Auto−Electric Basic Technology − Part 2

Table of Contents

Auto−Electric Basic Technology − Part 2

WRITTEN BY:

HARTMUT ARLITT/GERMAN DEVELOPMENT SERVICE IN NAMIBIA
INSTRUCTOR AT THE RUNDU VOCATIONAL TRAINING CENTRE

BY USING PARTS OF:

1. Automotive Encyclopedia/Fundamental Principles, Operation, construction, Service and Repair
1995 Edition; South Holland, Illinois; The Goodheart−Willcox Company, Inc.

2. Different information material of the BOSCH company Germany

3. Different teaching material from the Deutsche Gesellschaft fuer Technische Zusammenarbeit (GTZ) GmbH

4. Own material, scripts and circuit diagrams

MAY 1999

CRYSTAL

Lehr− und Lernmittel,
Informationen, Beratung

Educational Aids
Literature, Consulting

Moyens didactiques,
Informations, Service−conseil

Material didáctico,
Informaciones, Asesoría

DED−Namibia

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

AUTO − ELECTRIC/BASIC − TECHNOLOGY

Special edition in the field of Vocational Training in Namibia

1. Fundamentals of magnetism

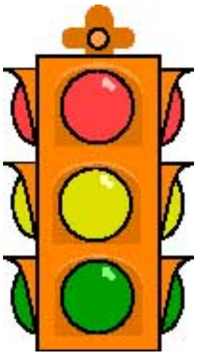
Effects of electric current

There are **four effects of electricity** that a flow of current will produce:

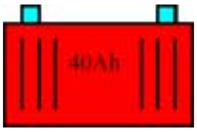
1. **Heating effect:** The friction created by the movement of the electrons causes a generation of heat in the material known as resistive heating. The resistive heating is made use of in

elements of electric stoves etc.

2. **Lighting effect:** By passing of an electric current through thin wires of metal with a high melting point (i. e. wolfram, tungsten) those wires heat up so strongly that they begin to glow. In this state they serve as a source of light. The higher the temperature, the greater the light yields. In bulbs the wires are placed in a vacuum or in a protective gas. So the wire cannot oxidise. A current flow trough gas can also be used to produce light as a result of the collisions between the charged gas particles (fluorescent tubes)

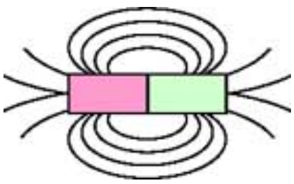


3. **Chemical effect:** The passage of a current can split up the molecules in liquids and solids, a process known as electrolysis. This forms the basis to produce an e.m.f. (electromotive force or voltage) by a battery.



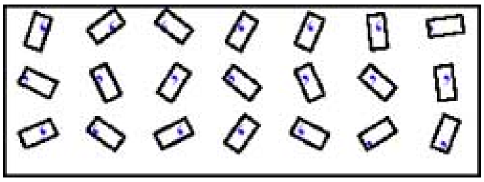
4. **Magnetic effect:** The current flow in a conductor or coil sets a magnetic field flux or force around it which is more pronounced when an iron core is present. The strength of that force (symbol: F) depends upon the value of the current and the number of turns on the coil/winding.

F = ampere–turns (A.T.)

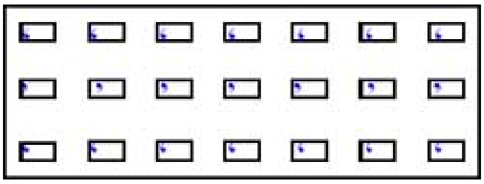


Magnetism is, like electricity as well, still a mystery. We know many laws governing its behaviour and have applied it in the automotive field but no one knows what magnetism really is.

The effects of magnetism were first discovered when it was found that pieces of iron core and also other pieces of iron on several places of the earth attract each other.



Not magnetised iron bar



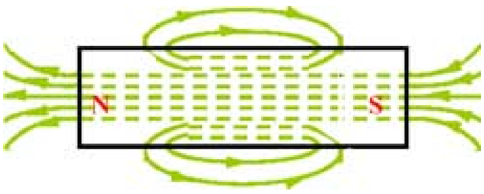
Magnetised iron bar

In the automotive needs of magnetism there are used **permanent magnets** as well as **electromagnets**, depending what we do want to reach with that different types of magnets.

Magnetism

Magnetism we do find in nature mostly as permanent magnets. Magnets attract iron filings (and nickel & cobalt). In the vicinity of the magnet there is a magnetic field with a definite direction, which is strongest at the ends of the magnet.

See below the field lines of permanent magnet bar:

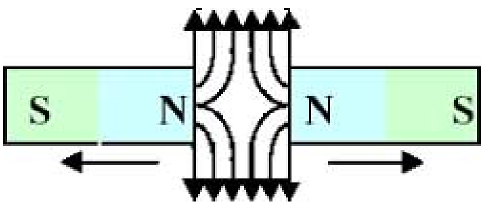


Field lines of a bar magnet

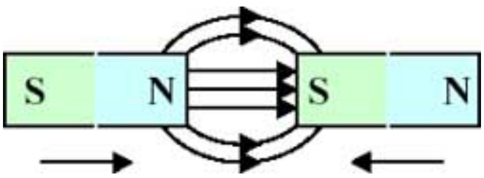
If a bar magnet is positioned on a pointed pivot so that it can move freely, it aligns it self in a north–south direction. The pole–pointing north (of the geographical pole of the earth) is the North Pole of the magnet; the opposite is the South Pole.

The field lines are imaginary plots, which indicate the direction of the magnetic force. In the space surrounding it (air or non–magnetic material) they run from the north to the South Pole. Inside the magnet, they run from the South Pole to the North Pole. The field lines are therefore closed (continuous).

If a magnet gets divided or broken, in **every part will be obtained a north and a South Pole**.



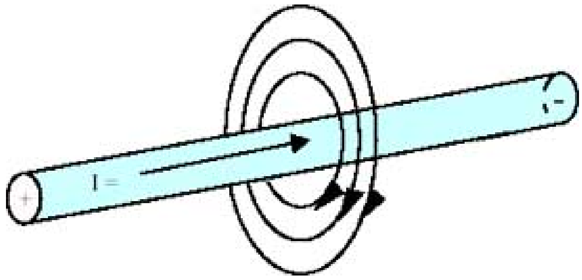
Field lines at like poles



Field lines at unlike poles

Electromagnetism

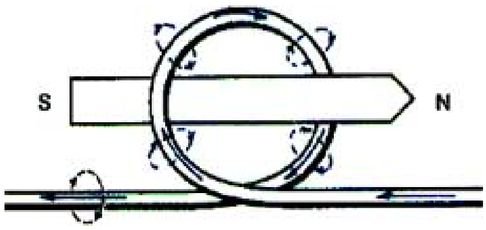
If trough a conductor a current flows then **it is surrounded by a magnetic field** in the form of concentric circles.



Magnetic field of a conductor with current flowing through it

If a **conductor** is **wound into a coil**, the magnetic field lines are concentrated together inside this coil. And there inside the field lines of the individual turn of the coil are added together.

If a **conductor** is **formed into a loop** the lines of force on the outside of the loop spread out into space.



Magnetic field around a loop

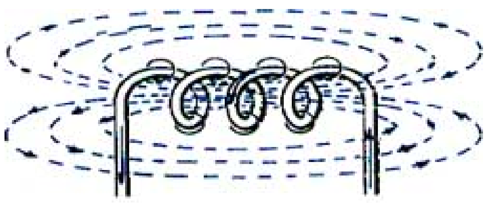
Lines on the inside of the loop are confined and crowded together. This increases the **density** of lines **of force** in that area and a **much greater effect is produced with the same amount of current.**

The total number of coil field lines refers to the magnetic force depending on the current intensity and the number of windings. That means, too, the same magnetic effect can be reached by

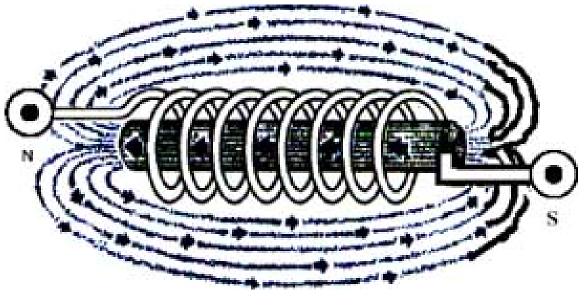
- – a low current strength and a large number of windings or by
- – a high current strength and a small number of windings.

By increasing the number of loops, the magnetic field will be greatly increased.

By winding the loops or a coil on a soft iron core, the field is further intensified. That means the magnetism of this electromagnet increases. On that way there is a possibility to build different electromagnets by using different strength of the magnetic fields.

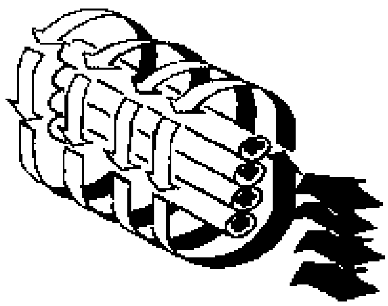


Magnetic field around a coil



Strengthened magnetic field of a coil wound around a core of soft iron

When **several more current−carrying conductors are placed side by side, the lines of magnetic force join and surround all of the conductors.**



Current−carrying conductors placed side by side

This kind of magnetic pattern is obtained i.e. in coils of the solenoid of starter motors, of the ignition coil etc.

Magnetic conductivity

The **conductivity of air for the lines of force is defined by Kelvin**. "**It is the ease with which lines of force may be established in any medium as compared with a vacuum**".

When a soft iron core is inserted in a coil to form a true electromagnet, the lines of force will be increased several hundred times. That means there are more lines of force created. Field coils in starter motors, regulator−windings on iron−cores and ignition coils are using all the same principle.

Solenoid

A solenoid is a tubular coil of wire. It is designed to produce a magnetic field. Mostly the solenoid includes an iron core that is free to move in the tubular coil. The **movement** of such kind **of an iron core is used** to operate in the case **of mechanical work** i.e. as a switch. If a solenoid is used to close/open the contact points of an electrical switch then is it called an electromagnetic switch.

> **NOTE:** The South Pole of the iron core is adjacent to the North Pole of the coil. The polarity of a **movable iron core** is induced by the lines of force from the coil. The poles of the coil and the core are in opposite polarity and **so there is an attraction that draws the movable core into the centre of the coil whenever current flows through the coil**.

2. Function of electromagnetic components

Out of the last chapter we do know already that in the automotive field is given a far use of electromagnetic components. In this chapter, you get not the information to all the possible components. The function of such parts/components like starter motors included starter solenoid or like generators and alternators included the types of electromagnetic regulators will be handled in the following chapters.

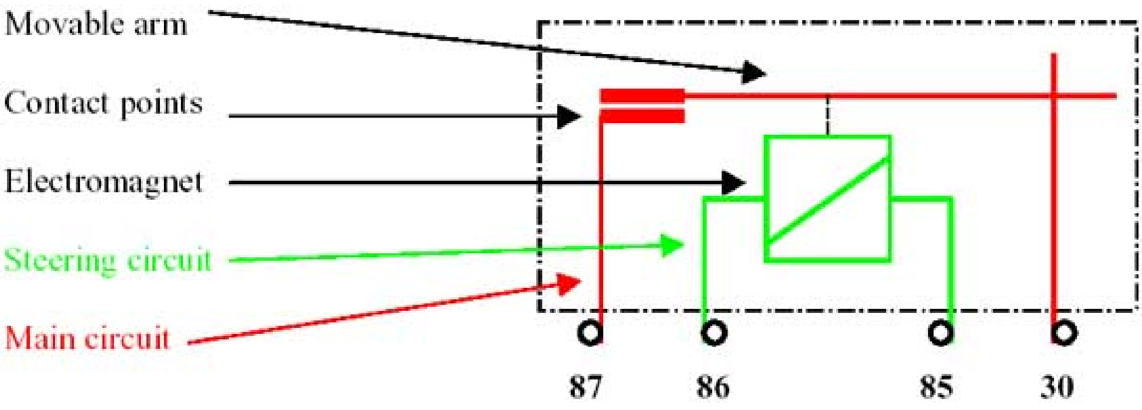
Kinds and function of relays

Now let us follow up three different kinds of relays:

The **main parts of a relay** are the **winding**, the **iron core**, the **contact points** and the **terminals**.

1. Normally open relay

As you can see in the sketch below the contact points **of this relay** are open **as long as** the electromagnet is not energized**.**



How works such kind of a relay?

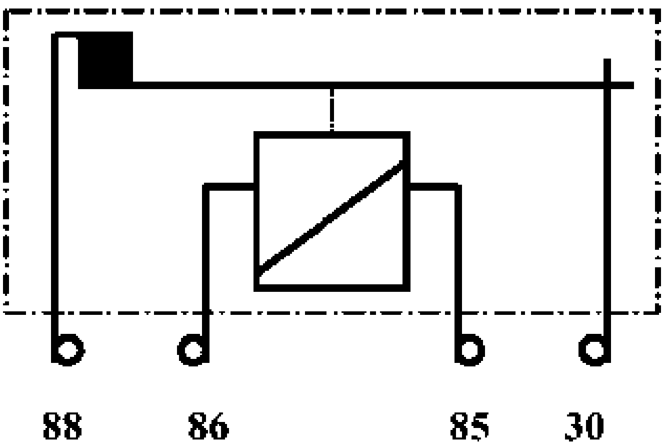
Between the terminal numbers “85” and “86” there is placed the electromagnet (winding & soft iron core). This part of the relay we may name as steering circuit. That means, if we connect one of these terminals to the ground and the other one to the positive a current flow through the winding and build up a magnetic field. The strength of the built up magnetic field develops higher by the soft iron core and is in the end strong enough to pull the movable arm with one contact point downwards by making contact with the other contact point. This is possible because the magnetic power is now stronger as the mechanical power of the spring what holds the movable arm normally in the top. When the contact points are closed the main circuit is closed as well.

Now the current from the side of the terminal “30” flows over the contact points to the terminal “87” and from there to the connected consumer.

> **Note**: if there is not a current flow through the steering circuit and **the contact points are not closed anymore** then the main circuit opens again and so **the connected consumer is switched off**.

2. Normally closed relay

The contact points **of the relay** are closed **as long as** the electromagnet isn’t energized**.**

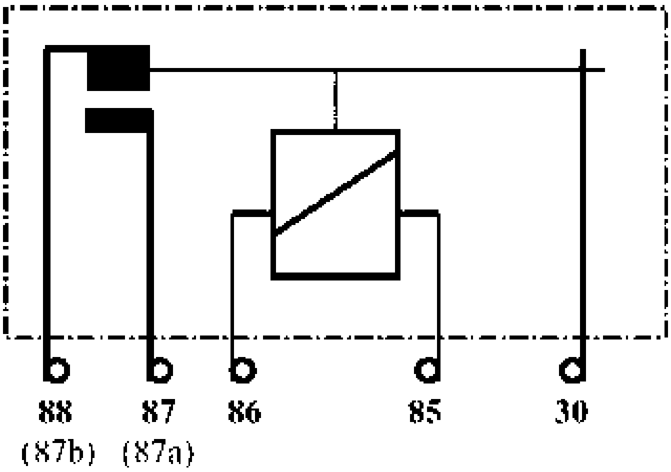


As you can see in the sketch above by the situation of closed contact points the so named main circuit of the relay between the terminals “30” and “87” is closed as well. That means when the electromagnet of this kind of relay isn’t energised the consumer connected to the terminal “87” works.

First by energising of the electromagnet (steering circuit) and so pulling down the movable arm the main circuit get switched off and the consumer doesn’t work anymore.

3. Change over relay

By using this third type of relay there is always one contact point (“87” or “88”) in closed position with the terminal “30”. By the example of the sketch below the contact point of the terminal “30” is in connection with the upper contact “88” as long as the steering circuit isn’t energised. **If the electromagnet is switched on the connection changes over to make contact between “30” and lower the contact point** (in the example of the sketch it is the terminal “87”).



Such a relay can be used for example to connect spot light and fog light over it to change automatically in connection with the dim light/bright light.

Why there is a need to use relays?

The reason to use in several cases a relay is given by a higher current flow in some circuits like for double horn, spotlight, fog light or for the headlight.

But practically you will find always again i. e. headlight circuits in motor vehicles without using a relay.

It is to realise that this depends on the kind of installation for some circuits in a motor vehicle include the use of different parts like switches.

By using a relay the needed stronger current follows up a shorter way (main circuit over the relay). For the steering circuit to the relay (by a small amount of the steering current) is it possible to use a much thinner cable. By looking to the **safety aspect** shorter ways of the high current flow can be created and about this is to think as well by the installation through the metal body of a car. The use of original installed switches is a further point by a later installation of a circuit and this is an **economically aspect**. For example a change from a single horn to a double horn circuit can lead to a problem by using the original horn button. If the contact points of that button are to weak/to soft the points can fast be damaged and on the other hand installing another horn button can be more expensive as the connection of a relay.

Final remark to the relays:

There is never a possibility to use inside a relay a permanent magnet. It have always to be an electromagnet (by the use of a winding and an iron core) to ensure the relay can be switched on and/or off.

Further electromagnetic components

Up to now there were handled relays only but we do have much more other electromagnetic components in motor vehicles in use.

Here let's mention only some of the other electromagnetic components because they get their necessary attention by following up that several topics in the later modules.

Solenoid:

It is a special kind of a relay used in connection with the starter motor by protection of the ignition lock and as link between the battery and the starter motor.

Electromagnetic regulator:

This types of electromagnetic components are used for the regulation of the voltage/current output of generators and alternators to ensure by speeding up of the engine that the voltage/current increases not to high and damages other electrical components.

The regulator is a very important component to ensure that the recharging process goes on properly and the battery remains always in good condition

Flasher unit:

The flasher unit is used in the indicator circuit and is responsible to let the switched on indicator lamps (left or right side) and if necessary all the indicator lamps by the use of the hazard unit flash.

Ignition coil:

Responsible to build up the high−tension voltage needed for developing of strong sparks for the ignition system.

Electric motors:

Such kind of motors, like wiper motor or washer motor are used in cars in different types. They can be built with permanent magnet (for the stator or the rotor) as well as with electromagnets. In the end the basic principles are always the same by using the magnetic force to let that different types of electric motors rotate in the case of the necessary target.

