

TRADE OF HEAVY VEHICLE MECHANIC

PHASE 2

Module 7

Auto Electricity

UNIT: 2

Electric Motors

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1.0 Learning Outcome

By the end of this unit each apprentice will be able to:

- State Fleming's Left Hand Rule
- Describe the construction and operation of DC motors in a motor vehicle
- Distinguish between permanent and electro magnet type motors
- State the advantages of permanent magnet and geared type starter motors
- Fit a solenoid to a starter motor
- Remove and refit a starter motor to a vehicle

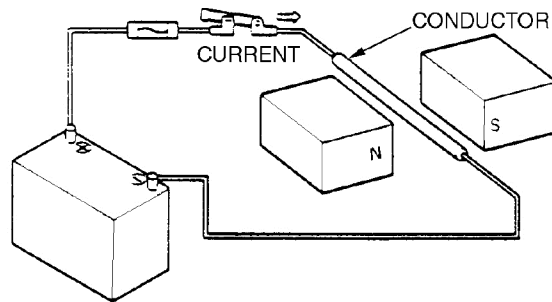
1.1 Key Learning Points

- Direction and strength of the magnetic field around a straight conductor
- Effect of magnetic deflection, Fleming's Left Hand Rule
- Construction and operation of a permanent magnet, DC motor and commutator
- Construction of DC motors, series and parallel windings. Reversing current flow through field coils or armature changes direction of rotation
- Function, operation and fitting of starter solenoid, brushes, field coils and armature
- Fire hazards associated with stalled motors (speed/current relationship)
- Isolating, removal, and refitting procedure of a starter motor from a vehicle

2.0 Electromagnetic Force

An electromagnetic force is a force that acts on a conductor when current flows in the conductor within a magnetic field. It is utilised to operate starter and wiper motors, and the pointers of ammeters, voltmeters, etc.

2.1 Direction of Electromagnetic Force



Let's assume the N and S poles of a magnet are placed near other, and a conductor is put between them, as shown. Then current is applied to the conductor.

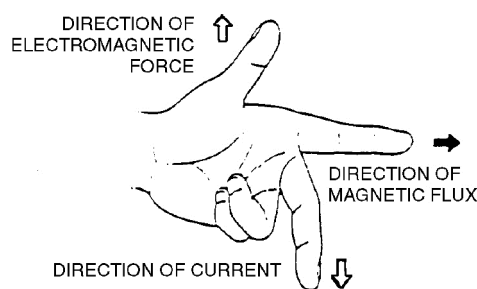
The following can be said about the magnetic flux

created in this case: There are a smaller number of magnetic lines of force above the conductor since the direction of the magnetic fluxes created by the magnet and the direction of those created by current oppose each other. In contrast, there are a larger number of magnetic lines of force under the conductor as their directions coincide.

Since magnetic lines of force act similarly to stretched rubber bands in many ways, the magnetic lines of force attempt to become straight. This tendency is stronger under the conductor than above it. Therefore, a force is generated that tends to push the conductor upward. This force (F) is called an electromagnetic force.

The direction of an electromagnetic force can be determined from another rule called Fleming's left-hand rule.

To understand this rule, open your hand, as shown below, with the thumb pointing perpendicular to the index finger, and the index finger perpendicular to the middle finger. Then, point the index finger in the direction of the magnetic flux, and the middle finger in the direction of the current. The direction in which the thumb points will then be the direction of the electromagnetic force, and therefore, the direction in which the conductor moves.

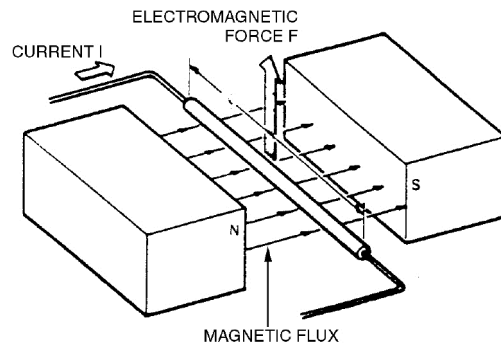


Fleming's Left-hand Rule

2.2 Strength of Electromagnetic Force

Strength F of an electromagnetic force varies in proportion to density B of the magnetic flux (the number of magnetic lines of force per unit area), current flowing I in the conductor, and length L of the conductor, as expressed below:

$$F = B \times I \times L$$



In other words, an electromagnetic force is greater when there is a stronger magnetic field, when more current flows in the conductor, or when the length of the conductor within the magnetic field is greater.

