MAR GREGORIOS COLLEGE
OF ARTS & SCIENCE

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DEPARTMENT OF ELECTRONICS & COMMUNICATION SCIENCE

SUBJECT NAME: INDUSTRIAL ELECTRONICS

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UNIT I

INDUSTRIAL ELECTRONIC DEVICES – Characteristics and applications of Thyratron, Ignitron, Thyristor, SCR and UJT – AC and DC switches – over voltage protection – flashers – static circuit breakers.

UNIT II

POWER SUPPLIERS – DC voltage regulators – different types of series voltage regulators – voltage and current regulation – controlled rectifiers and inverters – uninterruptible power supplies – Switched Mode Power Supply (SMPS).

UNIT III

MOTORS AND CONTROLS – DC motors – automatic regulation of speed and overload – reversing motors – AC motors – Induction motors – Speed control – Synchronous motors.

UNIT IV

WELDING AND HEATING – Principle and theory of induction heating – dielectric heating – resistance welding – Control Processes – Sequence timer – Synchronous Welding control – Temperature control circuits.

UNIT V

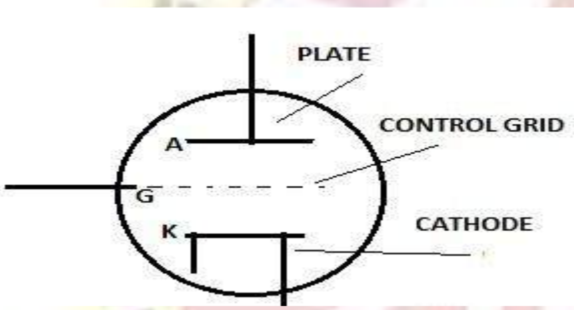
APPLICATIONS IN INDUSTRY – Relays and their characteristics and applications – Generation , Detection and Application of Ultrasonic's Application of LASER in industry.

UNIT I

INDUSTRIAL ELECTRONIC DEVICES

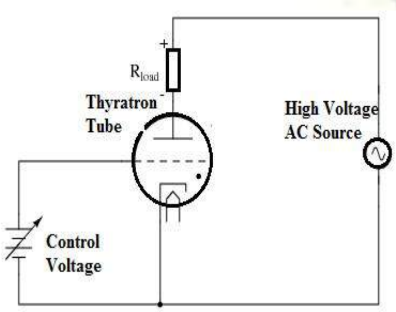
Thyratron

A thyratron is one kind of tube filled with gas and it is used like a controlled rectifier as well as a high power electrical switch. These tubes handle high currents like hard vacuum tubes. Whenever the gas within the tube becomes ionized then multiplication of electron can take place. This occurrence is called Townsend discharge. The gases used in this tube mainly include xenon, mercury vapor, neon, and hydrogen. Not like a vacuum tube, these tubes cannot be employed for amplifying the signals linearly.



Thyratron Circuit Diagram

Thyratron tube is a controlled version of the neon lamp & specially designed for providing current supply to a load. The dot symbol within the circle specifies a gas fill. In the above, the thyratron permits the flow of current throughout the load in only one direction while switched by the little DC control voltage which is connected among the grid as well as a cathode.



The source of power to load is AC, which gives a sign regarding how this tube will deactivate once it's been switched on: because AC voltage sometimes flows through a 0V condition among half-cycles, and the flow of current throughout a load which is powered by AC should also sometimes stop.

This brief flow of current among these cycles will provide the gas time of tube to cool, allowing it to go back to its regular "off" state. Transmission may start again only if sufficient voltage is applied using an **AC power** source & if the DC control voltage permits it. The load voltage in an oscilloscope display will look like the following waveform.

Thyratron Working Principle

The hydrogen thyratron works on the principle of switching which is achieved through transmitting from insulating neutral gas toward conducting ionized gas. This is an electrical switch that uses high peak power. By using this principle only thyratron tube will be designed to control at high-voltage using high crest current pulses as well as high recurrence rates.

n exclusive capability of this tube will make it the perfect switch for microwave sources like magnetrons as well as klystrons. In addition, these tubes are electrically robust.

Applications

The applications of thyratron include the following .

These tubes are high voltage and quick-acting switches. These are used in a variety of applications like laser, radar & scientific use

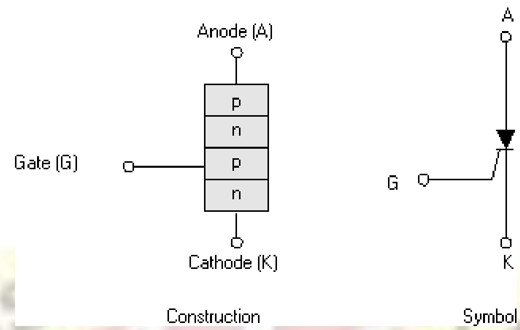
This tube is used as an electric switch.

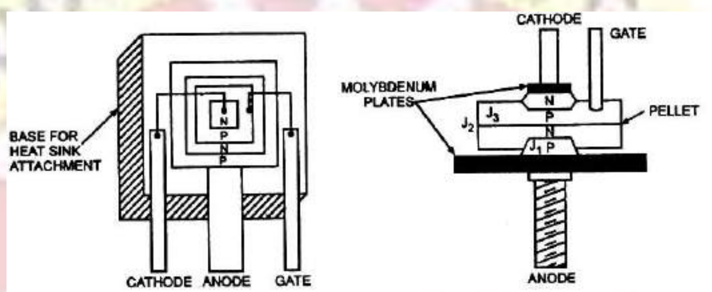
This tube is used as a grid controlled rectifier

This tube is used like a sawtooth sweep generator in TVs as well as radar equipment.

THYRISTORSILICON CONTROLLED RECTIFIER (SCR):

Construction:





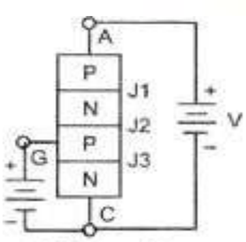
Planar Type Construction *Mesa Type Construction*

Silicon Controlled Rectifier

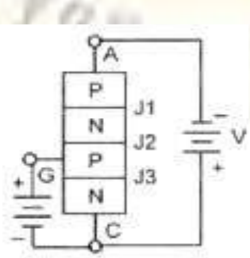
It is a four layer P-N-P-N device. It has 3 junctions. For low power SCRs, planner construction isused. This construction is used for making a number of units from a single silicon wafer. Here all thejunctionsarediffused.

For high power SCRs Mesa construction is used. Here the inner junction is obtained by diffusionandtheothertwolayersarealloyedtoit.Tohandlelargecurrents,itisbracedwithtungstenormolybdenumplates toprovide mechanicalstrength. From theseplates, heatsinks areattached.

OPERATION



(a) Forward bias



(b) Reverse bias

When gate is at zero potential:

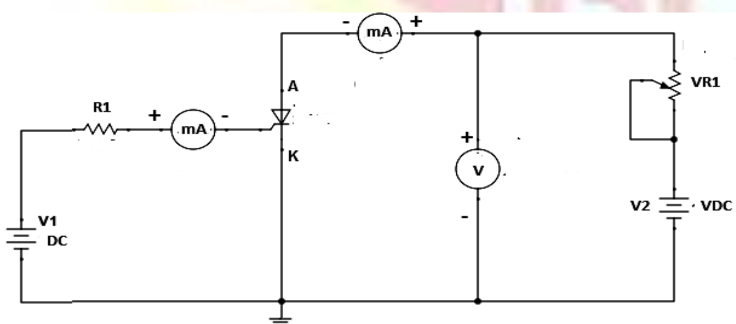
Theanodeismade+vew.r.tcathode.JunctionsJ1&J3areforwardbiasedandjunctionJ2isreverse biased. The SCR is in forward blocking state or off state. When the voltage is increased, junctionJ2 breakdown. This is the avalanche breakdown. There will be free carrier movement across all the threejunctions.So,theanodecurrentincreases.Thevoltagedropacrossthedevicewillbetheohmicdropin the four layers. The device is now in the conducting state (or) ON state. The voltage at which junctions J2breaksdown is called forward breakover voltageV_B.

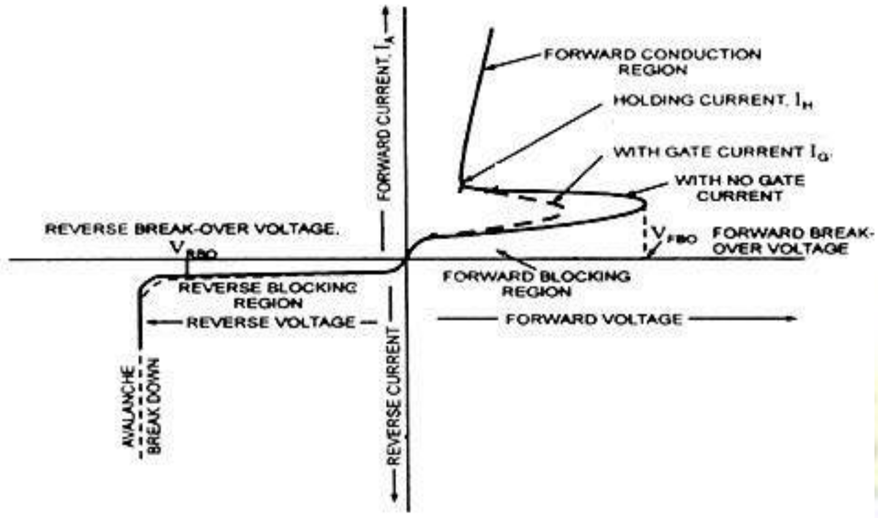
When the anode is made –ve w.r.t cathode, j1&j3 are reverse biased and j2 is forward biased. Asmallreverseleakagecurrentwillflow.Thisisthereverseblockingstate.Whenthevoltageisincreased,atsomevoltagejunctionsj1&j3willbreakdown.ThisvoltageiscalledreversebreakdownvoltageV$_{BR}$.Heavycurrent flow throughthedevice.

When gateis atpositive potential:

When gate is given +ve potential, the reverse leakage current through junction j2 is increased.Because the gate current consist mainly of e^{-n}flow from the cathode to gate. These e^{-ns}reach regionnearer to j2 and add to the minority carrier concentration in the layer. This leads to the breakdown eventhough the applied forward voltage islower than V$_{BO}$. Thus the gate provides a very convenient methodfor switching the device from OFF to ON, with low anode-to- cathode voltages. Once the device becomeson,the anodecurrent is limited onlybythe external impedance. The gate lossesits control.

Characteristics:





V-I Characteristics of SCR

Region OA:forwardblockingstate.Smallleakage currentflows

AB:conductionregion

OC:reverseblockingstate.

CD:breakdownregion

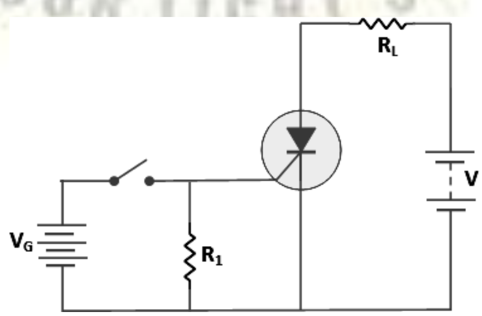
I_h:Holdingcurrent:when theanodecurrent falls below this current, thedevices goes to offstate.

I_L:latchingcurrent: theforward current requiredtoswitch on theSCR from offstate.

Comparison betweenSCRandBJT:

S.No	SCR	BJT
1	4Layerdevice	3layerdevice
2	Highvoltage andhighcurrentdevice	Lowvoltageandhighcurrent device
3	Lesstemperaturesensitive	Moretemperaturesensitive
4	Usedasa controlledrectifier	Usedasan amplifier

SCRAS A SWITCH:



The SCR has only two states namely ON state and OFF state. When proper gate current is passed,the SCR starts conducting heavily and becomes ON. This corresponds to the ON condition. When theanode current is reduced below the holding current, the SCR is turned OFF. This is the OFF state. Theseoperationsareverysimilar to that of mechanical switch.

Advantages:

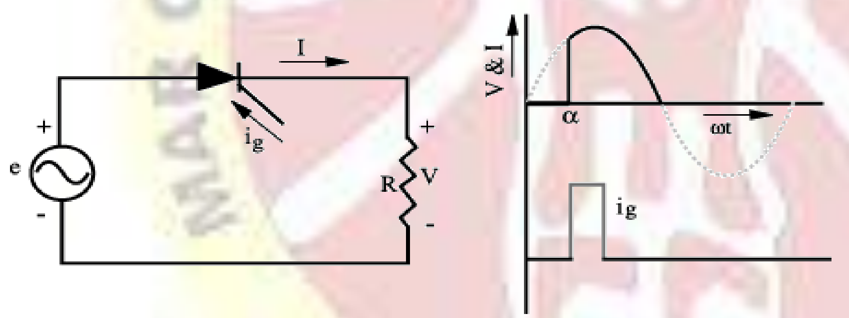
It givesnoiselessoperation.

Switchingspeedis high(upto 10^9 operations persecond).

Smallsize.

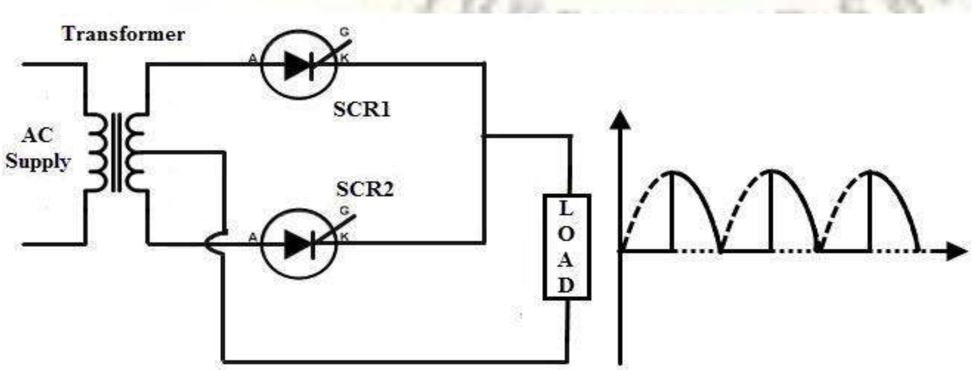
SCRASHALFWAVE CONTROLLEDRECTIFIER:

Duringthepositivehalfcycleofi/pACvoltage,theSCRwillconductbygivingpropergatecurrent.WhenSCRbecomesONitconductsthroughoutthepositivehalfcycle.WhentheACvoltage becomes 0, it stops conducting. During the negative half cycle of the AC, SCR does not conduct. The SCRalso block the part of the positive I/p up to a point where SCR is triggered ON. So by proper gate current,the SCR can be made to conduct full or part of positive half cycle. Thus the power fed to the load iscontrolled.



(a) SCR Half-wave Rectifier (b) Waveform & Trigger Pulse

SCRASFULLWAVE CONTROLLEDRECTIFIER:



During the positive half cycle of the i/p, anode of SCR1 is positive and that of SCR2 is negative.When the i/p reaches V1, SCR1 becomes on. During this period SCR2 is in OFF condition. During thenegativehalfcycleofthei/p,anodeofSCR2ispositiveandthatofSCR1isnegative.Whenthei/preaches V1, SCR2 becomes on. During this period SCR1 is in OFF condition. Thus by changing the gatecurrent,theconduction can bechanged.

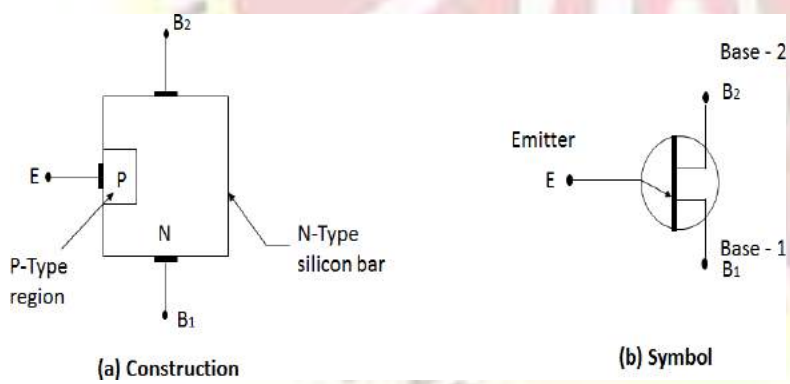
Firing angle:The angle at which the SCR starts conducting during the positive half cycle is called firingangle.

Conductionangle:Theanglethroughwhichthe SCRisconductingiscalledconductionangle.

Conductionangle =(180–Firingangle).

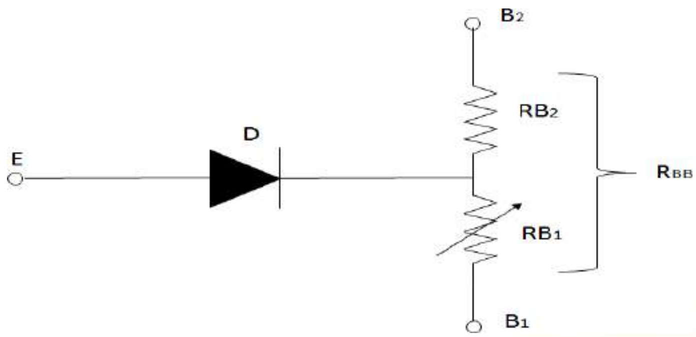
UNIJUNCTION TRANSISTOR (UJT):

UJT is a three terminal semi-conductor switching device. It has only one PN junction. The basicstructure and symbol of UJT is shown in fig. It consists a lightly doped N-type silicon bar with a heavilydoped P-type material is diffused into the bar, forms a PN junction. The ohmic contacts are provided at theends emitter(E). Two ohmic contacts are provided at the ends of N-type silicon bar called base-1 (B_1) andbase-2(B_2). TheresistancebetweenBandBis called interbaseresistance.



Equivalent circuit of UJT:

TheequivalentcircuitofUJTisshowninthefig.ThediodeDrepresentsthePNjunction.According to the emitter terminal,interbase resistance (R) is separated into two resistances, R_{B1} andR_{B2}.Hence R_{BB} =R_{B1}+R_{B2}. The resistance R_{B1} is variable, because its value can be varied, according to thebiasvoltagebetween P and N junction.



Fromtheequivalentcircuit,

R_{B1}T

Thevoltageacross theresistor $RB_1=V_1$ =---------------- x V_{BB}

$R_{B1}+R_{B2}$

$R_{B1}=$ xV_{BB}

R_{BB}

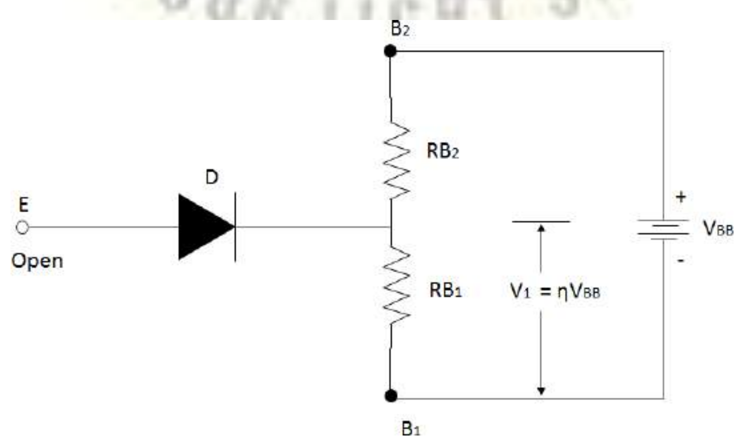
$V_1=\eta V_{BB}$ $(\eta=R_{B1}/R_{BB})$

Where,ηis knownasintrinsic standoffratio. Thevalue ofηvariesbetween0.51 to 0.82.

UJTOPERATION:

The biasing arrangement of UJT is shown in the fig. The terminal B_2 is always positive voltage(V_{BB}) with respect to B_1. Usually a positive voltage (V_{EE}) is applied to the terminal E with respect to B_1.Theopratingcondition of UJT depends upontheiremittervoltage(V_{EE}).

According to the base voltage V_{BB}, voltage V_1 is always developed across the resistor R_{B1} and,which is applied to the cathode terminal of the PN junction diode (in equivalent circuit). When the emittervoltage is zero, the diode works in reverse bias, so no emitter current flows. Now theUJT is in



OFF state.Nowasmall leakagecurrent onlyflowsfrom $B_2$to E

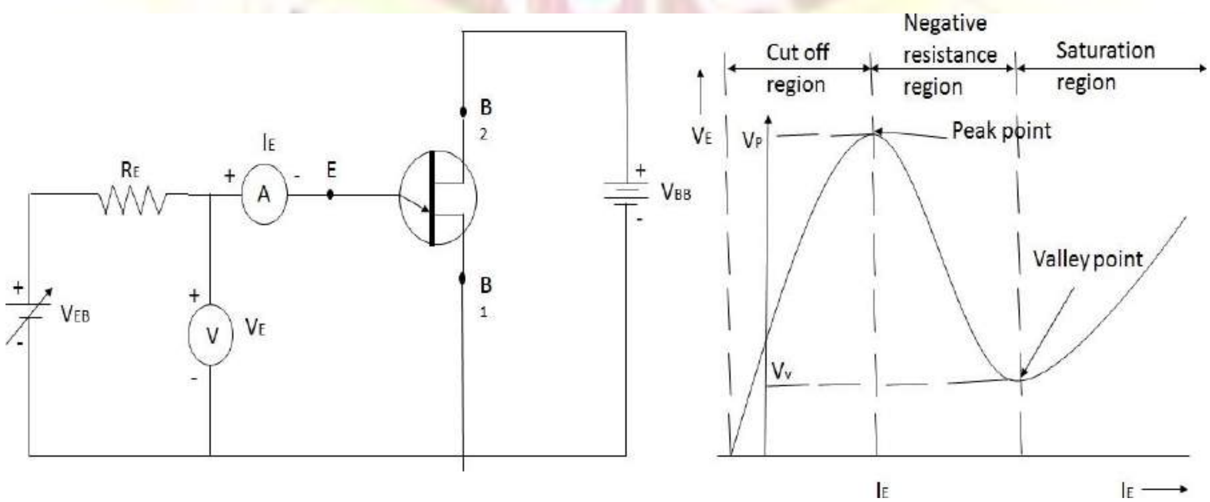
When a positive voltage is applied to the emitter, the PN junction is also in reverse biased.If theemitter voltage is linearly increased, which reduces the amount of reverse bias of the PN junction?Whenthe applied voltage is increased greater than V_1, the PN junction will be forward biased. Now the holes areinjectedfromP-regionintoN-region.TheholesarerepelledbytheterminalB$_2$andareattractedbythe terminal B_1. Now the accumulation of holes in E to B_1 region reduces the resistance in this section. Henceemittercurrent $I_E$isincreasedandthevoltage$V_E$isdecreased.Nowthedeviceisinthe„ON‟state.

When a negative voltage is applied to the emitter (E), the PN junction is reverse biased, and theemittercurrentisverylow.Thedeviceisnowin„OFF‟ state.