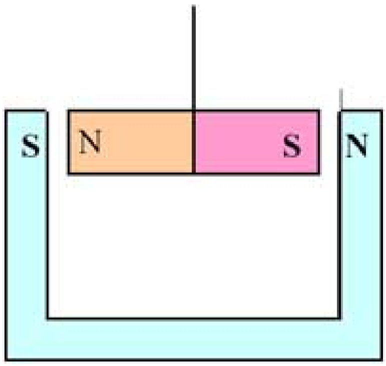
3. Starting systems

Principles of electric motors

In the first step we have to find out how generally an electric motor works. Mainly the work of an electric motor is based on magnetic force.

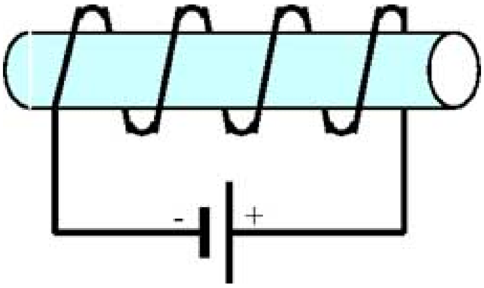
But let's follow up step by step what is going on.

An important fact about a magnet is its pole seeking. If we bring a bar magnet free movable into the magnetic field of a horseshoe magnet, the bar magnet will swing to line up with its North Pole pointing to the horseshoe's South Pole. So the South Pole of the bar magnet will point to the opposite of the horseshoe magnet. That means **like poles repel**, **unlike poles attract** − **a basic fact for the work of an electric motor** but the first step only.



Magnets are pole seeking when free to

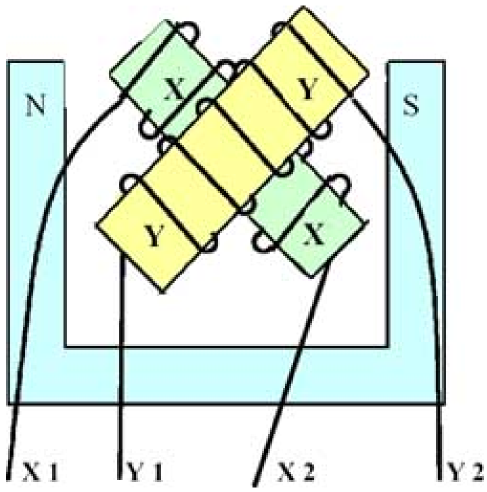
The next step is to take a short iron bar what is nonmagnetic. Around this iron bar we wind a few turns of a wire and the ends of the wire we do connect to a battery. In fact **we do have now an electromagnet**. An electromagnet works as long as it is connected to the electrical source. If we bring this (switched on) electromagnet between the jaws of a horseshoe magnet than the magnetised bar will line up north to south and south to north.



Basic electromagnet

Now, here is the **most important** part: **reverse the battery connections** and the **polarity will also reverse**. The bar will swing round into opposite position, but it may swing clockwise or anti–clockwise.

To ensure that the electromagnet swings always in the same direction there is a need to take another small bar, form a cross with the first piece and wind the same number of turns of wire on each bar. So we do have now four loose ends of wires.



1. **If we connect the wires (X 1 and X 2) of the bar "X" to the battery by suspending the cross between the jaws of a horseshoe magnet again than the cross will swing round and the bar with the connected wire ends will line up with the horseshoe poles.**

2. **If we disconnect those wires from the battery and we connect the wires (Y 1 and Y 2) of the other electromagnet bar "Y" than this one will now line up with its ends to the horseshoe poles.**

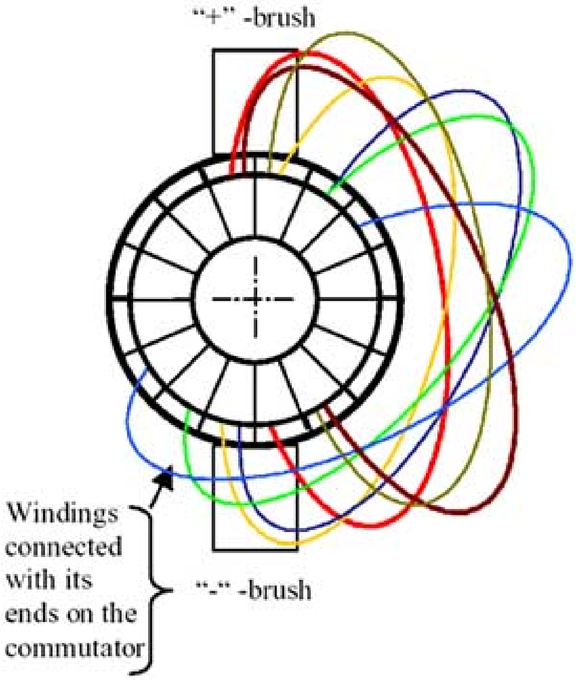
3. **Now we go back to the first pair of wires (X 1 and X 2) and** reconnect them but in reverse **than we will realise the** cross swings further in the same direction **as before.**

This is already a simple kind of an electric motor!

What is to do now? We have to bring the ends of the wounded wires together in a kind of a commutator (as shown on the left) and by the use of two brushes (+ and −) that simple kind of electric motor will rotate.

By using **more windings** with wire ends around an iron core and by the use of **stronger material** for the windings **the magnetic force gets strengthened**. By connecting the windings around a commutator on all its different segments we ensure that the rotating movement goes on in a straight way in one direction. And of course, all the windings must be connected like already explained.

The segments of the commutator are insulated to each other. The necessary “positive” and “negative” connections for the, now so−called, armature is going over at least two brushes. By rotation of our simple armature the brushes are moving over the commutator. To avoid irritation of the direction of the rotating movement, the windings (wire ends) of the armature of an electric motor are not by direct 180^0 connected as you can see on the sketch on the left as well.



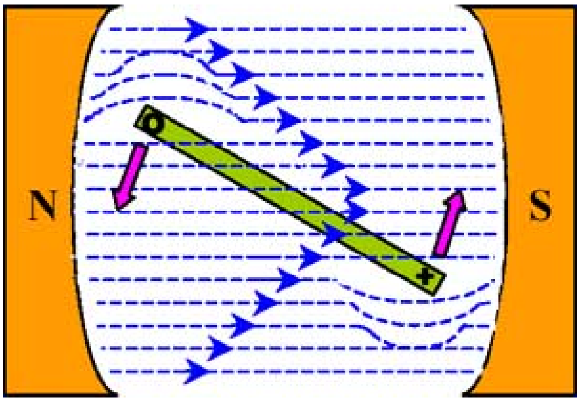
Front sight of a commutator include examples of connected windings

Starter motor principles

A starter motor is −this we do know now− an electric motor and operates on the principle that **a current−carrying conductor moves inside a magnetic field**.

The direction of movement of all these conductors wound on the armature goes on from a strong magnetic field to a weaker magnetic field. So we get a **circular magnetic field**. This leads to weaken and to cancel−out the lines of magnetic field force from the side of the exciter windings with its pole shoes.

The effect is, there is a **stronger magnetism above the current−carrying conductors** then below them and therefore **this leads to a downward thrust**. The **downward thrust** on one side **and** the **upward thrust** on the other side **of every current carrying winding** of the armature in a starter motor **causes the rotation**.



Field force lines react to distortion of the magnetic field

(left: downward thrust/right: upward thrust)

The rotation will continue because each time the armature windings pass the vertical position and over the commutator (together with the armature rotating) the armature windings are automatically so connected that the current continues to flow away from the right−hand toward the left−hand winding. And as mentioned already the winding ends of the armature windings are so connected that it is ensured that the rotation goes on in one direction.

Practical starter motors

Although we do have now the basic motor design as above, it needs a great deal to build a real starter motor.

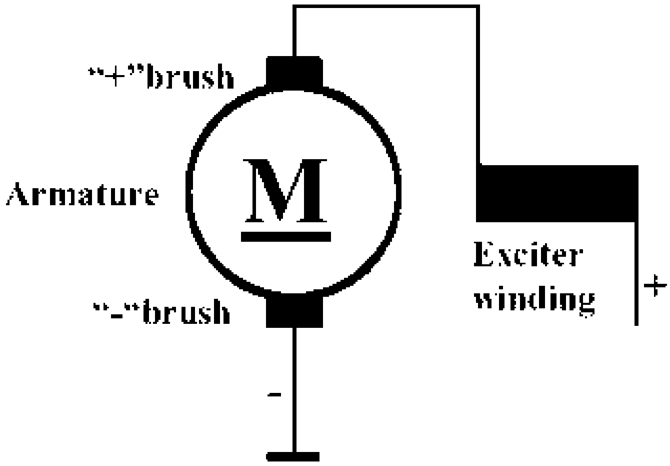
A starter motor must be able to turn a cold engine fast enough to get it started and so it must be able to rotate with an amount of current up to 350 amps.

The horseshoe magnet is changed for a starter motor into **pole shoes with strong windings** around them inside the housing. The **commutator is composed of separate copper bars** by the use of **insulation material between them** and the amount of windings is now much higher. Modern starter motors have four brushes and four magnetic pole pieces (shoes) and the armature runs now in bearings and as well as often in bushes. There are also possibilities of **different types of commutator**. Often we can realise on the armature is existing a **drum commutator** but it can be as well a **face** (disc) **commutator**.

How ever, **all these are not affecting the basics; it is a design feature to give extra power for the work what the starter motor is supposed to do**.

Starter motors are **DC series−wound motors** and so the exciter windings (field windings) and the armature windings are **arranged in series**.

The current consumption of a starter motor is very high. The range of current may set up **between 350A and 2000A**. Therefore the **windings** are **relatively few but thick** strands of copper wire. In these kind of motors the **current strength** at the greatest rate at the time the starter motor begins to rotate.



DC Series–wound motor

For that there are **three reasons**:

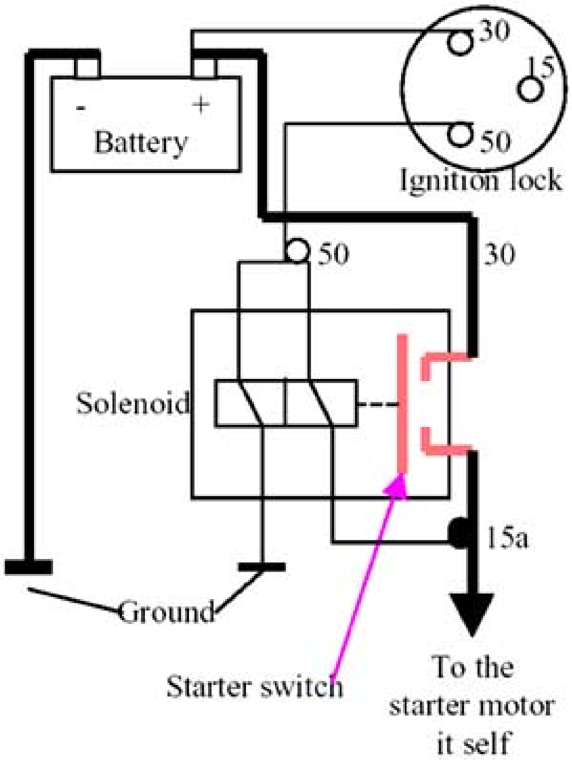
– at the time the starter motor begins to rotate the **torque of the motor** has the highest rate and get reduced after;

– when the motor torque gets reduced the speed builds up and the current level falls in the case of **self induction of current** (because of rotation of the armature with its windings in the magnetic field of the field windings);

– beginning the starting process the **friction of the engine** is at the highest rate as well and gets reduced afterwards.

Another part of the starter motor is also essential to look for although it is not direct a part of the motor itself: **the solenoid**.

Because of the enormously heavy current needed to turn the car's engine, by trying to let it pass through the ignition lock would create a big problem. That means, the flowing strong current during the starting process would result in a strong burning inside the ignition lock because that current flow let melt the lock over the connected contact points. **The solenoid is the link between the heavy cable from the battery** and from there **to the starter motor**. **Over the ignition lock flows** during the starting process **a small amount of current only to energise the electromagnet** of the solenoid which is responsible for closing the heavy–duty switch inside.



You have to realise now:

The purpose of the starting system is to use electricity from the battery for the rotation of an electric motor (starter motor) to turn over the engine during the starting process.

The starting system consists of:

– the **battery**,
– a **starter motor**,
– a **solenoid of the starter motor**,
– an **ignition switch** and
– related **electrical wires**.

Starter drives

We can operate now with a powerful motor for the starting process and we do have a method of switching it. But still there is a need to couple it to the engine. In this case we do use a starter drive.

There are **four different main types of starter drives** generally in use:

– the **inertia drive** (shock drive),
– the **pre–engaged drive**,
– the **single–stage sliding gear drive** and
– the **sliding–armature drive**.

In all of the cases, the flywheel of the engine in which they are used is fitted with a toothed ring around the circumference. The **pinion** of the different types **of starter motors** is mostly **made from steel** and **has a special pattern of teeth**.

The **pinion cannot rigidly be attached to the armature shaft** of the starter motor **because** the armature **would be driven at a too high speed** when the engine had started and **so the starter motor would be damaged**. To avoid such kind problems there are may be used

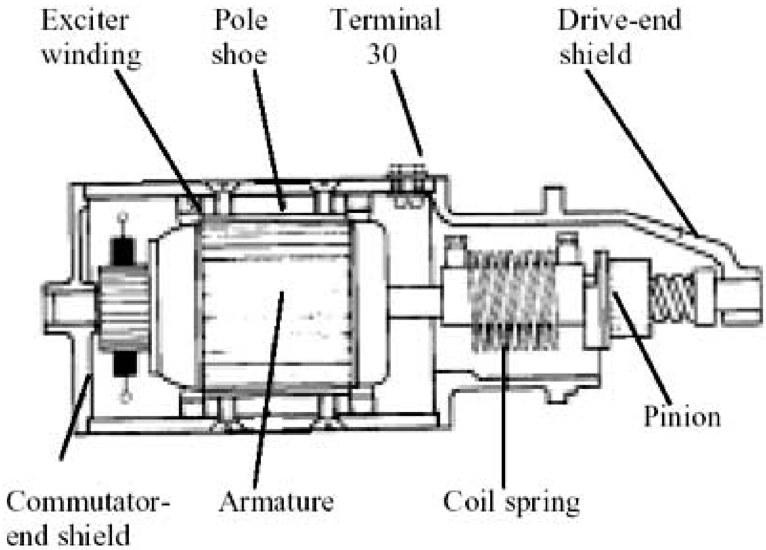
– a **roller–type overrunning clutch** or
– a **multi–plate clutch**.

During the operation of the starter motor the used type of **clutch interrupts the power flow** between the pinion and the armature shaft when the engine begins to turn faster then the starter motor. By stopping the starting process the pinion will withdraw from the flywheel under the use of one of the above mentioned four types of starter drives.

Inertia drive starter motor

Inertia drive starter motors use the rapidly accelerated energy in the armature. This goes on before the engagement of the pinion takes place.

The starter motors pinion is carried by a steeply pitched screw thread on the armature shaft. This kind of starter motor works **without a solenoid** and therefore the starter switch has strong contact points (operated by hand or by foot) to connect the current flow from the battery to the starter. **When the starter motor operates and runs rapidly up to full speed; the inertia drive** (bendix drive) **is forced by action of the thread on the armature shaft.** So the drive get propelled in the direction of the ring gear into engagement with the flywheel. A **damping spring is arranged** between shaft and pinion hub **to ensure that the power flow to the flywheel starts not too violently**.



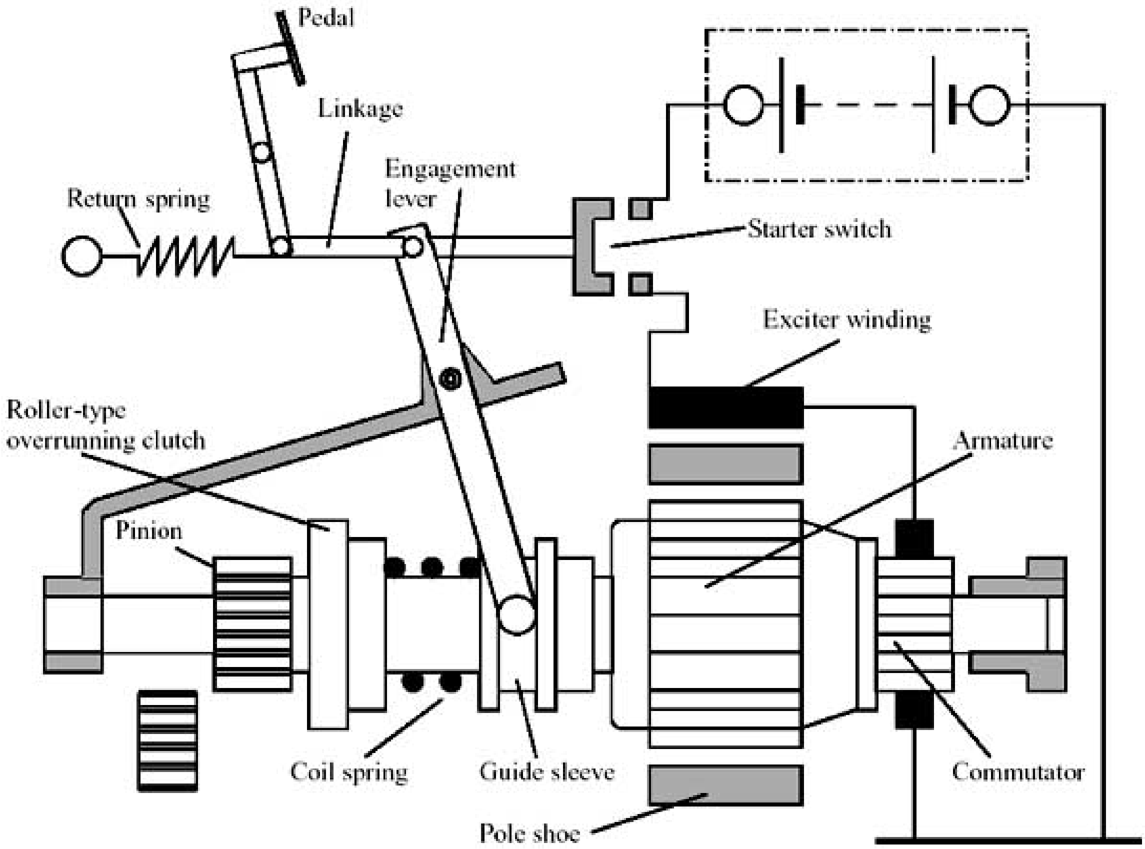
After engine has started and runs faster then the engaged pinion get ejected from the flywheel by moving backwards on the spiral thread.

