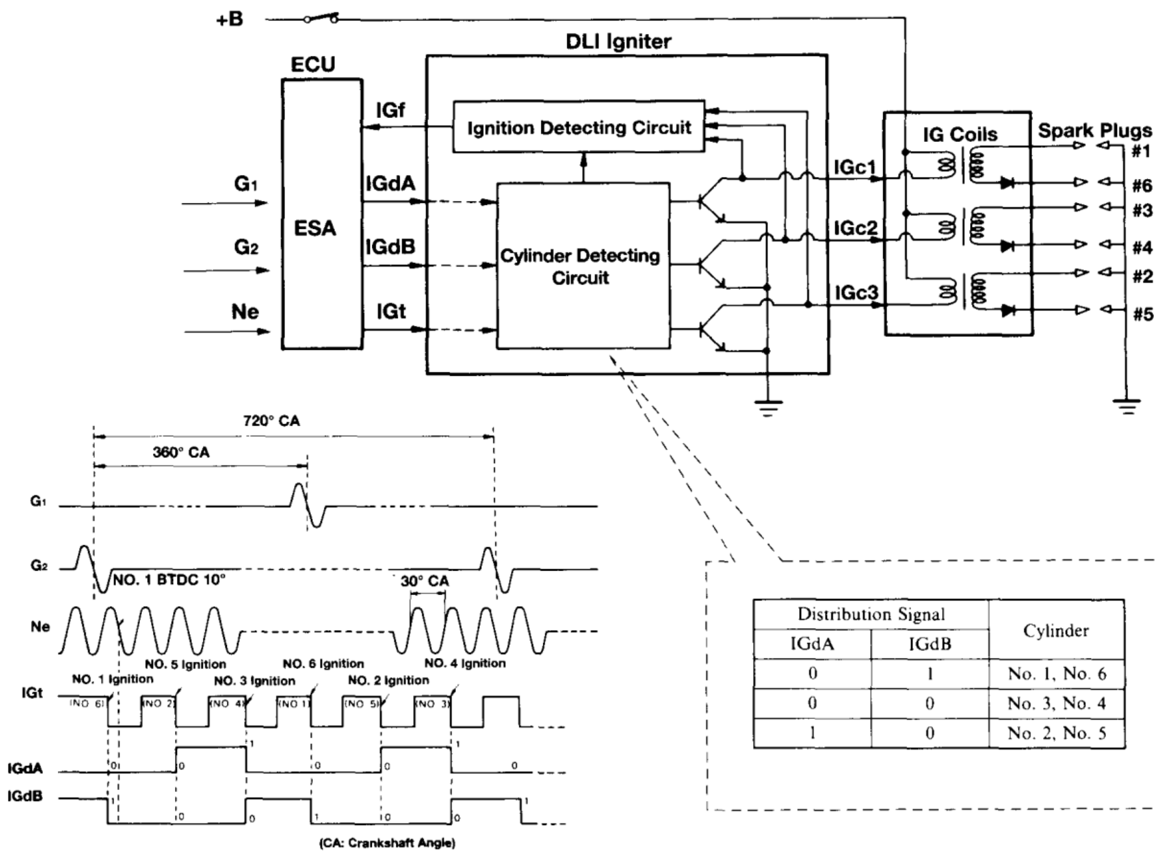
When the engine is cranked, alternating current signals are generated by the 24-tooth Ne sensor and the two G sensors (G1 and G2). The G sensors are 360' out of phase.

The G sensors represent #1 and #6 pistons approaching TDC on the compression stroke. These signals are received by the ECU where they are conditioned and processed by the ESA microprocessor.

The ESA microprocessor serves two functions. It generates an IGt signal and generates cylinder identification signals, IGdA and IGdB, which allow the DLI igniter to trigger the correct coil while cranking the engine. These signals are sent to the DLI igniter which electronically determines proper primary signal distribution based on the combination of IGdA and IGdB signals.

The igniter distributes the IGt signal to the proper coil driver circuit and determines dwell period based on coil primary current flow. The ESA calculations for spark advance angle work the same as with distributor type ignition systems.

The table below shows how the igniter is able to calculate crankshaft position and properly distribute the IGt signal to the transistor driver circuit connected to the relevant ignition coil.



Distribution Signal		Cylinder
IGdA	IGdB	
0	1	No. 1, No. 6
0	0	No. 3, No. 4
1	0	No. 2, No. 5

3.11 IGNITION TIMING

Ignition timing is the measurement, in degrees of crankshaft rotation, of the point at which the spark plugs fire in each of the cylinders. It is measured in degrees before or after Top Dead Center (TDC) of the compression stroke.

Because it takes a fraction of a second for the spark plug to ignite the mixture in the cylinder, the spark plug must fire a little before the piston reaches TDC. Otherwise, the mixture will not be completely ignited as the piston passes TDC and the full power of the explosion will not be used by the engine.

Ignition timing on many of today's vehicles is controlled by the engine control computer and is not adjustable. However the timing can be read using a scan tool connected to the data link connector.

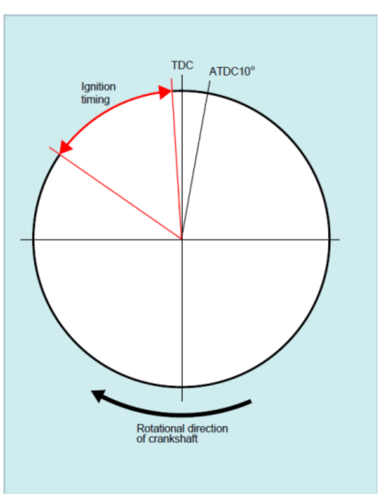
3.11.1 Necessity of Ignition Timing Control

In a gasoline engine, the air-fuel mixture is ignited to cause combustion, and the force that is generated by the explosion causes the piston to push downward. The thermal energy can be most efficiently converted into a motive force when the maximum combustion force is generated at a crankshaft position of 10°ATDC (After Top Dead Center).

An engine does not produce the maximum combustion force simultaneously with ignition; instead, it generates the maximum combustion force slightly after ignition has occurred.
Therefore, ignition takes place in advance so that the maximum combustion force is generated at 10°ATDC.

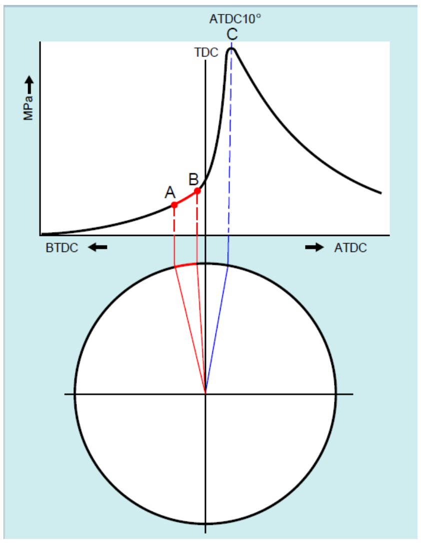
The ignition timing that enables the engine to generate the maximum combustion force at 10°ATDC changes every moment, depending on the operating conditions of the engine.

Therefore, the ignition system must be able to ignite the air-fuel mixture at a timing that enables the engine to generate an explosive force in the most efficient manner in accordance with the operating conditions.