Characteristicsof UJT:

The circuit diagram for finding the emitter characteristics of UJT is shown in the fig. The curveplottedbetweenemittervoltage(V_{EE})andtheemittercurrent(I_E)atagivenV_{BB}iscalledemittercharacteris ticsofUJT

Here up to the peak point, the diode is reverse biased. Hence the region to the left of the peak pointis called cut-off region. The UJT has a stable firing voltage (peak voltage) which depends on V_{BB}. Afterthe firing voltage, the diode starts conduction. Now the current I_E is linearly increased and V_E is linearlydecreased, which produce a negative resistance region. This region lies in between peak point and valleypoint. After the valley point, current becomes saturation. The region beyond the valley point is calledsaturationregion.InthisregiontheUJTisin„ON‟state.



Applications:

Itis usedin timingcircuits

Itisusedin phasecontrolcircuits

ItisusedintriggerSCR"sandTRIAC"s

Itisusedinpulse generator

Itisusedinsawtoothgenerator

Itisused inswitchingcircuits.

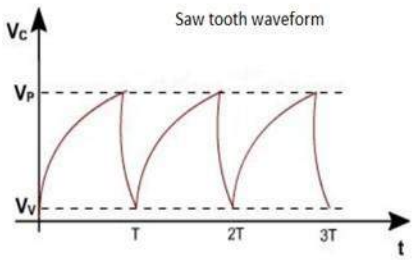
UJTas a Relaxation Oscillator

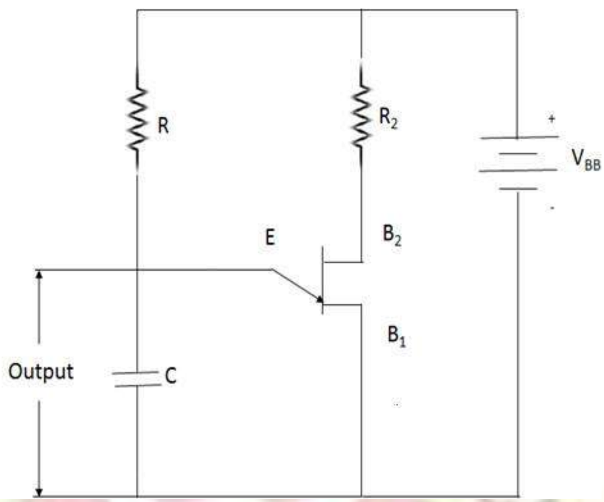
Unijunction transistor can be used to generate saw tooth signal. In sawtooth signal, the voltageincreases slowly and falls down to zero in short time. The circuit diagram and waveform of UJT relaxationoscillatoris shown in fig

A capacitor C is connected in between the terminals E and B_1. This capacitor voltage is used totrigger the UJT, and also acts as the output signal of the relaxation oscillator. The charges of the capacitordepend upon the conduction level of UJT. Before conduction, the capacitor charges through R_1, and thenafter conduction the capacitordischargesthrough theemitter tobase1 (B_1)path ofUJT.

When the supply voltage is given, the capacitor charges through R_1. As long as the capacitorvoltage is less than the base1 to emitter voltage V_{EB1}, thejunction is reverse biased and the UJT will notconduct. When the capacitor (output) voltage exceeds the reverse biased voltage (V_{EB1}), the UJT startsconducting.

During conduction, the resistance between emitter and base 1 falls to a lower value. Hence thecapacitor discharges the voltage in a low time, and the UJT again goes to non-conduction level. Thecapacitorrepeatsthechargeanddischargesfunctionscontinuously.Bythiscumulativeaction,acontinuous sawtooth signal is produced at its output.





Applications:

UsedinTelevision

UsedinRadarequipment

UsedinOscilloscope

Over Voltage Protection

Over voltage protection is a power supply feature which shuts down the supply, or clamps the output, when the voltage exceeds a preset level.

Most power supplies use an over-voltage protection circuit to prevent damage to the electronic components. The impact of an over-voltage condition varies from one circuit to the other and ranges from damaging the components to degrading the components and causing circuit malfunctions or fire.

An over-voltage condition might occur in the power supply due faults inside the supply, or from external causessuch as those in the distribution lines.

The magnitude and duration of the over-voltage are some of the major considerations when designing an effective protection. The protection involves setting a threshold voltage above which the control circuit shuts down the supply or diverts the extra voltage to other parts of the circuit such as capacitor.

Ideal characteristics of an over voltage protection circuit

Prevent the excess voltage from being applied to the components.

The protection circuit should not interfere with the normal function of the system or circuit. The protection circuit should not load the power supply and cause related voltage drops.

The protection circuit should be able to distinguish between normal voltage fluctuations and harmful over-voltage.

Be fast enough to respond to transient events that can damage the power supply and downstream components.

The OVP method should not to have false trips or undetected real over-voltage conditions. This can be a nuisance in the case of false trips and also dangerous if it is unable to see the real over-voltage conditions.

The over voltage protection circuit may be constructed using discrete components, integrated circuits, mechanical devices such as relays, etc. These can either connected internally or externally depending on the circuits involved.

There are various protection circuit designs, each with its merits, mode of operation, sensitivity, ability, and reliability. The protection can either clamp off the excess voltage, or completely shut down the power supply.

A crowbar over-voltage protection circuit

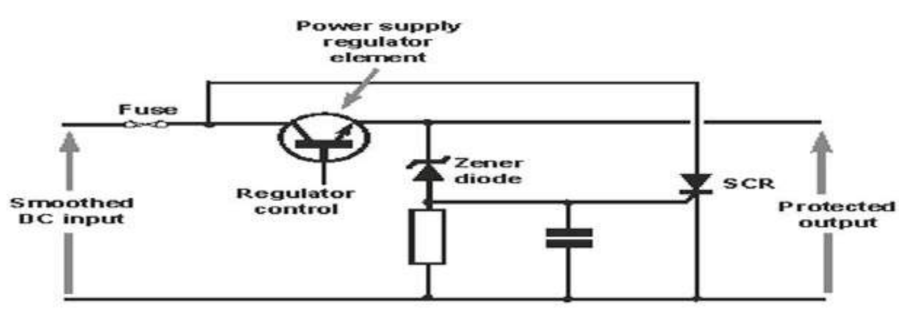
A crowbar circuit provides one of the simplest, cheap and effective over-voltage protection methods. This is usually connected between the regulated output and the protected circuit or load. The series regulating transistor controls the output current and voltage while the crowbar consists protects the load when the voltage exceeds a preset value. A basic circuit consists of:

Silicon controlled rectifier (SCR)

Zener diode

Resistor

Capacitor



Over-voltage protection crowbar circuit

During the normal operation, the zener diode is reverse biased and does not conduct, all the current through the series transistor appears at the output. Once the voltage rises and goes beyond the zener breakdown voltage, the diode breaks down and starts conducting. The current develops a voltage across the resistor which then triggers the SCR. This places a short circuit across the output and all the current is sank into the ground. This caused the fuse to open and removes the voltage from the series transistor and the protected circuit.

The zener diode selected must be slightly above the output voltage. The capacitor prevents the triggering of the SCR by short spikes.

The simple circuit is widely used due to its effectiveness; however it has some limitations, such as Zener diode being not adjustable while the best tolerance for the diode is 5%.

The SCR firing voltage must also be designed to be far above the power supply's output voltage to prevent erroneous firing by short spikes such as those generated when powering

Static Circuit Breakers.

The static circuit breaker is basically semiconductor-based circuit. This circuit breaker is capable of providing a fast and also a reliable interruption current.

The static circuit breaker is of two types :

Static AC circuit breaker

Static DC circuit breaker

Here this article gives information about two circuit breaker to know more details about circuit breaker.

Static AC circuit breaker :

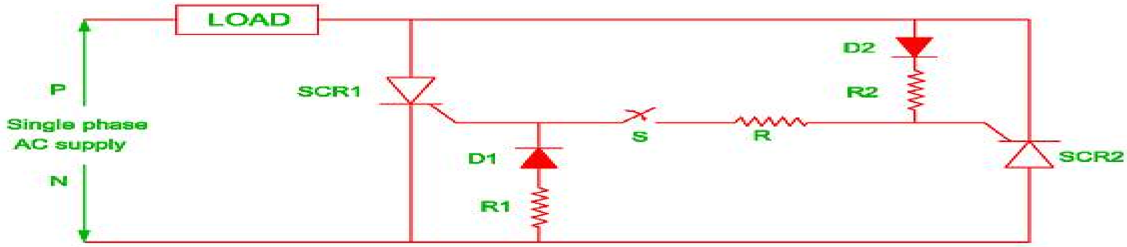
A simple arrangement of static ac circuit breaker shown in the figure. The circuit can switch on and switch off by using two thyristors SCR 1 and SCR 2.

When thyristor SCR 1 is turn on a positive cycle alternative supply when the switch is on condition.

When SCR 1 is off, the current becomes automatically zero.

When SCR 2 turn on the negative cycle of alternative supply.

SCR 1 receives the gate pulse through the diode D2 and SCR 1 receives the gate pulse through the diode D1.



Static DC circuit breaker :

A simple arrangement of static dc circuit breaker shown in the figure given below. Force commutation is essential for turning off a thyristor device.

When SCR1 turn on, load voltage becomes equal to supply voltage and capacitor get charge through the circuit source voltage Vs, resistor R, capacitor C and SCR 1.

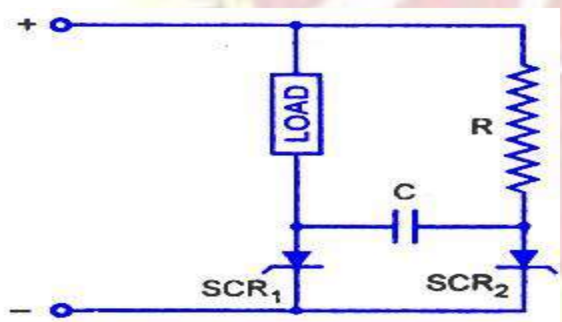
When breaking the circuit, SCR 2 is turned on.

SCR 2 turn on and SCR 1 turn off due to reverse voltage across it.

The capacitor again charge +Vs to -Vs through the circuit Vs, load C and SCR 2.

When capacitor C is totally charged to -Vs, a current through load will be zero and the same time current through R will less than the holding current of SCR 2.

At that time SCR 2 will get turn off naturally, from this the value R can be determined



UNIT II **POWER SUPPLIERS –**

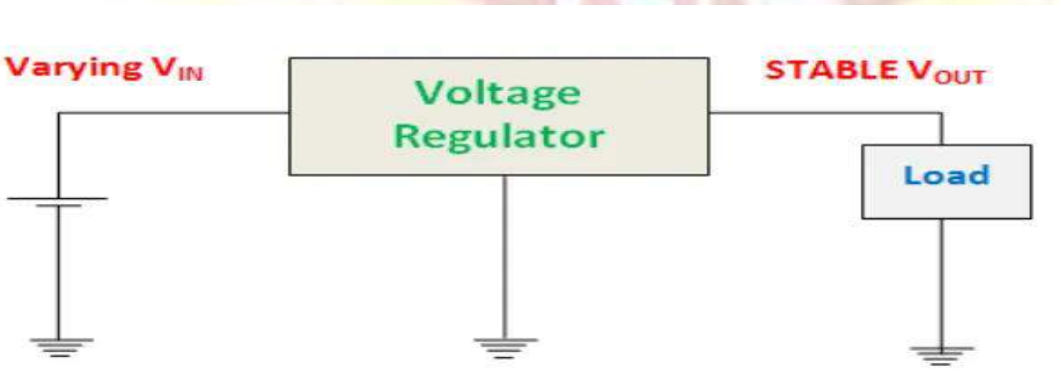
A voltage regulator is a circuit that creates and maintains a fixed output voltage, irrespective of changes to the input voltage or load conditions.

A voltage regulator is an electronic or electrical device that can sustain the voltage of power supply within suitable limits. The electrical equipment connected to the voltage source should bear the value of the voltage. The source voltage should be in a certain range which is acceptable for the connected pieces of equipment. This purpose is fulfilled by implementing a voltage regulator.

A voltage regulator – as the same suggests – regulates the voltage, regardless of the adjustments in the input voltage or connected load. It works as a shield for protective devices from damage. It can regulate both AC or DC voltages, depending on its design

There are a number of terms that are used to describe the performance of any regulator. .

Parameter	Explanation
Load Regulation	A percentage, being the change of voltage for a given change of output current
Line Regulation	A percentage. being the change in output voltage for a given change of input voltage
Dropout Voltage	The minimum voltage differential between input and output before the regulator can no longer maintain acceptable performance
Maximum Input Voltage	The absolute maximum voltage that may be applied to the regulator's input terminal with respect to ground
Ripple Rejection	Expressed in dB, the ratio of input ripple (from the unregulated DC supply) to output ripple
Noise	Where quoted, the amount of random (thermal) noise present on the regulated output DC voltage
Transient Response	Usually shown graphically, shows the instantaneous performance with changes in line voltage or load current



There are two main types of voltage regulators available:

Linear Voltage Regulators

Switching Voltage Regulators

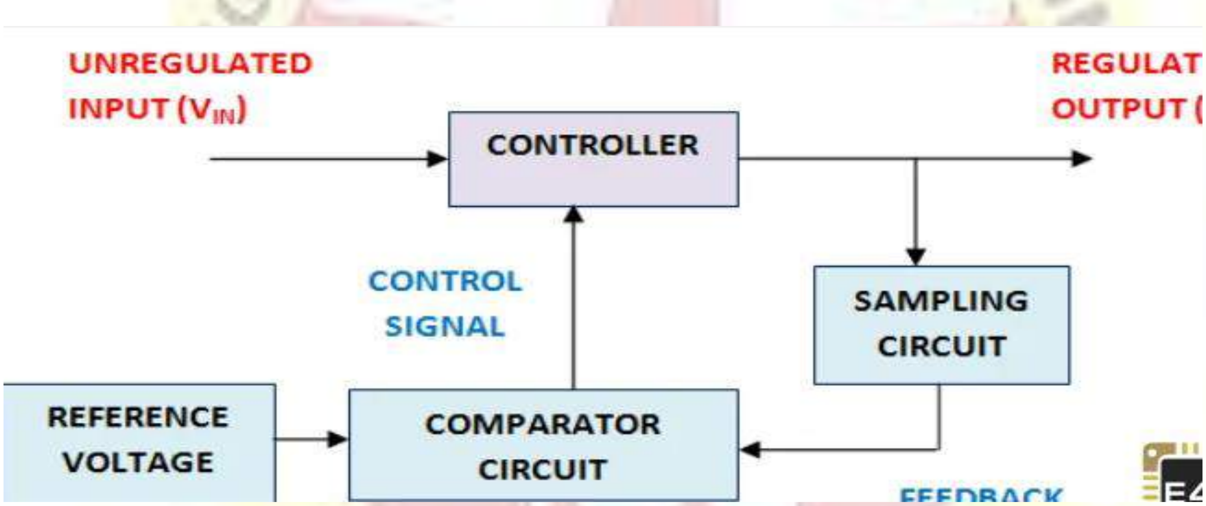
This type of voltage regulator performs as a **voltage divider**. It employs **FET** in Ohmic region. The steady output is sustained by varying the **resistance** of voltage regulator with respect to the load. Generally, these types of voltage regulator are of two types:

Series voltage regulator

Shunt voltage regulator

Discrete Transistor Series Voltage Regulator

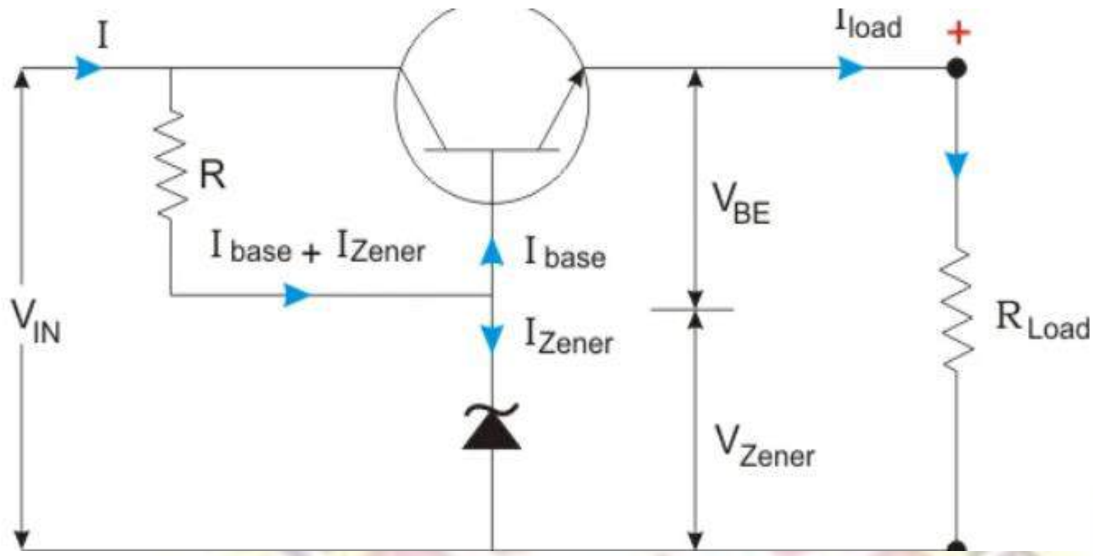
Here from the block diagram, we can see an unregulated input is first fed into a controller. It actually controls the input voltage magnitude and given to the output. This output is given to the feedback circuit. It is sampled by the sampling circuit and given to the comparator. There it is compared by the reference voltage and given back to the output.



Zener Diode as Voltage Regulator

When a **Zener diode** is used as a voltage regulator, it is known as a Zener controlled transistor series voltage regulator or an emitter follower voltage regulator. Here, the **transistor** used is emitter follower (see figure below). The emitter and the collector terminals of the series pass transistor used here are in series with respect to load. The variable element is a transistor and the Zener diode will supply the reference voltage.

$$V_{OUT} = V_{Zener} + V_{BE}$$



Discrete Transistor Shunt Voltage Regulator

Here, the current is shunted away from the load. The **controller** will shunt a portion of the total current that is developed by the unregulated input which is given to the load. The voltage regulation takes place across the load.

Here, the comparator circuit will give a control signal to the controller whenever there is an increase or decrease in the output voltage because of the variation in load. Thus, the controller will shunt the extra current from the load so as to get a sustained voltage as the output.

Zener Controlled Transistor Shunt Voltage Regulator

Here, the unregulated voltage is directly proportional to the voltage drop occurs in the series resistance. This voltage drop is related to the current given to the load. The output voltage is related to the transistor base emitter voltage (V_{BE}) and the Zener diode.

Zener Controlled Transistor Shunt Voltage Regulator

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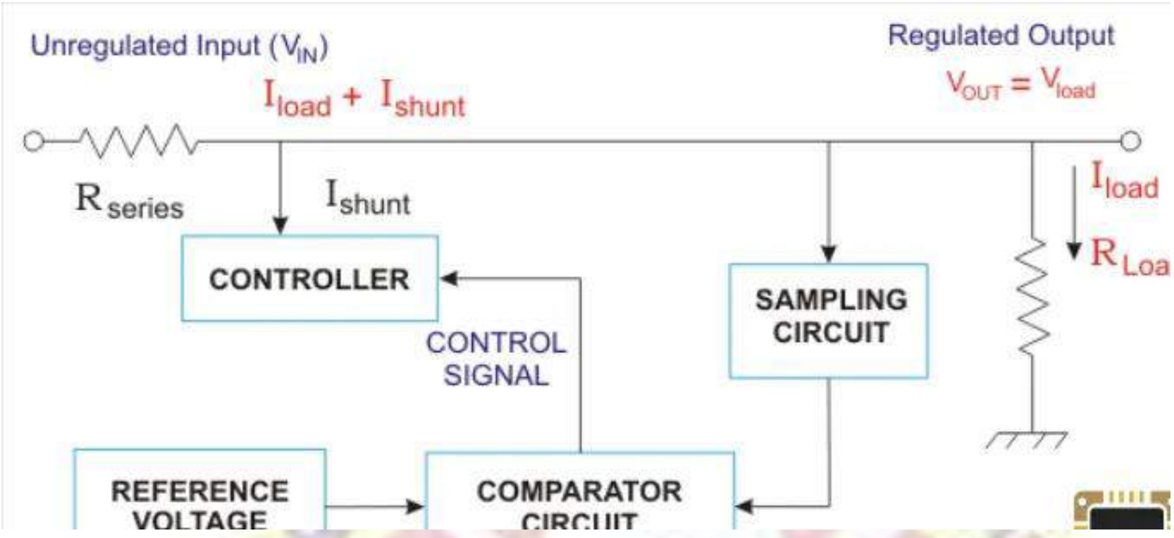
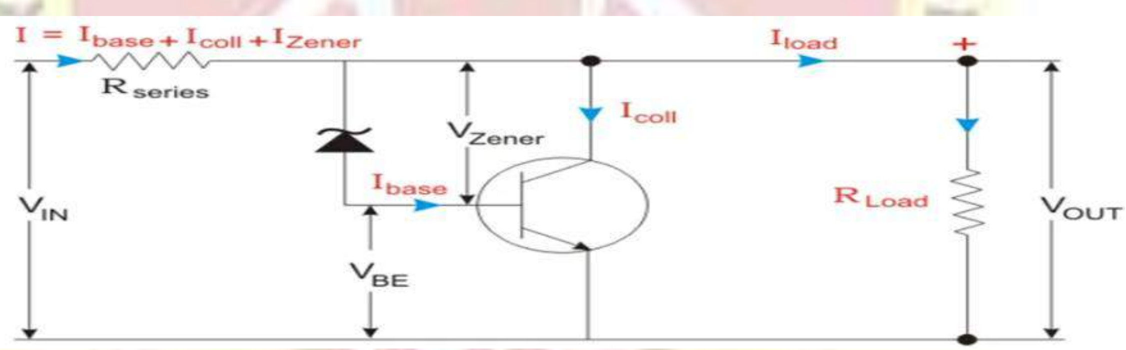


Zener Controlled Transistor Shunt Voltage Regulator

Here, the unregulated voltage is directly proportional to the voltage drop occurs in the series resistance. This voltage drop is related to the current given to the load. The output voltage is related to the transistor base emitter voltage (V_{BE}) and the Zener diode.

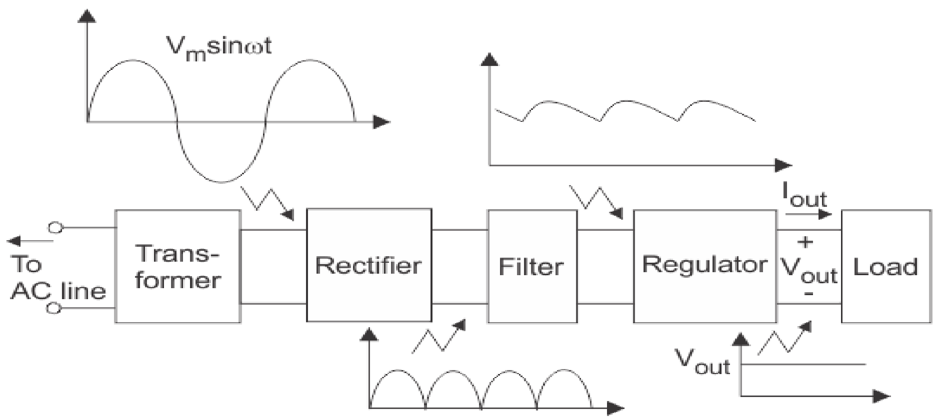
$$V_{OUT} = V_{Zener} + V_{BE} = V_{IN} - I \times R_{series}$$



REGULATED POWER SUPPLY

A regulated power supply converts unregulated AC (Alternating Current) to a constant DC (Direct Current). A regulated power supply is used to ensure that the output remains constant even if the input changes.