Because of the violent engagement of the pinion into the flywheel damages can easy appear. That is the reason to use in modern cars instead of these types the **pre−engaged starter motors**.

Single−stage sliding gear starter motor

The mechanical operated starter switch is often operated by foot.

On the armature shaft are existing **longitudinal grooves** where the **pinion** is located and **it may move axially**. Mostly the pinion gets engaged with the flywheel by the use of a lever. Only then **when the pinion is fully engaged into the flywheel the starter switch gets closed** and therefore **the starter motor starts to rotate**. The pre−loaded engagement spring behind pinion and clutch takes responsibility for fast pinion engages in the flywheel.



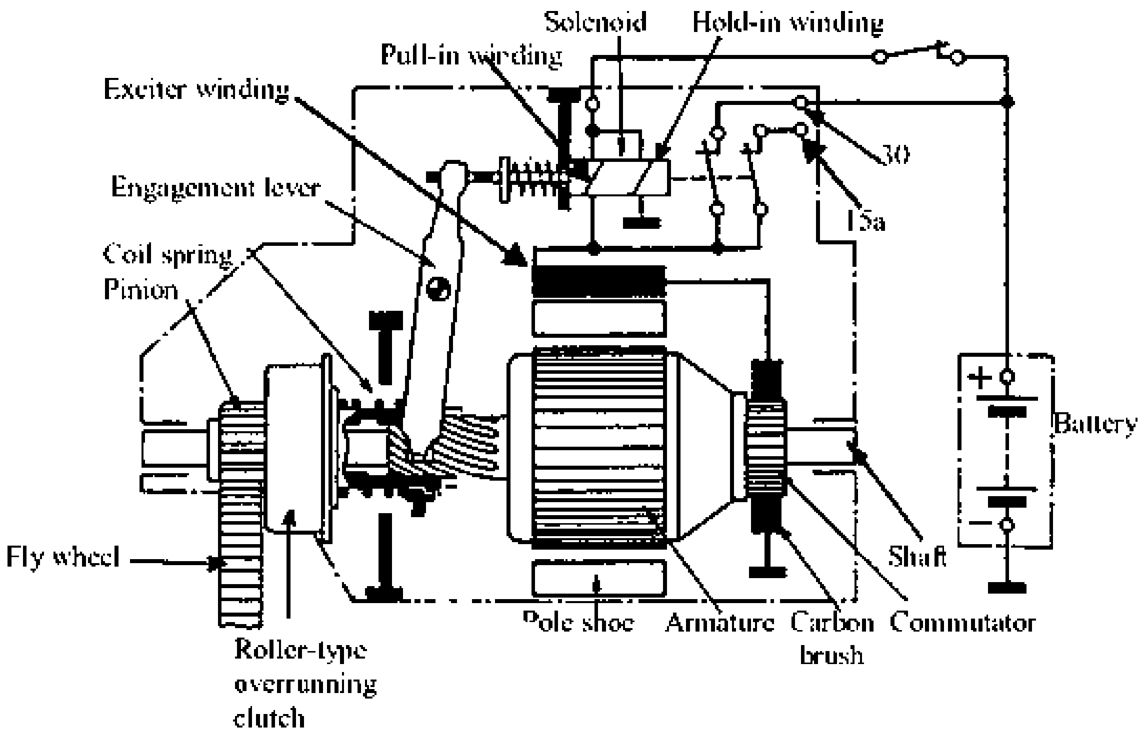
Remark: See explanation of the roller−type−overrunning clutch.

Pre−engaged starter motor

Like the inertia drive the pre−engaged starter motor has a **thread on the armature shaft** for the engagement of the pinion into the flywheel.

The **driving assembly moves forwards** against the spring **by the help of an engagement lever/fork**. Energising the solenoid (ignition lock in start position) and therefore building up a magnetic field pulls the shaft of the electromagnetic starter switch inside. **The steeply pitched thread causes a slow rotation of the pinion and let its teeth easy engage between the tooth gaps of the flywheel.** If the teeth of the pinion cannot mesh between those of the flywheel the spring of the driving assembly is compressed. This will be the case until the armature starts slightly to turn and finalise the engagement (the starter switch inside the solenoid closes and now the armature of the starter motor is able to rotate). **The starter motor builds up its whole electric power and so the starting process goes on.**

After the engine is running faster then the starter motor, the still engaged **pinion runs freely in the flywheel**. **The roller−type−overrunning clutch avoids damages** of the starter motor **due to a higher speed** as long as the pinion isn't disengaged by the release of the ignition lock.



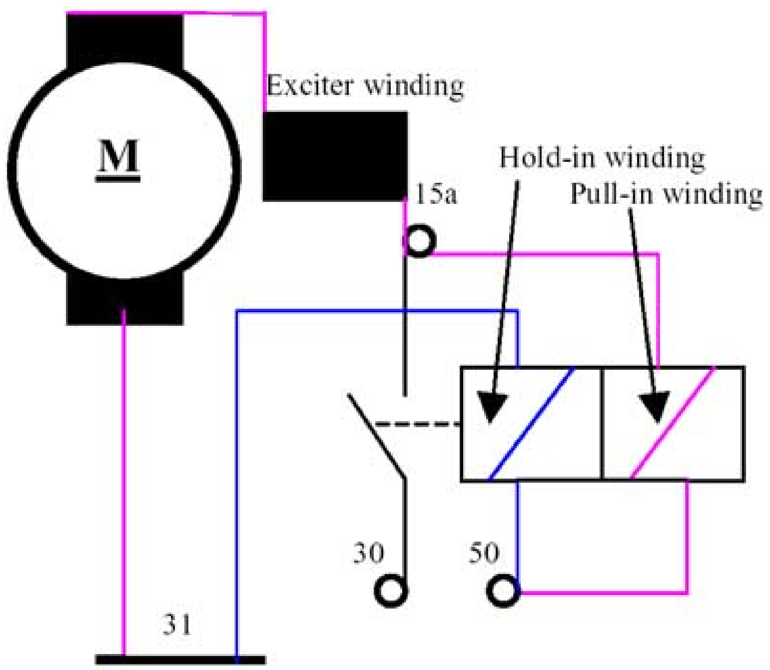
Solenoid

The **solenoid** switch **has two windings**. **One is the so–called pull–in winding and the other one is the hold–in winding.** Both of them build up (by energising them) a magnetic field what ensures that the solenoid shaft gets pulled inside the solenoid it self.

The **pull–in winding is connected with** one end to the **terminal "50" and** with the other end to the **"15a"**. Therefore this winding get its negative connection over the exciter windings, the plus brushes, the commutator, the armature windings and then over the minus brushes by connection to the ground. As long as the armature doesn't rotate that minus connection is available.

> **Note:** When the rotation takes place the pull–in winding isn't energised anymore.

The **hold–in winding is connected to** the **terminal "50"** as well **and** on the other side **direct to the ground**.

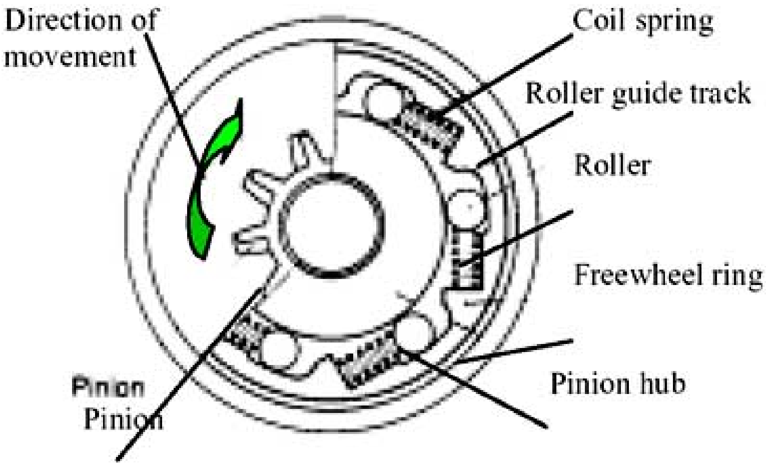


Internal circuit of a pre–engaged starter motor with the solenoid

The built up magnetic field of this winding is strong enough to hold the shaft inside of the solenoid. Therefore is it acceptable when the pull−in winding switches off.

Roller−type−

The main parts are the **freewheel−ring** with its roller slide tracks, the **rollers**, the **coil springs** and the **housing for the clutch**. In driving direction of the starter motor the rollers are pressed into the narrower section of their tracks and this couples the pinion to the starter motor.



After starting the rollers are forced into the opposite direction and so against the springs.

The rollers reach the wider section of the tracks and so the armature of the starter motor is not engaged anymore by having a higher engine speed as long as the ignition lock is still hold in start position.

Now there is not a need anymore to hold the ignition switch in start position and the **starting process should be stopped** realising that the engine runs it self.

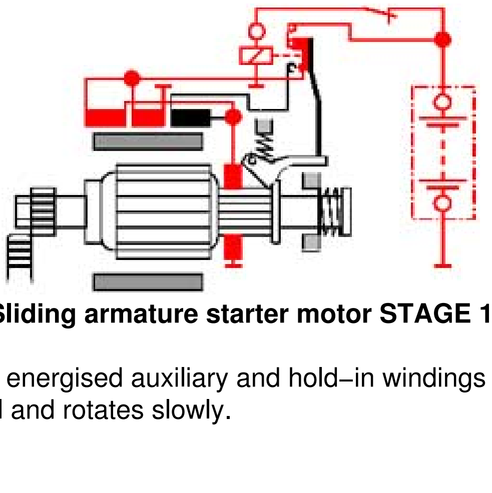
Sliding armature starter motor

Such kind of **heavy starter motors** are especially used in trucks, tanks and big stationary diesel engines etc. and mostly they are built as 24 V motors. **In switched off position the armature is axially placed out of the exciter windings.** The pinion is driven from the armature shaft in connection with a multi−plate clutch.

The starter motor has three exciter windings behind each other:

- the **auxiliary windin**g,
- the **hold−in winding** (shunt−wound) and
- the **main winding** (series−wound).

For the need **to move axially the armature has extra long sizes for the bearings/bushes and a special wide commutato**r. Further important parts are the return spring, a control relay with a contact bridge and a locking part with release disc and release lever.

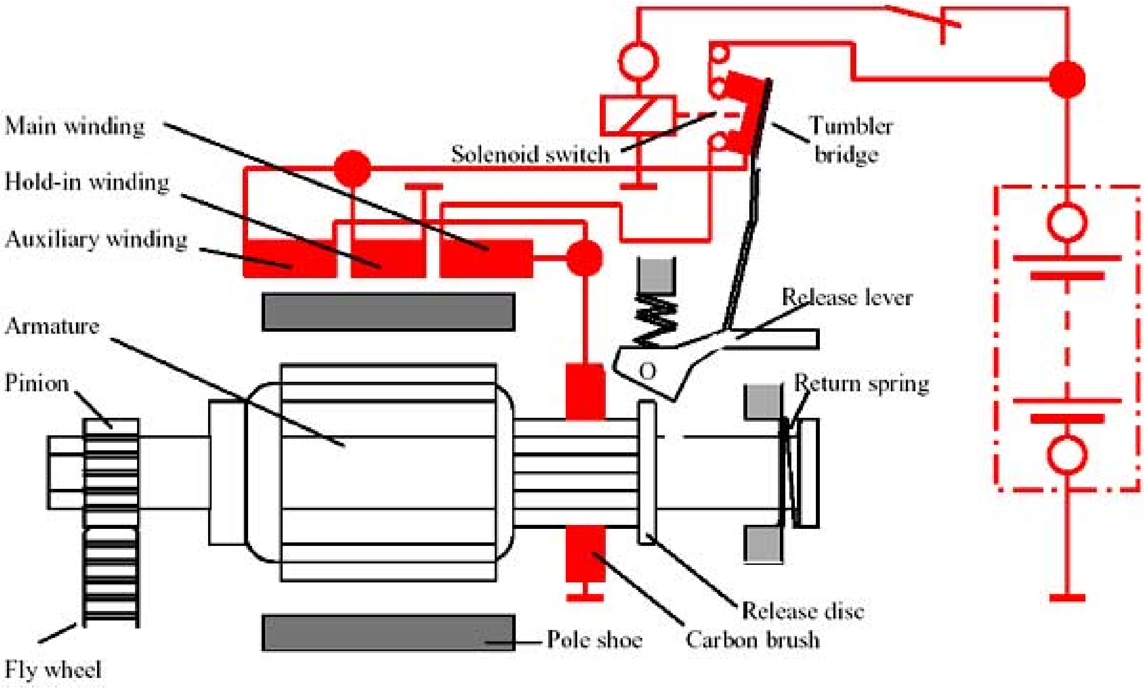


Sliding armature starter motor STAGE 1

In the **first step** the armature is by energised auxiliary and hold−in windings still axially displaced but starts already to engage into the flywheel and rotates slowly.

In **step two** the release disc raises the release lever to switch on the control relay. And now the main winding is over the relay switched on as well, the armature is forced (by the magnetic field from the side of the main winding) to slide in the driving position.

The installed clutch ensures the smoothly process by engaging of the pinion into the flywheel. After the engine has started the clutch prevents dangerous speed of the starter motor as long as the pinion is engaged in the flywheel by interrupting the power flow.



Sliding armature starter motor STAGE 2

Working rules

- The commutator must be clean with a smooth surface. There is no need to go over the commutator with sandpaper if the surface is smooth. If the commutator is not round it must be skimmed. Never try to dress the surface with a file or with emery cloth.

- The insulation between the commutator segments must be cut or milled out to a depth about half of the width of the gap.

- The carbon brushes must move freely in the brush holders. There should never be any kind of lubricant. Worn out brushes must be renewed and if necessary the commutator surface must be skimmed.

- If the armature shaft runs in bearings (they are normally self–lubricating types) they should not come into contact with cleaning agents which dissolve crease. If there used bushes than they should lubricate with oil.

- Oxidised battery clamps, loose terminals, burned switch contacts and defective wiring all increase circuit resistances and often lead to starter failures.

- The starting process needs a strong current flow. Therefore is it a good practice to switch off all other consumers during starting the engine.

Faultfinding and repair of starter motors

To remove a starter motor out of a car is usually easy.

Don't forget: The first step has to be the disconnection of the battery.

After that are to disconnect the cables from the starter motor. Now the bolts (what are holding the starter motor) are to loosen. Mostly the starter motors are hold by so called “through bolts” with these the starter motor is fixed through the flange of the drive end shield of the starter and the clutch housing. But we should take care to avoid the starter motor falls down. To remove it out of the clutch housing can be necessary from above or from under the engine. This depends on the type of car and the space in the engine room.

By dismantling the starter motor we will find several different ways in concerning the type of the starter motor. These differences are to follow up during the practice and therefore here are mentioned the basically steps only. If fitted we have to remove the cover band and than we have to withdraw the brushes from their holders by hooking up the springs and pulling the brushes free. By removing the bolts/nuts from the solenoid and the starter motor we dismantle the whole unit further.

> **Note:** Always is to ensure **knowing the order by reassembling the unit**. The separated **parts** should be **orderly placed** to avoid falling down or loosing them.

By working on the armature shaft **hold it firmly** but not too tightly in a vice. Care should be taken by removing the **pinion stop collar**. To do this the stop collar is first to move in direction of the drive assembly. Than can be removed the **pinion stop retaining ring** (normally by using a snap ring pliers) and now is it easy to remove the stop collar and the drive assembly.

After dismantling the whole starter motor all the parts must be washed and for this is **paraffin** to use.

Avoid the use of any explosive liquid.

By the use of compressed air/non–fluffing cloth the parts are to dry.

Most of the **faults on starter motors** are mechanical and can be **checked by visual inspection**.

The following pages show up general information to

- **troubleshooting** and
- **inspection of a starter motor**.

Troubleshooting

Inoperative starter motor

- loose or corroded battery terminals,
- discharged or unserviceable battery,
- open cranking circuit,
- inoperative solenoid or relay,
- faulty ignition switch,
- defective starter motor,
- inoperative neutral safety switch,
- internal ground in starter motor windings,
- grounded starter motor field windings,
- armature is rubbing on pole shoes.

Starter motor rotates but pinion does not engage

- broken teeth in flywheel gear ring,
- rusted starter drive shaft,
- defective starter drive,
- slipping overrunning clutch.

Slow cranking speed

- discharged battery or defective cell,
- excessive resistance in starter motor,
- excessive resistance in starting circuit,
- engine oil too heavy for condit ions,
- excessive engine friction,

– burned solenoid contacts,
– loose terminal connection – battery/starter motor,
– worn bushes/bearings,
– bent armature.

Starter motor does not disengage

– faulty ignition switch,
– short circuit in solenoid,
– broken solenoid plunger spring,
– broken solenoid starter switch,
– faulty starter relay,
– worn out bush on drive end shield,
– broken drive return spring,
– defective overrunning clutch.

Inspection of a starter motor

1. Commutator end shield

– cracks on the shield,
– brush spring tension,
– length and leads of brushes,
– size of bush.

2. Drive end shield

– cracks on the shield,
– size of bush,
– mouthing of holes and threads.

3. Armature

– rub marks on the armature core,
– wear of shaft,
– rotation marks on shaft,
– wear of commutator.

4. Field windings

– insulation of the windings,
– tightness and rub marks of pole shoes.

5. Drive assembly

– stickiness and slip of overrunning clutch,
– size of bush,
– wear of drive gear,
– drive spring tension.

6. Solenoid

– damages on plastic housing,
– wear of main posts/terminals,
– wear of plunger and return spring,
– wear of engagement lever and pin.

Reassemble a starter motor

To reassemble a starter motor we have just to realise that this is a straightforward reversal of the dismantling procedure. It is to check that no necessary insulation get out of order by reassembling the motor. There is **never** a need to **try** a step of **reassembling with force** because all the parts right handled are easy to fit.

During the reassemble procedure there are some parts to lubricate. On the **solenoid plunger is to apply** a light smear of **light oil** to make sure it can slide freely. The **engagement lever is to tip** on the movable connections **into grease** and **grease** as well **is to bring on the spiral thread of the shaft** of the armature. The armature shaft ends are running mostly in bushes and so the **bushes must be well lubricate with light oil**. If **bearings** are used (they should not be washed with paraffin!) than is to **ensure that enough grease is inside** for a freely movement of the armature.