3.11.2 Ignition delay period

Combustion of the air-fuel mixture does not occur instantly after ignition. Instead, a small area (flame nucleus) in the immediate vicinity of the spark starts to burn, and this process eventually expands to the surrounding area. The period from the time when the air-fuel mixture is ignited until it is burned is called the ignition delay period (between A and B in the diagram). The ignition delay period is practically constant, and is not affected by the changes in the conditions of the engine.

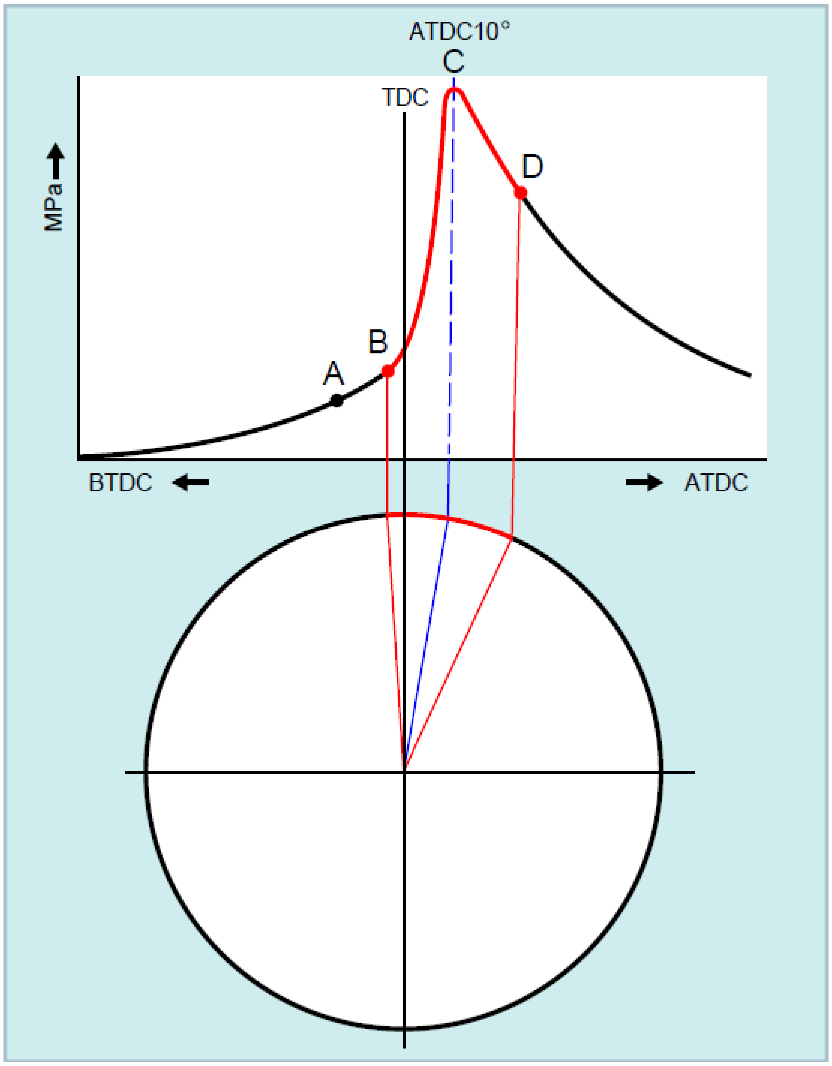


3.11.3 Flame propagation period

After the flame nucleus is formed, the flame gradually expands outward. The speed at which the flame expands is called the flame propagation speed, and its period is called the flame propagation period (B~C~D in the diagram). When there is a large amount of the intake air, the airfuel mixture becomes denser. For this reason, the distance between the particles in the air-fuel mixture decreases, thus accelerating the flame propagation.

Also, the stronger the swirl of the air-fuel mixture, the faster the flame propagation speed will be.

When the flame propagation speed is fast, it is necessary to advance the ignition timing. Therefore, it is necessary to control the ignition timing according to the engine condition.

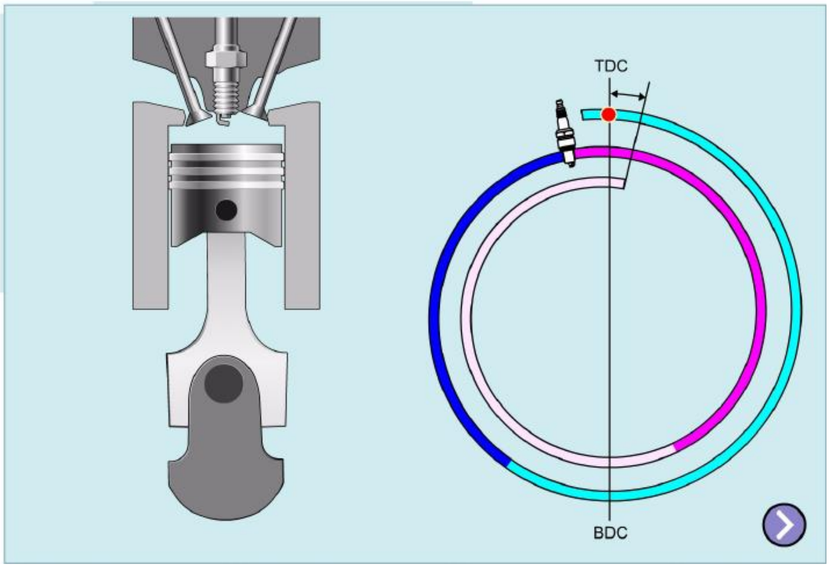


3.11.4 Ignition timing control

The ignition system controls the ignition timing in accordance with the engine speed and load so that the maximum combustion force occurs at 10°ATDC.

HINT:

In the past, ignition systems used a governor advancer and vacuum advancer to control timing advancing and retarding. However, most ignition systems today use the ESA system.



3.11.5 Engine speed control

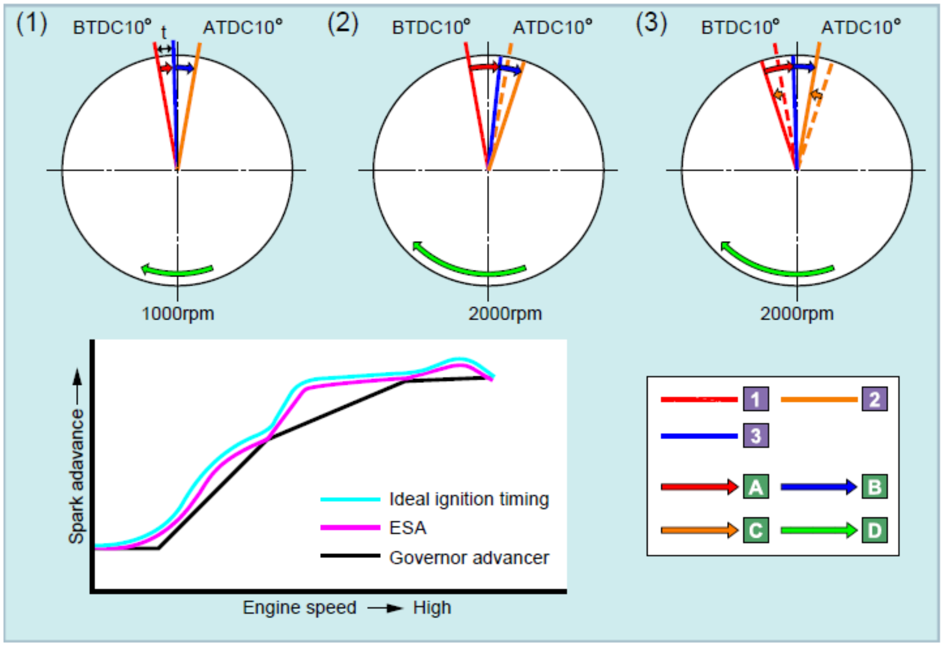
a) It is considered an engine to output power most efficiently when the maximum combustion force occurs at 10°・ ATDC, on which the optimal ignition timing is set to 10°・ BTDC