A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks. The regulated power supply will accept an AC input and give a constant DC output. The figure below shows the block diagram of a typical regulated DC power supply.



Components of typical linear power supply

The basic building blocks of a regulated DC power supply are as follows:

A step-down transformer

A rectifier

A DC filter

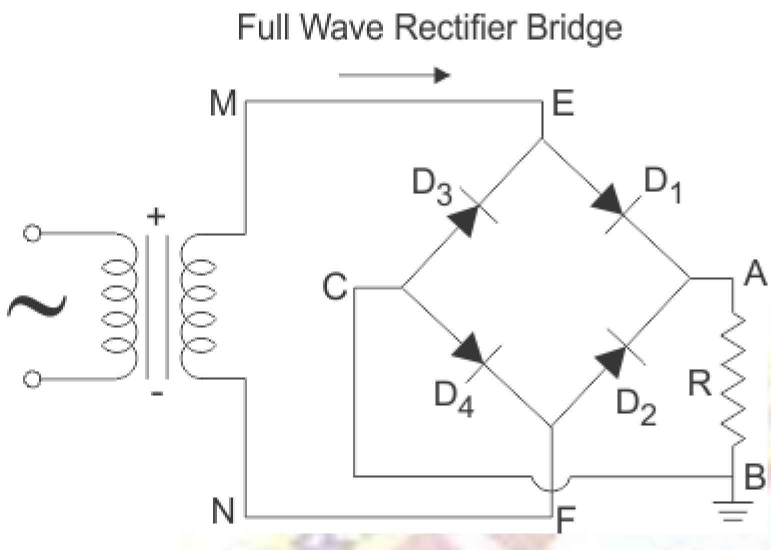
A regulator

A step down transformer will step down the voltage from the ac mains to the required voltage level. The turn's ratio of the transformer is so adjusted such as to obtain the required voltage value. The output of the transformer is given as an input to the rectifier circuit.

Rectification

Rectifier is an electronic circuit consisting of diodes which carries out the rectification process. Rectification is the process of converting an alternating voltage or current into corresponding direct (DC) quantity. The input to a rectifier is AC whereas its output is unidirectional pulsating DC.

Although a half wave rectifier could technically be used, its power losses are significant compared to a full wave rectifier. As such, a full wave rectifier or a bridge rectifier is used to rectify both the half cycles of the ac supply (full wave rectification). The figure below shows a full wave bridge rectifier.

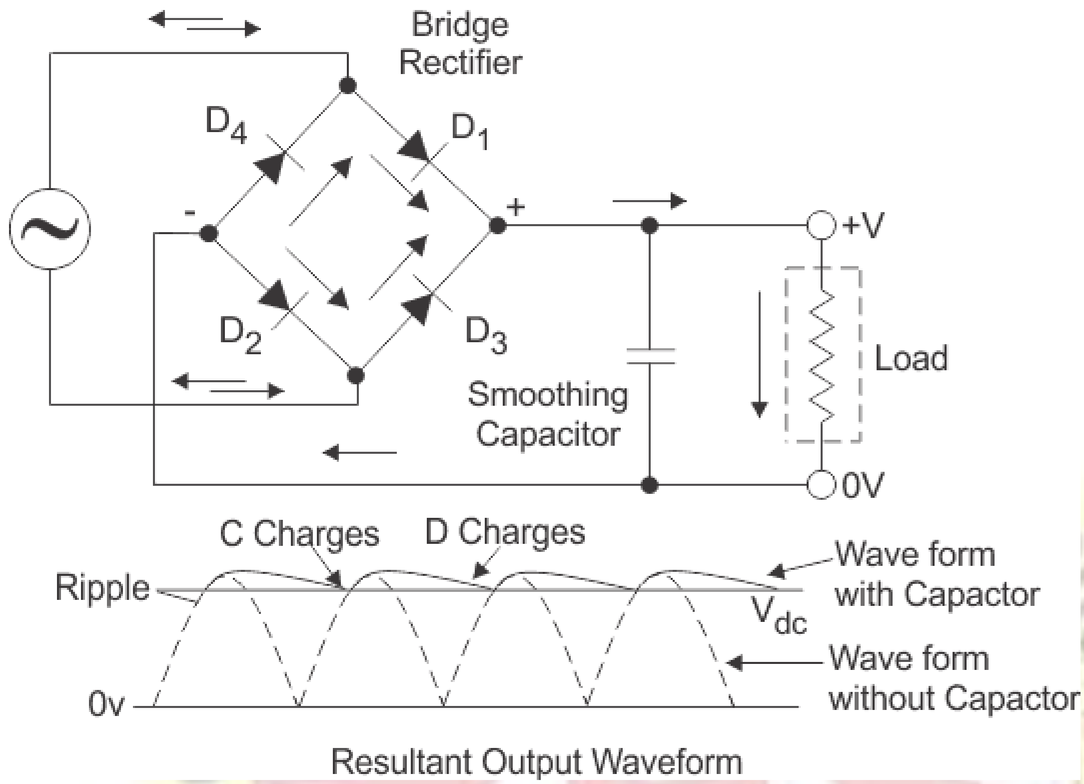


A bridge rectifier consists of four p-n junction diodes connected in the manner shown above. In the positive half cycle of the supply, the voltage induced across the secondary of the electrical transformer i.e. VMN is positive. Therefore point E is positive with respect to F. Hence, diodes D_3 and D_2 are reversed biased and diodes D_1 and D_4 are forward biased. The diode D_3 and D_2 will act as open switches (practically there is some voltage drop) and diodes D_1 andD_4 will act as closed switches and will start conducting. Hence a rectified waveform appears at the output of the rectifier as shown in the first figure. When voltage induced in secondary i.e. VMN is negative than D_3 and D_2 are forward biased with the other two reversed biased and a positive voltage appears at the input of the filter.

DC Filtration

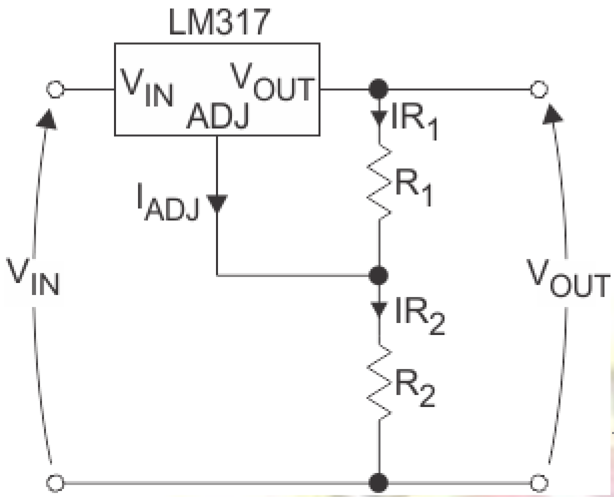
The rectified voltage from the rectifier is a pulsating DC voltage having very high ripple content. But this is not we want, we want a pure ripple free DC waveform. Hence a filter is used. Different types of filters are used such as capacitor filter, LC filter, Choke input filter, π type filter. The figure below shows a capacitor filter connected along the output of the rectifier and the resultant output waveform.

As the instantaneous voltage starts increasing the capacitor charges, it charges until the waveform reaches its peak value. When the instantaneous value starts reducing the capacitor starts discharging exponentially and slowly through the load (input of the regulator in this case). Hence, an almost constant DC value having very less ripple content is obtained.

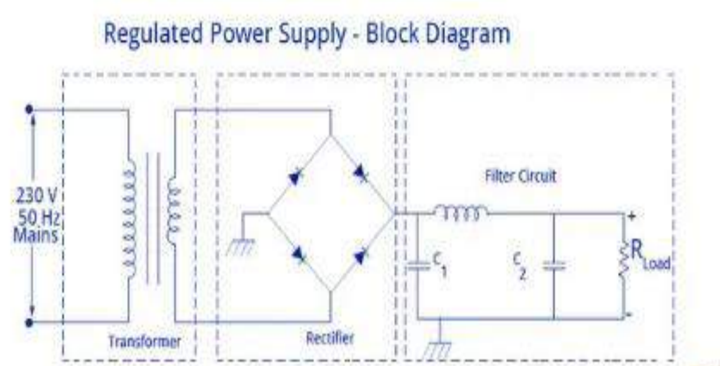


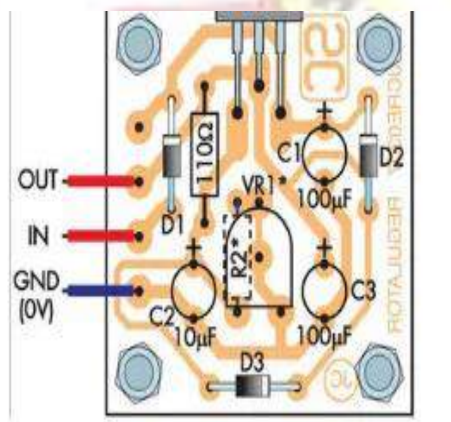
This is the last block in a regulated DC power supply. The output voltage or current will change or fluctuate when there is a change in the input from ac mains or due to change in load current at the output of the regulated power supply or due to other factors like temperature changes. This problem can be eliminated by using a regulator. A regulator will maintain the output constant even when changes at the input or any other changes occur. Transistor series regulator, Fixed and variable IC regulators or a zener diode operated in the zener region can be used depending on their applications. IC's like 78XX and 79XX (such as the IC 7805) are used to obtained fixed values of voltages at the output.

With IC's like LM 317 and 723, we can adjust the output voltage to a required constant value. The figure below shows the LM317 voltage regulator. The output voltage can be adjusted by adjusting the values of resistances R_1 and R_2. Usually, coupling capacitors of values about 0.01µF to 10µF need to be connected at the output and input to address input noise and output transients. Ideally, the output voltage is given by



$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$





The source or Line regulation is defined as the change in regulated output voltage for a specified rage of lie voltage.

$$\textbf{Line regulation} = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}}\right)100\%$$

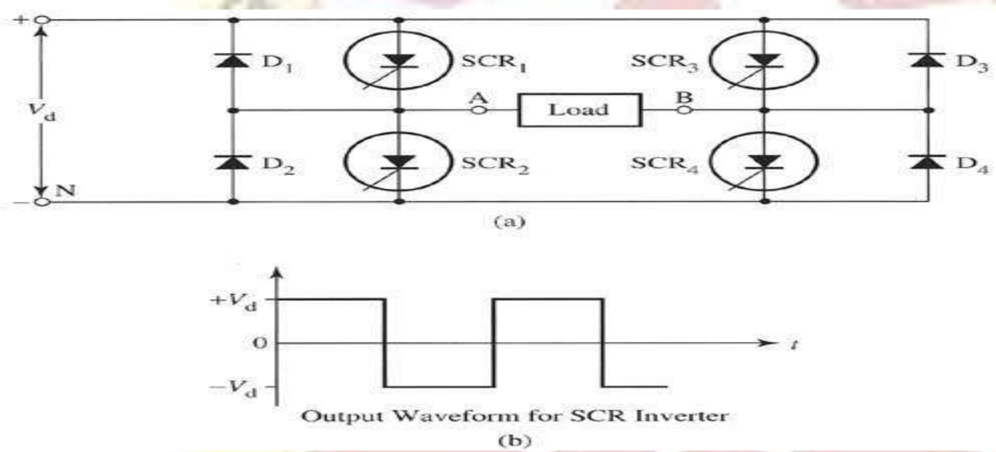
$$\textbf{Line regulation} = \frac{(\Delta V_{OUT}/V_{OUT})100\%}{\Delta V_{IN}}$$

The load regulation or load effect is the change in regulated output voltage when the load current changes from minimum to maximum value.

$$\text{Load regulation} = \left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right)100\%$$

CONTROLLED INVERTERS

The simplest inverter to understand is the single-phase inverter, which takes a dc input voltage and converts it to single-phase ac voltage. The main components of the inverter can be either four **silicon controlled rectifiers (SCRs)** or four transistors. Fig. 1 shows a typical inverter circuit that uses four SCRs, and Fig. 2 shows a typical inverter circuit that uses four transistors. Originally called a dc-link converter, now it's simply called an inverter.

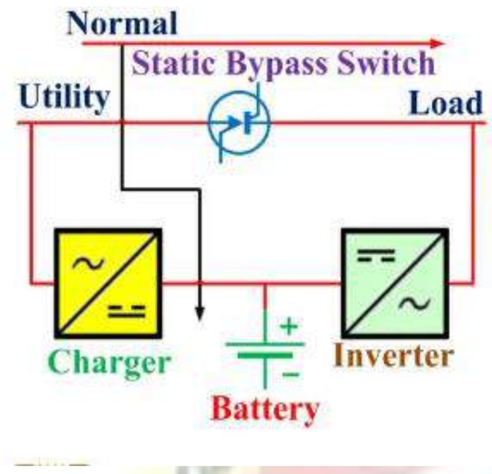


Above: Fig. 1 (a) Electrical schematic of a typical inverter circuit that uses four silicon controlled rectifiers (SCRs). (b) Output waveform for SCR inverter.

In this circuit SCR1, and SCR4 are fired into conduction at the same time to provide the positive part of the ac waveform and SCR2 and SCR3 are fired into conduction at the same time to provide the negative part of the ac waveform. The waveform for the ac output voltage is shown in this figure -- notice that it's an ac square wave. A phase-angle control circuit is used to determine the firing angle, which provides the timing for turning each SCR on so that they provide the ac square wave. The load is attached to the two terminals where the ac square wave voltage is supplied.

Uninterruptible Power Supply | UPS

An Uninterruptible Power Supply (UPS) is defined as a piece of electrical equipment which can be used as an immediate power source to the connected load when there is any failure in the main input power source.



In a UPS, the energy is generally stored in flywheels, batteries, or super capacitors. When compared to other immediate power supply system, UPS have the advantage of immediate protection against the input power interruptions. It has very short on-battery run time; however this time is enough to safely shut down the connected apparatus (computers, telecommunication equipment etc) or to switch on a standby power source.

UPS can be used as a protective device for some hardware which can cause serious damage or loss with a sudden power disruption. Uninterruptible power source, Battery backup and Flywheel back up are the other names often used for UPS. The available size of UPS units ranges from 200 VA which is used for a solo computer to several large units up to 46 MVA.

Major Roles of UPS

When there is any failure in main power source, the UPS will supply the power for a short time. This is the prime role of UPS. In addition to that, it can also able to correct some general power problems related to utility services in varying degrees. The problems that can be corrected are voltage spike (sustained over voltage), Noise, Quick reduction in input voltage, Harmonic distortion and the instability of frequency in mains.

Types of UPS

Generally, the UPS system is categorised into On-line UPS, Off- line UPS and Line interactive UPS. Other designs include Standby on-line hybrid, Standby-Ferro, Delta conversion On-Line.

Off-line UPS

This UPS is also called as Standby UPS system which can give only the most basic features. Here, the primary source is the filtered AC mains (shown in solid path in figure 1). When the power breakage occurs, the transfer switch will select the backup source (shown in dashed path in figure 1). Thus we can clearly see that the stand by system will start working only when there is any failure in mains. In this system, the AC voltage is first rectified and stored in the storage battery connected to the rectifier.

When power breakage occurs, this DC voltage is converted to AC voltage by means of a power inverter, and is transferred to the load connected to it. This is the least expensive UPS system and it provides surge protection in addition to back up. The transfer time can be about 25 milliseconds which can be related to the time taken by the UPS system to detect the utility voltage that is lost. The block diagram is shown below.

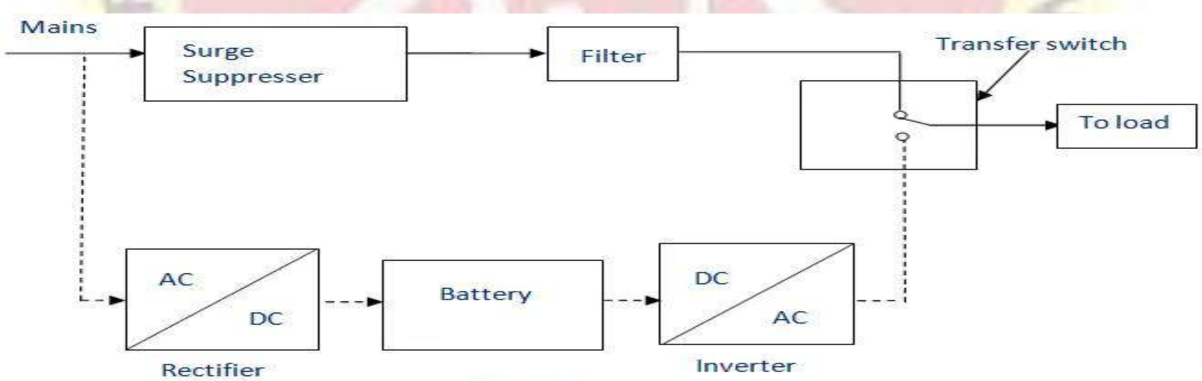


Figure 1

On-line UPS

In this type of UPS, double conversion method is used. Here, first the AC input is converted into DC by rectifying process for storing it in the rechargeable battery. This DC is converted into AC by the process of inversion and given to the load or equipment which it is connected (figure 2). This type of UPS is used where electrical isolation is mandatory. This system is a bit more costly due to the design of constantly running converters and cooling systems. Here, the rectifier which is powered with the normal AC [current](#) is directly driving the inverter. Hence it is also known as Double conversion UPS. The block diagram is shown below.

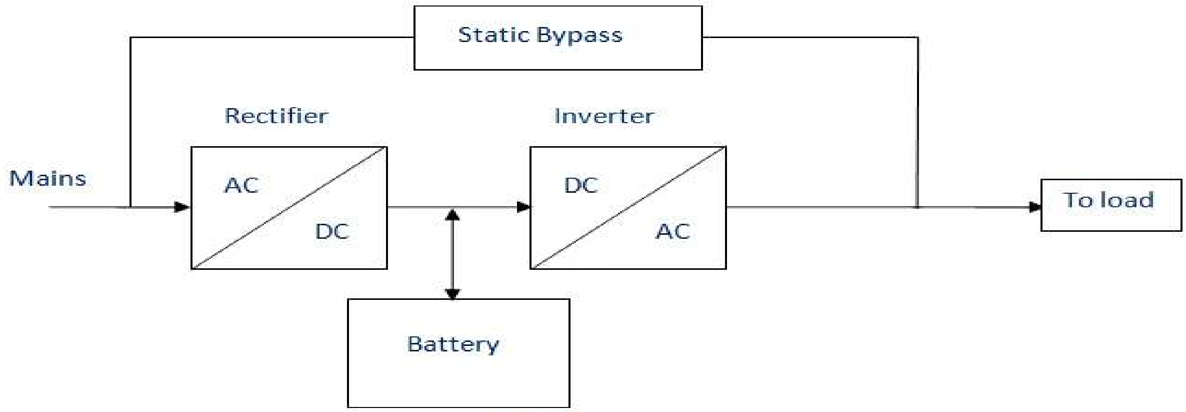


Figure 2

When there is any power failure, the rectifier have no role in the circuit and the steady power stored in the batteries which is connected to the inverter is given to the load by means of transfer switch. Once the power is restored, the rectifier begins to charge the batteries. To prevent the batteries from overheating due to the high power rectifier, the charging current is limited. During a main power breakdown, this UPS system operates with zero transfer time. The reason is that the backup source acts as a primary source and not the main AC input. But the presence of inrush current and large load step current can result in a transfer time of about 4-6 milliseconds in this system.

Line Interactive UPS

For small business and departmental servers and webs, line interactive UPS is used. This is more or less same as that of off-line UPS. The difference is the addition of tap changing transformer. Voltage regulation is done by this tap-changing transformer by changing the tap depending on input voltage. Additional filtering is provided in this UPS result in lower transient loss. The block diagram is shown below

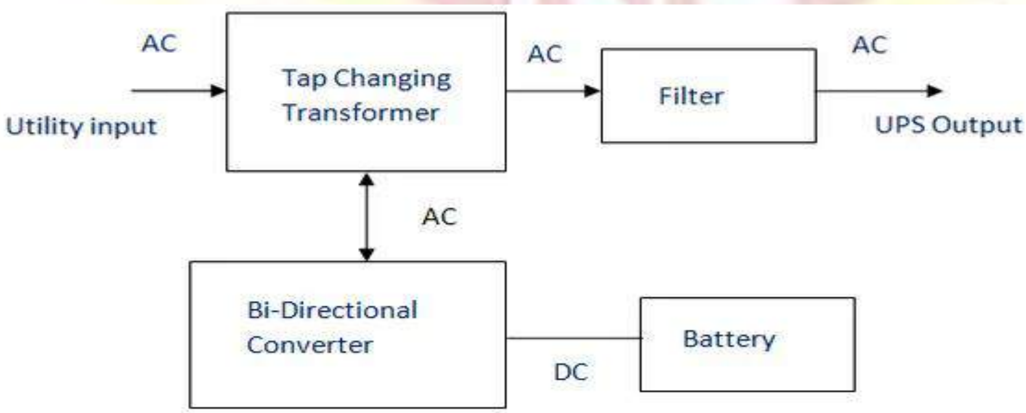


Figure 3

UPS Applications

Applications of a UPS include:

Data Centers

Industries

Telecommunications

Hospitals

Banks and insurance

Some special projects (events)

Switched-Mode Power Supply (SMPS)

A switch mode power supply (SMPS) is a type of power supply that uses semiconductor switching techniques, rather than standard linear methods to provide the required output voltage. The basic switching converter consists of a power switching stage and a control circuit. The power switching stage performs the power conversion from the circuits input voltage, VIN to its output voltage, VOUT which includes output filtering

SMPS operates by rapidly switching a transistor between two efficient operating states: cutoff, where there is a high voltage across the transistor but no current; and saturation, where there is a high current through the transistor but at a very small voltage drop. Essentially, the transistor operates as a power switch that creates an AC voltage from the DC input voltage. This AC voltage can be stepped up or down and then filtered back to DC.

Types of SMPS

SMPS is the Switched Mode Power Supply circuit which is designed for obtaining the regulated DC output voltage from an unregulated DC or AC voltage. There are four main types of SMPS such as

DC to DC Converter

AC to DC Converter

Fly back Converter

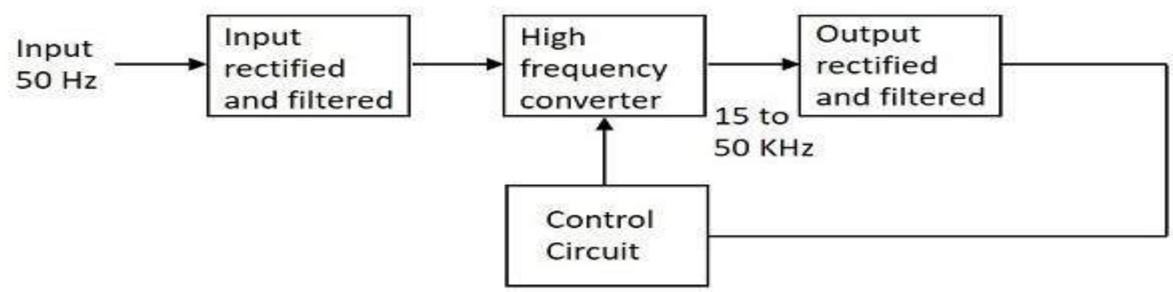
Forward Converter

The AC to DC conversion part in the input section makes the difference between AC to DC converter and DC to DC converter. The Fly back converter is used for Low power applications. Also there are

Buck Converter and Boost converter in the SMPS types which decrease or increase the output voltage depending upon the requirements. The other type of SMPS include Self-oscillating fly-back converter, Buck-boost converter, Cuk, Sepic, etc.