3.0 Permanent Magnet Motors

Small motors are used for fans, window lifters and windscreen wipers and washer pumps. These often use permanent magnets to produce the magnetic field within which the armature rotates.

4.0 Large Motors

Motors which have to produce high power outputs, like starter motors and some window lifters, often use a field coil to produce the magnetic field. This is because, until recently, this was the only way to produce the powerful, concentrated magnetic flux required for compact high-power motors.

5.0 Starter Motors

This motor has an armature with many coils each of which is connected to a segment of the commutator. The segmentation produces rotational power smoothly just as engines with many cylinders do. The whole rotating assembly is supported by bearings at each end. At the end opposite to the commutator and brushes is the drive pinion which engages with the ring gear on the engine's flywheel used.

5.1 How a Starter Motor Works

The starting motor does the actual job of cranking the engine. It is a special type of electric motor:

- It is designed to operate for short intervals under great overload.
- It produces very high horsepower for its size.

The basic starting motor has a solenoid, a field frame assembly, an armature, and a drive mechanism. Let's see how these parts work to convert electrical energy from the battery into mechanical energy to crank the engine.

First consider the pole pieces in the field frame assembly of the starting motor as the ends of a magnet (**Fig. 1**). The space between these poles is called the magnetic field.

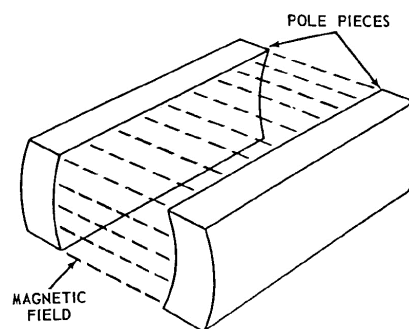


Fig. 1 — Pole pieces and their magnetic field

If a wire, called a field winding, is wrapped around these pole pieces and current is passed through it, the strength of the magnetic field between the pole pieces is increased (**Fig. 2**).

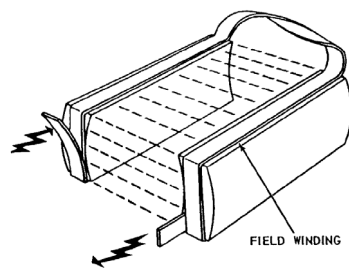


Fig. 2 - Field winding added to pole pieces

Now let's consider a loop of wire (**Fig. 3**). When we feed electrical energy from the battery into this loop, a magnetic field is also formed around the wire.

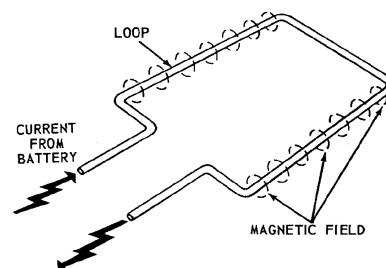
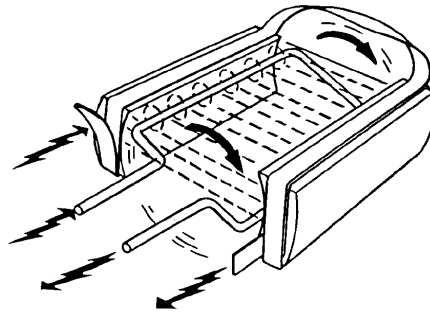


Fig 3 – Loop of “live wire and its magnetic field



If we place the loop of wire in the magnetic field between the pole pieces and pass current through the loop, we have the makings of a simple armature (Fig. 4). The magnetic field around the loop and the field between the pole pieces repel each other, causing the loop to turn.

Fig. 4 - Loop of wire placed in field between poles

In an actual armature we use more loops (Fig. 5). By attaching separate metal segments to the ends of each loop, we form a simple contact surface called a commutator. When we feed electrical energy to the commutator through sliding contacts called brushes, the repelling or kicking action causes a continuous rotation. All starting motors use this basic principle to develop useful mechanical energy.