(BeforeTop Dead Center) at a speed of 1,000 rpm.

b) It is supposed that the engine speed is increased to 2,000 rpm. The duration for the ignition delay is practically constant regardless of the engine speed. Therefore, the crankshaft rotational angle increases, as compared to when the engine is running at 1,000 rpm. If the same ignition timing described in (1) is used at 2,000 rpm, the timing at which the engine produces the maximum combustion force will be retarded more than 10・ ATDC.

c) Therefore, to produce the maximum combustion force at 10°・ ATDC while the engine is

running at 2,000 rpm, the ignition timing must be advanced in order to compensate for the crankshaft rotational angle that was retarded in (2). This process for advancing the ignition timing is called timing advance, and for retarding the ignition timing is called timing retard.



t : Duration for ignition delay

1 Ignition timing

2 Timing that produces the maximum combustion force

3 Boundary between the ignition delay period and flame propagation speed

A Ignition delay period

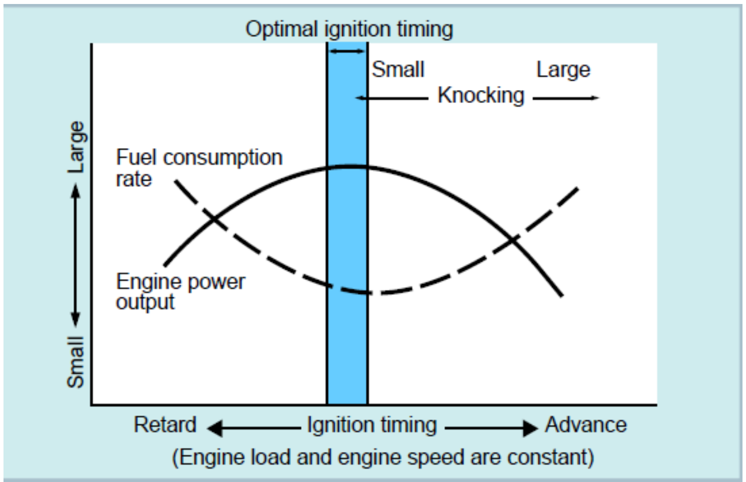
B Flame propagation period

C Timing retard

D Crankshaft rotational angle

3.11.6 Knocking control

Knocking in the engine is caused by spontaneous combustion that occurs when the air-fuel mixture selfignites in the combustion chamber. An engine becomes more susceptible to knocking as its ignition timing is advanced. Excessive knocking negatively affects the performance of the engine, such as by causing poor fuel economy or reduced power output. On the other hand, slight knocking has the opposite effect of improving both fuel economy and power output. Recent ignition systems effect ignition timing control to retard the timing when a knock sensor detects knocking, and advance the timing when the knocking is no longer detected. By preventing the engine from knocking in this manner, these systems improve the power output and fuel economy.



3.11.7 Engine load control

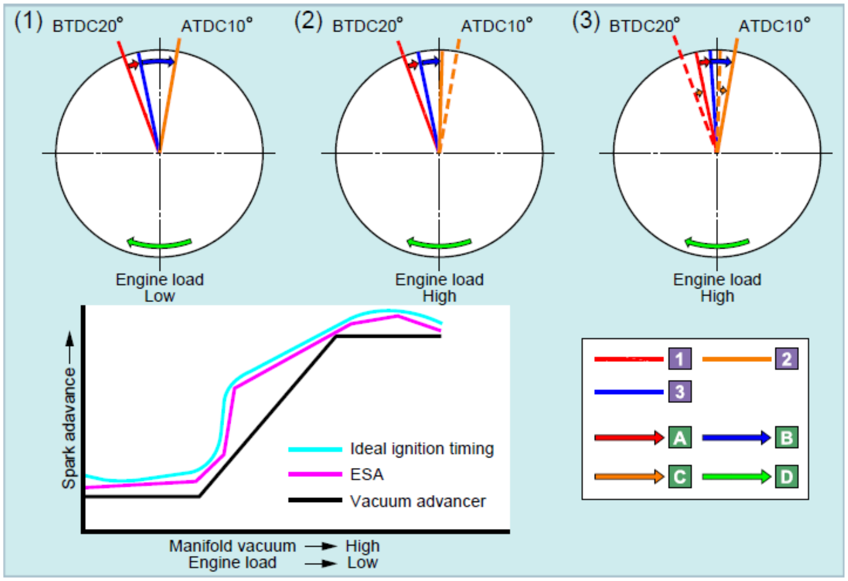
a) It is considered when the maximum combustion force occurs at 10◦ATDC, on which the

optimal ignition timing is set to 20・・BTDC when the engine load is low.

b) As the engine load increases, the air density increases and the flame propagation period decrease.
Therefore, if the same ignition timing described in (1) is used when the engine load is high, the timing at which the engine produces the maximum combustion force will be more advanced than 10◦ATDC.

c)To produce the maximum combustion force at 10◦ATDC when the engine load is high, the

ignition timing must be retarded in order to compensate for the crankshaft rotational angle that was advanced in (2).Conversely, when the engine load is low, the timing must be advanced. (When the engine is idling, however, the amount of timing advance must be kept small or zero, to prevent unstable combustion.)



1 Ignition timing

2 Timing that produces the maximum combustion force

3 Boundary between the ignition delay period and flame propagation speed

A Ignition delay period

B Flame propagation period

C Timing retard

D Crankshaft rotational angle

3.12 CAPACITOR DISCHARGE IGNITION SYSTEM

Most ignition systems used in automobiles are inductive ignition systems, which are solely relying on the electric inductance at the coil to produce high-voltage electricity to the spark plugs as the magnetic field breaks down when the current to the primary coil winding is disconnected (disruptive discharge).

Capacitor discharge (CD) ignition systems differ from inductive storage-type ignition systems in that they store ignition energy in a capacitor rather than in an ignition coil. They still use an ignition coil, but the coil is used as a pulse transformer to quickly step up the current. In a CDI system, a charging circuit charges a high voltage capacitor, and during the ignition point the system stops charging the capacitor, allowing the capacitor to discharge its output to the ignition coil before reaching the spark plug.

In a CD ignition system, the primary circuit powers a mini-oscillator or a transformer which charges a capacitor to about 400 to 600 volts and relies on the distributor to trigger the system. The distributor can have either a magnetic triggering system, as in a electronic ignition system, or a light-emitting diode (LED) triggering system. If it has a LED triggering system, a tiny infra-red light beam between a LED and a photo transistor is interrupted by a rotor to produce the triggering signal. When the signal is triggered, the capacitor delivers its stored energy to the coil's primary winding. The coil then acts as a pulse transformer and steps up the current from the capacitor to the 30,000 to 40,000 volts that is required to create a spark across the plug gap.