Working

The working of SMPS can be understood by the following figure.



Each Stage ofSMPS Circuit.

Input Stage

The AC input supply signal 50 Hz is given directly to the rectifier and filter circuit combination without using any transformer. This output will have many variations and the capacitance value of the capacitor should be higher to handle the input fluctuations. This unregulated dc is given to the central switching section of SMPS.

Switching Section

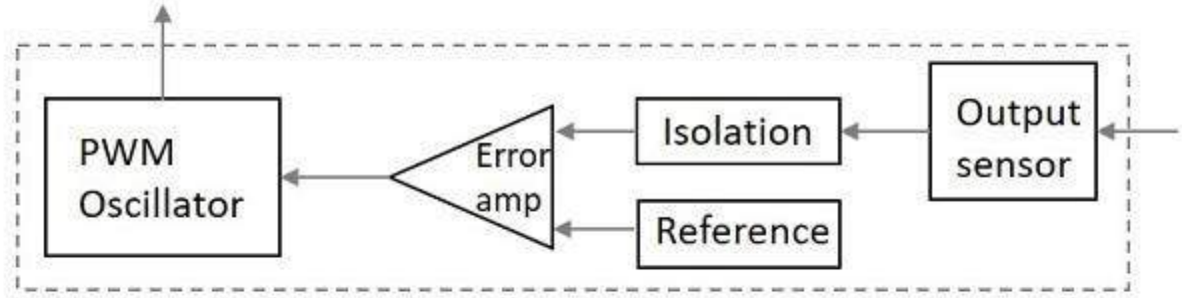
A fast-switching device such as a Power transistor or a MOSFET is employed in this section, which switches ON and OFF according to the variations and this output is given to the primary of the transformer present in this section. The transformer used here are much smaller and lighter ones unlike the ones used for 60 Hz supply. These are much efficient and hence the power conversion ratio is higher.

Output Stage

The output signal from the switching section is again rectified and filtered, to get the required DC voltage. This is a regulated output voltage which is then given to the control circuit, which is a feedback circuit. The final output is obtained after considering the feedback signal.

Control Unit

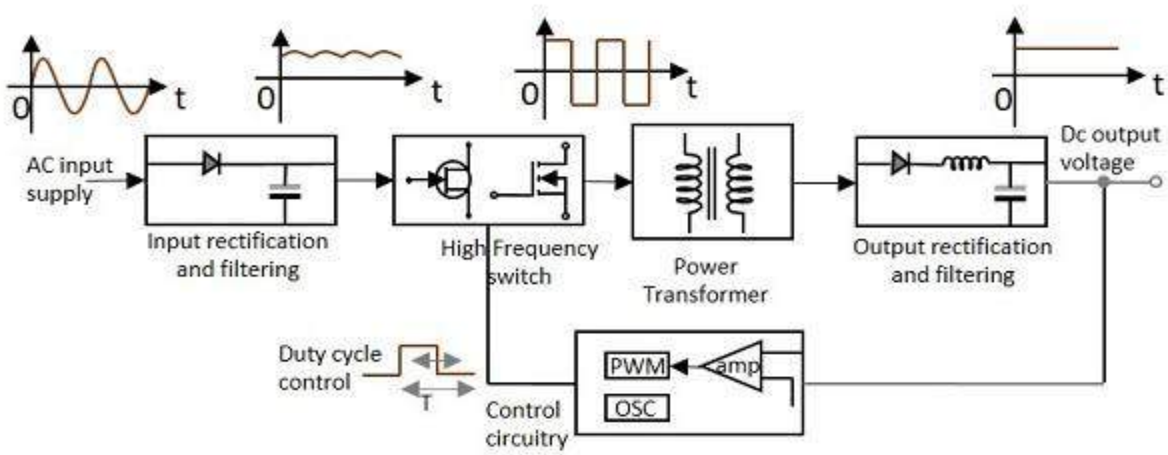
This unit is the feedback circuit which has many sections. Let us have a clear understanding about this from The following figure.



The above figure explains the inner parts of a control unit. The output sensor senses the signal and joins it to the control unit. The signal is isolated from the other section so that any sudden spikes should not affect the circuitry. A reference voltage is given as one input along with the signal to the error amplifier which is a comparator that compares the signal with the required signal level.

By controlling the chopping frequency the final voltage level is maintained. This is controlled by comparing the inputs given to the error amplifier, whose output helps to decide whether to increase or decrease the chopping frequency. The PWM oscillator produces a standard PWM wave fixed frequency.

We can get a better idea on the complete functioning of SMPS by having a look at the following figure.



Functional block diagram of SMPS

The SMPS is mostly used where switching of voltages is not at all a problem and where efficiency of the system really matters. There are few points which are to be noted regarding SMPS. They are

SMPS circuit is operated by switching and hence the voltages vary continuously.

The switching device is operated in saturation or cut off mode.

The output voltage is controlled by the switching time of the feedback circuitry.

Switching time is adjusted by adjusting the duty cycle.

The efficiency of SMPS is high because, instead of dissipating excess power as heat, it continuously switches its input to control the output.

Disadvantages

There are few disadvantages in SMPS, such as

The noise is present due to high frequency switching.

The circuit is complex.

It produces electromagnetic interference.

Advantages

The advantages of SMPS include,

The efficiency is as high as 80 to 90%

Less heat generation; less power wastage.

Reduced harmonic feedback into the supply mains.

The device is compact and small in size.

The manufacturing cost is reduced.

Provision for providing the required number of voltages.

Applications

There are many applications of SMPS. They are used in the motherboard of computers, mobile phone chargers, HVDC measurements, battery chargers, central power distribution, motor vehicles, consumer electronics, laptops, security systems, space stations, etc.

UNIT III

Motors and Controls

Introduction

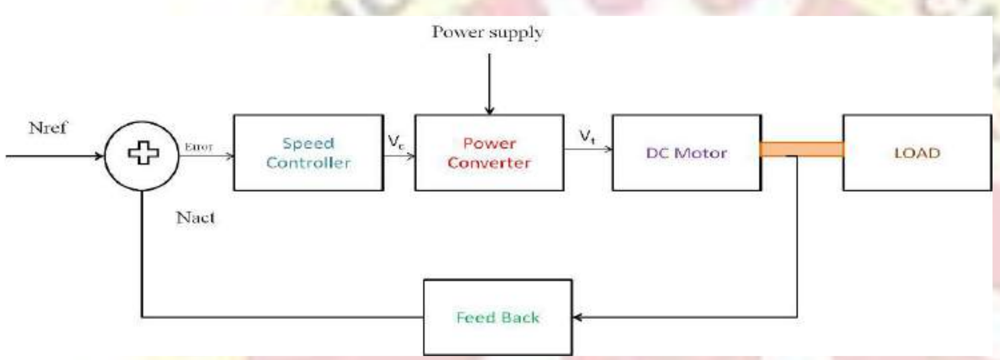
Electric Drives:

There are two types of Drive system. They are

1. DC Drive
2. AC Drive

The DC drives are mainly used for variable speed requirements.

The AC drives are used in chemical and petrochemical industries.



Advantages of Electric Drives:

- The control characteristics are flexible as per requirement.
- Simple and easy speed control methods
- Wide range of torque speed and power.
- The efficiency is high
- Short time overload capacity
- They can be operated in different environment conditions.
- Self starting motors
- Pollution free and low maintenance

Electric drive system:

It consists of electric motor along with control circuits. There are different types of motor available. The selection of motor is by the speed torque characteristics of motor. Electrical motor converts electrical energy into mechanical energy.

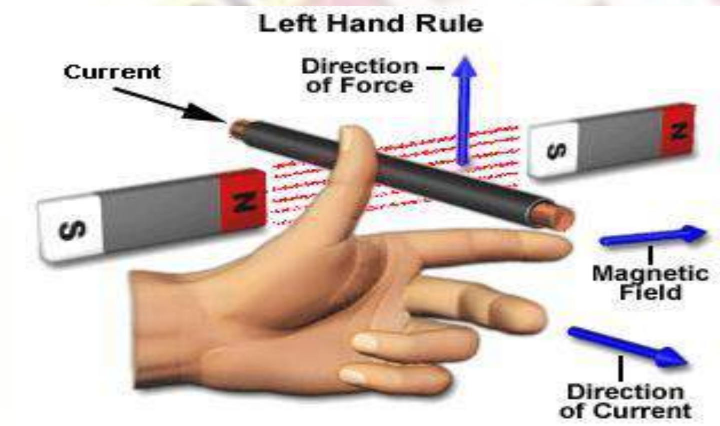
DC Motor

The electric motor operated by dc is called dc motor. This is a device that converts DC electrical energy into a mechanical energy.

Principle:

When a current carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move. In other words, when a magnetic field and an electric field interact, a mechanical force is produced. The DC motor or direct current motor works on that principal. This is known as motoring action.

The direction of rotation of a motor is given by Fleming's left hand rule, which states that if the index finger, middle finger, and thumb of your left hand are extended mutually perpendicular to each other and if the index finger represents the direction of magnetic field, middle finger indicates the direction of current, then the thumb represents the direction in which force is experienced by the shaft of the DC motor.



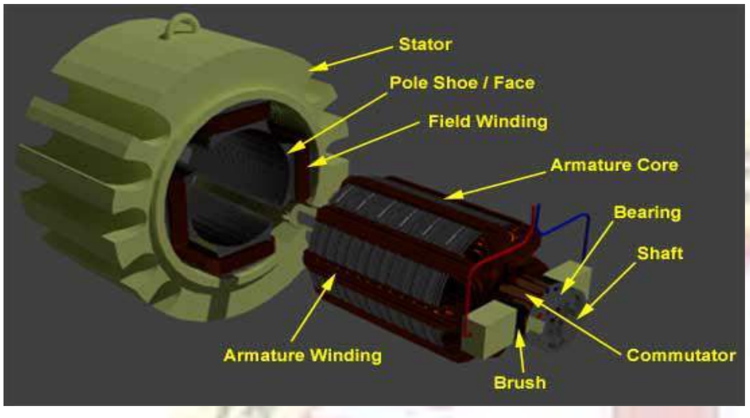
Construction wise a direct current motor is exactly similar to a DC generator, but electrically it is just the opposite.

In a DC motor, the supply voltage E and current I is given to the electrical port or the input port and we derive the mechanical output i.e. torque T and speed ω from the mechanical port or output port.The parameter K relates the input and output port variables of the direct current motor.The motor is just the opposite phenomena of a DC generator, and we can derive both motoring and generating operation from the same machine by simply reversing the ports.

Stator

A stator is the static part of the DC machine that houses the field windings and receives the supply. A rotor is the rotating part of the DC machine that brings about the mechanical rotations.

All these parts put together make up the total construction of a DC motor.



Yoke of DC Motor

The magnetic frame or the yoke of DC motor made up of cast iron or steel and forms an integral part of the stator or the static part of the motor. Its main function is to form a protective covering over the sophisticated inner parts of the motor and provide support to the armature. It also supports the field system by housing the magnetic poles and field winding of the DC motor.

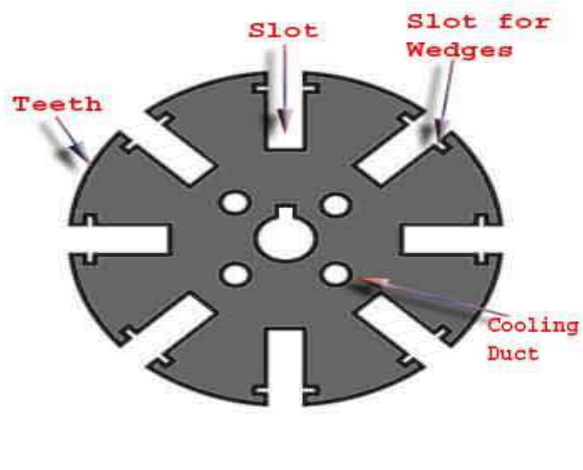
Poles of DC Motor

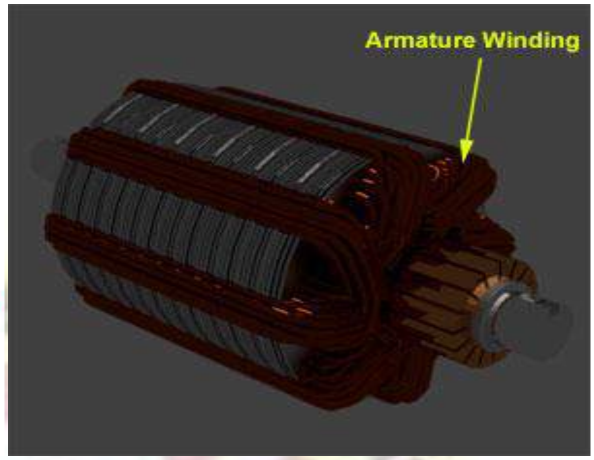
The magnetic poles of DC motor are structures fitted onto the inner wall of the yoke with screws. The construction of magnetic poles basically comprises of two parts. Namely, the pole core and the pole shoe stacked together under hydraulic pressure and then attached to the yoke. The pole core is of small cross-sectional area and its function is to just hold the pole shoe over the yoke. The pole shoe having a relatively larger cross-sectional area spreads the flux produced over the air gap between the stator and rotor to reduce the loss due to reluctance. The pole shoe also carries slots for the field windings that produce the field flux.

Field Winding of DC Motor

The field winding of DC motor are made with field coils (copper wire) wound over the slots of the pole shoes in such a manner that when field current flows through it. The field winding basically form an electromagnet, that produces field flux within which the rotor armature of the DC motor rotates, and results in the effective flux cutting.

Armature Winding of DC Motor





The armature winding of DC motor is attached to the rotor, or the rotating part of the machine, and as a result is subjected to altering magnetic field in the path of its rotation which directly results in magnetic losses. For this reason the rotor is made of armature core, that's made with several low-hysteresis silicon steel lamination, to reduce the magnetic losses like hysteresis and eddy current loss respectively. These laminated steel sheets are stacked together to form the cylindrical structure of the armature core. The armature core are provided with slots made of the same material as the core to which the armature winding made with several turns of copper wire distributed uniformly over the entire periphery of the core.

The slot openings a shut with fibrous wedges to prevent the conductor from plying out due to the high centrifugal force produced during the rotation of the armature, in presence of supply current and field.
Commutator of DC Motor

The commutator of DC motor is a cylindrical structure made up of copper segments stacked together, but insulated from each other by mica. Its main function is to commute or relay the supply current from the mains to the armature winding housed over a rotating structure through the brushes of DC motor.

Brushes of DC Motor
Working of DC motor

The circle in the center represents the direct current motor. On the circle, we draw the brushes. On the brushes, we connect the external terminals, through which we give the supply voltage. On the mechanical terminal, we have a shaft coming out from the center of the armature, and the shaft couples to the mechanical load. On the supply terminals, we represent the armature resistance R_a in series. Let us consider the input voltage E, is applied across the brushes.

Electric current which flows through the rotor armature via brushes, in presence of the magnetic field, produces a torque T_g. Due to this torque T_g the dc motor armature rotates. As the armature conductors are carrying currents and the armature rotates inside the stator magnetic field, it also produces an emf E_b in the manner very similar to that of a generator. The generated Emf E_b is directed opposite to the supplied voltage and is known as the back Emf, as it counters the forward voltage.

The brushes of DC motor are made with carbon or graphite structures, making sliding contact over the rotating commutator. The brushes are used to relay the current from external circuit to the rotating commutator form where it flows into the armature winding. So, the commutator and brush unit of the DC motor is concerned with transmitting the power from the static electrical circuit to the mechanically rotating region or the rotor.

$$E_b = \frac{P.\varphi.Z.N}{60.A} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where, P = no of poles

φ = flux per pole

Z= No. of conductors

A = No. of parallel paths

and N is the speed of the DC Motor.

From the above equation, we can see E_b is proportional to speed 'N.' Whenever a direct current motor rotates; it results in the generation of back Emf. let's represent the rotor speed by ω in rad/sec. So E_b is proportional to ω. when the application of load reduces the speed of the motor, E_b decreases. Thus the voltage difference between supply voltage and back emf increases that means $E - E_b$increases.

Due to this increased voltage difference, the armature current will increase and therefore torque and hence speed increases. Thus a DC Motor is capable of maintaining the same speed under

Armature current I_a is represented by

$$I_a = \frac{E - E_b}{R_a}$$

At starting,speed $\omega = 0$ so at starting $E_b = 0$.

$$\therefore\ I_a = \frac{E}{R_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Back emf

When the current-carrying conductor placed in a magnetic field, the torque induces on the conductor, the torque rotates the conductor which cuts the flux of the magnetic field.When the conductor cuts the magnetic field, EMF induces in the conductor.On applying the right-hand rule the direction of the induced emf is opposite to the applied voltage. Thereby the emf is known as the *counter emf or back emf*.The back emf is developed in series with the applied voltage, but opposite in direction, i.e., the back emf opposes the current which causes it.

Advantages of Back Emf in DC Motor

The back emf opposes the supply voltage. The supply voltage induces the current in the coil which rotates the armature. The electrical work required by the motor for causing the current against the back emf is converted into mechanical energy. And that energy is induced in the armature of the motor.

Thus, we can say that energy conversion in the DC motor is possible only because of the back emf. The mechanical energy induced in the motor is the product of the back emf and the armature current, i.e., E_bI_a.

The back emf makes the DC motor self-regulating machine, i.e., the back emf develops the armature current according to the need of the motor.

How the back emf makes motor self-regulating?

Consider the motor is running at no-load condition. At no load, the DC motor requires small torque for controlling the friction and windage loss. The motor withdraws less current. As the back emf depends on the current their value also decreases. The magnitude of the back EMF is nearly equal to the supply voltage.If the sudden load is applied to the motor, the motor becomes slow down. As the speed of the motor decreases, the magnitude of their back emf also falls down. The small back emf withdraws heavy current from the supply. The large armature current induces the large torque in the armature, which is the need of the motor. Thus, the motor moves continuously at a new speed.

If the load on the motor is suddenly reduced, the driving torque on the motor is more than the load torque. The driving torque increases the speed of the motor which also increases their back emf. The high value of back emf decreases the armature current. The small magnitude of armature current develops less driving torque, which is equal to the load torque. And the motor will rotate uniformly at the new speed.

Relation between Mechanical power (Pm), supply voltage (Vt) and Back EMF (Eb)

- The back emf in the dc motor is expressed as

$$E_b = V_t - I_a R_a$$

Where E_b – Back Emf

I_a – Armature Current

V_t – Terminal Voltage

R_a – Resistance of Armature

The maximum power developed on the motor is expressed by

$$P_m = VI_a - 2I_a R_a$$

On differentiating the above equation we get

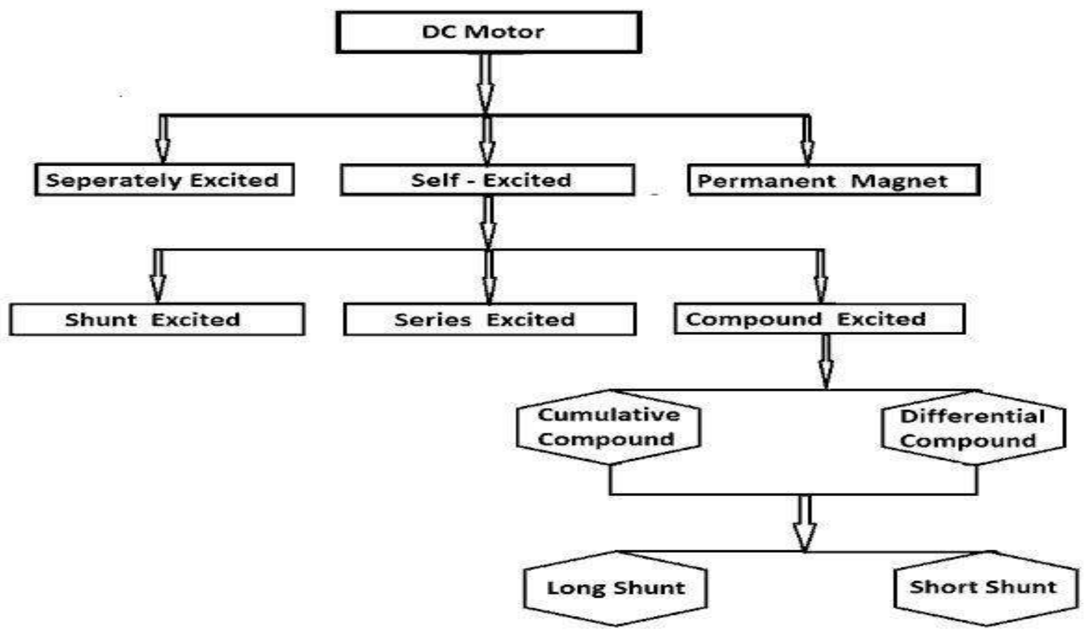
$$\frac{dP_m}{dI_a} = VI_a - 2I_a R_a$$

$$VI_a - 2I_a R_a = 0$$

$$V = 2I_a R_a$$

$$\frac{V}{2} = I_a R_a$$

Thus the maximum power is developed in the motor when the back emf is equal to half of the supply voltage.



DC Shunt Motor: Speed Control, Characteristics

A DC shunt motor (also known as a shunt wound DC motor) is a type of self-excited DC motor where the field windings are shunted to or are connected in parallel to the armature winding of the motor. i.e.the armature and field windings are exposed to the same supply voltage.

Let us now consider the voltage and current being supplied from the electrical terminal to the motor which be given by E and I_{total} respectively.

This supply current in case of the shunt wound DC motor is split up into 2 parts. I_a, flowing through the armature winding of resistance R_a and I_{sh} flowing through the field winding of resistance R_{sh}. The voltage across both windings remains the same.

$$I_{total} = I_a + I_{sh}$$

$$Where\ I_{sh} = \frac{E}{R_{sh}}$$

$$or,\ I_a = I_{total} - I_{sh} = \frac{E}{R_a}$$

Thus we use this value of armature current I_a to get general voltage equation of a DC shunt motor.

$$E = E_b + I_a R_a$$

$$Or\ E = E_b + (I_{total} - I_{sh}) R_a$$

When the motor is in running condition, and the supply voltage is constant then the shunt field current given by,

$$I_{sh} = \frac{E}{R_{sh}}, \ remains \ constant$$

we know $I_{sh} \propto \Phi$ i.e. field flux Φ is proportional to filed current I_{sh}

Thus the field flux remains more or less constant, and for this reason, a shunt wound DC motor is called a constant flux motor.

Construction:

To produce high torque, the following conditions has to be satisfied.

- The armature winding must be exposed to an amount of current that's much higher than the field windings current, as the torque is proportional to the armature current.
- The field winding must be wound with many turns to increase the flux linkage, as flux linkage between the field and armature winding is also proportional to the torque.