Fig. 5 — Armature for starting motor

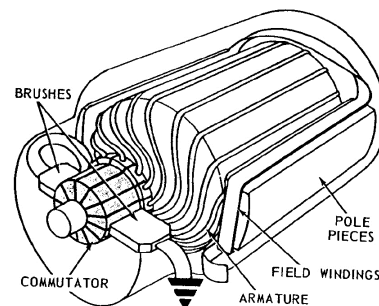
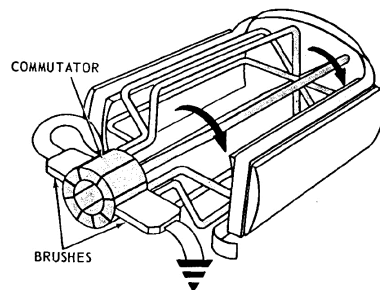
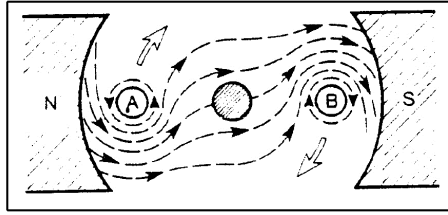


Fig.6 Armature and brushes in starting motor

The interaction of the two magnetic fields causes the armature to rotate, as can be seen in Fig. 7. The lines of force of the field coils are travelling from “N” to “S”, and the lines of force from the loop travel at ‘A’ in an anti-clockwise direction and at ‘B’ in a clockwise direction. As previously described, the lines of force never cross one another even if they have to distort.

This is what happens in the motor, the line of force from the field coil travelling from “N” to “S” are directed under ‘A’ because at ‘A’ the lines of force are travelling in an anticlockwise direction on top of ‘A’, these lines are travelling towards “N” and they repel each other and the lines under ‘A’ are travelling the same direction as “N” to “S” and these support one another. This results in weak lines of force on top of ‘A’ and strong lines of force under ‘A’.



The strong lines push 'A' upwards. At 'B' the opposite happens and 'B' is pushed downwards. With 'A' being pushed upwards and 'B' downwards rotation of the armature takes place in a

clockwise direction.

Fig. 7 — Interaction of magnetic fields

6.0 Commutation

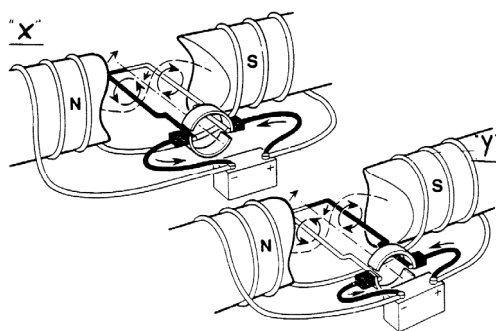
When the armature rotates a half a revolution 'A' is positioned at the south pole "S" and 'B' positioned at the north pole "N". As the magnetic field surrounding 'A' is in the anti-clockwise direction the magnetic field would be stronger under 'A' and above 'B', which would mean that the armature would now rotate in the opposite direction. The motor would never rotate. To maintain rotation of the armature in the one direction the flow or current through the armature must be reversed when 'A' is at the "S" pole of the field coil.

A commutator is used with the motor to reverse the current flowing in the armature. **Fig. 8 "X"** shows the black half of the armature at "N" and is connected via the segment of the commutator through the carbon brush to the battery negative terminal. In this position, the current flow through the armature produces a magnetic field of anti-clockwise direction through the black half 'A' of the armature and clock-wise through the white 'B'.

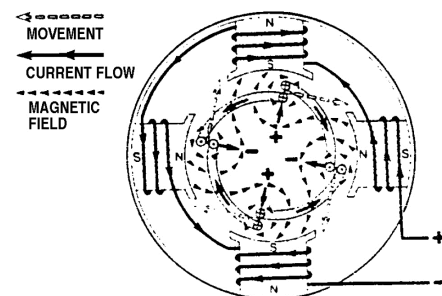
Interaction occurs and the loop rotates.

Fig. 8 'Y', the armature has moved through half a turn so the white section is now at "N". The brush which connects to the negative side of the battery is now in contact with the white segment of the commutator. The current flowing in the armature is now reversed which means the direction of the lines of force of white is now anticlockwise and clockwise in the black "A".