If the **solenoid** was opened the **starter switch** there inside **must be clean and dry**. For the **contacts** of the switch is to ensure that they are **in good condition** because they are the link to the starter motor it self for the whole current flow.

Starter motor tests

There are many ways to test starter motors. First of all there should be a test of a starter motor on−car followed up with a no−load test. If there is still a need than is to test the starter motor on the test bench to find finally out the cause of the problem.

On−car test for voltage drop:

1. The voltmeter leads are to connect to the positive terminal of the battery and to the starter motor terminal “30”. The voltage drop should not exceed 0,5 volt.

2. The voltmeter leads connected to the positive terminal of the battery and to the solenoid terminal “50” should in the result not bring a higher voltage trop then 0,1 up to 0,3 volt.

3. For connection of the voltmeter leads to the battery negative terminal and the ground is a drop of 0,3 volt acceptable.

On−car test for amperage draw:

In that case the engine must be at normal operating temperature.

1. The secondary wire on the ignition coil is to disconnect and to ground.

2. Connect the load tester to the battery negative and positive terminal while the load control knob of the tester is in decreased (counter−clockwise) position.

3. Observe during starting operation the amount of voltage but do not crank the engine for more then 15 seconds.

4. There after turn the load control knob of the tester clockwise (increase) until the voltmeter indicates the same voltage as while the starter motor cranked the engine.

5. Observe now the amperage draw on the ammeter and compare it with the manufacturer’s specification (normally between 150 A and 350 A).

Bench tests:

Armature and exciter winding ground circuit test:

If the armature insulation or exciter winding insulation has failed it would exist conduction to the armature core or to the starter motor housing.

Armature test:

The test can be done by using a voltmeter. By testing the armature is the positive terminal of a battery to connect to the armature shaft (jumper cable). The voltmeter is to connect to the battery negative terminal and in turn to each commutator segment. If there **appears** any amount of **voltage** on the scale the **armature winding is grounded**.

The armature can be tested as well by using the armature growler.

Exciter winding test:

To test the exciter winding there is to connect a jumper cable from one battery terminal to the starter housing. The other battery terminal is to connect with one voltmeter lead while the other voltmeter lead is to bring in contact with the starter terminal. By doing this keep the brushes away from the housing. If any **voltage is indicated** than the **windings are grounded**.

Bench test of the starter motor:

First of all the starter motor has to be mounted firmly by using the right flange and by bringing it into the right position to the flywheel of the test bench. The right position can be found easier when energising the solenoid what brings the pinion in front to mesh the flywheel. But in that way should not be connected the positive lead to the main post of the starter motor. By testing on the starter motor test bench is possible a no–load test as well as a load test and by cranking of the pinion in the flywheel the properly function of the drive assembly can also be ensured.

By running the engaged starter motor can be made a **no–load test** without using the break pedal for the flywheel. Typical can be a **current flow from 50 A up to 90 A** and a **speed** of the starter motor between **6,000 and 11,500 rpm** at **10 volts**.

Using the break pedal and therefore the **load test** should **not** take **longer then 15 seconds**. The **amperage draw** is to follow up concerning the manufacturer specification (normally between **150 A and 350 A**). The **overrunning clutch** of the drive assembly **should not slip** at this time. If it is slipping the overrunning clutch is suspect.

> **Note: Testing** a starter motor **on the test bench needs knowledge** and **injures are possible if care is not taken**. The **testing procedure has to be done from authorised workshop members only** and **by following up the instructions** step by step for working on the test bench.

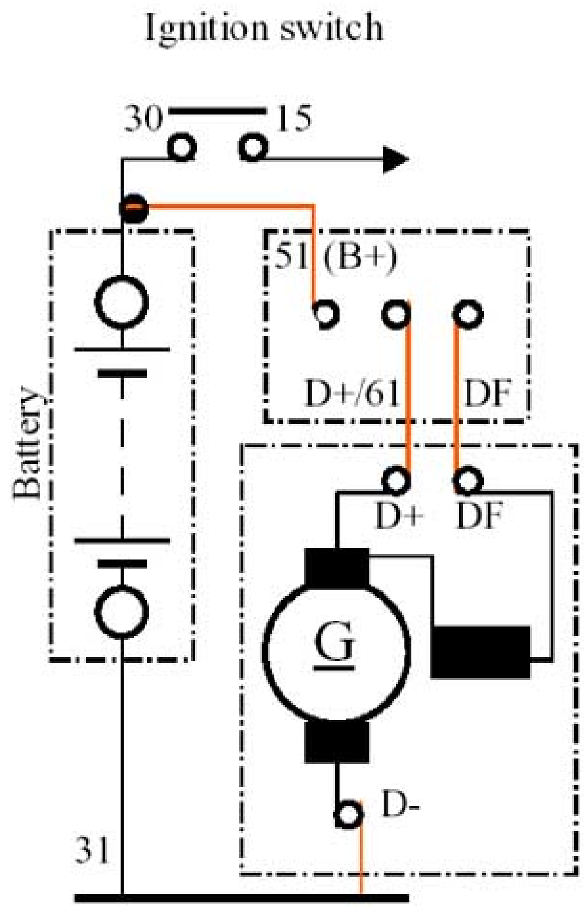
4. Charging systems

Fundamentals

By **using a generator or an alternator** we are able **to supply the electrical system** of a motor vehicle **with energy**. That means, by using a motor vehicle we do need electrical energy and for that we can use the stored energy in the battery. But this energy is only as long available as the battery is not discharged. Without generator or alternator we can not drive over longer distances and especially at night by the use of such strong consumers like headlights the stored energy of a battery is relatively fast completely used.

The purposes of a recharging system – with its components like generator or alternator and of course a regulator – is **to supply electrical energy during the vehicle operation**. That process **is directed to all the switched on electrical consumers** (i. e. ignition system, lighting and signal equipment) **and** at the same time **there is a supply of energy to the battery** to keep this electrical source in charged condition.

The **regulator** of the recharging **system is needed to regulate the output of the generated energy**. The reason is that by **raising up of the engine speed more electrical energy** is produced. Therefore is a need to **regulate this process to prevent overcharging of the battery and possible damages on the consumers**.



Connection of a shunt–wound generator and a regulator into the battery circuit

How we can now explain what **an automotive generator** is?

It is an **electromagnetic device that converts mechanical energy supplied by the (running) engine into electrical energy**. The automotive generator is therefore driven over the connection of a V–belt from the engine and produces **based on electromagnetic induction** electrical energy.

Electromagnetic induction

Do we look back to the basically explanation of the working principles of a starter motor than we should remember how electromagnetic induction takes place. But let's repeat again:

If an electric conductor (wire or wire loop) **cuts through its rotation in a magnetic field the lines of force of this magnetic field, a voltage gets induced in the conductor.**

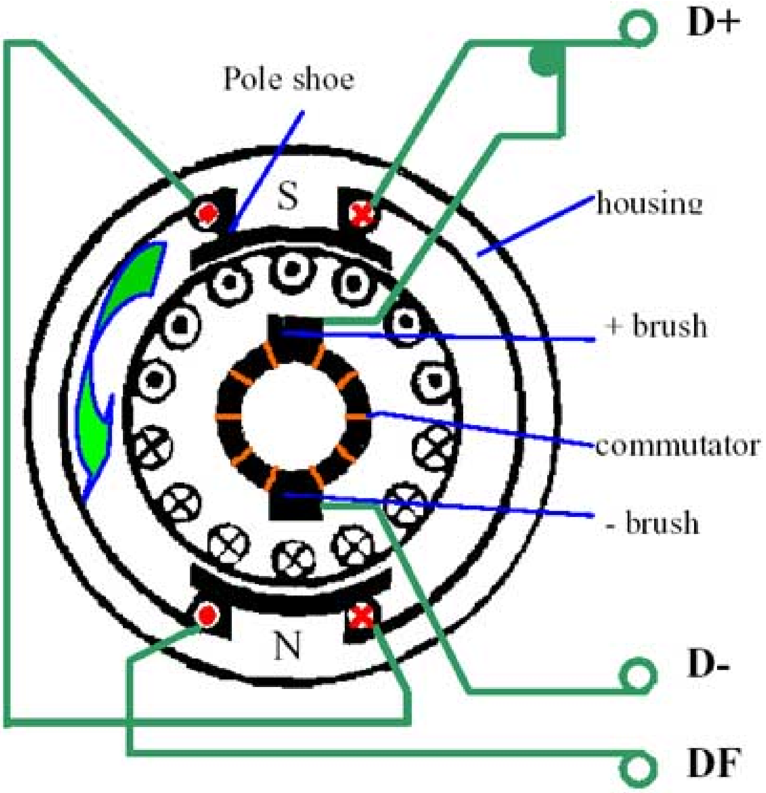
As **more conductors** are **rotating in a magnetic field** and as the **speed of rotation increases** as **more** and faster the **field lines get cut** and **therefore the induced voltage raises** up. **See** also pages 57 and 58 in the chapter **"Starting systems"**.

But now there is another question to clear up. **How is the magnetic field produced?**

The magnetic field can exist by using permanent magnets where the rotating windings (wire loops) can be placed in. This could be a very simple design without big technical problems. Such construction we do use in dynamos for bicycles. But we do know **an electromagnet allows** in the end **a higher output**. The term electromagnetism includes further the fact that the **strength of an electromagnetic field results** from the **number of windings**, the **strength of current flow** through them and the magnetic field can even **get more strengthened by placing an iron core** inside a winding. To work therefore with **electromagnets as excitation (exciter) windings** make it possible to **increase or decrease the current in the winding and also to increase or decrease the induced voltage**.

After the current flow of the exciter windings is switched off the electromagnet loses its magnetism. But **a slightly rest magnetism remains** and this we do need for starting the inducing of voltage again by running the recharging system next time.

In order to multiply the induction of voltage not only one wire loop is rotating in the magnetic field of the exciter windings. **A number of loops** all together **known as armature winding are rotating inside the exciter windings**.



Circuit of a DC–generator in connection with exciter windings and armature winding

Output of the system and demands on it

Power demand of consumers:	
Ignition	20 W
Electric fuel pump	50…70 W
Electronic fuel	
injection	70..100 W
Car radio	10…15 W
Side/rear lights (each)	5…10 W
Headlamps (each)	55..100 W
Car heater	20…60 W
Indicator lamps (each)	21 W
Stop lamps (each)	21 W

The **output** of the generator or alternator **must match the whole electrical system** of a motor vehicle. That means the output must be ideally as far as possible to enable the entire system in case of a **powerful and trouble–free operation** and **this includes the battery capacity and the need of electrical power in demand** of all the installed electrical systems. What this means?

– The **ignition system** must be always ready for operation.

– The **electric radiator fan** and the **fuel pump** must operate properly.

– The **signals** and in darkness the **lighting system** must get enough electrical energy to operate in all situations.

– Additional systems like **hazard system, wipers, cooling and heating system, electric windows, car radio** and so on must work as needed and last not least.

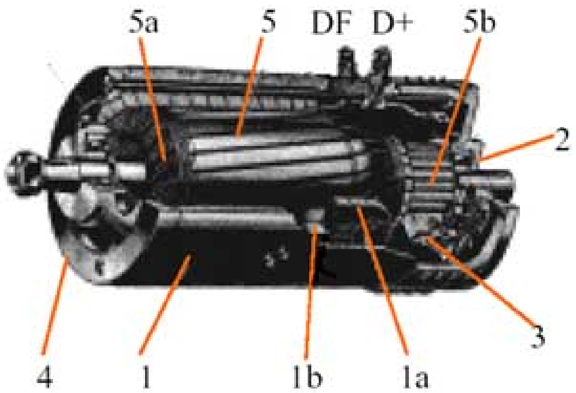
– The **battery must get regularly charged**.

Power demand of consumers:	
Electric radiator	200 W
Blower for heating/	
cooling	80 W
Heated rear window	120 W
Rear window wiper	30…65 W
Horns/fanfares (each)	25…40 W
Electric arial	60 W
Fog lamps (each)	55 W
Starter motor	250..2000 W
Glow plugs/diesel	
engines (each)	100 W

Therefore **it is never a right way to use** in a motor vehicle just only **a battery with a higher capacity without to ensure that the whole system is working properly together**. In such a case is to **approve** how far is it possible and necessary to adjust the generator/alternator **output** over the regulator so **that the system operates further powerful and proper** by recharging the battery fully. It can be a need by the use of a stronger generator/alternator to replace the regulator as well.

DC–generator

The lead–acid battery in motor vehicles led to the development of the **DC–generators**. For a long time this generator system was used and has been able to fulfil the given demands.



The **main components** of a DC–generator:

– **Housing** (stator frame) {1} with exciter windings {1a}, pole shoes {1b} and terminals (DF; D+ and sometimes D–);

– **Commutator end shield** {2};

– **Brush holder** with carbon brushes {3};

– **Drive end shield** {4};

– **Armature** {5} with armature winding {5a}, laminated iron core and commutator {5b} and mounted bearings;

– **Pulley** with **fan**.

Function

The **DC−generator is a shunt wound type**. **Exciter windings** are **in parallel to** the **armature winding**. The DC−generator is a **self−exciting machine.** A small amount of **rest magnetism** always remains in the pole shoes after it was magnetised ones. The pole shoes are surrounded by the exciter windings. **These windings generate the magnetic field.** The **armature rotates** supported accurately in its bearings between the pole shoes whereby the **air gap** is kept as small as possible (reason: a **bigger air gap reduces due to magnetic resistance the magnetic field force**). The insulated **armature wires** are wound in the slots of the laminated iron core and with its **ends connected** (soldered or pressed) **to the laminated commutator**. The **winding heads are wrapped to resist the centrifugal force**.

If the armature starts to rotate the small amount of **rest magnetism** of the pole shoes **induces a low voltage** in the armature winding. A **corresponding excitation current flows** than **in the exciter winding** what causes that **the slight magnetic field gets built up** and the rest magnetism get therefore **strengthened**. A **larger voltage** will now be **induced in the armature winding** what **leads** further **to strengthen the magnetic field** of the exciter windings. This **process is repeating** as long as the predetermined level is reached whereby the induced voltage depends on the speed of the armature rotation.

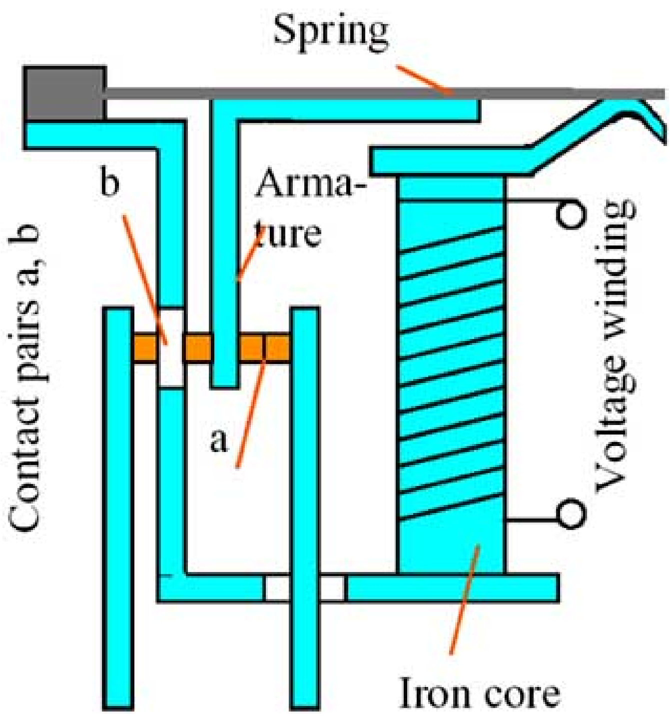
The **voltage output** of a DC−generator can be **regulated in terms of varying the exciter current**.

DC−generator voltage regulation

The **generator voltage** must be kept as **constant** as possible. The **current value** must be **correct regardless of speed and load** to ensure that electrical consumers are **not** troubled by **a higher voltage output**. So is it necessary to **protect** the consumers **against over−voltage** and to prevent the **battery from** being **over−charged**.

The **voltage regulation element varies** the **strength of the magnetic field** of the exciter winding **by decreasing or increasing the exciter current** depending on the rotation speed. In the end this means, a **current decrease in the exciter winding** causes a **voltage drop in the armature**.

To **regulate the generator voltage** is possible by opening and closing the contacts of an **electromagnetic voltage regulator** because the **self−induction in** the **exciter winding prevents** a suddenly **rising of** the **exciter current when** the **contacts are closed**. On the other hand it leads to a **current drop** when the **contacts are open**.

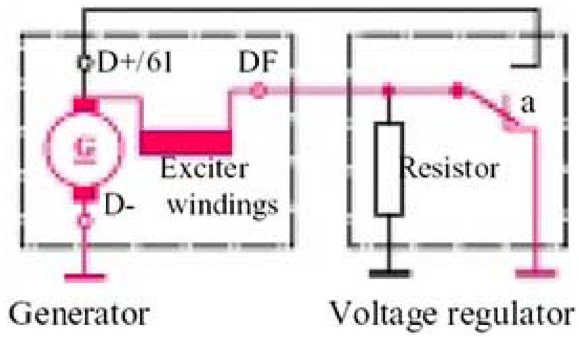


Voltage regulation element (schematic diagram)

In the following diagrams is shown how **the voltage regulation** takes place. It is to realise that the different **settings don't show up the output** of the generator directly. **It gives** you **the different situations** depending on the running speed concerning increase/decrease **of voltage of the exciter windings** and therefore the increased/decreased strength of the magnetic field. **Out of this we do get the regulated output** from the DC–generator over the regulator.

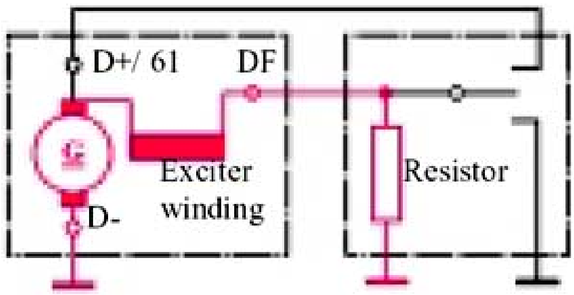
Lower setting:

The running speed in this situation is low as well as the voltage of the exciter windings. Therefore holds the spring the **contact pair "a" closed** and the regulating resistor is bridged. The **exciter windings** are direct **connected to ground** and so **the voltage** of those windings is able to **rises up**.