So the DC shunt motor has been designed in a way, that the field winding possess much higher number of turns to increase net flux linkage and are lesser in diameter of conductor to increase resistance(reduce current flow) compared to the armature winding of the DC motor.

Self-Speed Regulation of a Shunt Wound DC Motor

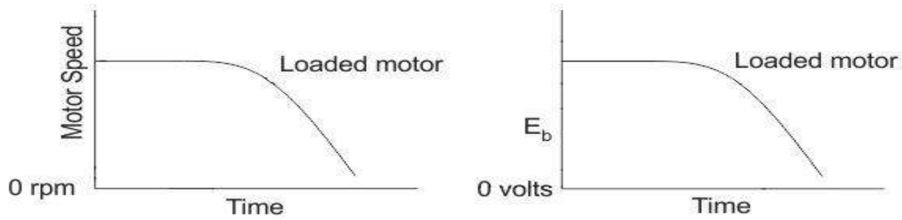
A very important and interesting fact about the DC shunt motor, is in its ability to self-regulate its speed on the application of the load to the shaft of the rotor terminals.

Initially, considering the motor to be running under no load or lightly loaded condition at a speed of N rpm, On adding a load to the shaft, the motor does slow down initially, but this is where the concept of self regulation comes into the picture.

At the very onset of load introduction to a shunt wound DC motor, the speed definitely reduces, and along with speed also reduces the back emf, E_b. Since $E_b \propto N$, given by,

$$E_b = \frac{P.\varphi.Z.N}{60.A} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

This can be graphically explained below.

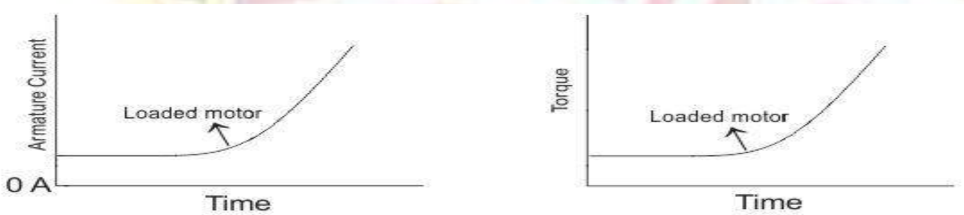


No load to loaded condition

- This increase in the amount of torque increases the speed and thus compensating for the speed loss on loading. Thus the final speed characteristic of a DC shunt motor, looks like. This reduction in the counter emf or the back emf E_b results in the increase of the net voltage. As net voltage $E_{net} = E - E_b$. Since supply voltage E remains constant. As a result of this increased amount of net voltage, the armature current increases and consequently the torque increases. Since, $I_a \propto T$ given by

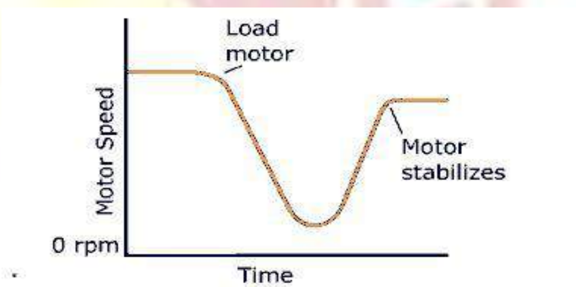
$$T = \frac{P.Z.\varphi.I_a}{2.\pi.A}$$

The change in armature current and torque on supplying load is graphically shown below.



No load to loaded condition

This increase in the amount of torque increases the speed and thus compensating for the speed loss on loading. Thus the final speed characteristic of a DC shunt motor, looks like.

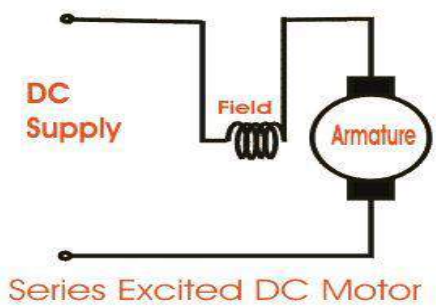


No load to loaded condition

From there we can well understand this special ability of the shunt wound DC motor to regulate its speed by itself on loading and thus its rightly called the constant flux or constant speed motor. Because of which it finds wide spread industrial application where ever constant speed operation is required.

DC Series Motor: Speed Control, Characteristics

A series wound DC motor is also a self-excited DC motor. The field winding is connected internally in series to the armature winding. The field windings are exposed to the entire armature current. Higher current flows through the field coils.



Construction:

The field coils of **DC series motor** are wound with fewer turns as the current through the field is its armature current and hence for required mmf less numbers of turns are required. The Field coil is heavier, as the diameter is considerable increased to provide minimum electrical resistance to the flow of full armature current.

Voltage and Current Equation of Series DC Motor

Let the supply voltage and current given to the electrical port of the motor be given by E and I_{total} respectively.Since the entire supply current flows through both the armature and field conductor,

$$\text{Therefore, } I_{total} = I_{se} = I_a$$

Where, I_{se} is the series current in the field coil and I_a is the armature current.

From the basic voltage equation of the DC motor,

$$E = E_b + I_{se}R_{se} + I_a R_{se}$$

Where, E_b is the back emf, R_{se} is the series coil resistance and R_a is the armature resistance.

Since $I_{se} = I_a$, we can write,

$$E = E_b + I_a(R_a + R_{se})$$

This is the basic voltage equation of a **series wound DC motor**.

In DC series motor field flux is proportional to field current.

$$I_{se} \propto \phi$$

Since $I_{se} = I_a = I_{total}$

$$\phi \propto I_{se} \propto I_a$$

i.e. the field flux is proportional to the entire armature current or the total supply current. And the flux produced in this motor is strong enough to produce sufficient torque, even with the bare minimum number of turns it has in the field coil.

Speed and Torque of Series DC Motor

A series wound motors has linear relationship existing between the field current and the amount of torque produced. i.e. torque is directly proportional to current over the entire range of the graph.Relatively higher current flows through the heavy series field winding with thicker diameter, the electromagnetic torque produced here is much higher than normal.

This high electromagnetic torque produces motor speed, strong enough to lift heavy load overcoming its initial inertial of rest.For this particular reason the motor becomes extremely essential as starter motors for most industrial applications dealing in heavy mechanical load like huge cranes or large metal chunks etc.

Series motors are generally operated for a very small duration, about only a few seconds, just for the purpose of starting. Because if its run for too long, the high series current might burn out the series field coils thus leaving the motor useless.

Speed Regulation of Series Wound DC Motor

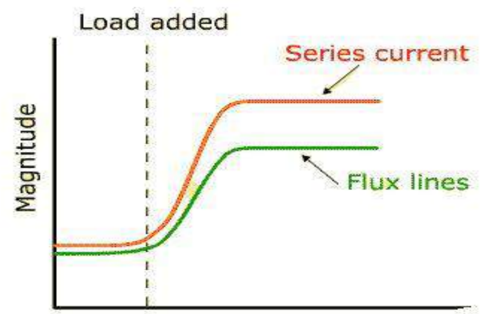
The **DC series motor** has very poor speed regulation. i.e. the series motor is unable to maintain its speed on addition of external load to the shaft. When mechanical load is added to the shaft at any instance, the speed automatically reduces whatever be the type of motor.

The term speed regulation refers to the ability of the motor to bring back the reduced speed to its original previous value within reasonable amount of time. This motor is highly incapable of doing that as with reduction in speed N on addition of load, the back emf given by,

$$E_b = \frac{P.\varphi.Z.N}{60.A} \quad \text{..........................} (1)$$

This decrease in back Emf E_b, increases the net voltage $E - E_b$, and consequently the series field current increases,

$$I_{se} = E - \frac{E_b}{R_a + R_{se}}$$



Effect of load addition on dc series motor.

The value of series current through the field coil becomes so high that it tends to saturate of the magnetic core of the field.As a result the magnetic flux linking the coils increases at a much slower rate compared to the increase in current beyond the saturation region.The weak magnetic field produced as a consequence is unable to provide for the necessary amount of force to bring back the speed at its previous value before application of load.Thus a **series wound DC motor** is most applicable as a starting motor for industrial applications.

DC Compound Motor

A compound wound DC motor is the combination of shunt wound DC motor and series wound DC motor.A compound wound DC motor (also known as a DC compound motor) is a type of self-excited motor, and is made up of both series the field coils S_1 S_2 and shunt field coils F_1 F_2connected to the armature winding.

Both the field coils provide the required amount of magnetic flux, that links with the armature coil and which provides the necessary torque for the rotation of motor at the desired speed.A shunt wound DC motor has an extremely efficient speed regulation characteristic, whereas the DC series motor has high starting torque.

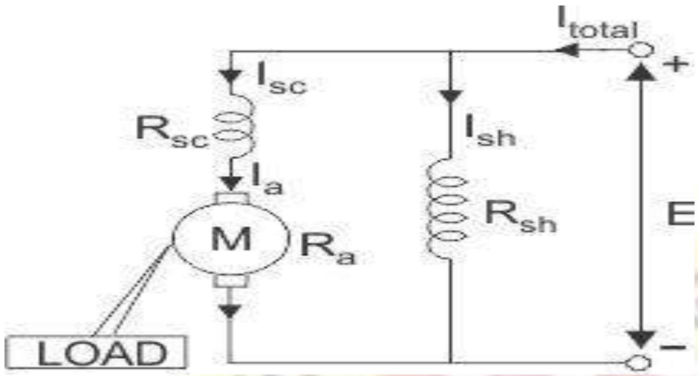
Types of Compound Wound DC Motor

The **compound wound DC motor** can further be subdivided into 2 major types on the basis of its field winding connection with respect to the armature winding. They are

- (1) **Long Shunt Compound Wound DC Motor**
- **(2) Short Shunt Compound Wound DC Motor**

Long Shunt Compound Wound DC Motor

In this method the shunt field winding is connected in parallel with the series combination of both the armature and series field coil.



Voltage and Current Equation of Long Shunt Compound Wound DC Motor

Let E and I_{total} be the total supply voltage and current supplied to the input terminals of the motor. And I_a, I_{se} , I_{sh} be the values of current flowing through armature resistance R_a, series winding resistance R_{se} and shunt winding resistance R_{sh} respectively.

In shunt motor, $I_{total} = I_a + I_{sh}$

In series motor, $I_{se} = I_a$

Therefore, the current equation of a compound wound DC motor is given by

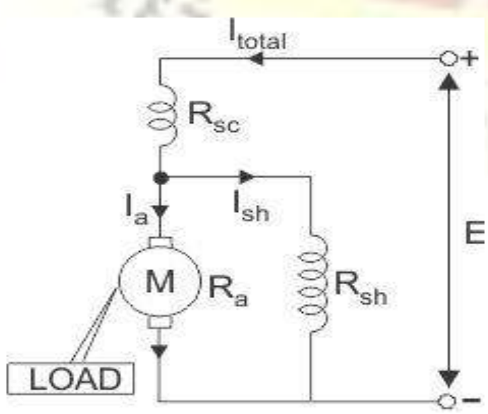
$$I_{total} = I_{se} + I_{sh} \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

And its voltage equation is,

$$E = E_b + I_a(R_a + R_{se})$$

Short Shunt Compound Wound DC Motor

The shunt field winding is connected in parallel across the armature winding only. And series field coil is exposed to the entire supply current, before being split up into armature and shunt field current.



Voltage and Current Equation of Short Shunt Compound Wound DC Motor

Let E and I_{total} be the total supply voltage and current supplied to the input terminals of the motor. And I_a, I_{se}, I_{sh} be the values of current flowing through armature resistance R_a, series winding resistance R_{se} and shunt winding resistance R_{sh} respectively.

In this circuit, $I_{total} = I_{se} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$

Since the entire supply current flows through the series field winding like in the case of a DC shunt motor,

$$I_{total} = I_a + I_{sh} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

Equation (2) and (3) gives the current equation of a short shunt compound wound DC motor.
Now for equating the voltage equation, we apply Kirchoff's law to the circuit and get,

$$E = E_b + I_a R_a + I_{se} R_{se}$$

But since $I_{total} = I_{se} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$

Thus the final voltage equation can be written as,

$$E = E_b + I_a R_a + I_{total} R_{se}$$

APPLICATIONS OF DC MOTORS

MOTORS..	APPLICATIONS...
D.C. SHUNT MOTOR	LATHES , FANS, PUMPS DISC AND BAND SAW DRIVE REQUIRING MODERATE TORQUES.
D.C. SERIES MOTOR	ELECTRIC TRACTION, HIGH SPEED TOOLS
D.C. COMPOUND MOTOR	ROLLING MILLS AND OTHER LOADS REQUIRING LARGE MOMENTARY TORQUES.

Speed Control of DC motors

DC Motor Speed Control Theory

To derive the speed of a DC motor, we start with the equation for the DC motor's EMF (Electromagnetic Force). We know that the EMF equation of DC motor is equal to:

$$E_b = \frac{P.\varphi.Z.N}{60.A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Rearranging the equation we get, N = 60A E / PZØ

With k = PZ/60A, then

N = E / kØ

Hence with $E = V - I_a R_a$, we derive the speed of the DC motor (N):

$$N = \frac{V - I_a R_a}{k\phi}$$

Speed control of a DC motor is either done manually by the operator or by means of an automatic control device. This is different to speed regulation – where the speed is trying to be maintained (or 'regulated') due to a change in the load.

The **speed of a DC motor** (N) is equal to:

$$N = \frac{V - I_a R_a}{k\phi}$$

Therefore speed of the 3 types of DC motors – shunt, series and compound – can be controlled by changing the quantities on the right-hand side of the equation above.Hence the speed can be varied by changing:

1. The terminal voltage of the armature, V.
2. The external resistance in armature circuit, R_a.
3. The flux per pole, φ.

Terminal voltage and external resistance involve a change that affects the armature circuit, while flux involves a change in the magnetic field.

Therefore **speed control of DC motor** can be classified into:

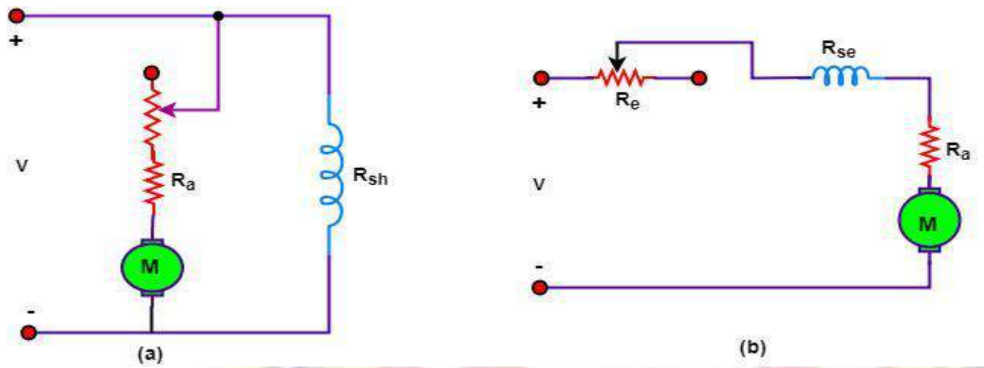
1. Armature Control Methods
2. Field Control Methods

Speed Control of DC Series and Shunt Motor

1. Armature resistance control (Rheostat Control):

In shunt motor, a variable series resistor R_e is connected in the armature circuit.

The field is directly connected across the supply and therefore the flux Φ is not affected by variation of R_e.



In D.C. series motor external resistance R_e is connected in the armature circuit.The current and hence the flux is affected by the variation of the armature circuit resistance.

The voltage drop in R_e reduces the voltage applied to the armature, and therefore the speed is reduced.

This method has the following drawbacks:

- In the external resistance R_e a large amount of power is wasted.
- Control is limited to give speed below normal and increase of speed cannot be obtained by this method.
- For a given value of R_e, the speed reduction is not constant but varies with the motor load.

Thus this method is only used for small motors.

2. Variation of field flux Φ (Field flux control):

$$I_{sh} = \frac{V}{R_{sh} + R_c}$$

gives the shunt field current

- Any of the one methods can vary the field current of the series motor:
- A variable resistance R_d is connected in parallel with the series field winding. The resistor connected in parallel is called the **diverter**. A portion of the main current is diverted through R_d.
- The second method uses a tapped field control.
- Here the ampere-turns are varied by varying the number of field turns. This arrangement is used in electric traction.

The advantages of field control are as follows:

- This is an easy and convenient method.

- The power loss in the shunt field is small because shunt field current I_{sh} is very small.

Armature Voltage control:

We can control the speed of the D.C. motors by varying the applied voltage to the armature.

Ward-Leonard system of speed control works on this principle of armature voltage control.

In this system, M is the main dc motor whose speed is to be controlled, and G is a separately excited dc generator. The generator G is driven by a 3- phase driving motor which may be an induction motor or asynchronous motor. The combination of ac driving motor and the dc generator is called the motor-generator (M-G) set.

Advantages of Ward-Leonard Drives:

- This drive has a smooth speed control of dc motors over a wide range in both directions.
- It has inherent regenerative braking capacity.
- By using an overexcited synchronous motor as the drive for the dc generator, the lagging reactive volt-amperes of the plant are compensated. Therefore the overall power factor of the plant improves.

Drawbacks of classical Ward-Leonard system:

- Its initial cost is high because of the use of two additional machines (M-G set) of the same rating as the main dc motor.
- It has a large size and weight.
- It requires more floor area and costly foundation.
- Very frequent maintenance is required.
- The losses are higher because of lower efficiency.
- Its drive produces more noise

Separately excited DC motor

In self excited DC motors, the field coil and the armature coil both are energized from a single source i.e. the field does not need any separate excitation. But, in separately excited DC motor, separate supply is Provided for excitation of both field coil and armature coil. The field coil is energized from a separate DC voltage source and the armature coil is also energized from another source.

Armature voltage source may be variable but, independent constant DC voltage is used for energizing the field coil.

Equations of Voltage, current and power for DC motors

In a separately excited motor, armature and field windings are excited form two different dc supply voltages. In this motor, Armature current Ia = Line current = IL = I

Back emf developed , Eb = V – I Ra

where V is the supply voltage and Ra is the armature resistance.

Power drawn from main supply , P = VI

Mechanical power developed ,

Pm = Power input to armature – power loss in armature

Characteristics of Separately excited dc motor

Both in shunt wound dc motor and separately excited dc motor field is supplied from constant voltage so that the field current is constant. Therefore these two motors have similar speed -armature current and torque – armature current characteristics. In this type of motor flux is assumed to be constant.

Speed – armature current (N – Ia) characteristics: We know that speed of dc motor is proportional to back emf/ flux i.eEb / φ . When load is increased back emf Eb and φ flux decrease due to armature resistance drop and armature reaction respectively .However back emf decreases more than φ so that the speed of the motor slightly decreases with load.

Torque – armature current (τ – Ia) characteristics : Here torque is proportional to the flux and armature current . Neglecting armature reaction, flux φ is constant and torque is proportional to the armature current Ia . τ – Ia characteristics is a straight lien passing through the origin. From the curve we can see that huge current is needed to start heavy loads. So this type of motor do not starts on heavy loads.

Speed control of separately excited DC motor

Speed of this type of dc shunt motor is controlled by the following methods:

I. Field control methods: Weakening of field causes increase in speed of the motor while strengthening the field causes decreases the speed. Speed adjustment of this type of motor is achieved from the following methods:

II. Field rheostat control: – Here a variable resistance is connected in series with the field coil. Thus the speed is controlled by means of flux variation.

Reluctance control involves variation of reluctance of magnetic circuit of the motor.

Field voltage is controlled by varying the voltage at field circuit while keeping armature terminal voltage constant.

III. Armature control methods: Speed adjustment of separately excited DC motor by armature control may be obtained by any one of the following methods.

i. Armature resistance control: – Here, the speed is controlled by varying the source voltage to armature. Generally, a variable resistance is provided with the armature to vary the armature resistance.

ii. **Armature terminal voltage control** involving variation of variation of voltage in armature circuit. This type of motors is used in trains and for automatic traction purposes.

AC Motors

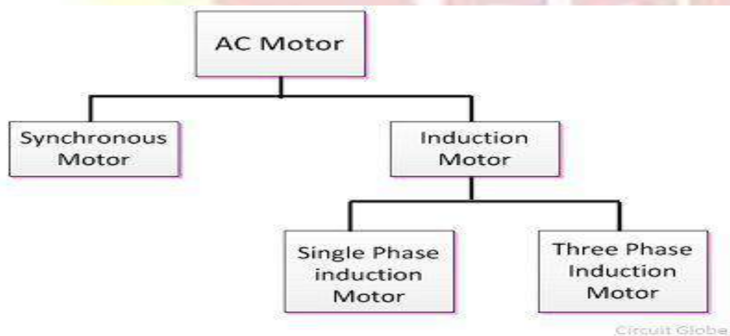
Definition:

The motor that converts the alternating current into mechanical power by using an electromagnetic induction phenomenon is called an AC motor. This motor is driven by an alternating current. The stator and the rotor are the two most important parts of the AC motors. The stator is the stationary part of the motor, and the rotor is the rotating part of the motor.

The AC motor may be single phase or three phase.The three phase AC motors are mostly applied in the industry for bulk power conversion from electrical to mechanical. For small power conversion, the single phase AC motors are mostly used.The single phase AC motor is nearly small in size, and it provides a variety of services in the home, office, business concerns, factories, etc. All the domestic appliances such as refrigerators, washing machine, hair dryers, mixers, etc., use single phase AC motor.

Types of AC motor:

The AC motor is mainly classified into two types. They are the synchronous motor and the induction motor.



When three-phase electric conductors are placed in certain geometrical positions (i.e. in a certain angle from one another) – an electrical field is generated. The rotating magnetic field rotates at a certain speed known as the **synchronous speed.**

If an electromagnet is present in this rotating magnetic field, the electromagnet is magnetically locked with this rotating magnetic field and rotates with the same speed of rotating field.

This is where the term **synchronous motor** comes from, as the speed of the rotor of the motor is the same as the rotating magnetic field.

It is a fixed speed motor because it has only one speed, which is synchronous speed. This speed is synchronised with the supply frequency. The synchronous speed is given by:

$$N_s = \frac{120f}{p}$$

Where:

- N= The Synchronous Speed (*in RPM – i.e. Rotations Per Minute*)
- f = The Supply Frequency (*in Hz*)
- p = The number of Poles

Construction of Synchronous Motor

Construction of Synchronous Motor

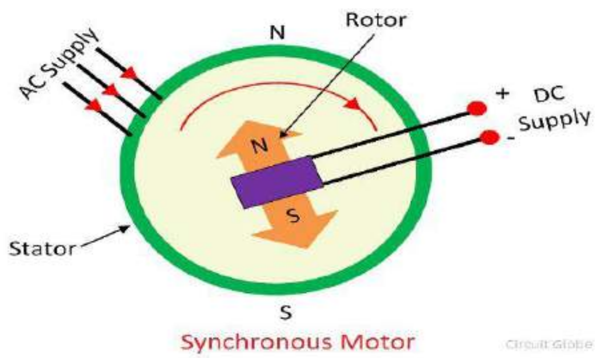
The stator and the rotor are the two main parts of the synchronous motor. The stator becomes stationary, and it carries the armature winding of the motor. The rotor carry the field windings. The main field flux is induced in the rotor. The synchronous motor uses the salient pole rotor. **The word salient means the poles of the rotor projected towards the armature windings**. The rotor of the synchronous motor is made with the laminations of the steel. The laminations reduce the eddy current loss occurs on the winding of the transformer. The salient pole rotor is mostly used for designing the medium and low-speed motor. For obtaining the high-speed cylindrical rotor is used in the motor.