3.14 MAGNETO SYSTEMS

The simplest form of spark ignition is that using a magneto. The engine rotates a magnet inside a coil, and also operates a contact breaker, interrupting the current and causing the voltage to be increased sufficiently to jump a small gap. The spark plugs are connected directly from the magneto output. Magnetos are not used in modern vehicles, but because they generate their own electricity they are often found on piston aircraft engines and small engines such as those found in mopeds, lawnmowers, chainsaws, etc. where there is no battery

Magnetos were used on older automobile gasoline engines and farm tractors the early twentieth century, before battery starting and lighting became common,. Magnetos were used in aircraft piston engines because of their simplicity and self-contained nature was more reliable, and because they weighed less than having a battery and generator or alternator.

Aircraft engines usually have multiple magnetos to provide redundancy in the event of a failure. Some older automobiles had both a magneto system and a battery actuated system running simultaneously to ensure proper ignition under all conditions with the limited performance each system provided at the time.

The output of a magneto depends on the speed of the engine, and therefore starting can be problematic. Some magnetos include an impulse system, which rotates the magnet quickly at the proper moment, making easier starting at slow cranking speeds. Some engines, such as aircraft but also the Ford Model T, used a system which relied on non rechargeable dry cells, to start the engine or for running at low speed; then the operator would manually switch the ignition over to magneto operation for high speed operation.

In order to provide high voltage for the spark from the low voltage batteries, however, a "tickler" was used, which was essentially a larger version of the once widespread electric buzzer. With this apparatus, the direct current passes through an electromagnetic coil which pulls open a pair of contact points, interrupting the current; the magnetic field collapses, the spring-loaded points close again, the circuit is reestablished, and the cycle repeats rapidly. The rapidly collapsing magnetic field, however, induces a high voltage across the coil which can only relieve itself by arcing across the contact points; while in the case of the buzzer this is a problem as it causes the points to oxidize and/or weld together, in the case of the ignition system this becomes the source of the high voltage to operate the spark plugs.

In this mode of operation, the coil would "buzz" continuously, producing a constant train of sparks. The entire apparatus was known as the Model T spark coil (in contrast to the modern ignition coil which is only the actual coil component of the system), and long after the demise of the Model T as transportation they remained a popular self-contained source of high voltage for electrical home experimenters, appearing in articles in magazines such as Popular Mechanics and projects for school science fairs as late as the early 1960s. In the UK these devices were commonly known as trembler coils and were popular in vehicles pre-1910, and also in commercial vehicles with large engines until around 1925 to ease starting.

The Model T (built into the flywheel) differed from modern implementations by not providing high voltage directly at the output; the maximum voltage produced was about 30 volts, and therefore also had to be run through the spark coil to provide high enough voltage for ignition, as described above, although the coil would not "buzz" continuously in this case, only going through one cycle per spark. In either case, the high voltage was switched to the appropriate spark plug by the *timer* mounted on the front of the engine, the equivalent of the modern distributor. The timing of the spark was adjustable by rotating this mechanism through a lever mounted on the steering column.

3.15 SUMMARY

The ignition system supplies high voltage to the spark plugs to ignite the air/fuel mixture in the combustion chambers.

The arrival of the spark is timed to coincide with the compression stroke of the piston. This basic timing can be advanced or retarded under certain conditions, such as high engine rpm or extremely light or heavy engine loads.

The ignition system has two interconnected electrical circuits: a primary circuit and a secondary circuit.

The primary circuit supplies low voltage to the primary winding of the ignition coil. This creates a magnetic field in the coil.

A switching device interrupts primary current flow, collapsing the magnetic field and creating a high-voltage surge in the ignition coil secondary winding.

The switching device used in electronic systems is an NP transistor. Old ignitions use mechanical breaker point switching.

The secondary circuit carries high voltage surges to the spark plugs. On some systems, the circuit runs from the ignition coil, through a distributor, to the spark plugs.

The distributor may house the switching device plus centrifugal or vacuum timing advance mechanisms. Some systems locate the switching device outside the distributor housing.

Ignition timing is directly related to the position of the crankshaft. Magnetic pulse generators and Hall-effect sensors are the most widely used engine position sensors. They generate an electrical signal at certain times during crankshaft rotation. This signal triggers the electronic switching device to control ignition timing.

DIS eliminates the distributor. Each spark plug, or in some cases, pair of spark plugs, has its (their) own ignition coil. Primary circuit switching and timing control is done using a special ignition module tied into the vehicle control computer.

Computerized Ignition System eliminates centrifugal and vacuum timing mechanisms. The computer receives input from numerous sensors. Based on this data, the computer determines the optimum firing time and signals an ignition module to activate the secondary circuit at the precise time needed.

In some distributors, one pick-up is used for ignition triggering and a second pick-up is used for injector sequencing.

In some DIS, the camshaft sensor signal informs the computer when to sequence the coils and fuel injectors.

In some DIS systems, the crankshaft sensor signal provides engine speed and crankshaft position information to the computer

Some DIS systems are called fast-start systems because the spark plugs begin firing within 120 degrees of crankshaft rotation.

Some DIS systems have a combined crankshaft and SYNC sensor at the front of the crankshaft.

Some DIS systems may be called slow-start systems because as many as nvo crankshaft revolutions are required before the ignition system begins firing.