Middle setting:

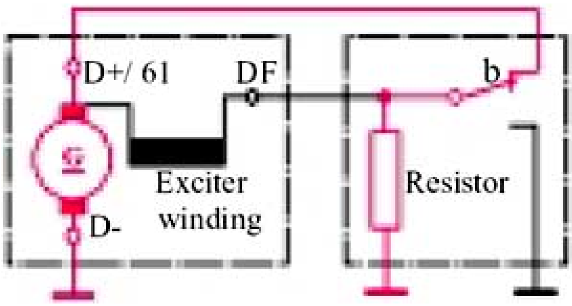
Depending on a **higher running speed** the **voltage** of the exciter windings **rises up further** and also the **magnetic field get strengthened**. Reaches the voltage a value above its predetermined setting than the **armature** of the regulator **moves into the middle setting** by a developed higher voltage of the voltage winding of the regulator and therefore a stronger magnetic field of that winding and the iron core. The **contact pair "a" opens** and the **resistor**, connected direct to the ground, is now brought **into the circuit**. This leads to a reducing of the exciter current and the **generator voltage output gets reduced** as well.



Upper setting:

If the **voltage output** of the generator **rises up further** induced by a stronger magnetic field and as a result of a increased speed the **magnetic field** of the voltage winding and iron core **of the regulator get** also **further strengthened**. This leads to the connection of the **contact pair "b"** by pulling further down the armature of the regulator. Now there are **connected both ends of the exciter winding to positive** what **causes the end of voltage induction** as long as the contact pair is closed. If therefore is no current flow anymore going on there will also **rapidly decrease the magnetic field of the regulator**. And in that case the spring–hold **armature returns to the middle/lower setting**. This means **the voltage** of the generator **increases again** and the whole **process** as it is explained above **continues**.

In the end there is going on by the regulation of the generator output a very fast **switching process** in the matter of milliseconds with a **frequency of 50 to 200 periods per second**. By following up this process the **voltage output of the generator remains approximately constant**. A sudden rise of the exciter current is not possible because of the self–induction in the exciter winding. **Increasing or decreasing** mechanically **the pressure of the spring in the regulator** make it possible to get a **higher or lower output of the regulated generator**.



The electromagnetic regulators where used in the past in connection with the Dc–generators as well as with AC–generators.

Regulator types for DC–generators

Voltage regulators can be attached to the generators or installed on a separate place.

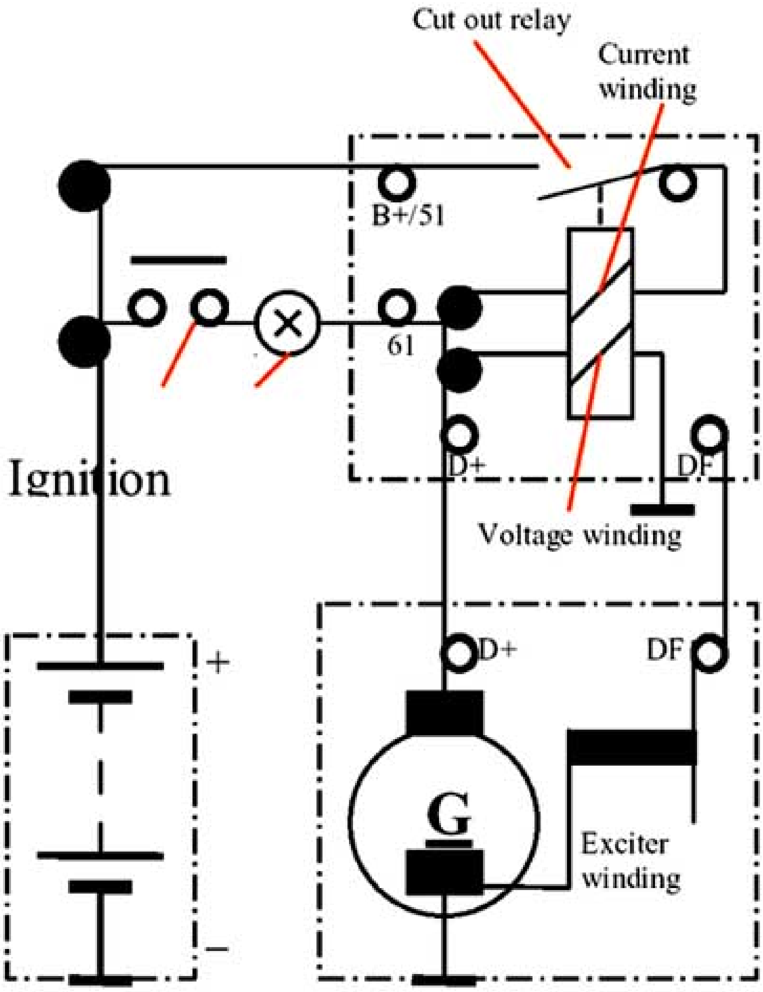
There are **regulators with different contact systems** (single or double contact) with varying numbers **of elements** (two– or three–element regulators) and different **regulating characteristics** (inclined, steep–droop or variode characteristic).

If there is used **a two–element regulator** it has a voltage regulation element and a cut out relay. By using **a three–element regulator** there is in addition a current regulation element attached.

Voltage regulation element controls the charging voltage on a safe value. When the battery needs to get charged the voltage regulator cuts out the resistor of the exciter field circuit – the flow of current increases – the generator output is boost. When the battery is fully charged the resistor is brought into the exciter field circuit – the charging current decreases – the generator output goes down. In addition this happens in the same way by switching on or off more or less consumers and by having therefore a higher or lower need of flowing current.

The **current regulation element is a magnetic switch** inside the charging circuit **to protect the DC−generator from overload** by limiting the current output to a safe value.

The **cut−out relay** is designed to **prevent the battery from discharging through the generator** when the engine is turning on a slow speed and therefore the charging rate of the generator goes below the rate of the battery. That means if the generator voltage is lower then the battery voltage the cut out relay interrupts the connection between generator and battery to prevent a reverse current flow. This prevents as well the generator from being connected as a motor.

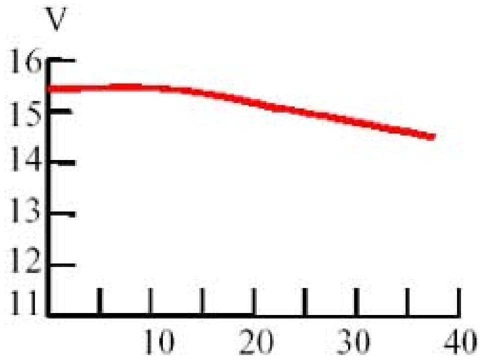


Because of increased electrical loads many DC−generator regulators are provided with **voltage regulator units of a double−contact type**. These units are equipped with two sets of contact points to hold the high field current of the exciter winding inside the generator and to prevent therefore an uncontrolled overload of the electrical system of the motor vehicle.

The voltages induced by a DC−generator in relation to the load are referred as regulator characteristic.

Regulator with inclined characteristic:

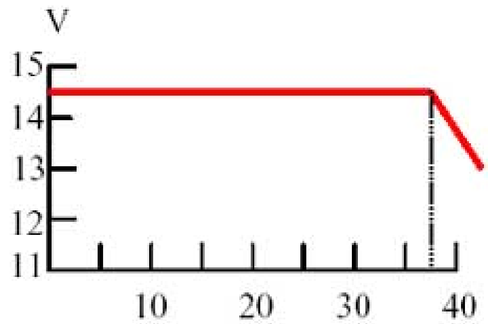
It **prevents overloading of the generator**. The current from the generator passes through a coil on the voltage regulation element (one up to two windings). The effective magnetic field of the voltage regulation element increases as result by this additional coil when the load current increases. The regulator contacts of the voltage regulation element move than to the middle/upper setting even when the generator voltage is lower. Therefore the regulated value of voltage becomes lower.



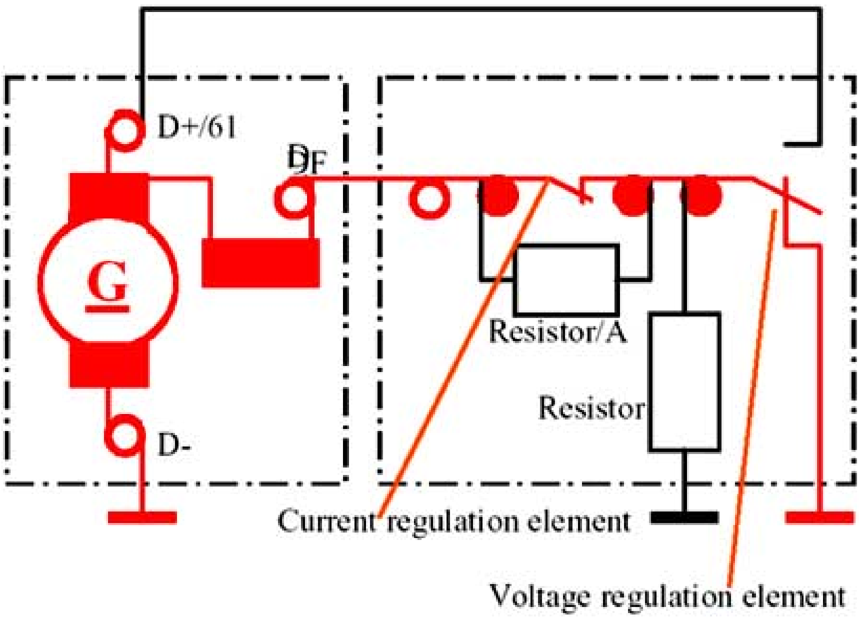
Inclined characteristic by an additional winding on the voltage regulation element

Regulator with steep−droop characteristic:

In this case there is built into the regulator an additional current regulation element. Starting with the idle speed of the engine the regulating voltage remains almost constant. Until the maximum generator current is reached the voltage regulation effect takes place only. When the maximum generator current is reached the voltage gets reduced steeply and so the output is controlled. This additional current regulation element protects the generator against overloading. On this type of regulator the lower setting contacts of the voltage regulation element are not direct wired to the ground. They are connected over the so−called off−load contact of the current regulation element. Therefore the exciter winding is then grounded when the lower setting contacts of the voltage regulation element and the regulation resistor is inserted into the circuit of the current regulation element. In this case the exciter current gets reduced and controls the voltage.



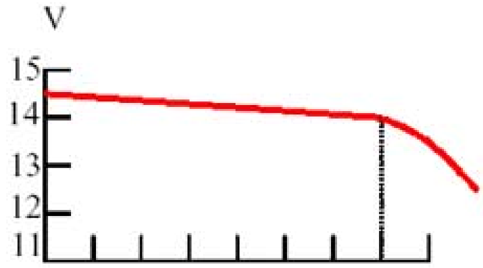
Steep−droop characteristic by an additional current regulation element



Regulator with voltage regulation element and additional current regulation element

Regulator with variode characteristic:

This type of regulator has a voltage regulation element and a cut out relay. The voltage regulation element has an additional control winding with an in series connected variode (diode). This additional winding and the variode are in parallel to the resistor of the regulator.



Variode characteristic By an additional control winding with a variode

A voltage drop takes place at the resistor when a load is applied by the control winding with its variode. When the maximum generator current is reached the voltage drop in the resistor gets so great that the variode becomes conductive and now current flows in the control winding. The voltage regulation contacts are in the lower setting because of the voltage drop in the generator armature occurring at maximum load. The magnetic field built up in the control winding strengthens the magnetic field of the voltage coil from the voltage regulation element when a load is present. The contacts of the voltage regulator element are now in middle or upper setting and therefore the generator voltage is controlled.

The characteristic is related to the steep−droop characteristic but the break−away−characteristic is not so abrupt.

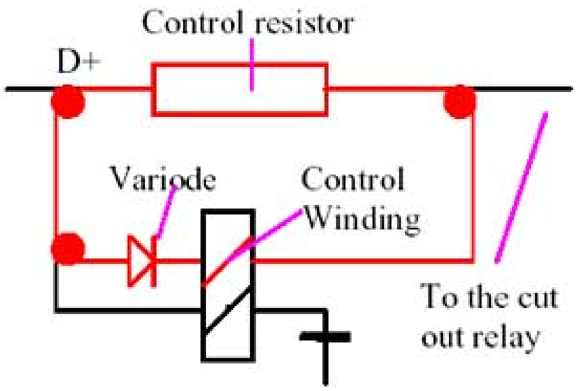
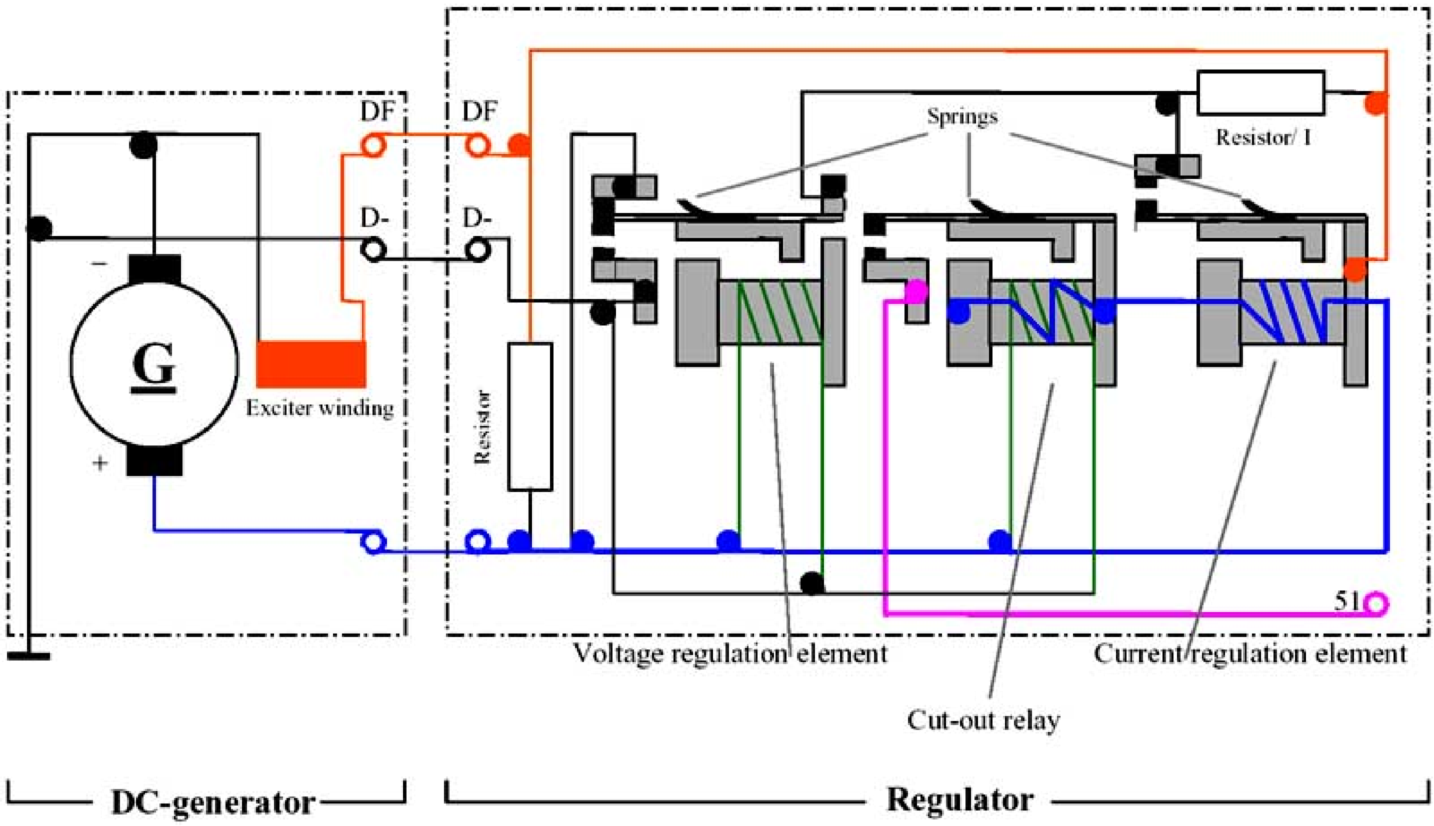


Diagram of the principle of the variode regulator



Regulator diagram with voltage regulation element, current regulation element and cut−out relay

DC−generator failures

Wear on the **carbon brushes** and the **commutator** are the mostly problems of generator failures.

Normally the brushes wear first but when they become smaller the **spring pressure** (holding them in contact with the commutator) weakens. This leads eventually to continuous sparking (**arcing**) between brushes and commutator. This **arcing causes rapid wear on the commutator**. If this process goes on over longer time the **soldered connection** between commutator segments and windings **may melt** what causes that the generator **output drops down** and finally it **can lead to cease**.

Loss of the generator output can also drain the **battery** because the current taken from it by the switched on consumers will not be replaced. A warning of the output drop of the generator is sometimes given over the **charging lamp** on the dashboard. That lamp **may glow slightly**. If the **charging lamp goes on** during vehicle operation than is after stopping the engine first the **V−belt** to check. Should it be in order than is to check the output of the generator or if necessary the generator is to **remove for further checks** and it is on the test bench and eventually repair.

Checks are made easier if the generator is clamped in a vice. To **check the brushes** the commutator end−shield is to remove by unscrew the through−bolts. Most of the generators are having a **lug** under the end−shield **to locate** it **correctly**.

Now is to follow up what condition the carbon brushes and of course the commutator have. Always the **brush holders** are to clean (to ensure a slightly move of the brushes) before fitting new brushes. The ends of the **brushes** must be shaped to match the curve of the commutator. The **commutator** is to clean as well and its **segment surfaces** should not be glazed, pitted or scored. Other major defects can be **faulty insulation** between the segments, **broken connection** to the windings, **melted solder connections** or **lost segments**. If the **commutator is to worn out** it has to be **skimmed** on a lathe and there after the **mica insulation** between the segments may need to **cut back** at least 0,5 up to 1,0 mm deep and **correctly** from one segment to the next one.

Always the **whole generator** is to clean before reassembling. To **remove** any **dust and dirt** is it possible to use a **soft brush** as well as a cleaning agent like **paraffin**. And before re−assembling all the generator parts have to be **dry**. The field terminal often has an **insulation sheet** fitted and this is not to forget to **replace it**. Also the **drive end−shield** the **commutator end−shield** and the **armature** (as well as the bushes or bearings) are to **check for wear**. The armature should not have **signs of rubbing** on the pole shoes.