Fig. 8 — Commutation



The main field in practice



The interaction of the magnetic fields will rotate the armature in the same direction as when black “A” was at “N”. As the armature rotates therefore the magnetic field of the armature remains constant to the main field.

To increase the power of the motor many wire coils or loops are used in the armature to maintain a constant push on the armature. Four poles are used — two north and two south to produce a strong main field and are wound to give alternate N and S poles. Because some starters use 200 amps when operating four carbon brushes are fitted to distribute the current load.

Starter motors are usually series-wound motors because they produce their maximum torque at the beginning of their armature rotation.

7.0 Starting Motor Circuits

All starting motors have a stationary member (field) and a rotating member (armature). The field windings and the armature are usually connected so that all current entering the motor passes through both the field and the armature. This is the motor circuit.

The brushes are a means of carrying the current from the external to the internal circuit — in this case from the field windings to the armature windings.

The brushes are carried in brush holders. Normally, half the brushes are grounded to the end frame while the other half are insulated and are connected to the field windings.

7.1 Types of Motor

In the past, motors with electromagnetic field systems have been popular, but improved permanent magnet materials have enabled the construction of lightweight, and more-compact starting motors.

Starting motors have field windings connected in series or series-parallel with the main circuit and armature. Since a series-wound motor is capable of producing a high torque at low speed, it is particularly suitable as an engine-starting motor.

Series motor: This type of motor has the thick field coils arranged in series with the armature windings and all current that passes to the armature also goes through the field: this gives the strongest possible field.

Fig. 9 shows a diagram of a simple series motor. When the switch is closed, the combined effect of the current in the armature and field windings distorts the magnetic flux; this generates a torque that pushes the armature away from the field pole.

Constant rotation and a steady torque is required, so a number of armature conductor coils are needed: these coils are set in slots around a laminated soft-iron core.

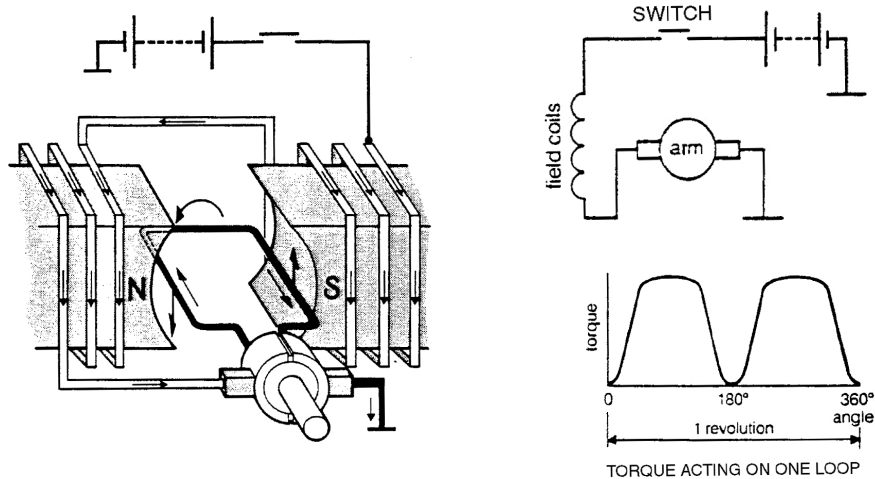


Fig. 9 — Principle of a series wound motor

The end of each coil is soldered to a copper commutator segment which is insulated from the adjacent segments by mica (**Fig. 10**). Armature conductors are made in the form of thick copper strips to provide a high current flow.

Fig. 10 — Commutator

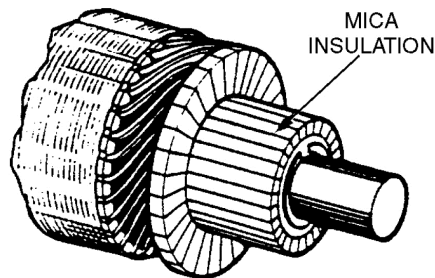
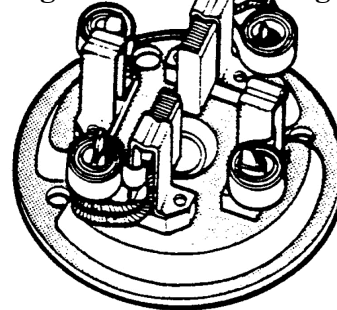


Fig. 11 — Brush springs



Comparatively hard brushes, often of a composition of carbon and copper, are used and these are pressed against the commutator by springs of a spiral shape (**Fig. 11**).