CHAPTER FOUR

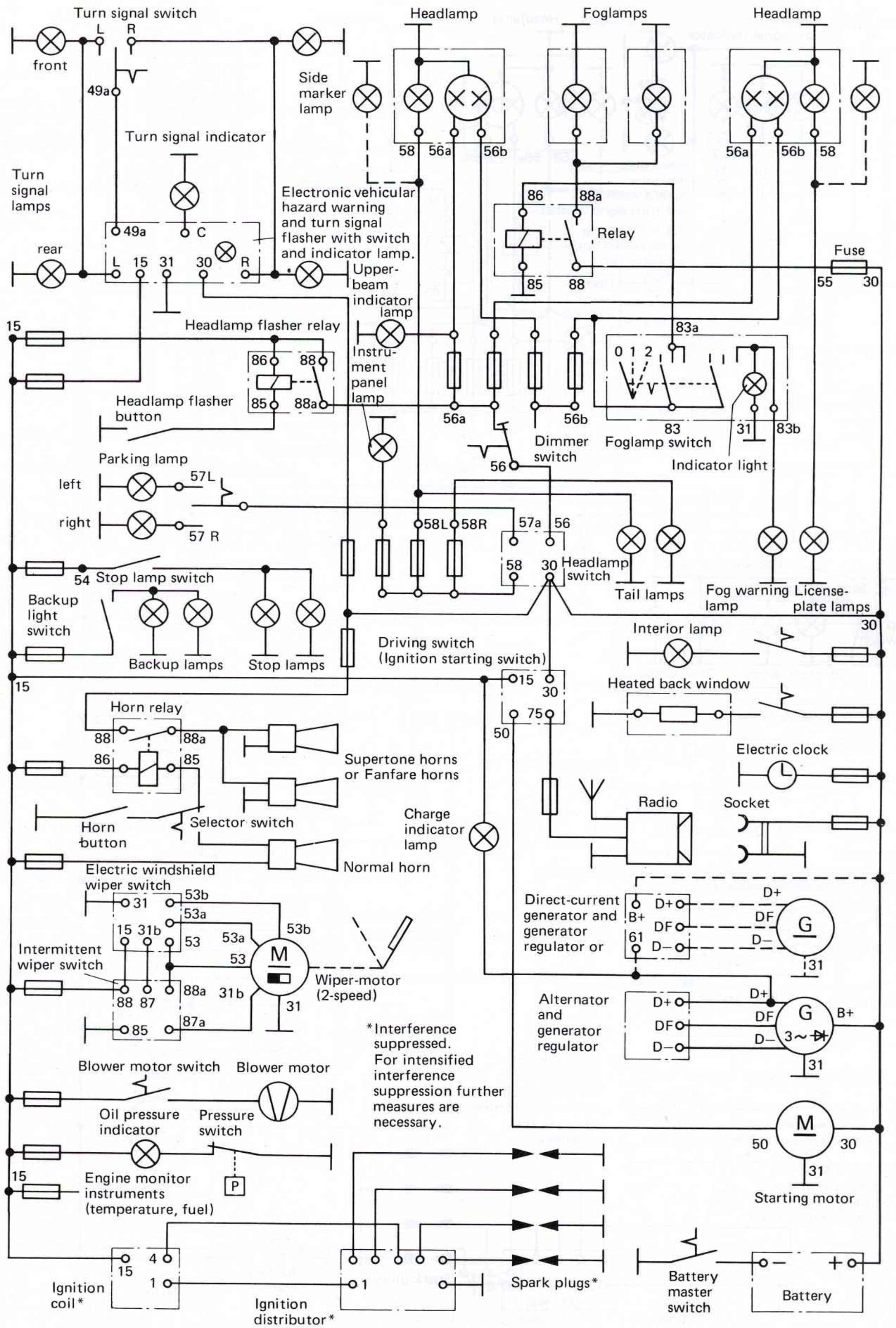
4.0 ELECTRIC WRING SYSTEM

The electrical equipment of automobiles is a complex system of numerous electrical components interconnected by a multitude of wires making up a system of their own. To help an enginner trace and service the wiring system, a wiring diagram is used.

Automobiles made in different countries use different wiring system in which the vehicle frame and other metal parts are employed as the second and other metal parts are employed as the second return wire. Therefore no separate wires are used for the return of electrical current to the battery or alternator. Hence the type of electric circuit used in automobiles is **one wire system**.

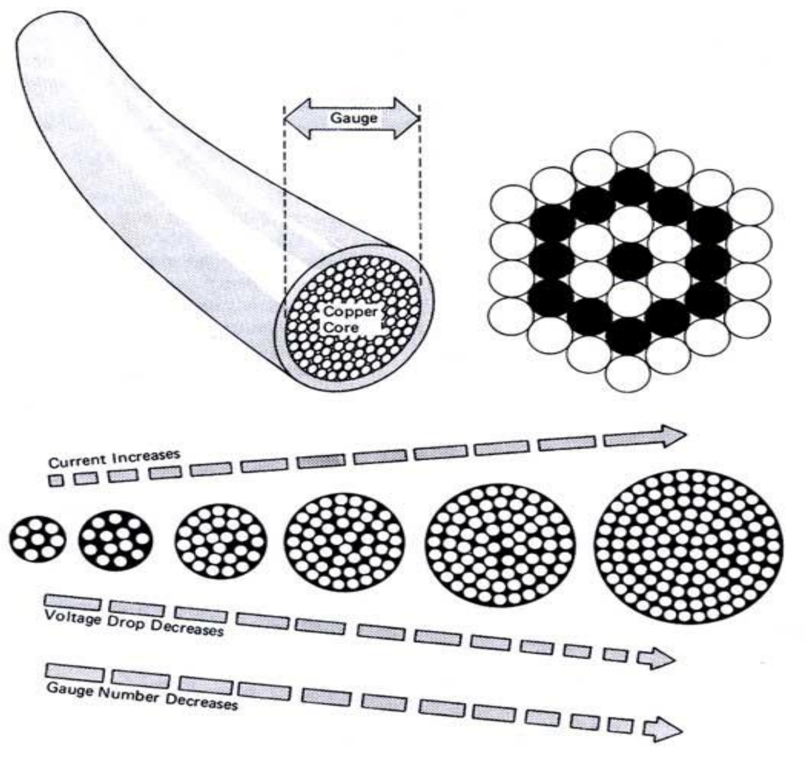
To facilitate the laying out of wires and to provide for better protection, individual wires are taped together in bundles. The wires are colour coded for tracing ease. Wire ends are equipped with lugs or connectors, which makes it easier to connect the wires to the various electrical system components.

The point of connection to power supply sources are essential, the principle here is to connect directly to the battery only such components which draw much current and operate for short period such as the starter motor, and those which operate in emergency situations such as horn. The other loads are connected to the alternator. In this case the loads are connected as dictated by their character of their operation. Those, which are connected to the alternator, are loads, which draw current for a long time, and those that are operative only when the engine is running are connected through the ignition switch.



Turn signal switch
L
R
front
49a
Turn signal indicator
Turn signal lamps
rear
49a
C
L
15
31
30
R
Electronic vehicular hazard warning and turn signal flasher with switch and indicator lamp.
Upper-beam indicator lamp
Side marker lamp
Headlamp
58
56a
56b
Foglamps
Headlamp
56a
56b
58
86
88a
Relay
85
88
Fuse
55
30
15
Headlamp flasher relay
86
88
85
88a
Headlamp flasher button
Instru-ment panel lamp
56a
56b
83a
0 1 2
83
31
83b
Dimmer switch
Foglamp switch
Indicator light
56
Parking lamp
left
57L
right
57 R
58L
58R
57a
56
58
30
Headlamp switch
Tail lamps
Fog warning lamp
License-plate lamps
54
Stop lamp switch
Backup light switch
Backup lamps
Stop lamps
30
Interior lamp
Driving switch (Ignition starting switch)
15
15
30
75
50
Heated back window
Horn relay
88
88a
86
85
Supertone horns or Fanfare horns
Electric clock
Horn button
Selector switch
Charge indicator lamp
Radio
Socket
Normal horn
Electric windshield wiper switch
31
53b
53a
15
31b
53
53a
53
53b
Intermittent wiper switch
88
87
88a
31b
85
87a
31
Wiper-motor (2-speed)
Direct-current generator and generator regulator or
D+
B+
DF
61
D–
G
31
Alternator and generator regulator
D+
DF
D–
G
3~
B+
31
*Interference suppressed. For intensified interference suppression further measures are necessary.
Blower motor switch
Blower motor
Oil pressure indicator
Pressure switch
P
15
Engine monitor instruments (temperature, fuel)
M
50
30
31
Starting motor
Ignition coil*
4
15
1
Ignition distributor*
1
Spark plugs*
Battery master switch
Battery

4.2 WIRE SIZE OR WIRE GAUGE



The wire or cable size is expressed in terms of standard gauge numbers. Size refers to the measure of the cross-sectional diameter of all the separate strands.

Wire size or gauge can be expressed either by metric system or unit or by American wire gauge numbers.

As the wire gets larger, the gauge number gets smaller where as the metric size increases with area. The circular area doubles for every gauge sizes Examples. No 12 has about twice the area of gauge No 15 wire.

Cables larger than 1 gauge are 0 gauge (pronounced ought). Hence for larger cables the designations 2/0, 3/0 can be used read as double ought, triple ought respectively.