Main Features of Synchronous Motors

Synchronous motors are inherently not self starting. They require some external means to bring their speed close to synchronous speed to before they are synchronized. The speed of operation of is in synchronism with the supply frequency and hence for constant supply frequency they behave as constant speed motor irrespective of load condition. This motor has the unique characteristics of operating under any electrical power factor. This makes it being used in electrical power factor improvement.

Working

The stator and rotor both are excited separately. **The excitation is the process of inducing the magnetic field on the parts of the motor with the help of an electric current.** A three-phase supply is given to a three-phase stator winding, and DC supply is given to the rotor winding.



The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux. The rotor carrying DC supply also produces a constant flux. Considering the 50 Hz power frequency, the 3 phase rotating flux rotates about 3000 revolutions in 1 min or 50 revolutions in 1 sec. At a particular instant rotor and stator poles might be of the same polarity (N-N or S-S) causing a repulsive force on the rotor and the very next instant it will be N-S causing attractive force. Due to the inertia of the rotor, it is unable to rotate in any direction due to the attractive or repulsive forces, and the rotor remains in standstill condition. Hence a synchronous motor is not self-starting.

Speed of the synchronous motor is controlled by the frequency of the applied current.The table below gives the number of poles and synchronous speeds for a power frequency of 50 hertz.

Number of Poles	Synchronous Speed NS in r.p.m
2	3000
4	1500
6	1000
8	750
10	600
12	500

Applications

- It is used for constant speed drives. Some typical applications of synchronous motor are in compressor motor in Oil & Gas industry, centrifugal pumps, reciprocating pumps etc.
- Synchronous motor is also used in household applications. It is used in microwave oven, clock, tape players etc. In microwave oven, it is used to rotate the turn table.

- Synchronous motor having no load connected to its shaft is used for power factor improvement.
- Synchronous motor finds application where operating speed is less (around 500 rpm) and high power is required.

Induction Motor:

An **induction motor** (also known as an **asynchronous motor**) is a commonly used AC electric motor. In an induction motor, the electric current in the rotor needed to produce torque is obtained via electromagnetic induction from the rotating magnetic field of the stator winding. The rotor of an induction motor can be a squirrel cage rotor or wound type rotor.

Induction motors are referred to as 'asynchronous motors' because they operate at a speed less than their synchronous speed.

Working Principle of Induction Motor

When we give the supply to the stator winding, a magnetic flux gets produced in the stator due to the flow of current in the coil. The rotor winding is so arranged that each coil becomes short-circuited.

The flux from the stator cuts the short-circuited coil in the rotor. As the rotor coils are short-circuited, according to Faraday's law of electromagnetic induction, the current will start flowing through the coil of the rotor. When the current through the rotor coils flows, another flux gets generated in the rotor.

Now there are two fluxes, one is stator flux, and another is rotor flux. The rotor flux will be lagging with respect to the stator flux. Because of that, the rotor will feel a torque which will make the rotor to rotate in the direction of the rotating magnetic field. This is the working principle of both single and three-phase induction motors.

Single Phase Induction Motor

The types of single phase induction motors include:

1. Split Phase Induction Motor
2. Capacitor Start Induction Motor
3. Capacitor Start and Capacitor Run Induction Motor
4. Shaded Pole Induction Motor

Three Phase Induction Motor

The types of three phase induction motors include:

1. Squirrel Cage Induction Motor
2. Slip Ring Induction Motor

What is a self-starting motor?

The single-phase induction motor is not a self-starting motor, and that the three-phase induction motor is self-starting.

When the motor starts running automatically without any external force applied to the machine, then the motor is referred to as 'self-starting'. For example, we see that when we put on the switch the fan starts to rotate automatically, so it is a self-starting machine.

In a three phase system, there are three single phase lines with a 120° phase difference. So the rotating magnetic field has the same phase difference which will make the rotor to move.

If we consider three phases a, b, and c when phase a gets magnetized, the rotor will move towards the phase a winding a, in the next moment phase b will get magnetized and it will attract the rotor, and then phase c. So the rotor will continue to rotate.

Construction of Single Phase Induction Motor

Like any other electrical motorasynchronous motor also have two main parts namely rotor and stator.

Stator:

As its name indicates stator is a stationary part of induction motor. A single phase AC supply is given to the stator of single phase induction motor. The stator of the single-phase induction motor has laminated stamping to reduce eddy current losses on its periphery. The slots are provided on its stamping to carry stator or main winding. Stampings are made up of silicon steel to reduce the hysteresis losses.

When we apply a single phase AC supply to the stator winding, the magnetic field gets produced, and the motor rotates at speed slightly less than the synchronous speed N_s. Synchronous speed N_s is given by

$$N_s = \frac{120f}{P}$$

Rotor:

The rotor is a rotating part of an induction motor. The rotor connects the mechanical load through the shaft. The rotor in the single-phase induction motor is of squirrel cage rotor type. he rotor is cylindrical and has slots all over its periphery. The slots are not made parallel to each other but are a little bit skewed as the skewing prevents magnetic locking of stator and rotor teeth and makes the working of induction motor more smooth and quieter (i.e. less noisy).

Working Principle of Single Phase Induction Motor

When we apply a single phase AC supply to the stator winding of single phase induction motor, the alternating current starts flowing through the stator or main winding. This alternating current produces an alternating flux called main flux. This main flux also links with the rotor conductors and hence cut the rotor conductors.

According to the Faraday's law of electromagnetic induction, emf gets induced in the rotor. As the rotor circuit is closed one so, the current starts flowing in the rotor. This current is called the rotor current. This rotor current produces its flux called rotor flux. Since this flux is produced due to the induction principle so, the motor working on this principle got its name as an induction motor. Now there are two fluxes one is main flux, and another is called rotor flux. These two fluxes produce the desired torque which is required by the motor to rotate.

Squirrel Cage Three Phase Induction Motor

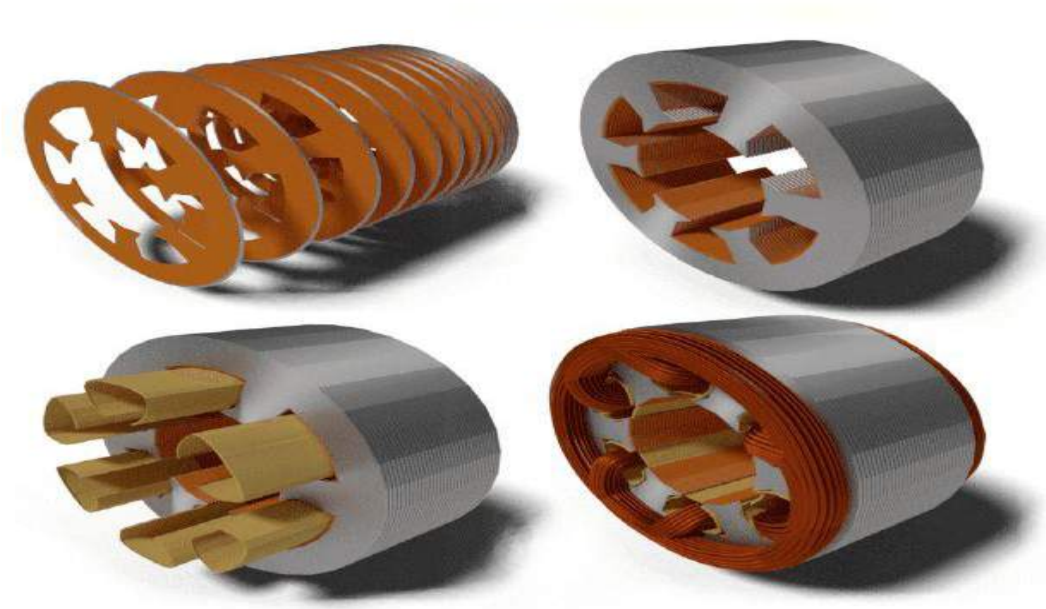
A **3 phase squirrel cage induction motor** is a type of three phase induction motor which functions based on the principle of electromagnetism. It is called a 'squirrel cage' motor because the rotor inside of it – known as a 'squirrel cage rotor' – looks like a squirrel cage.This rotor is a cylinder of steel laminations, with highly conductive metal (typically aluminum or copper) embedded into its surface.
When an alternating current is run through the stator windings, a rotating magnetic field is produced.This induces a current in the rotor winding, which produces its own magnetic field. The interaction of the magnetic fields produced by the stator and rotor windings produces a torque on the squirrel cage rotor.

Squirrel Cage Induction Motor Working Principle

When a 3 phase supply is given to the stator winding it sets up a rotating magnetic field in space. This rotating magnetic field has a speed which is known as the synchronous speed. This rotating magnetic field induces the voltage in rotor bars and hence short-circuit currents start flowing in the rotor bars.These rotor currents generate their self-magnetic field which will interact with the field of the stator.The moment rotor catches the rotating magnetic field the rotor current drops to zero as there is no more relative motion between the rotating magnetic field and rotorSlip is a measure of the difference between the speed of the rotating magnetic field and rotor speed. The frequency of the rotor current = slip × supply frequency.

A squirrel cage induction motor consists of the following parts:

- Stator
- Rotor
- Fan
- Bearings



Rotor

It is the part of the motor which will be in a rotation to give mechanical output for a given amount of electrical energy. The rated output of the motor is mentioned on the nameplate in horsepower. It consists of a shaft, short-circuited copper/aluminum bars, and a core.

The rotor core is laminated to avoid power loss from eddy currents and hysteresis. Conductors are skewed to prevent cogging during starting operation and gives better transformation ratio between stator and rotor.

Fan

A fan is attached to the back side of the rotor to provide heat exchange, and hence it maintains the temperature of the motor under a limit.

Bearings

Bearings are provided as the base for rotor motion, and the bearings keep the smooth rotation of the motor.

Advantages of Squirrel Cage Induction Motor

- They are low cost
- Require less maintenance (as there are no slip rings or brushes)
- Good speed regulation (they are able to maintain a constant speed)
- High efficiency in converting electrical energy to mechanical energy (while running, not during startup)
- Have better heat regulation (i.e. don't get as hot)
- Small and lightweight
- Explosion proof (as there are no brushes which eliminate the risks of sparking)

Disadvantages of Squirrel Cage Induction Motor

- Very poor speed control
- Although they are energy efficient while running at full load current, they consume a lot of energy on startup
- They are more sensitive to fluctuations in the supply voltage. When the supply voltage is reduced, induction motor draws more current. During voltage surges, increase in voltage saturates the magnetic components of the squirrel cage induction motor
- They have high starting current and poor starting torque (the starting current can be 5-9 times the full load current; the starting torque can be 1.5-2 times the full load torque)

Application of Squirrel Cage Induction Motor

- Squirrel cage induction motors are commonly used in many industrial applications. They are particularly suited for applications where the motor must maintain a constant speed, be self-starting, or there is a desire for low maintenance.
- These motors are commonly used in:
- Centrifugal pumps
- Industrial drives (e.g. to run conveyor belts)
- Large blowers and fans
- Machine tools
- Lathes and other turning equipment

Slip Ring or Wound Rotor Three Phase Induction Motor

In this type of three phase induction motor the rotor is wound for the same number of poles as that of the stator, but it has less number of slots and has fewer turns per phase of a heavier conductor.The rotor also carries star or delta winding similar to that of the stator winding.The rotor consists of numbers of slots and rotor winding are placed inside these slots. The three end terminals are connected together to form a star connection.

The three phase slip ring induction motor consists of slip rings connected on the same shaft as that of the rotor.The three ends of three-phase windings are permanently connected to these slip rings. The external resistance can be easily connected through the brushes and slip rings and hence used for speed controlling and improving the starting torque of three phase induction motor. The brushes are used to carry current to and from the rotor winding. These brushes are further connected to three phase star connected resistances.

In a slip ring or wound rotor induction motor, the torque is increased by adding external resistance in the rotor circuit from a star-connected rheostat.
This rheostat resistance is gradually cut out as the speed of the motor increases. This additional resistance increases the rotor impedance hence also reduces the rotor current.

Rotor Resistance/Rheostat Starting
The slip ring induction motor is practically always started with full line voltage applied across the stator terminals.

The value of starting current is adjusted by introducing a variable resistance in the rotor circuit. The controlling resistance is in the form of star-connected rheostat; the resistance is being gradually cut out as the motor gains speed.

By increasing the rotor resistance, the rotor current is reduced at starting, and hence stator current is also reduced but at the same time torque is increased due to improvement in power factor.

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How to Control Speed of a Wound Rotor Motor

Rotor Resistance Control

The speed of the wound rotor or slip ring induction motor can be controlled by varying the resistance in the rotor circuit. This method is applicable to slip ring induction motor only.

When the motor is running and if the full resistance is connected in the rotor circuit the speed of the motor decreases.

Advantages of Wound Rotor Motor

Some of the advantages of wound rotor induction motor are discussed below.

- High starting torque – Slip ring induction motor can provide high starting torque due to the presence of external resistance in the rotor circuit.
- High overload capacity – Slip ring induction motors have high overload capacity and smooth acceleration during heavy loads.
- Low starting current in comparison with squirrel cage motor – The additional resistance in the rotor circuit increases the rotor impedance hence reduces the starting current.
- Adjustable speed – speed can be adjusted by varying the rotor circuit resistance. So that it is considered as a "variable speed motor".
- Improved power factor

Other differences between the two motors are discussed in the table below.

Specifications	Wound-rotor or slip ring induction motor	Squirrel cage induction motor
Construction	Complicated due to the presence of slip rings and brushes	Simple due to the absence of slip rings and brushes

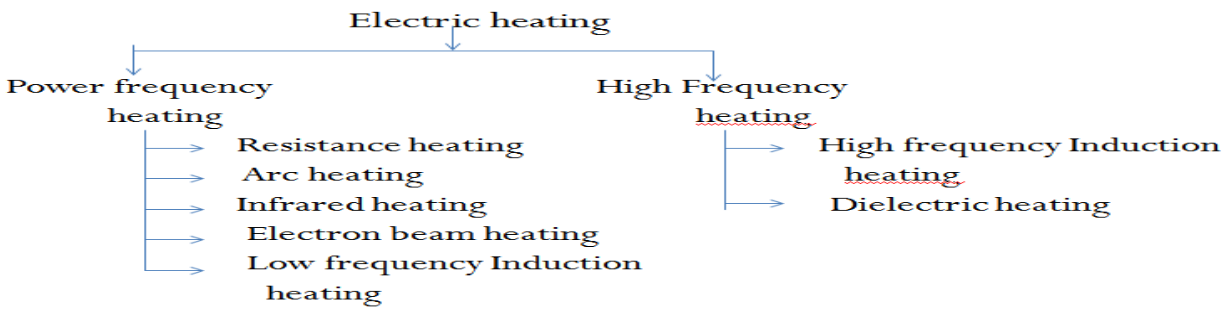
Starting Method	The motor requires slip rings, brush gear, short-circuiting device and starting resistance, etc.…	The motor can be started with a star-delta starter.
Starting Torque	High starting torque can be obtained due to the presence of external resistance in the rotor circuit.	Poor starting torque and cannot be improved.
Space factor in slots	Better	Poor
Rotor	The rotor is wound rotor type with its terminal ends connected to 3 slip rings on the output shaft.	The rotor is skewed rotor type with its terminals are short-circuited at end rings.
No. of turns on the rotor	More	Less
The induced voltage in the rotor	Higher	Less
Speed Control	Speed control by rotor resistance method is possible	Speed cannot be controlled by the rotor resistance method
Maintenance	Frequent maintenance is required due to the presence of brushes and slip rings	Less maintenance is required
Copper Losses	High	Less
Efficiency	Low due to power loss in external resistance	High
Cost	High Cost	Cheaper in cost
Applications	Used where high starting torque required such as cranes, hoist, elevator, etc.… Rarely used about 5%-10% of the industry uses slip ring induction motor.	Used in lathe machines, drilling machines, blowers, fan, etc.… Widely used about 90% of the industry uses squirrel cage induction motor.

UNIT IV

Heating

Introduction to Electric Heating

Electric heating is a process in which electrical energy is converted to heat energy. Common applications of electric heating include the heating of buildings, industrial processes and cooking of food. The heat generation through energy conversion processes is related with energy losses. Electric heating are broadly categorized



Induction Heating

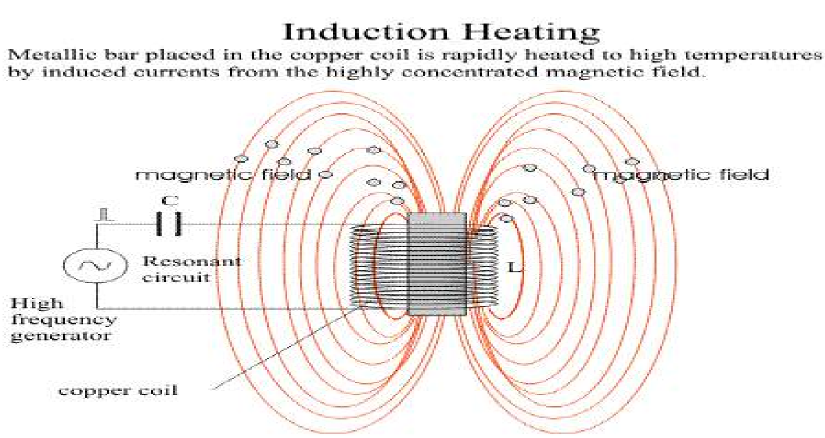
Induction heating is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction, where eddy currents (also called Foucault currents) are generated within the metal and resistance leads to Joule heating of the metal.The induction heating is a well known method for producing heat in a localized area on a susceptible metallic object.

Induction heating is a form of **non-contact heating** for conductive materials.

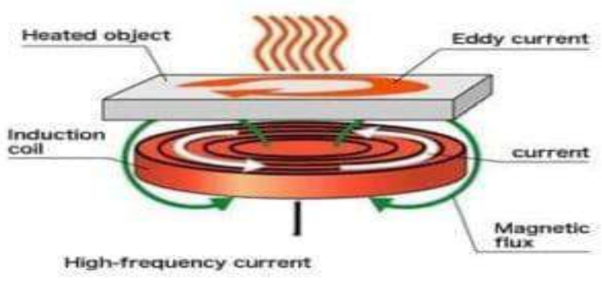
Working principles of Induction heating

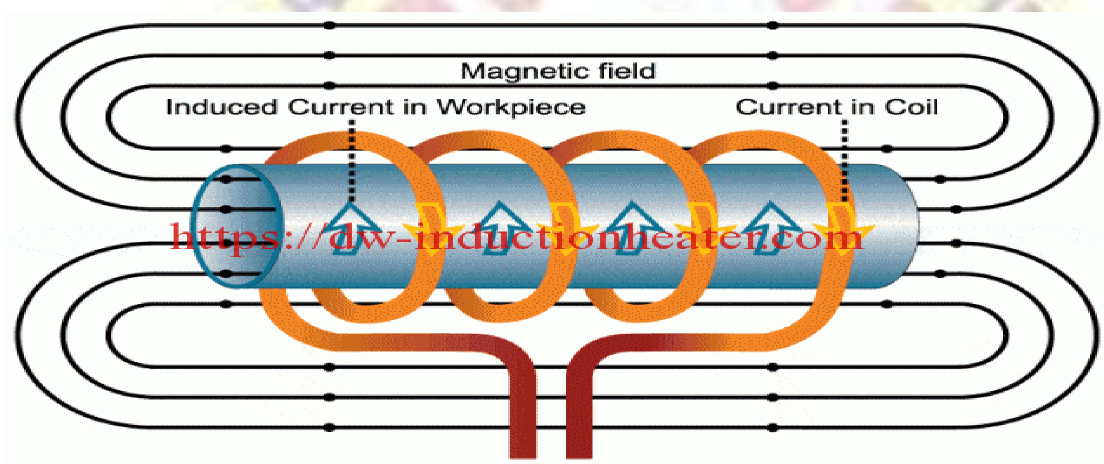
When alternating current flows in the induced coil, varying electromagnetic field is set up around the coil, circulating current(induced, current, eddy current) is generated in the workpiece(conductive material), heat is produced as the eddy current flows against the resistivity of the material. The Principle involved is skin effect.

Induction heating involves applying an ac electric signal to a heating loop or coil placed near a specific location on or around the metallic object to be heated.



The alternating current in the loop creates an alternating magnetic flux within the metal to be heated. Current is induced in the metal by the electromagnetic flux and heats up the material.





Fundamental theory of induction heating is similar to transformer, where primary coil is treated as heating coil and the current induced in the secondary is directly proportional to primary current according to turn ratio.

If the metal of the workpiece to be heated is non-magnetic then heat is generated only due to eddy current. Whereas, for magnetic material there will be some contribution from hysteresis loss.

Advantages of Induction heating:

- Quick heating: Development of heat within the work piece by induction provides much higher heating rates than the convection and radiation processes.
- Improved process efficiency
- Localized, constant and precise heating
- Temperature control

- Energy saving
- Pollution free, fast and secure technology
- Low operating costs
- Ease of automation and control
- Less requirement of floor space
- Quick, safe and clean working conditions
- Requirement of less maintenance

Applications of Induction heating

Annealing:

Induction annealing and tempering processes are used to soften metal for improved ductility. In contrast to hardening, annealing involves a much slower heating step followed by gradual cooling of the metal. Tempering refers to a reheating and slow cooling of metal which has become too brittle as a result of a hardening process.

Brazing:

Brazing is the process of joining two or more pieces of metal or ceramic material with a molten filler metal such as silver, aluminum alloy or copper. Brazing requires a higher temperature than soldering but produces a very strong bond which withstands shock, vibration and temperature change.

Heat Staking:

When one piece of metal is designed to be inserted into a second piece, induction heating can be used to "shrink fit" the two pieces together. The first or larger piece containing the opening is heated to expand the size of the hole. The second piece is then inserted into the opening, and as the first piece cools and shrinks back to its original size, the resulting pressure holds the two pieces together in a strong bond.

Preheating prior to metal working

Induction heating prior to metal working is well accepted in the forging and extrusion industries. It is readily adapted through preheating of steels, aluminum alloys and specialty metals such as titanium and nickel base alloys. The work pieces in this type of application consist of round, square or round cornered square bar stock. For steels, the high heating rates of induction process minimize scale and hence metal losses. The rapid heating boosts the production rates.

Melting:

Induction processes are frequently used to melt high quality steels and nonferrous alloys (such as aluminum, copper etc.). Advantages of induction melting in compare with other melting processes include a natural stirring action which makes more uniform melt and a long crucible life.

Adhesive bonding:

Induction heating used as thermosetting adhesives for making certain automobile parts, such as clutch plates and break shoes. As in paint curing, induction heating of the metal parts to curing temperatures can be an excellent means of adhesive rapid bonding. Metal to nonmetal seals, widely used in vacuum devices also rely heavily on induction heating.

Semiconductor Fabrication:

The growing of single crystals of germanium and silicon often relies on induction heating. Zone refining, zone leveling, doping and epitaxial deposition of semiconductor materials also makes use of the induction process.