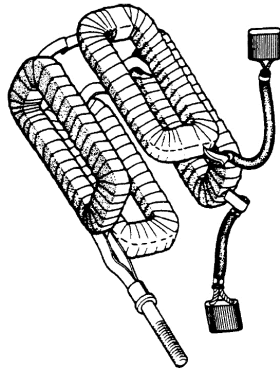


Fig. 12 — Field coil construction

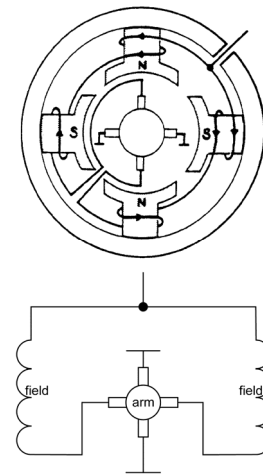
Using a normal armature and commutator allows the brushes to ‘feed’ the armature conductor that is positioned where the field flux is most dense. When this conductor is pushed away, another conductor takes its place. By using a number of conductors, a near-uniform rotation is obtained. A typical armature has about 30 slots for conductors: the larger is the number of slots, the smoother the motion.

Fig. 12 shows the construction of the field coils. These are made of copper or aluminium alloy and are wound in a direction which produces N and S poles. Each coil is bound with tape to provide insulation.

Series-parallel motor — **Fig. 13** shows a series-parallel motor. This has the field coils in series with the armature but connects the two pairs of field coils in parallel. Current flowing to the armature divides as it enters the motor; half passes through one pair of field coils and the remainder flows to the other pair.

A lower field resistance is achieved with this arrangement, so the motor can handle more current and give a higher torque output.

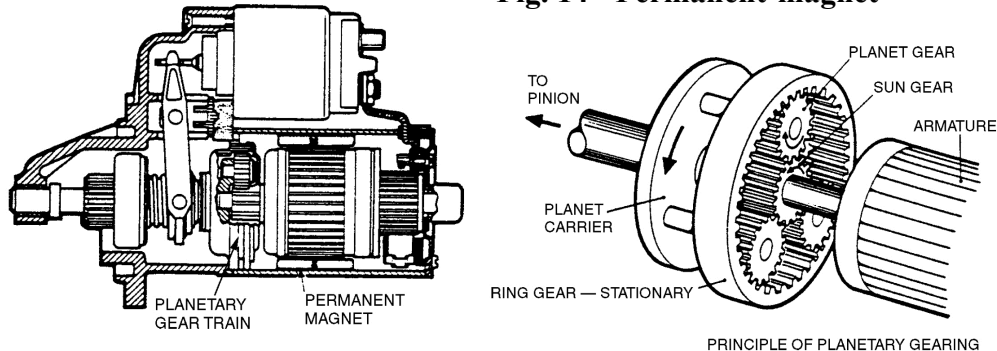
Fig. 13 — Series-parallel motor



Permanent-magnet motor: A significant improvement in performance-to-weight ratio is achieved by using a permanent-magnet field system. Used in conjunction with a planetary gear-reduction drive, this type of motor is very compact and is suitable for use as a starting motor for a car engine.

Fig. 14 shows the basic construction of a permanent-magnet motor. This type uses a planetary gear train made of a new plastic-steel material. The sun gear is attached to the armature and the output is taken from the three planets which revolve around the inside of a fixed ring gear.

Fig. 14 - Permanent-magnet



starting motor (Bosch type)

8.0 Relays

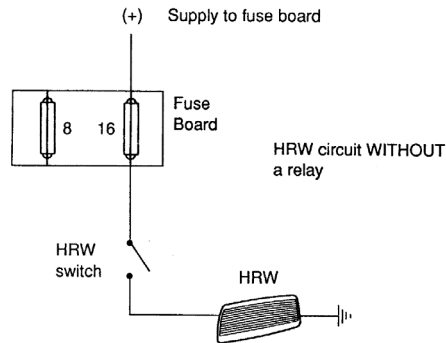
Relays are used extensively in modern vehicles. They can be thought as electro/mechanical switches. They are often used to switch on circuits that require a heavy current e.g. the heated rear windscreen (H.R.W.) circuit. If a relay was not used the contacts inside the HRW switch would need to be quite large to carry the heavy current. By using a relay, smaller switch contacts can be used. The relay then acts as a switch saver.