4.2.1 Necessities of selecting wire gauges

For any wire system it is necessary to select the correct wire size or gauge for the following reasons.

a) To keep the voltage drop in the wire as low as possible
b) To make the voltage in the consumer as high as possible

4.2.2 The criteria to select wires are:-

a) The maximum permissible voltage drop
b) The permissible heat of the conductor during operation
c) The cost of the material

4.2.3 Current density

When a new cable or wire is installed, one has to take in to consideration that those components get heated up by current flowing through them when in operation. If the current density is too high, this might cause damage to the insulation of wires or cables. This leads to the insulation of wires or cables. This leads to the burning of the whole vehicle.

4.2.4 Approximate valves of current densities

a) Wire size up to $6mm^2$ can be loaded 10 ampere $/mm^2$
b) Wire size up to $35mm^2$ can be loaded 6 amper$/mm^2$
c) Wire sizes up to $120mm^2$ can be loaded 4 amper$/mm^2$

But for short period of time all electrical lines can be loaded with current density of 20 amp$/mm^2$

$$Current\ Density = \frac{Current}{Cross\ Section\ area}$$

$$Icd = \frac{I}{A}$$

The standard wire sizes manufactured for workshop use are available 1.0, 1.5, 2.5, 4.0, 6.0, 10.0, 16.0, 25.0, 35.0, 50.0, 90.0, 120.0 mm^2

Examples

A starter motor rating voltage E = 12v, and rating current I = 630A, the resistance of the conductor = 0.0175 $\Omega mm^2/m$ cable length 0.8 meter permissible voltage drop = 0.5v calculate the required cross sectional area.

Given E = 12v
I = 630A
R= 0.0175 $\Omega mm^2/m$
L = 0.8m

Ed= 0.5v

The required cross section will be;

$$\textbf{Cross Section Area} = \frac{\textbf{Conductor Resistance in } (\Omega\textbf{mm}^2)\textbf{x Wire lenth x Current}}{\textbf{Voltage Drop}}$$

$$\textbf{Cross Section Area} = \frac{0.0175(\Omega\textbf{mm}^2)\,\textbf{x}\,0.8M\,\textbf{x}\,630A}{0.5\,V} = 17.64$$

A = 17.64 mm²

The wire size calculated usually is rounded to the standard size. There fore A = ~_25mm^2 standard

4.2.5 Wire gauge number

The following chart indicates the wire conversion chart of the metric wire size to the American wire gauge number

Metric (mm^2)	AWG Number
0.5	20
0.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13	6
19	4

4.2.6 How to measure the gauge of a cable

To determine, the gauge of a cable, using the table as follows,

a) Count the number of stands of wire
b) Measure the diameter of a single strand in thousands of an inch
c) In column A of the table, find the diameter of the wire you have measured and on the same line in column ' C' find area
d) Multiply the area of a single wire by the number of strands to get the total area

e) In column 'C' find the figure closest to the area obtained in step (d) and on the same line in column B note the gauge.

Example

A cable is found to have 19 strands of wire, the individual strands being 0.0112 inch in diameter. The table (column C) shows the circular mil area of each strand to be 127. multiplying this by the number of strands 19, results in 2413 total circular miles the closest figure in column C is 2583, and on the same line, in column B we find that 16 is the nearest cable gauge number.

Size and area of wire		
Wire diameter (inch) (A)	American wire gauge (B)	Circular mill area
0.4600	0000	211600
0.4096	000	167800
0.3648	00	133100
0.3249	0	105500
0.2893	1	83690
0.2576	2	66370
0.2296	3	52640
0.2043	4	41740
0.1620	6	26250
0.1283	8	16510
0.1019	10	10380
0.8080	12	6530
0.0640	14	4107
0.0508	16	2587
0.0403	18	1624
0.0319	20	1022
0.0284	21	810.1
0.0253	22	642.4
0.0225	23	509.5
0.201	24	404.0
0.159	25	320.4
0.142	26	254.1
0.126	27	201.5
0.126	28	159.8
0.0112	29	126.7
0.0100	30	100.5
0.089	31	79.70
0.079	32	63.21
0.0070	33	50.13
0.0063	34	39.75
0.0056	35	31.52
0.0050	36	25.00

4.2.7 Colour coding of electrical wires

Automotive electric wires are colour coded to make fault finding in the electrical circuit very easier for further distinction according to its purpose electric wires in automotive vehicles are additionally provided with colour trailers or strips. The first colour mentioned is always the base colour.

Example

A Red wire with white strips may be designated as RED/WHT, RO/WH, R/W, RED/W or RD/W

4.3 MAIN LIGHTING SWITCH

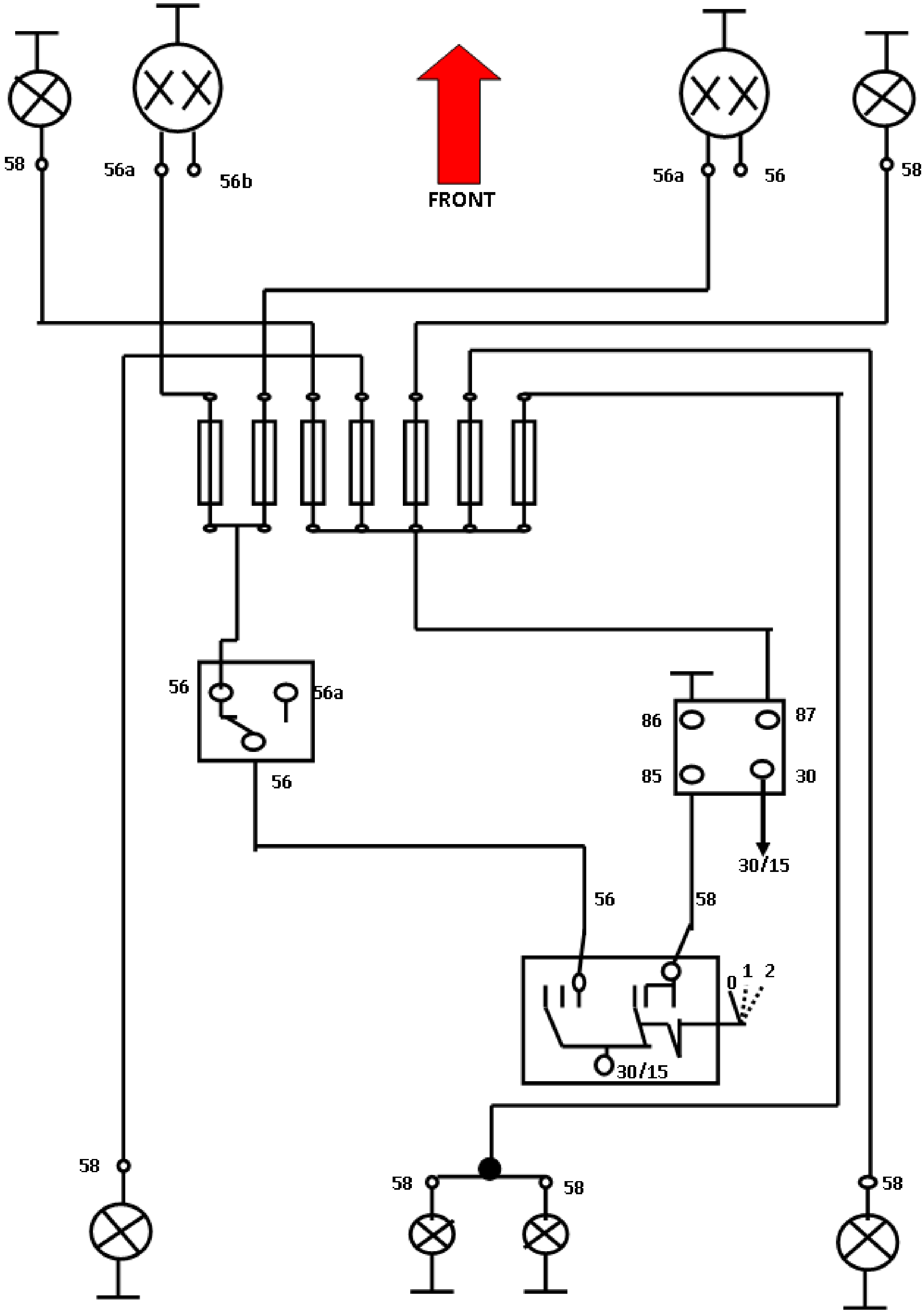
The main lighting switch (sometimes called the headlight switch) is the heart of the lighting system. It controls the headlights, parking lights, side marker lights, taillights, license plate light, instrument panel lights, and interior lights. Individual switches are provided for special purpose lights such as directional signals, hazard warning flashers, back up lights, and courtesy lights. The main lighting switch may be of either the "push-pull" or "push-pull with rotary contact" types. A typical switch will have three positions: off, parking, and headlamps. Some switches also contain a rheostat to control the brightness of the instrument panel lights. The rheostat is operated by rotating the control knob, separating it from the push-pull action of the main lighting switch.