Than the **exciter windings** are to **test for continuity**. A **circuit tester** used between the terminals D+ and DF will light up if they are intact. The armature is finally to test with the so−called **armature growler**.

By re−assembling the whole generator is to make sure that all the parts get fitted together in the **right position** and there after the generator should be tested on **the test bench** (testing on the test bench will be a complete topic under the chapter "alternator".

Routine checks

The unit of DC−generator and regulator should be checked once a year. Looking at the generator it should **not** be **dirt or dampness placed on the side of the commutator end−shield** where it can easily **lead to stacked carbon brushes and further problems affecting the commutator**. A very important maintenance job is to **inspect the fan belt** of its correct tension. A loose fan belt is a short way to flat the battery. But overtighten the belt puts excessive strain on the generator bearings especially on the side of the drive end−shield. The usual recommendation is **13 – 20 mm deflections** in the belt's longest run.

The **regulator** is to check as well. Also here dirt and dampness may affect the resistors placed under the base plate of the regulator. Two further parts are mainly important to be looked for:

− checking of the **contacts of cleanliness** and that they are **not burned out** to ensure the proper function;

− controlling the **spring plate tension** on the contact points because they are the ones to ensure the **right adjustment for operating** the regulator bent with the correct strength;

− checking the **output** of the recharging unit we should follow up by using a voltmeter an amount of **13 – 13,5V** (or the correct value given from the manufacturer) for a 12V unit;

Adjustment of the regulator is normally not necessary. If there is on any way a need than is to use a voltmeter for the output adjustment of the recharging unit as above mentioned. For the eventually adjustment of the cut−out relay is to use a sensitive voltmeter by connecting it between the generator output terminal and earth. Than the speed of the engine is to increase slowly. Above idle speed when the voltage output take place higher then 12,8V the contacts of the cut−out relay should close. **Even a small bend on the spring plates can create a bigger voltage change**. Therefore it is not easy to get the correct adjustment for opening/closing these contact points.

Generator terminology

Nominal voltage: The voltage of the electrical system of a motor vehicle included the battery.

Generator voltage: The voltage at which the generator is normally operated (7, 14 or 28 V).

Maximum current: The current what the generator is able to deliver without exceeding its speed and temperature limit.

Zero−current speed: The speed of the generator at which (after it is warmed up) the generator voltage is reached by not delivering any current. In that stage the voltage regulator connects the generator to the battery.

Maximum speed limit: The speed of the generator rotation at maximum. Exceeding it let the risk of mechanical damages occur.

Type references: These references show up letters and numerical specifications and gives details of size and pattern of the generator and its electrical specification. The regulator must be always the right specification according to the generator to which it will be connected.

A DC–generator with 12V and a specified output of 130W needs a regulator with 12V and 130W. A higher wattage of the regulator reduces the output of the recharging unit; a less regulator wattage may lead to burning out of the regulator windings.

Permanent magnet generators

Such kind of generators we do find built in motorcycles and small stationary engines. **The rotating pole wheel includes a number of permanent magnets as well as the generator armature (voltage winding).** By rotation of the permanent magnets an **alternating current is induced** in the armature. The current needs to be **rectified by using diodes** (see chapter "alternator").

The generator armature is built for a **specified current** to supply the whole electrical system with the right current strength. Permanent magnet **generators need not to get regulate** because **they are self–regulating** in terms of the specific generator armature.

Reasons for introduction of alternators/AC–generators

Especially the increase of **power demands** on modern cars by the **growing number of electrical and electronic devices** led together with further requirements to the situation that a stronger output of the recharging system was needed. By the use of DC–generators was it not possible to reach this. World wide was going on also an increase of town driving include longer waiting times on engine idle speed. Waiting times and many stops by increased traffic were **resulting in insufficient battery charging**. The development of the **alternator brought a successful improvement in all that cases**. But it was only possible by the advance of **semiconductor technology**. The reason for this is that **a<u>lternators are generating alternating current</u>**. Therefore the **<u>output of an alternator must get rectified using rectifier diodes</u>**. First then the output is usable for the electrical system of a motor vehicle

<u>Advantage</u>: Power gets delivered even **when** the **engine is idling**. The **rotational speed** of the alternator can be **higher** what is important by using modern engines with higher engine speed. The equipment of an alternator is **<u>much better</u>** by a **less of mechanical–dynamic influences**, by the **influence of higher temperatures** and in the case of **much longer operation times and longer periods before maintaining** is needed.

Alternator/AC–generator

For modern **engines running at higher revs** in motor vehicles with **extra electrical equipment** the **DC–generator has limitations**. To generate the extra current **demand requires a much bigger physical size of the armature** and therefore of the complete **generator** until weight and size **become excessive**. The higher revs of the armature **increase the centrifugal force** what causes the **armature windings** in a tendency to **throw outwards**. Also the increased current output **increases the wear between brushes and commutator**.

That we do know. The way out of these problems was (by developing the field of electronic and its semiconductors) the alternator**.** The **alternator output** is alternating current what **needs to get rectified by the use** of special semiconductors called **diodes.**

Whereas the DC–generator consists of a series of windings (coils) rotating inside a magnetic field, **the alternator is also something like that but hereby a magnetic field is rotating inside a series of coils** (inside changed to outside). This gives us several advantages (mentioned already on page 40). Let's follow up these figures step by step again:

1. **The rotating magnet, the rotor**, is an electromagnet with variable strength (as in the DC–generator field coils) can be made strong enough to rotate at much **higher speed without getting damaged**. **The field windings** contain a relatively small amount of wires

and so the damage in case of centrifugal force is minimised.

2. **The field current is low** and also when it must be a contact by using brushes to conduct the current to the field windings, **the wear on the brushes is very little**. A **second reason for reduced wear on brushes is they** have not to **run over a commutator** anymore but instead of this **over smoothly slip rings**.

3. **The main windings** now existing and **fixed on the side of the stator can be made much heavier**. They are **kept cooler** during operating then in a DC–generator and therefore in the end **a higher output is possible** by probably the same unit weight.

4. An **alternator delivers an useful amount of current already at idle speed of the engine** and there are not developing difficulties facing **traffic problems** at low speeds or "stop and go" situations.

Getting an output of alternating current out of the alternator is the use of diodes to rectify AC to DC. The diode assembly/rectifier is a **small unit** mostly built in the alternator. Such a **unit can handle quite large current and let the current pass in one direction only**.

The generated current from the alternator flows first in one direction and then in the other one. But **the rectifier unit using these diodes block the reverse current** and therefore the **result is a pulsing unidirectional current**.

Alternator construction

Three major units are existing in an alternator:

- A **rotor**, which provides the magnetic field.
- A **stator**, where voltage and current gets produced.
- A **diode assembly** (rectifier), which changes ac to dc.

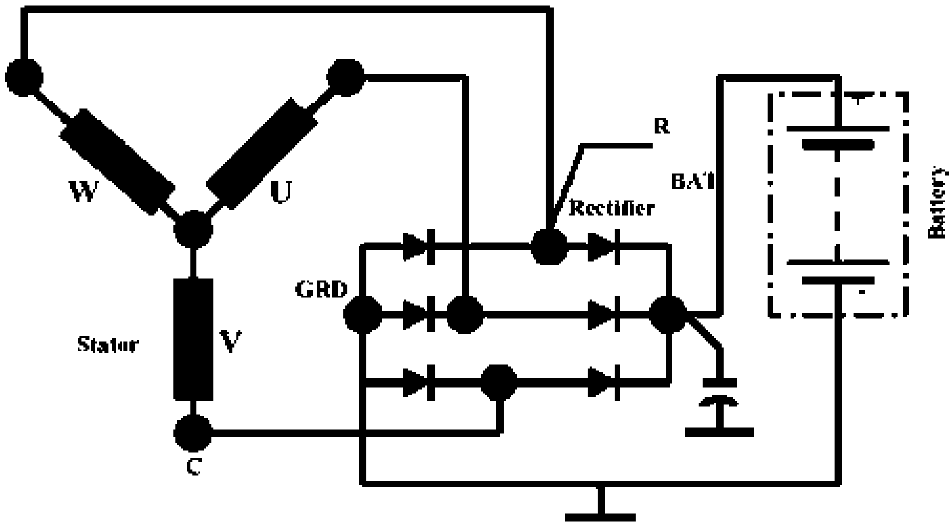
The rotor has an **iron core** on a shaft **with a wire wound as coil** around it. This coil is enclosed between two iron pole pieces with **inter spaced claws**. The ends of the coil are connected to two slip rings. There over are riding during rotation **small brushes**. **One** of these brushes **is connected to the alternator field terminal** (the insulated brush). **The other brush is grounded**.

The **stator has three sets of windings** that are assembled around the inside circumference of a laminated iron core.

The iron core is also often used as a part of the alternator frame. In its function **it provides** between those inter spaced pole claws of the rotor **a path for the flow of the magnetic flux**. **Each winding** of the stator **generates a separate voltage.**

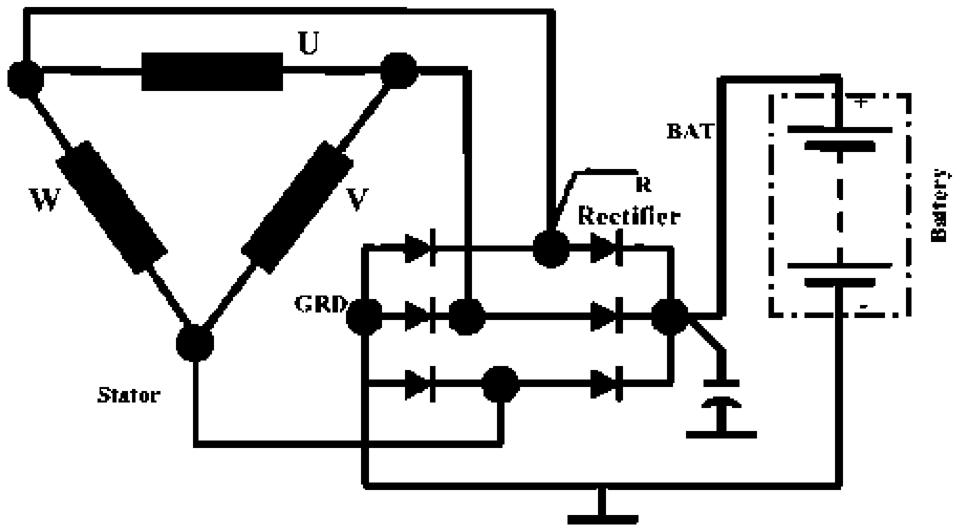
One end of each winding is connected to a positive and a negative diode as a first possibility. The other ends of the stator windings **are connected to form a "Y" arrangement**.

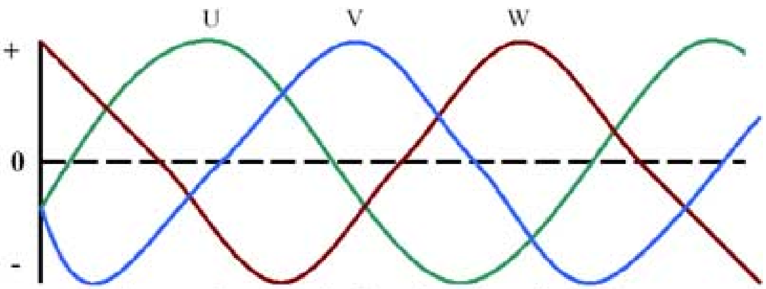
The **other type of connection** is used especially on heavy–duty applications. In that case **the windings are connected to form a triangle (delta–connected stator)**. However, each winding of the stator generates a separate voltage and therefore the **alternator is a three– phase unit**.



Three-phase "Y" circuit stator is formed

Three-phase "delta-connected" stator is formed



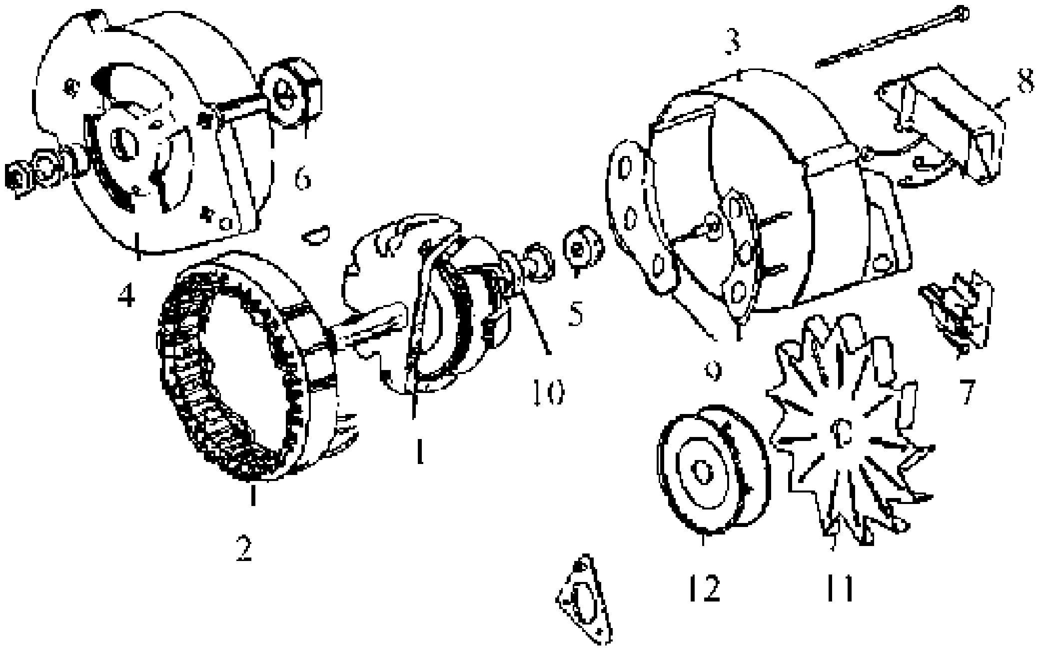


Curves of generated voltage in a three phase alternator

The **diode assembly** consists of six diodes (basically) but often we do find alternators having **nine diodes**. The **diodes** are **connected to** the **stator leads**. So a diode assembly may have six power diodes and three exciter diodes **for converting** the **three–phase current into direct current**. The **negative diodes** are mounted into the slip ring end shield or in a heat sink bolted to the end shield. The **positive ones** are mounted in a heat sink and they are **insulated** from the end shield.

The stator is clamped between slip ring end shield and drive end shield. These front and rear housings are hold together by through bolts. The rotor is rotates in **bearings** housed in both of the end shields.

The **carbon brushes** are pressed against the **slip rings** for supplying the excitation current to the rotating excitation winding. Often **electronic regulators** are built into alternators. They form a unit with the brush assembly. Using **electromagnetic regulators** – they are built in a motor vehicle separate from the alternator.



Legend to the alternator components shown below

1 – Claw pole rotor

2 – Stator

3 – Slip ring end shield

4 – Drive end shield

5 – Bearing (on slip ring side)

6 – Bearing (on pulley side)

7 – Brush holder with brushes

8 – Regulator

9 – Diode assembly/Rectifier

10 – Slip rings

11 – Fan

12 – Pulley

Function of an alternator

In an **alternator are no permanent magnets to provide the magnetic field**. A magnetic field gets induced first when the engine is switched on. That means, **the battery has to provide current for building up the electromagnetic field**. This is **the reason for not getting push–started a car with an alternator by having a totally flat battery**.

Voltage can be induced over **two ways**:

1. By **moving a coil** of wires through a magnetic field;

– **Remember (!):** this way was used in the old **DC (direct current) –generator**. Voltage gets induced in coils of wires as the assembly (armature) rotated in a stationary magnetic field.

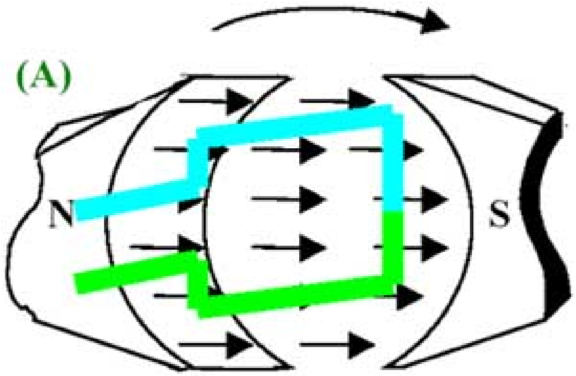
2. By keeping the coil stationary and **moving the magnetic field**;

−On this principle the **AC (alternating current) –generator, the alternator**, operates. The magnetic field (rotor) is rotated and voltage gets generated in the stationary coils (stator).

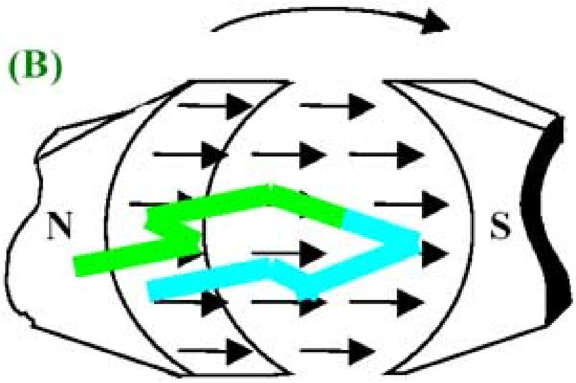
Therefore the **rotor becomes an electromagnet supplied with a small amount of electricity from the battery** through the brushes running over the slip rings. The **rotation** of this electromagnet **induces a much larger current in the stator windings**.

Let's remember: In general **we do know** that **voltage will be induced** in a coil **whenever** there **is a change in the magnetic field lines** (lines of force**) by cutting these lines** passing through the coil **because of the rotation of the coil or the magnetic field**.

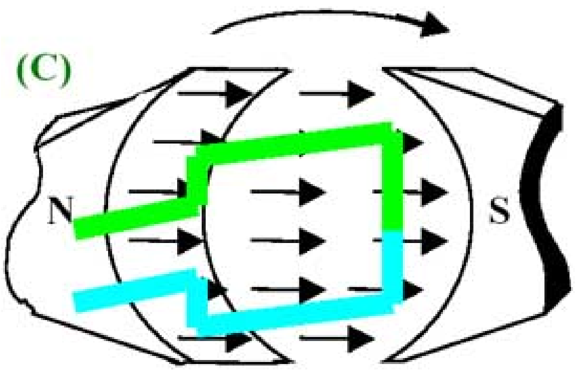
When the **coil** is **in vertical position** then is a balance of the lines surrounding the conductor, **no field lines are cut** and so **no voltage** gets **induced (Figure A)**.