Relays can be used to avoid voltage drop and reduce the amount of heavy duty cable required. They can also ensure that contacts make and break cleanly. Relays also make a convenient point for testing individual circuits. On the following page you can see from the circuit diagrams that with **circuit A** the HRW switch has to carry the full current. However, with **circuit B** the HRW switch only needs to carry enough current to activate the relay. When the relay is activated it closes the relay switch. The feed for the HRW then comes through the 16 amp fuse and the contacts of the relay. By taking this route it saves the contacts of the HRW switch.

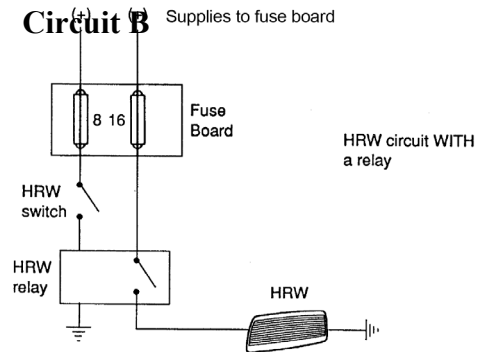
Circuit B has the advantage that the relay switch can be located almost anywhere in the vehicle. With circuit A, if the switch was mounted too far away from the heated rear window, it could cause pressure loss i.e. voltage drop.

Heated Rear Window Circuit

Circuit A



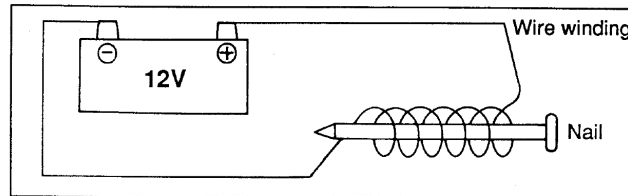
Circuit B



9.0 Magnetism

Now you know what a relay does, it is time to see how it does it. If you assembled the circuit below, what do you think you would create?

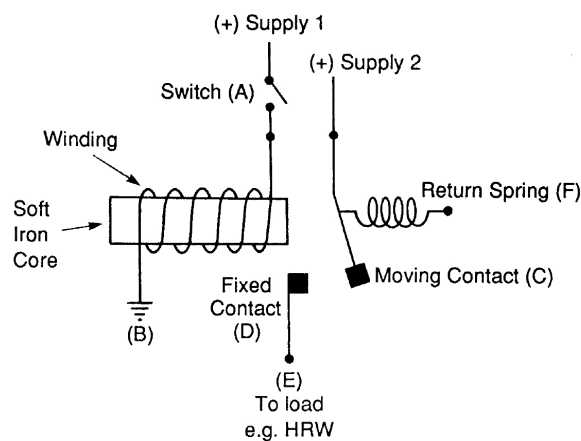
The correct answer would be the nail would become an electromagnet. If the



number of turns of wire were increased you would increase the strength of the magnet.

The diagram below shows the components of a four pin relay.

The soft iron core, like the nail, becomes magnetised once a current flows



through the winding.

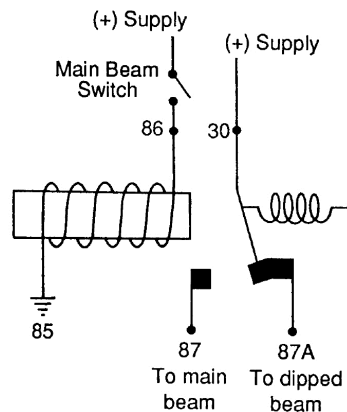
Many other relays are available, some need a signal to be sent from an E.C.U. for them to operate. Some operate on a time basis i.e. interior light delay, and some have their own integrated circuit built into them i.e. electronic relays. The two types of relay used most often are the four pin switch saving relay and the five pin relay which we can look at now.