When the main lighting switch completes the circuit to the headlamps, the low beam lights the way for city driving and for use when meeting oncoming traffic on the highway. When the dimmer switch is actuated, the single filament headlamp's go "on," along with the high beam of the two filament headlamp's. The next actuation of the dimmer switch returns the head lighting system to low beams only on the two filament lamps. Some cars are equipped with an electronic headlight dimming device, which automatically switches the headlights from high beam to low in response to light from an approaching vehicle or light from the taillight of a vehicle being overtaken. The dimmer switch in the automatic headlamp dimming system is a special override type. It is located in the steering column as part of a combination dimmer, horn, and turn signal switch.

The override action occurs when a slight pull toward the driver on the switch lever provides high beam headlights regardless of the amount of light on the sensor-amplifier.

For some years there has been discussion about the advantages of a polarized headlight system. Such a system comprises headlights which produce polarized light in a particular plane. The windscreens of all cars would be fitted with polarizing glass, which would be oriented so that glare from an approaching vehicle would be essentially eliminated, while the forward vision would still be kept at the present levels. The advantages the system appear attractive, but the practical problems of making the transition are very great, since it would not be practical to convert all existing vehicles to this type of lighting. Also, any benefits would only be marginal because glare itself is not a frequent cause of accidents. However, many cars now have refracting or colored glass to cut down on glare.

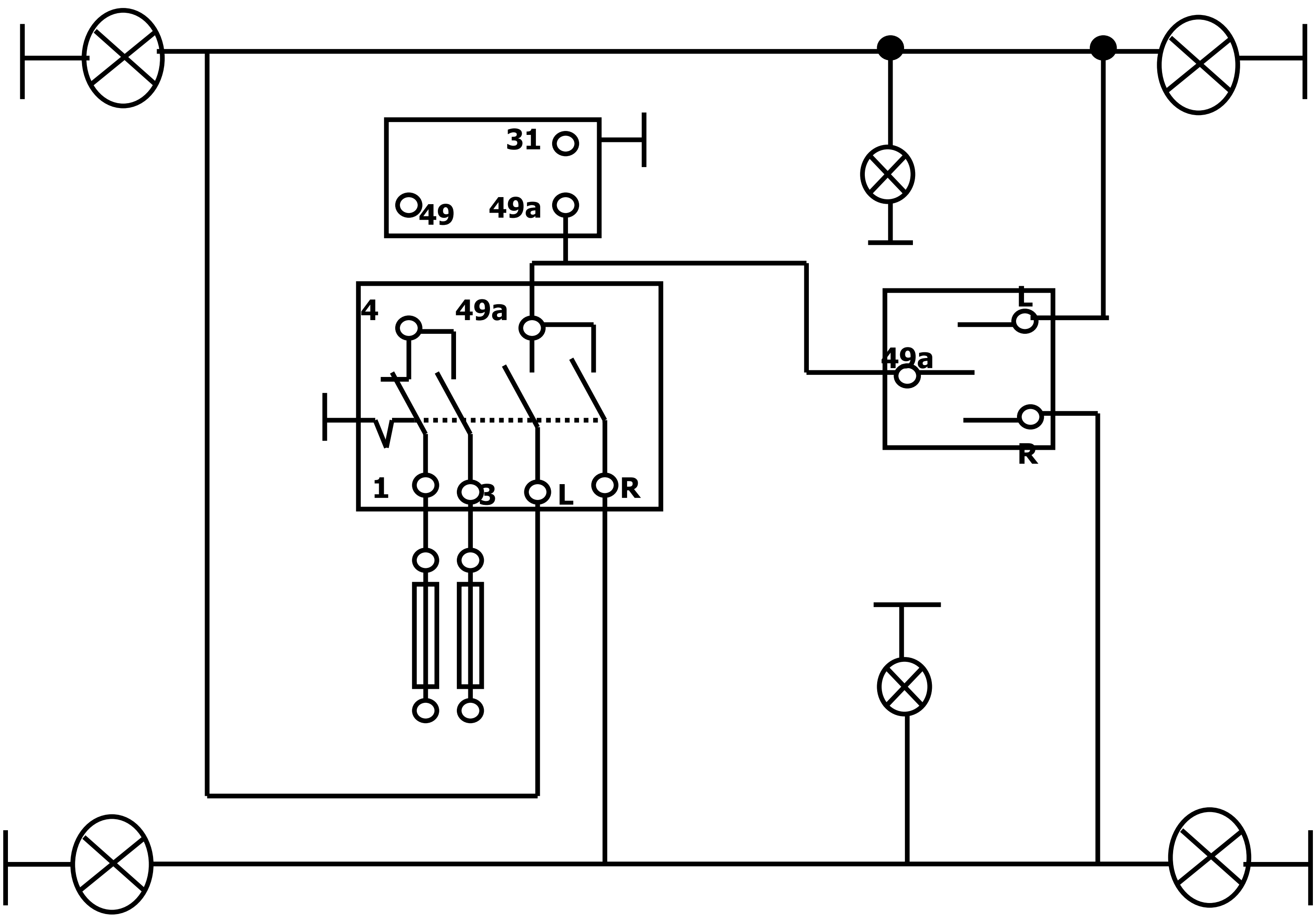
LOW BEAM, CLEARANCE, TAIL &LICENSE PLATE LIGHT
CIRCUIT DIAGRAM



Due to recent legislation, newer cars in Texas with the dimmer switch mounted on the steering column will have to be refurbished with standard floor-mounted dimmers. Too many Aggie's are being found in the ditch with their legs caught in the steering wheel.

4.4 DIRECTIONAL SIGNAL SWITCH

The directional signal switch is installed just below the hub of the steering wheel. A manually controlled lever projecting from the switch permits the driver to signal the direction in which he wants to turn. Moving the switch handle down will light the "turn signal" lamps on the left front and left rear of the car, signaling a left turn. Moving the switch upward will light the turn signal lamps on the right (front and rear), signaling a right turn. With the switch in a position to signal a turn, lights are alternately turned "on" and "off" by a turn signal flasher. Incorporated in the directional signal switch is a "lane change switch mechanism." This feature provides the driver the opportunity to signal a lane change by holding the turn lever against a detent, then releasing it to cancel the signal immediately after the maneuver is completed.