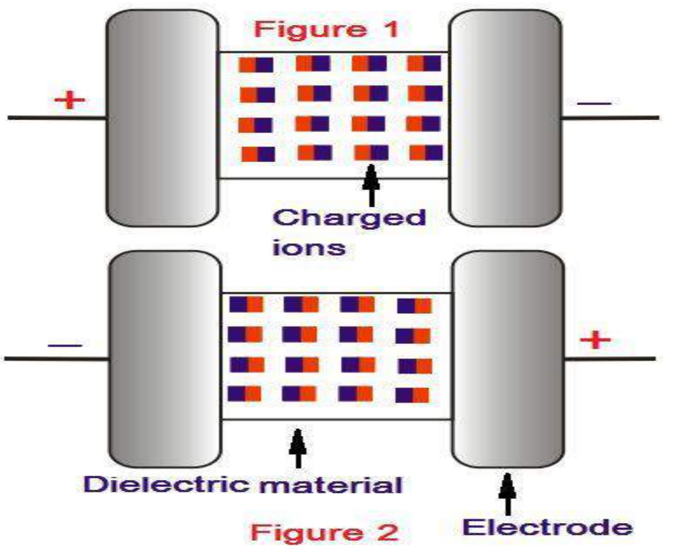
Induction heater as domestic cooking appliance:

In electrical heating process high frequency induction heating is more energy efficient as compared to other power frequency electrical heating for domestic cooking purpose. High rate of heat generation, immediate response, more uniform heat distribution, full automation, good compactness, safe, higher efficiency, constant output power, absence of shock hazard in the cooking pan, flexible temperature control and high reliability are major features of high frequency induction cooking.

Dielectric Heating

Principle

When non-metallic parts such as wood, plastics, bones are subjected to an alternating electrostatic field dielectric loss occurs. This loss appears in the form of heat in dielectric heating. It is the basic dielectric heating principle.



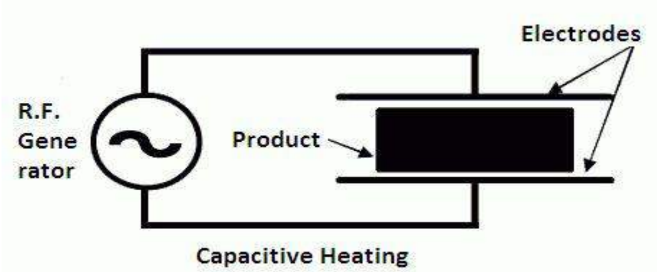
A dielectric material has positively and negatively charged ions. If we place such material between two electrodes and charge them positive and negative, respectively, the molecules will tend to line up all in one direction. If we reverse the charge on the electrodes, they will tend to flip around and line up in the opposite direction.

Reversing the charge causes the molecules to rub against one another. This process produces 'frictional' heating in the material. The rate of heating will increase as the frequency of reversal is increased.When we apply a high-frequency voltage across a material during the dielectric heating, its molecules line up again and again. In doing so, they rub against one another and produces frictional heating. As the frequency of reversal of the field (i.e., supply frequency) is very high, a large amount of heat is produced.

Construction

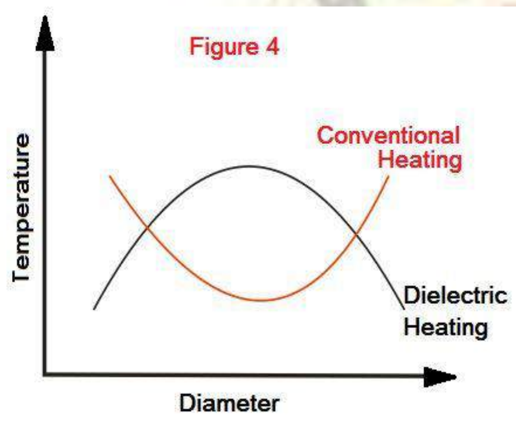
The material to be heated is placed as a slab between two metallic electrodes across which high-frequency voltage is applied. The applied voltage varies from 10 to 20 kV. At higher frequencies, we can obtain better heating efficiencies and better coupling.

The whole setup of the dielectric heating is equivalent to a capacitor. Here, material to be heated is just equal to the dielectric material of the capacitor.



The current drawn by the capacitor, when an A.C. supply voltage is applied across its two plates, does not lead the supply voltage by 90° exactly. It means that there is a particular component of the current which is in phase with the voltage. This component of the current produces heat in dielectric material placed in between the two plates of the capacitor. This electric energy, dissipated in the form of heat energy in the dielectric material, is known as the dielectric loss. The dielectric loss is directly proportional to V^2f. That is why we use a high-frequency voltage in dielectric heating.

In the dielectric heating process, the high-frequency waves heat the material in the complete volume by penetrating the material, depending on the penetration depth of the waves.



It provides the same temperature to every volume of the element. In a practical situation, the surface of the material would lose heat to the ambient atmosphere, which is not heated by the high-frequency waves. Therefore the surface temperature is reduced.

So the highest temperature is on the inside, whereas the lowest temperature is on the surface of the material. So this temperature profile is inverse to one of the conventional heating processes.The heating is very much dependent on the dielectric properties of the material, and they depend on the frequency and temperature.

Advantages of Dielectric Heating

1. Since the heat is produced throughout the whole mass of material, we get uniform heating. By the conventional methods of heating, it is not possible.
2. A shorter time is required to complete the process as compared to other methods.
3. It is suitable for non-conducting materials like wood, plastics, and synthetic compounds, etc.

Disadvantages of Dielectric Heating

1. Since heat produced in dielectric heating very much depends upon the type of material, the product size, the power density, etc., so we can heat only those materials which have a high dielectric loss. It is not possible to heat a transparent or reflective material by this method.

2. The cost of equipment required for dielectric heating is so high that we use this method only where other methods are impracticable or too slow.

3. The overall efficiency of dielectric heating is very low (about 50%).

4. High frequencies may cause radio interference.

Applications of Dielectric Heating

1. It is used for drying of textiles, manufacture of plywood, paper, etc. The overall efficiency in this case of dielectric heating is about 50%.

2. It is used also employed in drying tobacco, paper, wood, gluing, and bonding of woods.

3.It is used to weld the PVC.

4. It is used in producing artificial fibers, heating of bones and tissues, etc.

5.It is used in food processing.

6. In high-temperature dielectric heating applications, we can combine it with other conventional heating methods like resistance heating or hot air heating.

UNIT V

RELAY

Introduction

A relay can be defined as a switch. Switches are generally used to close or open the circuit manually .Relay is also a switch that connects or disconnects two circuits. But instead of manual operation a relay is applied with electrical signal, which in turn connects or disconnects another circuit.

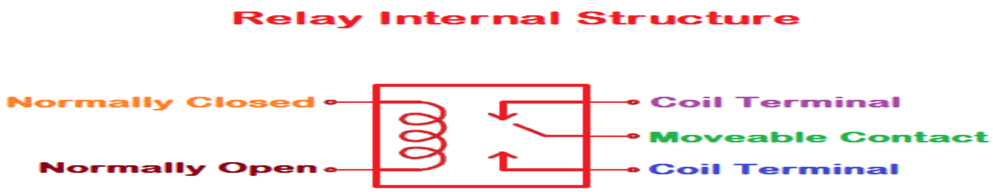
Relay is an switch, which opens and closes the circuit electronically. It uses electromagnetism from small voltage to provide higher voltages. It has two basic contacts i.e. NO (Normally Open) and NC (Normally Closed). When input voltage is applied across its coil, NC changes to NO and NO changes to NC. When input voltage is supplied, we say that the relay is energized. It has several features e.g. it can be used for switching smaller voltage to higher. But it can not be used in power consuming devices.

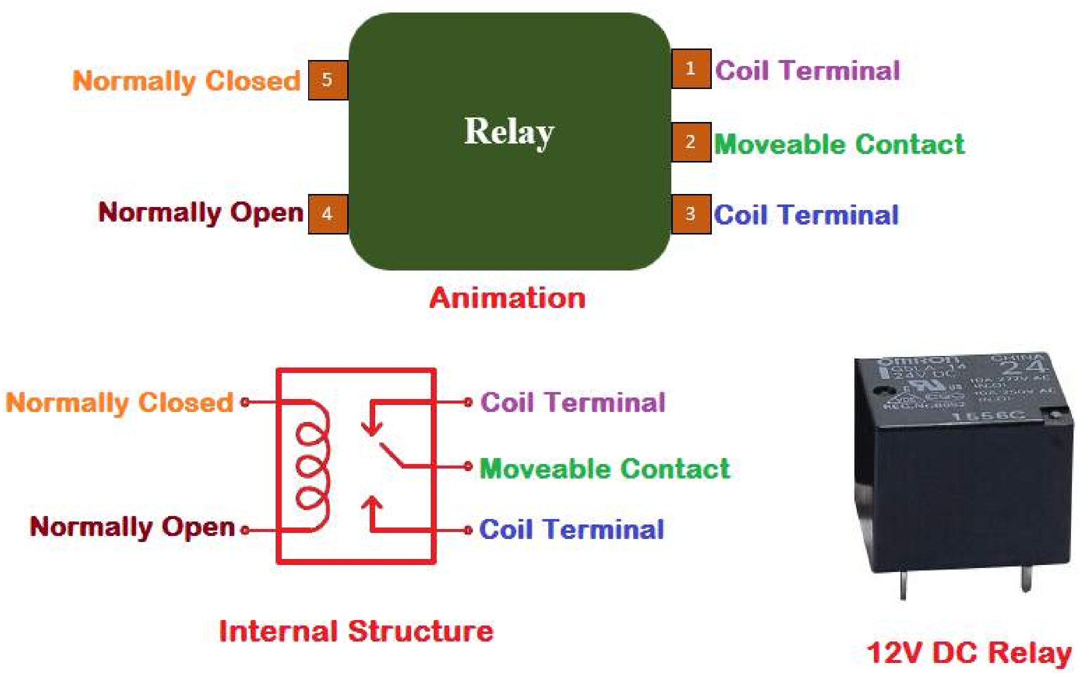
Relay Pins

Relay has total five (5) pins with different individual functions.

Three pins are at one side of the structure.

The other two pins are on the opposite side of the structure.





Relay Working Principle

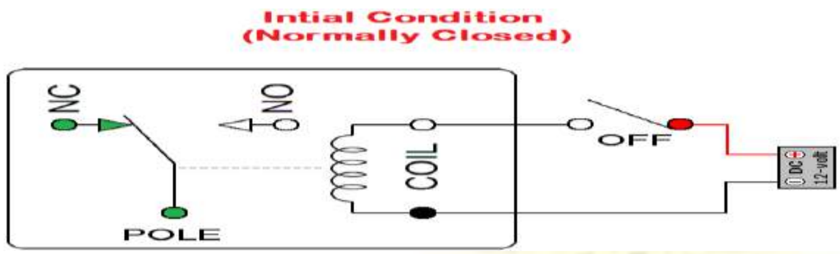
Initially when the power is not supplied and relay is in normally open condition, its contact will be opened.

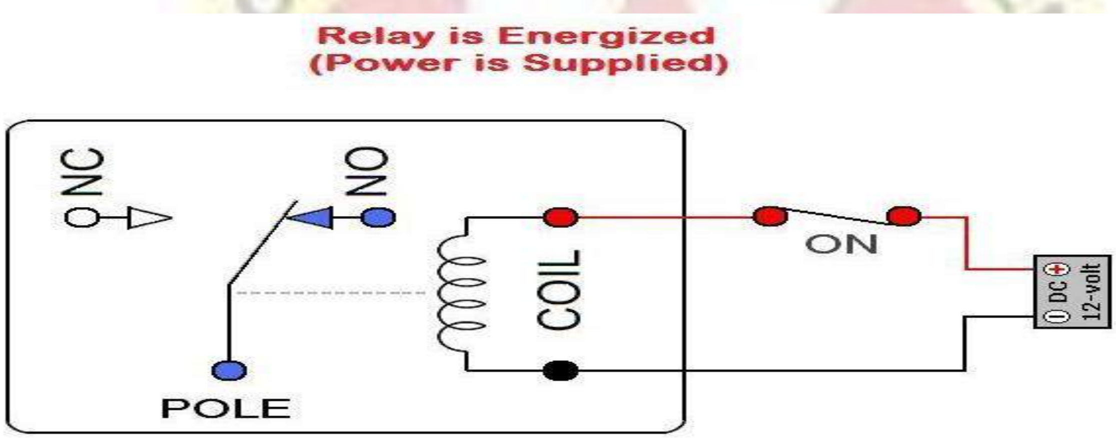
When relay is in normally closed condition, its contact will be closed.

When power is supplied to its coil, it gets energized and its normally open condition is changed to normally closed and normally closed condition is changed to normally open.

If we want to control the device via relay through a software then we have to attach this device to its normally open terminal.

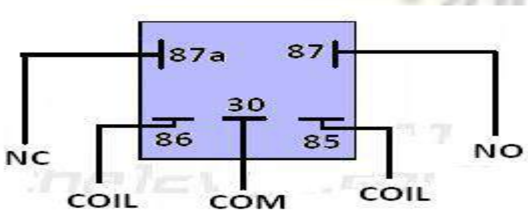
When the relay gets energized, that device will be turned on for the appropriate operation.





WORKING OF SINGLE-POLE DOUBLE-THROW RELAY

SPDT relay is an electromagnetic switch consisting of a coil (terminals 85 & 86), 1 common terminal (30), 1 normally closed terminal (87a) and a normally open terminal (87).



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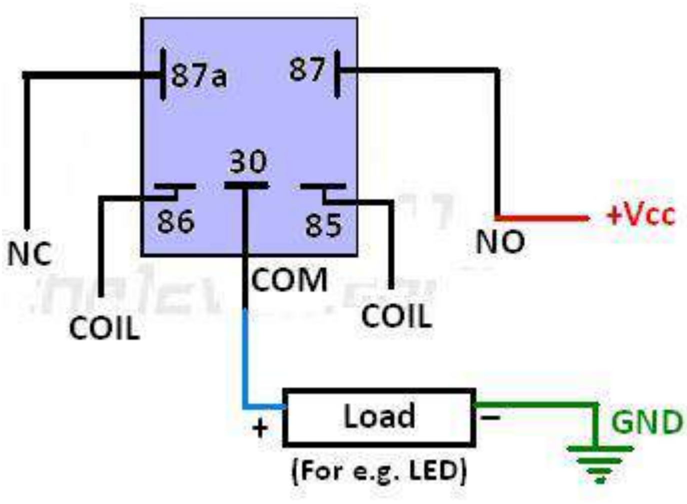


When the relay coil is energized, contact is established between the common (COM) and normally-open (NO) terminal thereby completing the supply connections to the load. Hence, the load is switched “on” when the relay is energized.

Different Types of Relay

As we have seen that relay is a switch. The terminology “Poles and throws” is also applicable for relay. Depending on the number of contacts and number of circuits it switches relays can be classified.

Before we know about this classification of contacts we have to know the poles and throws of a relay switch.

Poles and Throws

Relays can switch one or more circuits. Each switch in relay is referred as pole. Number of circuits a relay connects is indicated by throws

Depending on the poles and throws, relays are classified into

Single pole single throw

Single pole double throw

Double pole single throw

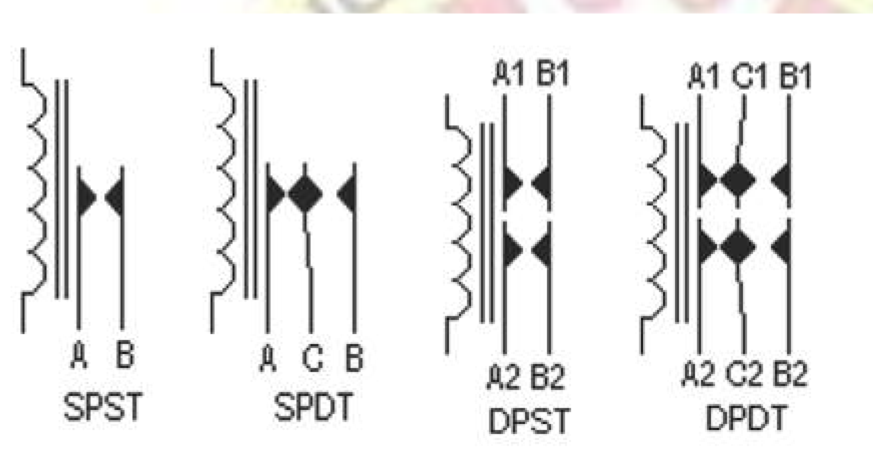
Double pole double throw

Single Pole Single Throw (SPST)– these types of relay comprise of 4 terminals. Two terminals are used as coil points and other two can be used to connect or disconnect the circuit (A and B).

2. Single Pole Double Throw (SPDT)– these types of relay comprise of 5 terminals two for coil one for common terminal(C) and rest two can be connected to the common terminal.

3. Double Pole Single Throw (DPST)– these types of relay comprise of 6 terminal two for coil and other four for connecting and disconnecting two device. In other words it contains two SPST relay in one package.

4.DoublePole Double Throw(SPDT)– these types of relay comprise of 8 terminal two for coil and another two as common point and rest for connecting and disconnecting devices. In another words in this two SPDT relay are connected in one package.



Symbols of SPST, SPDT, DPST and SPDT Relays

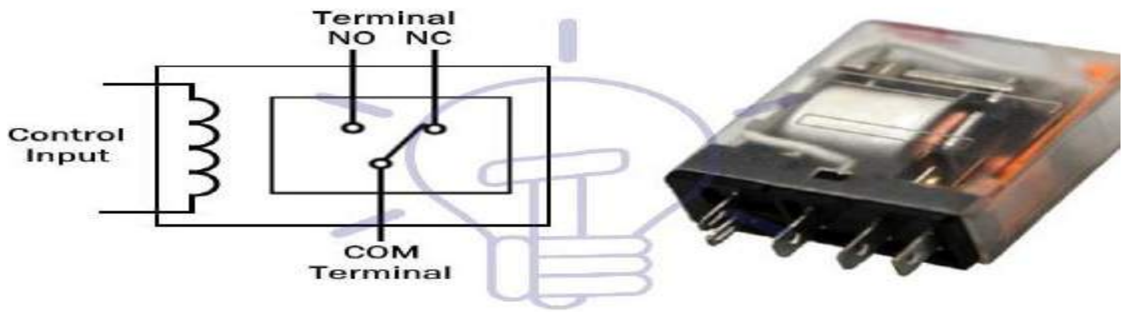
Based on Operation Principles:

These following types of relays are classified based on their different operation principles.

EMR (Electromechanical Relay)

This type of relay has an electromagnetic coil and a mechanical movable contact.

When the coil is energized it produces a magnetic field. This magnetic field attracts the armature (movable contact). When the coil is de-energized the coil loose magnetic field and a spring retract the armature to its normal position.



ElectroMechanical Relay

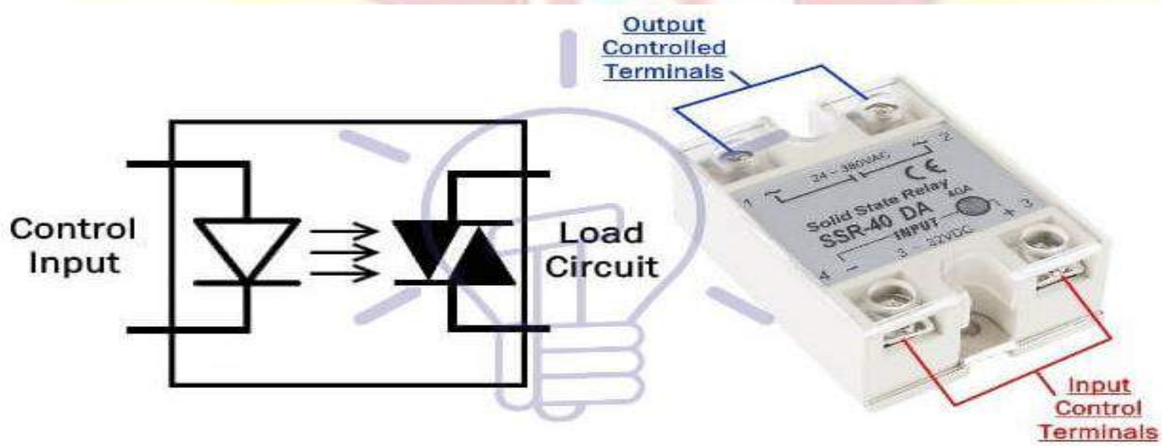
The EMR relay is designed for AC or DC source depending on the application it is used for. The structure of AC & DC EMR relay differs from each other by having a slight difference in its coil construction. The DC coil has a freewheeling diode for protection against back EMF & de-energizing the coil.

The polarity of the source in EMR relay does not matter, it energizes the coil in either way but if there is a back EMF diode installed then polarity should be considered.

The main disadvantage of EMR relay is that its contacts produce arc during breaking which leads to increasing its resistance over time & decreasing the lifespan of the relay

SSR (Solid State Relay)

SSR relay is made up of semiconductors instead of mechanical parts and it works on isolating the low voltage circuit from high voltage circuit using an optocoupler.



Solid State Relay (SSR)

When the control input is applied to a solid state relay, an LED lights up which produce infrared light. This light is received by a photosensitive semiconductor device which converts the light signal into an electrical signal and switches the circuit.

SSR operates on relatively high speed & has very low power consumption as compared to EMR relay. It has a longer lifespan because there are no physical contacts to burn out.

The main disadvantage of SSR relay is its nominal voltage drop across the semiconductor which wastes power in the form of heat.

Relay Applications

Relays are used to protect the electrical system and to minimize the damage to the equipment connected in the system due to over currents/voltages. The relay is used for the purpose of protection of the equipment connected with it.

These are used to control the high voltage circuit with low voltage signal in applications audio amplifiers and some types of modems.

These are used to control a high current circuit by a low current signal in the applications like starter solenoid in automobile. These can detect and isolate the faults that occurred in power transmission and distribution system. Typical application areas of the relays include

Lighting control systems

Telecommunication

Industrial process controllers

Traffic control

Motor drives control

Protection systems of electrical power system

Computer interfaces

Automotive

Home appliances

Ultrasonics

Introduction:

The term ultrasonics applies to sound waves that vibrate at a frequency higher than the frequency that can be heard by the human ear (or higher than about 20,000 hertz).

Sound is transmitted from one place to another by means of waves. The character of any wave can be described by identifying two related properties: its wavelength (lambda, λ) or its frequency (f). The unit used to measure the frequency of any wave is herz. One hertz is defined as the passage of a single wave per second.

INTRODUCTION

The human ear can hear the sound waves having frequencies in between 20 Hz to 20 kHz. These frequencies are known as audible frequencies.

The sound waves having frequencies less than 20 Hz are known as infrasonic waves o

The sound waves having frequencies greater than 20 kHz are known as ultrasonic waves.

The wavelength of ultrasonic waves are very much less than the wavelengths of audible sound waves.

So they applications in non-destructive testing of materials, medical diagnostics, military and marine.

Ultrasonic method is widely used in industries to find the size, shape, and location of flaws such as cracks, voids, laminations, and inclusions of foreign materials, walls thickness of produced pipes and vessels.

The wall thickness measurements are very important in corrosion studies.

Properties of ultrasonic waves

Ultrasonic waves are high frequency and high energetic sound waves.

Ultrasonic waves produce negligible diffraction effects because of their small wavelength.