9.1 5-pin Relay

This is sometimes known as an ‘either/or’ relay because you can use either one circuit or the other.

This type of relay is particularly useful for headlights. Pin number 87A feeds the dipped beam circuit. When the driver selects main beam the relay is energised so the moving contact moves to pin 87 and feeds the main beam circuit. So with the five pin relay you can have **either** dipped beam **or** main beam.

The above diagram represents the wiring for a basic four-pin relay. The



basic relay works in three stages.

Stage 1:

When the switch (A) is closed, current flows through the winding around the soft iron core and down to earth at (B). This action magnetises the iron core.

Stage 2:

The magnetised iron core attracts the metal moving contact (C) which touches the fixed contact (D). Current can now flow from supply 2 through the contacts and on to the load (E) e.g. a heated rear window.

Stage 3:

When the switch (A) is opened the current stops flowing around the iron core, so the magnetic field collapses. The moving contact is then pulled away from the fixed contact by the return spring (F). Current cannot now flow.

1. Switch on current to iron core.
2. Magnet closes relay contacts and current flows.
3. Switch off relay contacts opened by return spring.

You now know how a basic four pin relay operates. If you look at the relay mounting plate in most vehicles (usually near the R-fuse carrier) you should see a few relays. The top of the range models usually have at least six. You need to know which relay pins are connected to the fixed and moving contacts in a relay. Each pin has a number or letter which tells you which contact the relay pins are connected to.

For a four pin relay the numbers and letters are.

- 86 or W2 Pin connected to supply side of the winding.
- 85 or W1 Pin connected to the earth side of the winding.
- 30 or C2 Pin connected to the moving contact.
- 87 or C1 Pin connected to the fixed contact.

With the basic four pin relay shown on page 90 the contacts are held open by a spring. A variation of this is when the contacts are normally closed. When a relay is not magnetised the contacts are said to be 'at rest'. The contacts can be at rest in either an open or closed position.

- Relays that have their contacts open when they are not magnetised are called normally open (N/O) relays.
- Relays that have their contacts closed when they are not magnetised are called normally closed (N/C) relays.

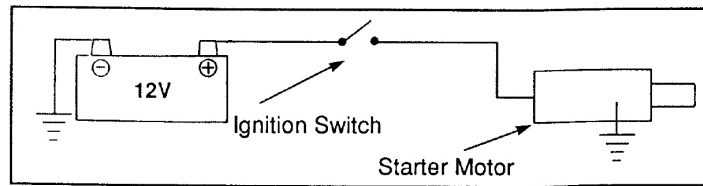
For example a four pin relay that is normally closed can, be identified by the number 87A.

- 87 fixed contact on a normally open relay.
- 87A fixed contact on a normally closed relay.

10.0 Solenoids

This section is going to look at solenoids and actuators. A solenoid is the term used for a heavy duty relay and like a relay acts as a switch saver. Solenoids are used to switch circuits that require a very large current to operate. An example of this type of circuit is the starter circuit.

Consider the diagram below.

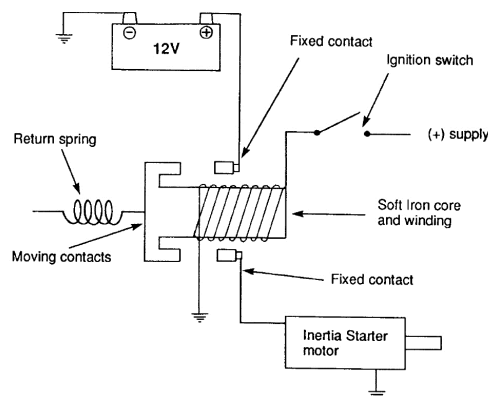


Since the starter circuit requires a lot of current to operate, the diagram above would be impractical. This is because the contacts of the ignition switch would need to be very large to carry the large current. Also the large cables required to carry the current would need to be very long. By using a solenoid, small ignition switch contacts can be used and the length of cable can often be reduced. This will reduce the voltage drop in the circuit.

Voltage drop is the term used to describe a reduction of voltage between two points. e.g. between the ignition switch and the starter solenoid. Voltage drop is proportional to resistance. Long cables, small diameter cables and corroded connections all cause an increase in resistance, which creates voltage drop. To avoid voltage drop, manufacturers design circuits so that, the shortest route, is used by the largest diameter cable with the minimum number of connections.