4.4.1 Flusher

A flusher unit is used to cause the front and front signal lights to flash on and off on the side of the vehicle nearest to the direction of turn, when the switch lever is operated.

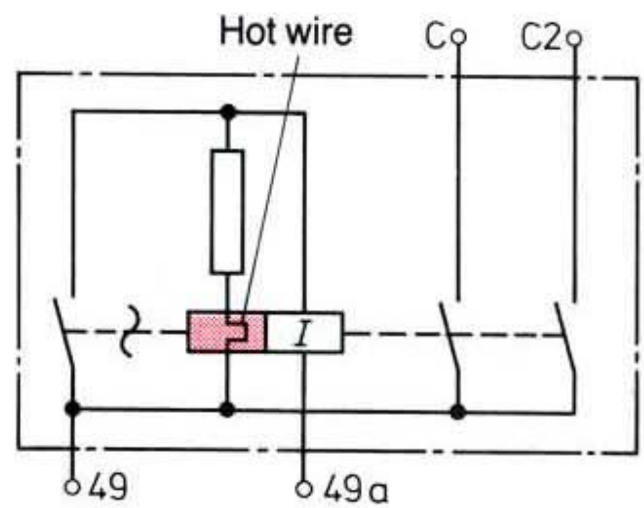
Flushers for signal light operation are thermal and electronic type.

a) Dark start flusher operation

The signal light contact is open when the flusher unit is current less.

Signal light switched on, current flows from terminal 49, hot wire, resistor, magnetic coil via signal light switch, signal lamps and ground.

The hot wire heats up and expands allowing the spring force of the signal light armature to close the contact. When the contact is closed, the hot wire and resistor are by passed and the signal light bulbs. When the hot wire cools it contracts and the contact is opened as a result the bulb lights off. This cycle is repeated as long as the switch is on.



b) Non dark start operation

Signal bulb immediately light when the signal switch is operated to indicated a turn. The signal light contact is closed when flusher is current less.

Signal light switch on, current flow via 49, signal contact, magnetic coil, 49a signal switch, signal bulbs and ground.

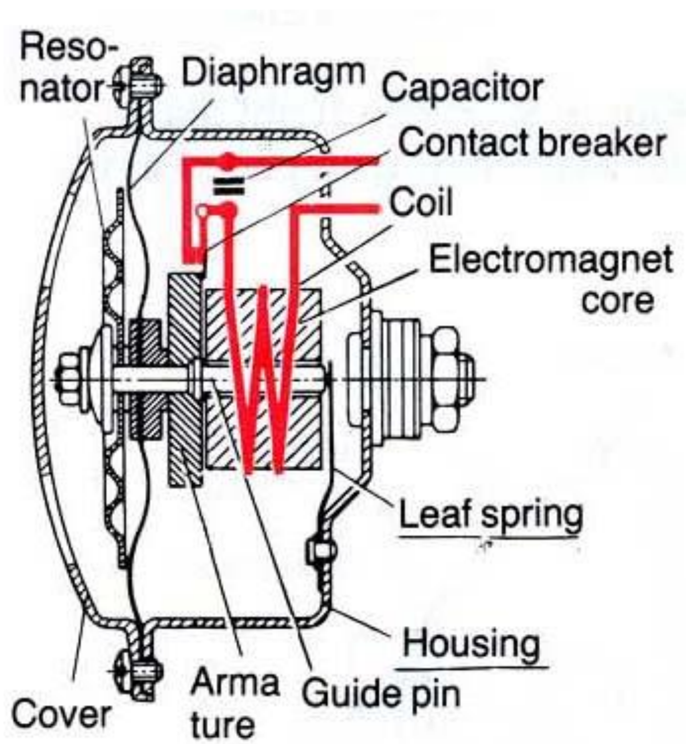
The magnetic force of the coil closes the contact and current can flow through the hot wire. Hence, the hot wire heats up and expand, allowing the signal contact to open. As a result of this action, the signal bulbs do not light contact to close then signal bulb lights again this procedure steadily repeated.

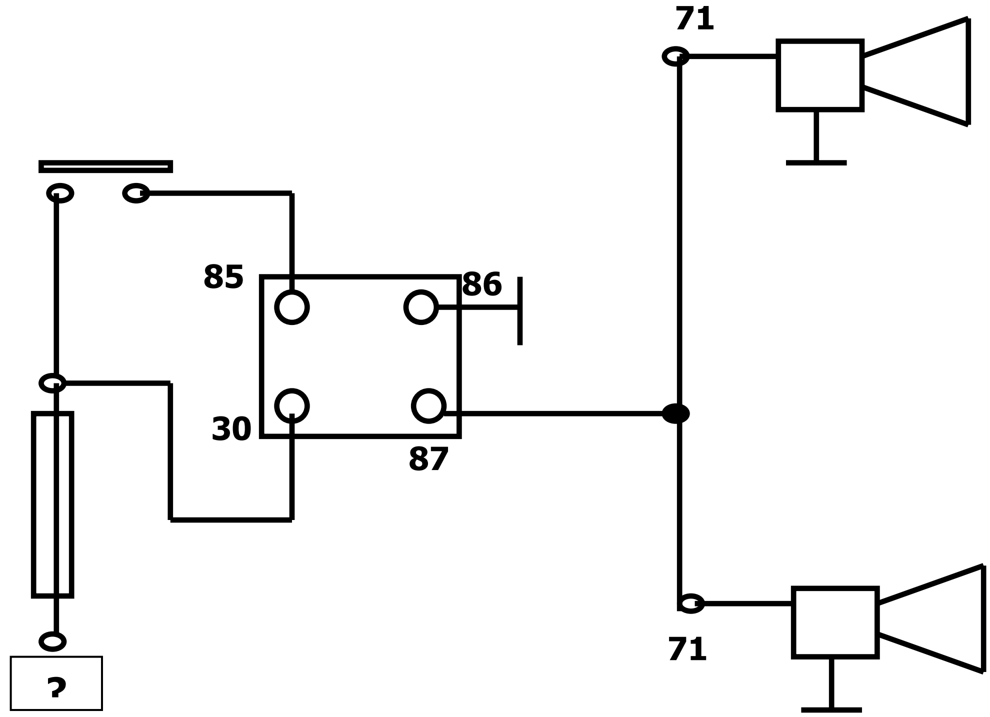
4.5 STOPLIGHT SWITCH

In order to signal a stop, a brake pedal operated "stoplight switch" is provided to operate the vehicle's stop lamps. In addition to lighting the conventional rear lights, the switch also operates the center high-mounted stop lamp, which became mandatory on later models. Cruise control equipped vehicles may also utilize a vacuum release valve. In this case, both the vacuum release valve and the stoplight switch are actuated by movement of the brake pedal.

4.6 HORN

The horn is an electromagnetic vibrating device. It consists of body, field winding diaphragm armature and contact breaker. When the horn button is depressed, current starts flowing through the field coil produces a magnetic field that pulls the armature with the diaphragm and it produces a click and the contact points are separated. So that current can not flow. The magnetic field in the coil collapses and the diaphragm is released and with another click. The action is rapid and this combination produces the horn sound.

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