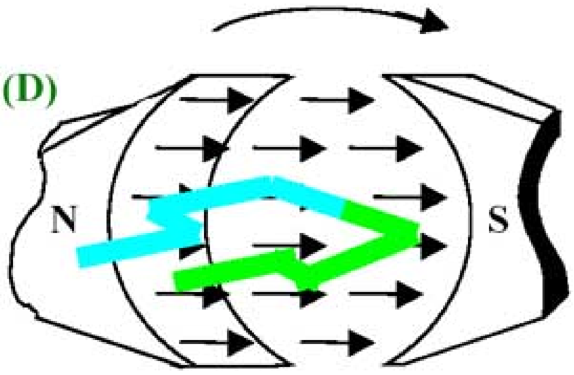


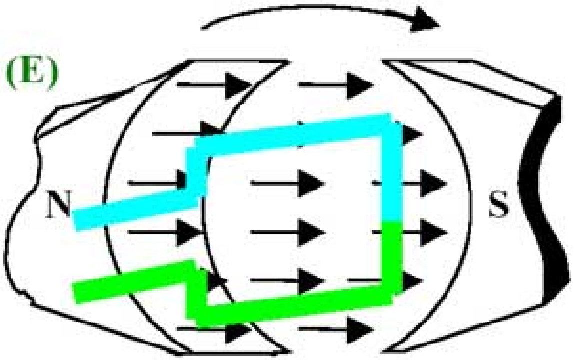
Coming by rotation **out of the vertical position** means, **increasingly lines will be cut**; the **generated voltage increases** as well and reaches its **maximum by** the **horizontal position (Figure B)**.



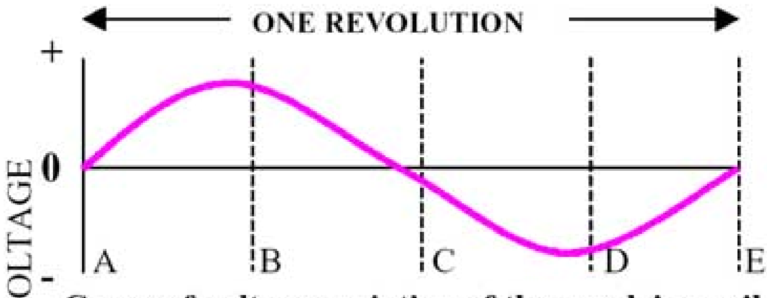
After passing position **(B)**, the **voltage** starts to **decrease** as fewer lines are being cut. It will become **zero when position (C) is reached**. As rotation continuous another maximum **(D)** and there after another zero−situation will be reached. But the **lines being cut in the opposite direction and** the **generated current will flow in the opposite direction (E)**.







Because of the **change of the current direction** it **is called alternating current**. All the automotive generators produce alternating current.



Curve of voltage variation of the revolving coil

To satisfy the needs of the storage batteries and the various electric systems the **alternating current must get rectified to direct current**.

To make use of the generated electrical energy by:

a) having a **DC–generator**

the **rectification is taking place by using the commutator** with its separate insulated segments.

b) using a **AC–generator (alternator)**

the electrical energy gets **rectified by diodes** built into the alternator.

We do know already; **before an alternator will start to induce voltage direct current must flow through the rotor winding in order to magnetise the claw poles**. That means, the rotor must be **externally excited** before the **alternator delivers voltage and current**.

When the **ignition switch** get switched **on**, voltage is supplied to one side of the charging indicator lamp on the dashboard. This causes a small amount of **current** to pass through the regulator to the insulated brush. That current flows through the slip ring to the winding, the other slip ring and the other brush to the ground. **By passing through the winding the current creates a magnetic field** (see: "Fundamentals of magnetism") in each section of the rotor. Because of the ground connection, the charging indicator lamp now works.

The **magnetic field** of the rotor **induces voltage in the stator windings** when the rotor starts turning. And ones again – **it is alternating current because**:

> **Do you know it?**
>
> The **rotor sections have alternate north and south poles** and the **current direction is reversed each half revolution** of the rotor (see: sketches before in this chapter and the chapter before).

The stator sends this **three-phase alternating current** to the **diode assembly** (rectifier) **what permits the current to pass in one direction only**.

Over this process **direct current is provided** at the alternator output terminal.

In an alternator there are three circuits:

1. Pre-excitation circuit

When the ignition switch is switched on, battery **current flows over** the charging indicator lamp to the **excitation winding of the rotor** and from there **to the regulator and to the ground** (alternator with mounted regulator).

Having an alternator with separate regulator, the current flows first to the regulator and after that it flows to the excitation winding.

The **alternator gets pre-excited**.

Do you still know why is this necessary?

The reason for that is, **to cause the self-excitation required for building up the magnetic field and so to generate by the running alternator the required voltage**. The **charging indicator lamp** is in the pre-excitation circuit **acting as a resistor** when the ignition switch get switched on. **Current flow through the lamp causes a magnetic field strong enough and needed for self-excitation**.

Later, even during idle speed of the engine the excitation filed is so strong that the alternator excites itself.

Then it isn't an external excitation necessary anymore and the generating of electric power takes place.

2. Excitation circuit

The **excitation circuit produces a magnetic field in the excitation winding and this in case to induce the required voltage in the three-phase winding of the stator as long as the alternator is operating**. **During operation** time of the alternator **there is no external power needed** because the **alternator excites itself** (see: pre-excitation circuit).

When alternator starts, the residual magnetism (very low) together with the pre-excited magnetism induces a slight voltage in the stator winding. That voltage causes a small flow of current in the rotor winding; the magnetic field gets further strengthened; the stator voltage increases. There is going on an **interaction (repeated continuously) while the speed of rotation increases** until the alternator is fully excited and the generator voltage reached.

Please follow up again the principles in order to ensure your knowledge!

3. Generator circuit

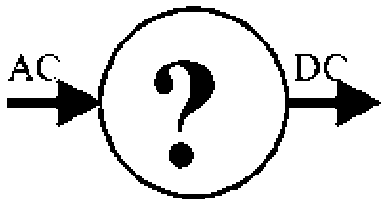
The **alternating voltage induced in the three phases must get rectified**. There are used the so−called **power diodes** in the **bridge circuit** for delivering **to the output terminal "B+"**. This is the path of the generator or main current for charging the battery and for the needs of the electrical loads of the switched on consumers.

For the **current** to **flow from the alternator to the battery**, the **alternator voltage must be higher than the battery voltage**. By using a regulator the output of the recharging unit is by 12V motor vehicles mostly adjusted between 13,8V and 14,8V. More about regulation you will find in "Regulation of alternators".

Why is a rectification of the generated current necessary?

Rectification of AC voltage

Semiconductor diodes are important getting a straight rectification. And first the development of diodes was allowing the introduction of three−phase alternators in motor vehicles.



Having **alternating current** produced in an alternator means we do have waves from each phase of the generated three−phase current. These **Waves are changing periodically (depending on the speed of rotor rotation) between negative and positive.** The **rectifier diodes (power diodes) cause negative half−waves to be suppressed** but they **allow flowing through only of the positive half−waves**. The **output** is in the end **a pulsating direct current**. **Each phase** is therefore **connected to two diodes**, one for **the positive half−wave** and the other one for the **negative half−wave**.

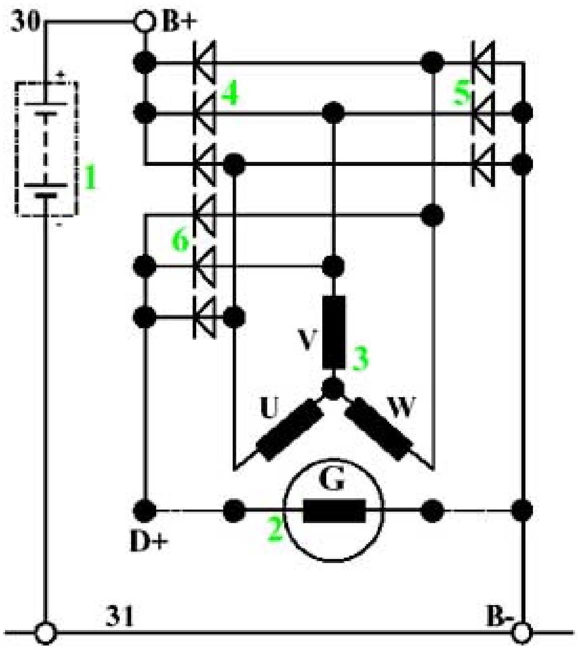
The connection of the all those six diodes of the so−called **bridge circuit**:

− the three positive diodes are connected on the terminal "B+";
− the three negative diodes are connected on the terminal "B−"/ground.

So we do get **after rectification a slightly rippled generator voltage**.

The **battery connected in parallel smoothes** the generated **electrical energy further**.

The **rectifier diodes** in the alternator **are used as well for preventing the battery from discharging** through the three−phase winding in the stator. For that is a need, **when the engine stops** or the **alternator operates to slowly so that the alternator isn't yet self−excited**. The **diodes do not allow** the **current flow in** this **reverse direction**.



1 – Battery

2 – Excitation winding

3 – Stator winding

4 – Diodes in positive plate

5 – Diodes in negative plate

6 – Exciter diodes

Three further diodes are often being used in the alternator are **the so–called exciter diodes**. These diodes are used **for** the **rectification** of the small amount **of excitation current** flowing to the rotor in case of magnetising the claw poles.

When **voltage** is **applied across a rectifier diode**, the diode allows **current flow in only one direction**. The current flow direction is in symbols shown by arrows indicating the forward direction. And the **current flow stops in the opposite direction** (reverse direction).

Diodes in the positive and negative plates are fully identical with other diodes in case of their operation. Differences are existing concerning the design by the use in alternators. **The knurled metal casings of the diodes in the positive plate act as cathodes** and they are **pressed into heat sink** which is connected in the end to the positive pole of the battery; the **diodes allows current to pass to the terminal "B+"**. The **diodes in the negative plate act as anodes** and they are **connected over the heat sink to the ground**.

The relatively small **exciter diodes** (dealing with the low excitation current) **consume** only **around 1W** (watt) but the larger and high–rated **power diodes** (in positive and negative plates) in the charging circuit **take up to 25W** per single diode.

Charging indicator lamp

Using a **charging indicator lamp** in a motor vehicle, is often done on the following basically way:

One lead can be connected to the side of the switched on ignition switch (terminal 15) and the other lead of the indicator lamp is then in connection with the terminal "**D+**". Over this "**D+**" the indicator lamp get ground being connected over the **"+"–brush,** to one **slip ring,** to the **rotor winding**, to the **other slip ring**, to the **"–"–brush** and to the **ground**. When the rotor starts to turn the ground connection isn't available anymore because of the inducing of voltage also in the rotor winding and therefore the indicator lamp goes off.

On anyway the connection of the charging indicator lamp depends on the use of electronic or electromagnetic regulators and on further possibilities followed up by the different manufacturers.

Regulation of alternators

Increase of the **rotor revolution** results in **increase** of **voltage and current**. For that reason is needed a **regulator to hold** the **output from the alternator -regulator unit** as **constant** as possible.

Up to now electromagnetic regulators are still in use but the built−in−regulator (electronic regulators) inside the alternator gets more popularity.

It was mentioned already that the **regulation of the output of an alternator** is a **very important** aspect. The **voltage** of an operating alternator **raises up as long as** the **rotation speed increases**. Therefore a decreasing of the engine speed brings as well a decrease of the voltage output.

A regulator brought in connection with the alternator **is needed to keep the voltage constant** over the changes of the **engine speed by differ load and rotation speed** of the alternator.

It is to ensure that there is a **protection against overvoltage** and **the battery must be prevented from being over−charged**. Therefore a **voltage regulator must** be connected to each alternator in order to ensure the requirements.

If there would not be provided a regulation then an excessively high current will damage the battery, the alternator and other electric elements connected in a motor vehicle.

Principle of voltage regulation

Basically **the voltage regulator is an automatic switch that controls the output of the charging system**. In **result** of this **voltage and current will not exceed a value once adjusted**.

The **principle of voltage regulation is based on** the **regulation of the excitation current and so of the excitation field in the rotor of the alternator**.

The **alternator terminal voltage (Va)** between the two terminals B+ and B− is the one to be kept constant. As it was mentioned already, in a motor vehicle with a 12V−battery the **regulation** takes place on a range **between 13,8V up to 14,8V**.

As long as the **generated voltage remains below the adjusted regulation value the regulator will not be in operation**. When the **generated voltage develops higher than the adjusted tolerance** then **the regulator reduces the voltage depending on the load**. This goes on **by interrupting the excitation current**. Therefore **the excitation of the alternator decreases and** that happens with **the voltage as well**. **Drops the voltage below the value**, by operation of the regulator **the excitation increases** again **and so the voltage raises up** to the set value **again**. This all is going on **very fast by** the means of **milliseconds and so the** alternator/generator **output is regulated to the required value**.

As you may realise now, **a periodic switching on and off of the excitation voltage regulates the alternator output**. The excitation winding of the alternator shows up as a high inductive load. When it is **switched on** then the **excitation current increases gradually** in a time **going along with the building up of the magnetic field**. **On the opposite** by **decreasing of the current** (switched−off situation), this **goes along with the decay of the magnetic field**. An immediate effect is therefore not taking place.

A **regulator of a DC−generator** fulfils **three functions** by acting with the **voltage regulator**, the **current regulator** and the **cut−out relay** as three parts.

On the side of a charging unit **by using an alternator the function of the cut−out relay is done by the diodes**. The **current limitation** is **not necessary** anymore because of the alternator function (current−limiting characteristic) where a **low voltage** is **induced in the excitation winding** what **counteracts with** the **resultant generator voltage**.

Do you know, why the excitation current does not undergo an abrupt increase and decrease?

Types of regulators

Mainly we have **build–in regulators** direct in connection with the alternators and we do have as well (still) **separate regulators** put on a protected place in the engine room of the vehicle.

1. **Electromagnetic vibrating–type regulators**

   – see on the pages 32 up to 36

2. **Transistor regulators**

   – in different types concerning to the types of alternators and the various manufacturer

3. **Hybrid regulators**

Transistor regulators

Transistor regulators got developed in terms of several demands concerning service life, regulating accuracy and maintenance freedom. These types of regulators **do not have mechanically moving parts** and therefore also not such contacts. The transistor regulators are in modern vehicles standard equipment and mostly built into the alternators.

The transistors gets always again to the working phases “switched” on and off in order **to control the alternator voltage output by regulating the alternator field current**. The most important elements are **transistors** and **zener diode**. What are the **advantages of these breakerless transistor regulators**?

The main points are:

– shorter switching times and electronic temperature compensation permit narrow regulation tolerances;

– there is no wear possible and this maintenance–free;

– high switching currents allow a reduction in the number of types;

– spark–free switching prevents radio interference;

– insensitive to shock, vibration and climatic effects;

– compact construction permits mounting on the alternator while regulator and brush holder are forming a unit.

All these are points for a **high reliability** and a **low failure rate** making the recharging unit safer under also difficult conditions.

Transistor

The transistor has the **function to switch the excitation current rapidly** with the **two phases “on” and “off”**. As well **higher currents can be handled**. A transistor is **very compact,** has **no mechanically moving parts** and is as well **maintenance free**.

Zener diode

This is a special type of diode named developer.

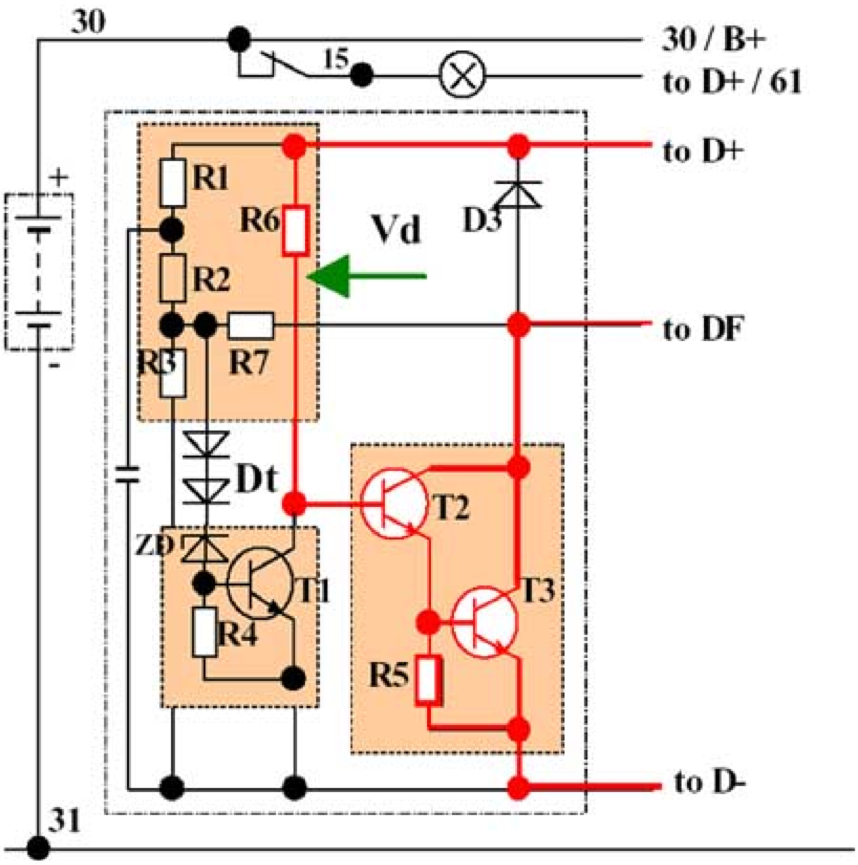
Zener diodes are in the regulators in order to **control the transistors**. Semiconductor diodes do not form an absolute barrier in the reverse direction.

When the breakdown voltage is exceeded then the **breakdown current raises** suddenly and steeply. If this **breakdown current is excessive**, **a normal diode can be destroyed**. **This situation is covered by the zener diode.**

Operating principles

Condition "ON": As long as the actual value is below the set value of the alternator and as long as the breakdown voltage of the zener diode is not reached! **no current flows in the circuit containing the zener diode**. **No current can reach the base of the transistor** (1) because **the zener diode is in nonconducting state**.