Consider the diagram below.

Like a relay a solenoid has a winding and contacts. When the ignition switch



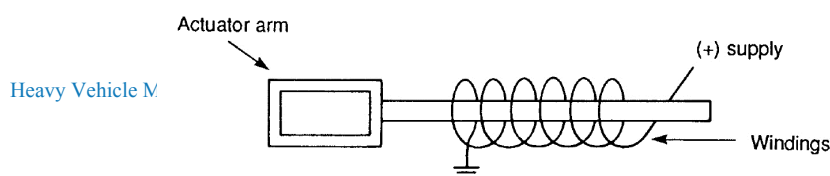
is turned to the cranking position, current flows through the winding and around the soft iron core. Unlike a relay the soft iron core is free to move. The magnetic effect of the winding pulls the iron core into the winding. This brings the moving and fixed contacts together which allows current to flow through the contacts and turn the starter motor.

When the ignition switch is moved away from the cranking position, current flow to the winding ceases. The return spring then pulls the moving contacts and iron core away from the winding. This breaks the current path to the starter so stopping the motor from turning.

11.0 Actuators

Actuators are operated in the same way as solenoids. They are used to move mechanisms remotely. Some examples of actuators on a vehicle are, door locks, pre-engaged starter motors and fuel cut off valves.

Consider the diagram below.



Like a solenoid or relay an actuator has a winding. When current flows around the winding, the winding is energised.

Two types of actuator are used, a short rated version and a continuously rated version.

The short rated actuator is used for simple on/off operation. This type of actuator has one winding which cannot be operated for longer than 15 seconds. An example where this type of actuator could be used would be a door lock.

The continuously rated actuator has two windings. The first winding is used to **pull** the actuator arm into the winding, the second is used to **hold** the actuator arm in the winding. The pull in winding may require a current of as much as 35 amps. The hold in winding may only require a current of 4amps. The continuously rated actuator is designed so that it can be operated for longer than 15 seconds. This-type of actuator is often used in pre engaged starter systems to move the starter pinion into mesh.

11.1 Summary

Solenoids can be thought of as heavy duty relays. They are used to switch a circuit on or off. They are often used to operate inertia type starter motors.

Actuators are used to mechanically move a component. There are two types. The **short** rated version and the **continuously** rated version.

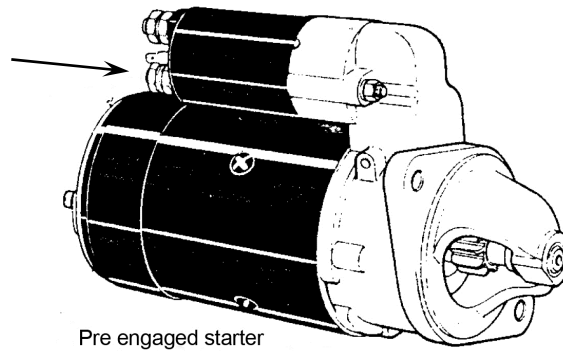
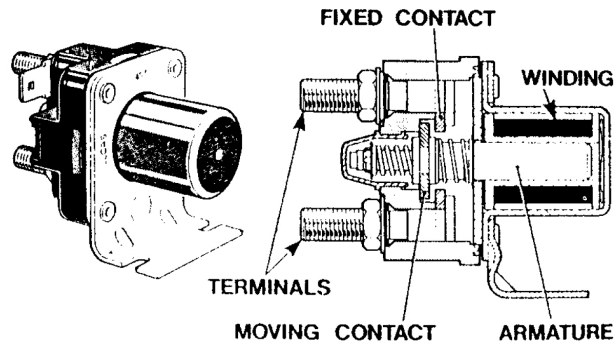
Solenoids and actuators operate on the same principles however they are often confused. A general rule of thumb is, solenoids directly switch a circuit on or off,

actuators mechanically move a component. For example:

This could be called a heavy duty relay or a solenoid. Using the 'rule of thumb' this would be a solenoid.

In the diagram the soft iron core is called an armature. This is the technical name to describe the iron core.

In some text books and workshop manuals this could be called a solenoid or an actuator. Using the 'rule of thumb', this would be and actuator.





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