But with the transistor (1) **a control current can flow from the exciter diodes and terminal "D+" over a resistor to the base of the transistor (2) and switch it on**. **Transistor (2) closes** now **the connection between terminal "DF" and the base of transistor (3)**. **Excitation current flows now through the transistor (3) and increases during "on"–time, raising up the alternator voltage. At the same time** there is as well a **raising up in the voltage across** the **voltage divider and** the zener diode.



ON – condition

R – Resistors

T – Transistors

ZD – Zener diode

Dt – Temperature compensation diodes

D3 – Decay diode

Vd – Voltage divider

Condition "OFF": When the **voltage exceeds the set value**, **the zener diode starts to conduct**. This goes on **when the breakdown voltage is reached**.

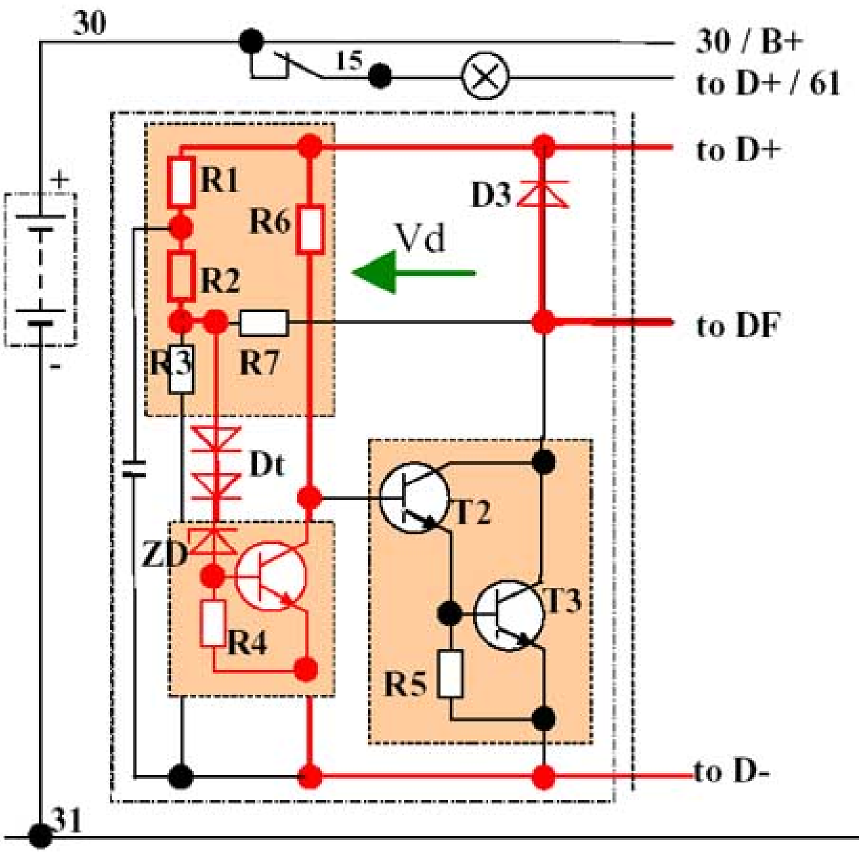
The **current flows** now **from terminal "D+" over the resistors** 1, 2 and 4 and **the zener diode** to the **base of transistor** (1). **The transistor conducts**.

Therefore **the voltage** at the base **of transistor (2) drops down to zero** with respect to the emitter and so the **base– current stops flowing**. Now the **transistor (2)** and **(3)** are **blocked**.

The **excitation circuit is suppressed and the alternator voltage drops**.

To avoid destroying of the transistors (2) and (3) –– as a **result of a voltage peak due to self–induction of the excitation winding** –– there is connected in parallel to the excitation winding a **"free–wheeling diode" (decay diode) to discharge the (decaying) excitation current**.

As soon as **the alternator voltage is below the set value and the zener diode has returned to the nonconducting state**, the excitation current is switched on again.



OFF – condition

R – Resistors

T – Transistors

ZD – Zener diode

Dt – Temperature compensation diodes

D3 – Decay diode

Vd – Voltage divider

The different types of regulators follow up in the end the same operating principles. The regulator must match the electrical system of a motor vehicle and must the voltage keep constant by different rotation speed and load situations.

And so **the “ON”/”OFF” ratio depends on the rotation speed** of the alternator and on **the load current**.

Often an **attached capacitor** can **smooth further the rippled DC–alternator voltage**.

Temperature influence

A further point is important to look for as well.

The **charging current must be higher in cold weather than in hot weather** concerning to the needs of the attached battery into the motor vehicle.

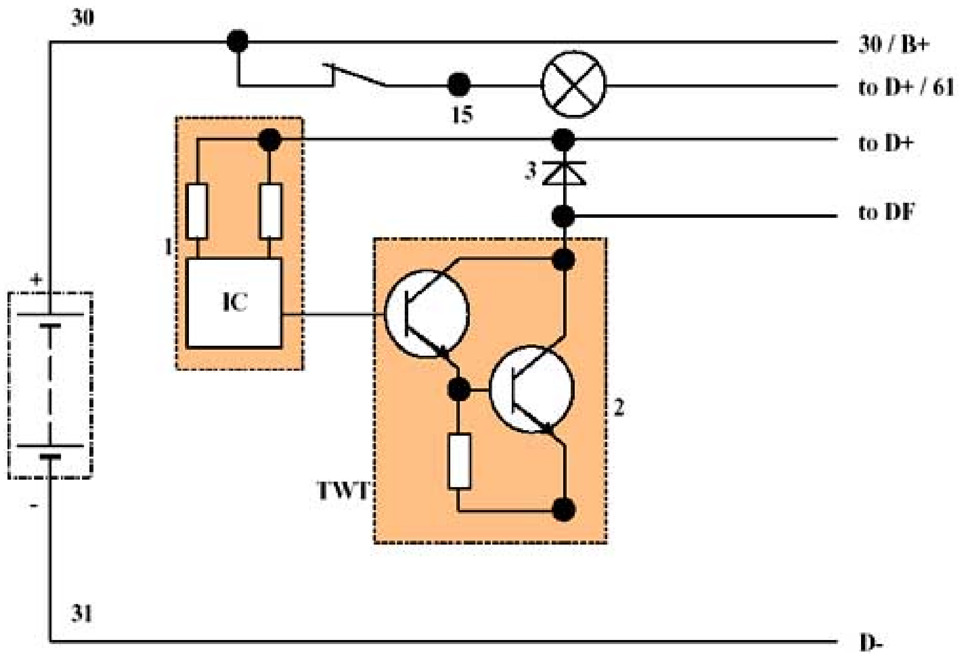
To meet the requirements, the **transistor regulators are provided with electronic temperature compensation**. For reaching that temperature compensation is used the zener diode, the resistors and the diodes “D1” and “D2” connected in forward direction.

Hybrid regulator

A **hybrid regulator** is further developed out of the transistor regulator. The main part of a hybrid regulator is an **integrated circuit (IC)**. The IC combines all the control functions:

- comparison of set and actual values (control stage)
- temperature compensation
- triggering of the output stage.

This **technique allows a very compact construction** by using a ceramic plate ––to make the arrangement of the components such as capacitors and resistors––, film techniques, integrated circuits and of course transistors. Near the very **compact construction** the remarkable points for the use of hybrid regulators are to see in the **few components and connections** and therefore allowing a **high production rate** and very important, the **high reliability by extreme operating conditions**.



IC – Integrated circuit

1 – Thick film substrate with IC control stage and resistors

2 – Power stage TWT

3 – Decay diode

Over–voltage protection

It is usually not a need for additional **protection against over–voltage** concerning the electronic components. The **battery** it self **with its very low internal resistance damps all the occurring voltage peaks** in the electrical circuits of the motor vehicle. But **in several cases** it can be **dangerous without protection for diodes**, **transistors** and **thyristors** in any of the built in electronic equipment inside a motor vehicle. It can lead to **punctures in the thin semiconductors** and in the insulating films. The **result may be operation failures or completely destroying** of those components.

For example in the case of a regulator failure overvoltage may occur. The **ignition system** may have an **influence** as well. When such equipment like **electric motors** get **switched off**, **lose contacts appear** or wires get broken then there **are possibilities of voltage peaks**. The **electronic components** like **diodes have to be secured against voltage** what can reach **up to 350V** (concerning the ignition system). **Over–voltage protection is also indicated** when the motor vehicle is **without connected battery** (by transport, during service etc.).

The **zener diode protects effectively** and on a simple way the electronic components in the alternator. For that reason the **zener diode is connected between the terminal "B+" and the ground**. But the connection is **in reverse direction to the battery voltage**. Voltage peaks are limited to about 30V in case of 12V systems. **In addition** can be **used a capacitor** also connected between "B+" and ground by getting voltage peaks up to 400 V.

Let's remind what was said to the so–called **decay diode** (see page 54 "Condition off") concerning the voltage peak generated in the excitation winding. This diode works therefore as well as **a component for over–voltage protection**.

Further equipment (with windings) like any kind of relays, electric motors, magnetic clutches etc. can **a similar effect of voltage peaks** let occur**. To avoid danger** for the semiconductor devices in the electrical system is **in addition a decay diode connected**.

Alternator cooling

The alternator is inside a motor vehicle to find direct near the engine. The **engine** is hot and so it heats up as well the alternator. The **radiation** of the alternator it self has of course an influence too. So, it is to ensure that the alternator works properly and for this reason **the alternator must get cooled**. The temperature should **not** be **higher than 70 up to 80° C**. The ventilation must be ensured by the **use of a fan** in order to cool the alternator and (very important) the diodes. Working on that system for any reason means therefore for an auto–electrician to ensure this situation. To do so means: **using the right fan and not any one**, **controlling the tension of the V–belt and cleaning the alternator from dust and dirt** what can easily come into the alternator especially by driving in wetness and on gravel roads.

System inspection and checks

There should be a regularly inspection followed up concerning to the recommended intervals from the manufacturer. But in modern alternators the maintenance is minimised by the **use of pre–lubricated rotor bearings and long brushes.** So we can expect a running of the alternator without problems over 100,000 up to 200,000 km if there are not extremely situations for the recharging unit. It is always a good decision to **check first** of all **the battery's state of charge** and the **condition of all the cables and their proper**

connection from the side **of the starting and charging systems**. Then is to go on with the necessary electrical tests of the charging system.

1. Drive end shield

– cracks on the shield,
– sit of the bearing,
– mouthing of holes.

2. Slip–ring end shield

– cracks on the shield,
– sit of the bearing,
– mouthing of holes,
– sit/threads of the brush holder/regulator unit,

3. Brush holder/regulator

– cracks on the holder,
– brush spring tension,
– length and leads of the brushes,
– leads on the regulator.

4. Rectifier assembly

– cracks on the heat sinks,
– sit of the pressed diodes,
– function of the diodes.

5. Stator

– rub marks on the core,
– insulation of the windings.

6. Rotor

– rub marks on the claw poles,
– wear on the shaft,
– rotation marks on the shaft,
– wear of the slip rings,
– sit of the bearings,
– lubricating of the bearings,
– insulation of the winding.

7. Fan and pulley

– wear on fan and pulley,
– bent flanks on fan and pulley,
– tightened sit of fan and pulley.

Check for tightness of all the **mounting bolts** (good ground connection).

Check the **V-belt** of the right size and for wear.

Check the alternator outside for **dust and dirt**.

Test the **alternator output**.

Working with care

- **Avoid reverse polarity** by doing any battery service. In that case the **diodes can be damaged**.

- When wires get disconnected or when the test leads get connected **the system should never get shorted**.

  – Grounding the field terminal leads to the **damage of the regulator**.
  – Grounding of the output terminal leads to **damages in the alternator and regulator**.

- The **alternator is never to operate in an open circuit**. If there is no battery or electrical load the alternator can build up a **high voltage up to 120V**. Out of this the **diodes can be damaged** and this situation is **dangerous for your health**.

- You should **never try to polarise an alternator**. There is no need to do so. It can further lead to **damages of the diodes and other components**.

By having a problem on a charging system, there are to do some **small checks before** for instance removing the alternator out of the motor vehicle:

– **Check the V-belt** of functioning without slipping by having the right tension.

– **Check charging indicator lamp** on the dashboard; it should work when the ignition switch is switched on and as long as the engine isn't running.

– **Check all the wires of proper connection** by being not corroded or burnt.

– **Measure the current output** by connecting an ammeter in series between the alternator output terminal and the positive terminal of the battery. If there is existing a problem then should be followed up a **circuit resistance test**. It is to find out whether the problem exists in the insulated circuit, the ground circuit or the alternator in general.

– **Insulated circuit resistance test:** The voltmeter is to connect across each insulated circuit connection. The charging system is to test under load. If the voltage exceeds the specification of the manufacturer then the connection has an excessive resistance.

– **Ground circuit resistance test:** One lead of the voltmeter is to connect to the negative battery terminal and the other voltmeter lead to the alternator housing. The voltage reading should appear concerning the specification of the manufacturer.

– Measure the voltage output in two steps:

1) Connect the voltmeter in parallel with the negative lead to the ground and the positive one to the output terminal. Follow up the readings according to the specification of the manufacturer.

2) Connect the voltmeter in parallel with the negative lead to the ground and the positive lead to the positive terminal of the battery. The readings should be nearly equal if there is not an excessive resistance. Concerning to the specification of the manufacturer by having 12V systems the **charging**

voltage will be between 13,8V and 14,8V.

Alternator removal

If there is finally a need to remove the alternator then it must be done by following up the these steps:

1) **Ignition switch** must be **switched off**.
2) **Negative connection** is to **remove from battery**.
3) The **leads from** the **alternator** are **to disconnect**.
4) **Unscrew** the **mounting bolts** (mostly three).

Alternator disassembly

Hold your **workplace in order** also then **when you are in the process of the work**. **Disassemble** the alternator **by being concentrated and knowing clearly how to reassemble** again. A last step by disassembling is **cleaning of the separated parts**. All **the disassembled parts and components** must get **kept for further procedures** on a save place on your workbench. Work carefully by means it is to clean, to keep and to handle on the right way but it is nothing to destroy. In the end all parts must be cleaned and dry for the ongoing tests.

Alternator tests

Rotor tests:

Testing the rotor for an open circuit, connect the test lamp leads to each slip ring. The test lamp should work. If the lamp fails to work then the circuit is open and therefore not operable.

Testing the rotor for a short circuit, connect one lead of the test lamp to the rotor shaft and the other one to one slip ring. If the lamp works then there is a short circuit between the winding and the shaft.

Stator tests:

Testing the windings for an open circuit the test lamp is to connect to each of the stator leads in turn and thereby two at the time. If the lamp does not work then there is an open circuit in a winding.

Testing the stator windings for a short circuit, the test lamp is to use by connecting one test lamp lead to the stator core and the other one to each of the stator leads. When the test lamp works then that winding has the failure to be connected to the ground.

Diode tests:

For **positive diode tests** is to connect one test lead to the output terminal of the alternator and the other one to the metal strap or pin of each positive diode in turn. Having a tester by showing the results as well in zones (good or bad) then the pointer should be on the good side and the value should be relatively equal.

For **negative diode tests**, one test lead is to connect with the heat sink and with the other one is to touch each negative diode in turn by getting again the same results as by the positive diodes if they are in order. By **testing separate diodes** there is to bring one test lead to the diode base and the other one to the diode lead. In one direction the test lamp should work while in the reverse direction the lamp shouldn't. If in both of the test procedures the lamp works then the diode is shorted. If the lamp doesn't work at all then the diode is open circuit.

Testing equipment

Those where the easiest ways to test basically components of the alternator. Depending on the different situation of workshops there can be more and very **varying testing equipment**.

For example the **combination of volt and ammeter and in addition a loading resistor and alternator tester** for testing diodes, rectifier assemblies, stator windings and rotor windings.

There are available as well the so−called **compact tester**. Also they can be used for alternator tests and in addition as motor tester, for the ignition system and as exhaust−gas analyser.

An **alternator test bench** is usable for all the necessary testing procedures of the alternator−regulator unit. In connection with this tester is the possibility to speed up the alternator and therefore the tests can go on under vary conditions. Of course the separated components of an alternator can be tested as well.

The surely best solution for a bigger workshop is the **combination test bench** for alternators and generators, diodes, starter motors, ignition distributors and ignition coils. But every workshop must decide what is the really need of what testing equipment and so it must suit for the purpose of the specified workshop.

By testing with the different equipment must definitely followed up the right steps by doing the tests. It should be always taken care not to damage any component by testing and therefore is strictly to handle like the given procedures from the manufacturer of the testing equipment. To ensure a long service life of the testing equipment always any test should be done only, when a responsible person is nearby.

Alternator reassembling

After all the tests are done and the may be defective parts are replaced as well as all the parts of the alternator are cleaned up and the bearings are lubricated the **alternator can be reassembled**. By doing this is to follow up the **reverse order of disassembling**. Care has to be taken to **make all the connection right and tighten all bolts properly**.

Troubleshooting

Charging indicator lamp is flickering:

– Alternator V−belt is loose or worn out
– Loose or corroded wiring connection
– Loose or corroded battery cable clamps/terminals
– Poor ground at alternator/regulator
– Defective regulator
– Faulty alternator

Charging indicator lamp works continuously:

– Loose, worn out or broken V−belt
– Open or grounded wire from battery to alternator
– Corroded/loose battery cable clamps/terminals
– Grounded field circuit
– Defective regulator
– Faulty alternator (rotor, stator, diodes, brushes)
– Malfunction in other electrical systems

Charging indicator lamp doesn’t work by switching on the ignition lock:

– Bulb is blown up
– Battery is discharged or defective
– Leads loose or defective
– Regulator defective
– Short circuit of a diode (positive) in the alternator
– Carbon brushes worn out
– Oxide surface on the slip rings
– Open circuit in excitation winding

Low charging/unsteady charging:

– Excessive charging circuit resistance
– Corroded or shorted cables
– Excessive carbon brushes or slip rings
– Defective alternator diodes
– Open stator winding

Excessive charging:

– Defective regulator
– Grounded alternator field wire, field terminal or connections
– Internally grounded alternator field

Lights and/or fuses burn out:

– Too high alternator output
– Defective wiring in charging circuit
– Defective regulator
– Grounded alternator field wire, field terminal or connections
– Internally grounded alternator field

Noisy alternator:

– Loose or worn out V–belt
– Bent pulley flanges
– Loose alternator mounting
– Worn out/defective alternator bearings
– Interference between rotor fan and stator leads
– Open or shorted diodes
– Open or shorted wiring in the stator