Ultrasonic wave travels longer distances without any energy loss.

The speed of propagation of ultrasonic waves increases with the frequency of the waves.

At room temperature, ultrasonic welding is possible.

Ultrasonic waves produce cavitation effects in liquids.

Ultrasonic waves produce acoustic diffraction in liquids.

Ultrasonic waves cannot travel through the vacuum.

Ultrasonic waves travel with speed of sound in a given medium.

Ultrasonic waves require one material medium for its propagation.

Ultrasonic waves can produce vibrations in low viscosity liquids.

Ultrasonic wave's produces heat effect passes through the medium.

Ultrasonic waves obey reflection, refraction, and absorption properties similar to sound waves.

Ultrasonic waves produce stationary wave pattern in the liquid while passing through it.

When the ultrasonic wave is absorbed by a medium, it generates heat. They are able to drill and cut thin metals.

Ultrasonic Production:

There are three methods for producing Ultrasonic waves. They are:

(i) Mechanical generator or Galton's whistle.

(ii) Magnetostriction generator.

(iii) Piezo-electric generator.

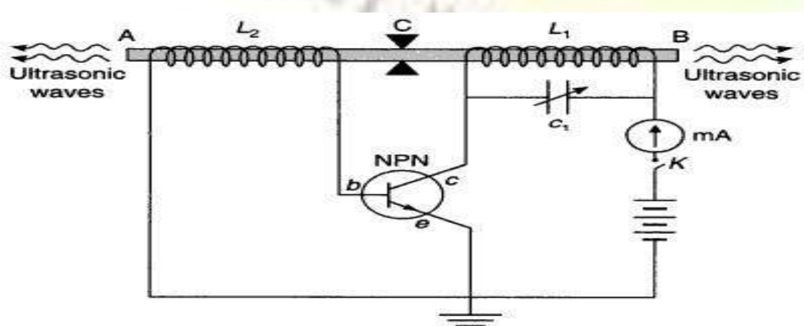
MAGNETOSTRICTION METHOD:

Principle:

The general principle involved in generating ultrasonic waves is to cause some dense material to vibrate very rapidly. The vibrations produced by this material than cause air surrounding the material to begin vibrating with the same frequency. These vibrations then spread out in the form of ultrasonic waves.

When a magnetic field is applied parallel to the length of a ferromagnetic rod made of material such as iron or nickel, a small elongation or contraction occurs in its length. This is known as magnetostriction. The change in length depends on the intensity of the applied magnetic field and nature of the ferromagnetic material. The change in length is independent of the direction of the field.

When the rod is placed inside a magnetic coil carrying alternating current, the rod suffers a change in length for each half cycle of alternating current. That is, the rod vibrates with a frequency twice that of the frequency of A.C. The amplitude of vibration is usually small, but if the frequency of the A.C. coincides with the natural frequency of the rod, the amplitude of vibration increases due to resonance.



Magnetostriction oscillator.

Construction:

The ends of the ferromagnetic rod A and B is wound by the coils L1 and L. The coil L is connected to the collector of the transistor and the coil L1 is connected to the base of the transistor as shown in the figure. The frequency of the oscillatory circuit (LC) can be adjusted by the condenser C and the current can be noted by the milliammeter connected across the coil L. The battery connected between emitter and collector provides necessary biasing i.e., emitter is forward biased and collector is reverse biased for the NPN transistor. Hence, current can be produced by applying necessary biasing to the transistor with the help of the battery.

Working:

The rod is permanently magnetized in the beginning by passing direct current. The battery is switched on and hence current is produced by the transistor. This current is passed through the coil L, which causes a corresponding change in the magnetization of the rod. Now, the rod starts vibrating due to magnet ostriction effect.

When a coil is wounded over a vibrating rod, then e.m.f. will be induced in the coil called as converse magnetostriction effect. Due to this effect an e.m.f. is induced in the coil L1. The induced e.m.f. is fed to the base of the transistor, which act as a feed back continuously. In this way the current in the transistor is built up and the vibrations of the rod is maintained.

The frequency of the oscillatory circuit is adjusted by the condenser C and when this frequency is equal to the frequency of the vibrating rod, resonance occurs. At resonance, the rod vibrates longitudinally with larger amplitude producing ultrasonic waves of high frequency along both ends of the rod.

Condition for resonance:

Frequency of the oscillatory circuit = Frequency of the vibrating rod

(i.e)

$$\frac{1}{2\pi\sqrt{LC}} = \frac{1}{2l}\sqrt{\frac{E}{\rho}}$$

where,

l is the length of the rod.

E is the young's modulus of the material of the rod.

ρ is the density of material of the rod.

Merits:

1. Magnetostrictive materials are easily available and inexpensive.
2. Oscillatory circuit is simple to construct.
3. Large output power can be generated.

Limitations

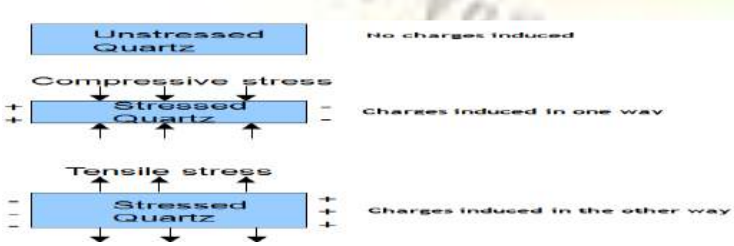
1. It can produce frequencies upto 3 MHz only.
2. It is not possible to get a constant single frequency, because rod depends on temperature and the degree of magnetization.
3. As the frequency is inversely proportional to the length of the vibrating rod, to increase the frequency, the length of the rod should be decreased which is practically impossible.

ULTRASONICGENERATION

PIEZOELECTRICEFFECT

Piezoelectric effect:

When crystals like quartz or tourmaline are stressed along any pair of opposite faces, electric charges of opposite polarity are induced in the opposite faces perpendicular to the stress. This is known as Piezoelectric effect.



Piezoelectric effect- Mechanism:

Piezoelectric and inverse piezoelectric effects are only exhibited by certain crystals which lack centre of symmetry. In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed, so that the crystal overall is electrically neutral. Each of these sides forms an electric dipole and dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned during poling , a process by which a strong electric field is applied across the material, usually at elevated temperatures.

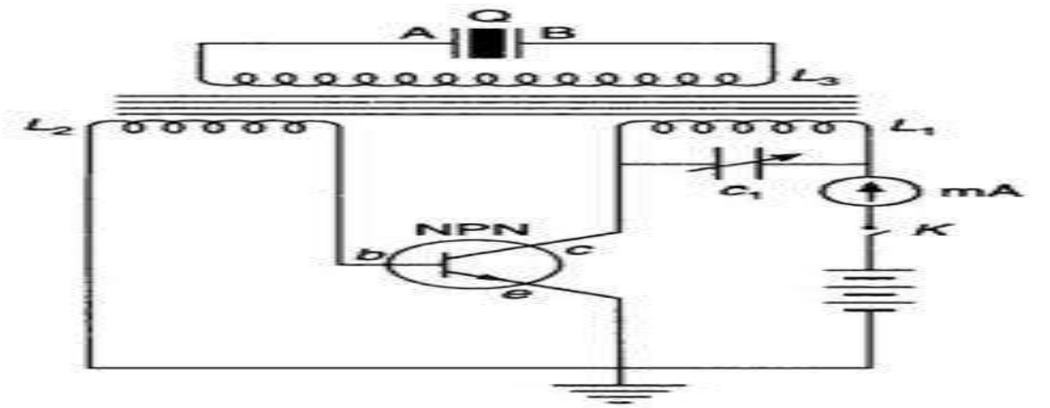
When a mechanical stress is applied, this symmetry is disturbed, and the charge asymmetry generates a voltage across the material. For example, a 1 cm cube of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12,500 V.

Piezoelectric materials also show the opposite effect, called converse (inverse) piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal.

Inverse piezoelectric effect:

When an alternating e.m.f is applied to the opposite faces of a quartz or tourmaline crystal it undergoes contraction and expansion alternatively in the perpendicular direction. This is known as inverse piezoelectric effect. This is made use of in the piezoelectric generator.

The tank circuit has a variable capacitor 'C' and an inductor 'L' which decides the frequency of the electrical oscillations. When the circuit is closed current rushes through the tank circuit and the capacitor is charged, after fully charged no current passes through the same. Then the capacitor starts discharging through the inductor and hence the electric energy is in the form of electric and magnetic fields associated with the capacitor and the inductor respectively. Thus we get electrical oscillations in the tank circuit and with the help of the other electronic components including a transistor, electrical oscillations are produced continuously. This is fed to the secondary circuit and the piezoelectric crystal (in our case a slab of suitably cut quartz crystal) vibrates, as it is continuously subjected to varying (alternating) electric field, and produces sound waves. When the frequency of electrical oscillations is in the ultrasonic range then ultrasonic waves are generated. When the frequency of oscillation is matched with the natural frequency of the piezoelectric slab then it will vibrate with maximum amplitude. The frequency generated is given as follows:



Piezoelectric oscillator.

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

$$f_1 = \frac{p}{2t}\sqrt{\frac{Y}{\rho}}$$

(d) Advantages

1. The maximum frequency of the ultrasonic wave produced using this method is 500 MHz.
2. The output frequency is independent of temperature and humidity.
3. A stable and constant output frequency is produced because the breadth of the resonance curve is small.
4. It is more efficient than magnetostriction oscillator.

(e) Drawbacks

1. The piezoelectric oscillator is costly.
2. The cutting and shaping of the piezoelectric crystal is difficult.

Ultrasonicwavedetection

Detectionofultrasonics

Thepresenceofultrasonicwavescanbedetectedbythefollowingmethods.

Piezoelectricmethod

Kundt'stubemethod

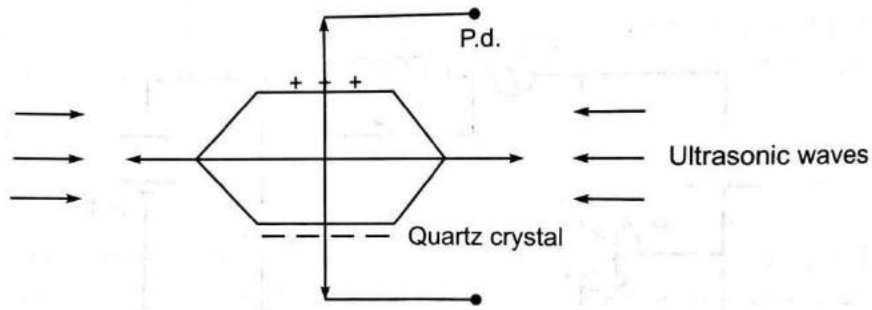
Sensitiveflamemethod

Thermaldetectionmethod

Piezoelectricmethod

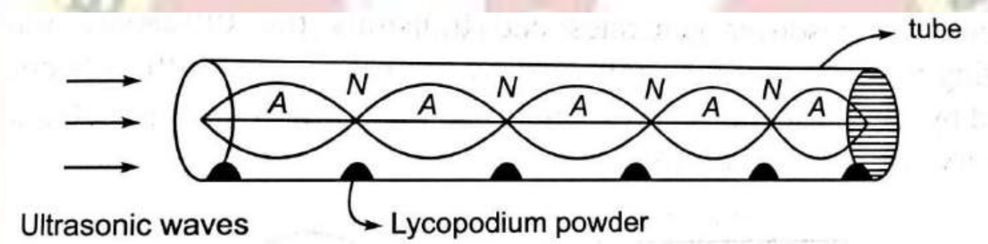
Piezoelectriceffectcanalsousedforthedetectionofultrasonics.

Whenevertheultrasonicwavesareincidentalongthemechanicalaxisofthecrystalacertainpotential differenceisdevelopedacrossthefaces.



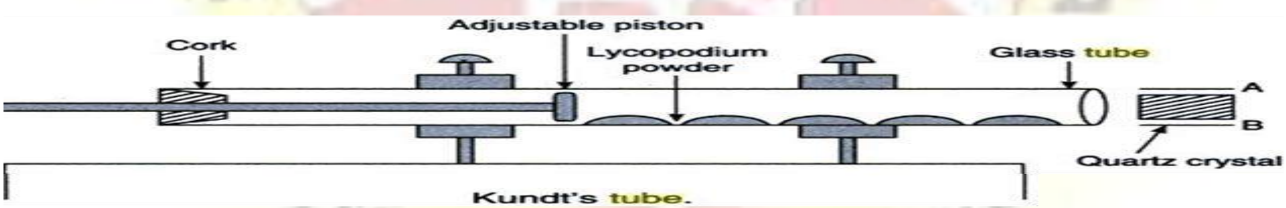
This potential difference indicates the ultra sonic waves.

As shown in figure Kundt'stu be filled with lycopodium power in the bottom portion of the tube can Also be used for detecting ultra sonic waves who seleng this of the order of a few millimeters. Whenultrasonicwavespassthroughtubethenstationarywavesareformedduetosuperpositionof incident and reflected waves. The power will be collected as leaps at nodes and dispended atantinodes.



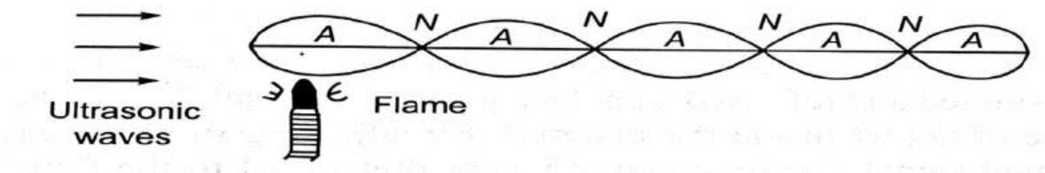
By observing this,wecandetecttheultrasonicwavesinthetube.

KUNDT'S TUBE



Sensitive flame method

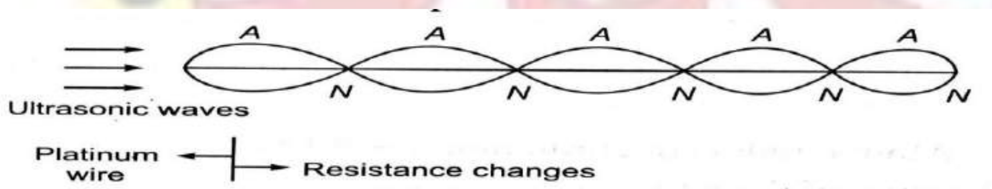
- A narrow sensitive flame is moved along the medium.
- At the positions of antinodes, the flame is steady.
- At the positions of nodes, the flame flickers because there is a change in pressure.
- In this way, positions of nodes and antinodes can be found out in the medium.
- By observing this, we can detect the ultrasonic waves



Thermal detection method

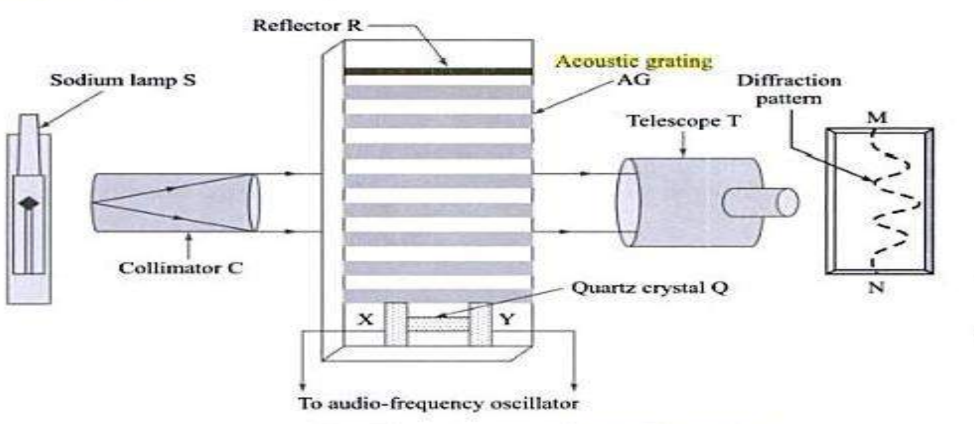
When ultrasonic waves pass through a medium, then alternative compressions and rare factors areformed. At compression, particles of medium are brought closer and collisions between themincreases. As a result of this the temperature of medium increases at compressions. On the otherhand, the temperature of medium decreases at rarefaction due to the fact that particles of mediumgo moveaway fromeachother andfrequencyofcollisionsisdecreased

When platinum wire is moved in the medium consists of standing waves of ultrasonics due tovariations of temperature at nodes and antinodes, the resistance of the wire changes. By noticingthechangingof resistance ofwire one candetectthepresenceofultrasonicwaves.



Application Acoustic Grating

The acoustic grating is based on the principle of diffraction of light by ultrasonic waves passing through a liquid. This phenomenon was discovered by Debye and Sears in 1932. When ultrasonic waves are propagated in a liquid, the density of liquid varies from layer to layer due to periodic variation of pressure. Hence the liquid behaves like a diffraction grating. Such a grating is known as acoustic grating as shown in Figure



Experimental set-up of acoustic grating.

$$d \sin \theta_n = n \lambda \quad (1)$$

where n = 0, 1, 2, 3, ... is the order of diffraction, λ is the wavelength of light used and d is the distance between two adjacent nodal or anti-nodal planes.

Knowing n, θ_n and λ, the value of d can be calculated from eqn. (1). If λ_u is the wavelength of the ultrasonic waves through the medium, then

$$d = \lambda_u/2$$

$$\text{or} \quad \lambda_u = 2d \quad (2)$$

If the resonant frequency of the Piezo-electric oscillator is N, then the velocity of ultrasonic wave is given by

$$v = f \lambda_u = 2fd \quad (3)$$

This method is useful in measuring the velocity of ultrasonic waves through liquids and gases at various temperatures. From these measurements, many parameters of the liquid such as free volume, compressibility, etc., can be calculated.

ApplicationsOfUltrasonicWaves:

They are used to detect any deformities (flaws, cracks) in metal blocks or sheets.

They are used to clean the hard to reach parts of machinery, like spiral tubes.

Bats use ultrasoung waves tp find their prey. Bats produce high- pitched ultrasonic squeaks. These squeaks are reflected by objects such as prey’s and are returned to the bat's ear. This allows a bat to know the distance of its prey.

Dolphins use ultrasound to find fish and to detect sharks that may attack them.

Ultrasound waves are commonly used for medical diagnosis and therapy, and also as a surgical tool.

They are used to check the development of foetus during pregnancy to detect any abnormalities.

They find their application in breaking stones formed in the kidneys into fine grains.

Ecocardiography: These waves are used to reflect the action of heart and its images are formed. This technique is called echocardiography.

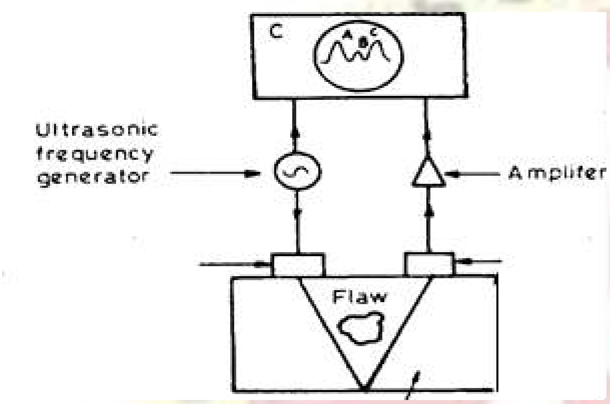
Ultrasonography: The technique of obtaining pictures of internal organs of the body by using echoes of ultrasound waves is called ultrasonography.

+

1. **Detection of flaws in metal or non destructive testing:**

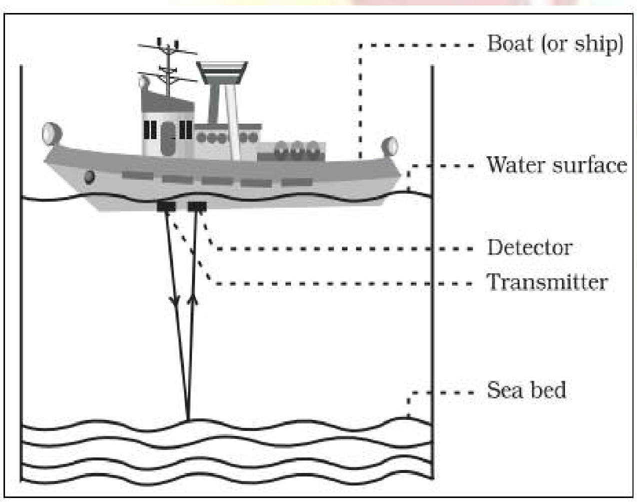
The purpose of non destructive testing is to find out whether any flaws exist in a finished product without causing dam- age to the body. Ultrasonic waves can be used to detect flaws in metal. We know that flaw in the metal produces a change in the medium due to which reflection of ultrasonic waves takes place. Hence when ultrasonic waves pass through a metal hav- ing some hole or crack inside it, an ap- preciable reflection occurs. The reflection also takes place at the back surface of the metal. The reflected pulses are picked up by receiver and are suitably amplified. These pulses are now applied to one set of plates of cathode ray oscillograph. The transmitted signal and reflected signal from the flaw and back surface of metal produce a peak each. The position of the second perk on the time base of oscillograph will give distance of flaw.

The experimental arrangement is shown in Fig. 1.2.7. Here the transmitting trans- ducer sends a beam of ultrasonic through the material under test. In the presence of flaw in the specimen, the waves will be reflected back and the corresponding recorded intensity in the receiver will be very weak. Similarly, if there is a crack in the specimen, the transmitted waves will have the intensity extremely small. The reflected beam is recorded by using cathode ray oscillograph (CRO).

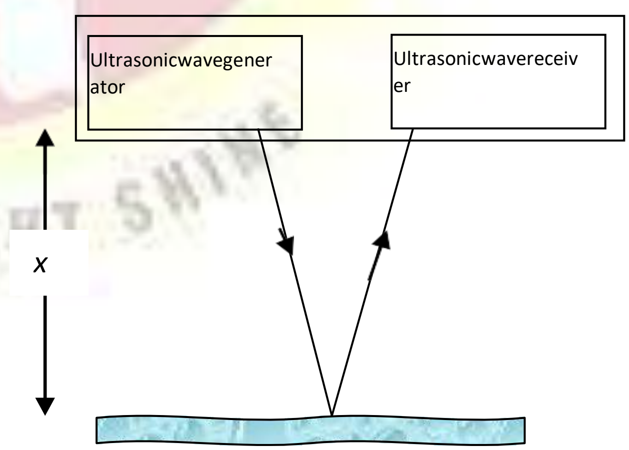


SONAR:

SONAR stands for "Sound Navigation And Ranging". Sonar is used to detect submerged objectsunderwater such as submarines, sinked boats inside the sea or depth of the sea. It is similar toRADARin the air.



Ultrasound sent by the transmitter and received by the detector.



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SONAR consists of a transmitter and a receptor or detector and is installed at the bottom of a ship.

The transmitter produces and transmits ultrasonic waves.These waves travel through sea water and after striking the objects on the bottom of sea, are reflected back and received and recorded by the detector.

The sonar device measures the time taken by ultrasound waves to travel from ship to bottom of sea and back to ship.

Half of this time gives the time taken by the ultrasound waves to travel from ship to sea bed.

Let the time interval between transmission and reception of ultrasound signal is t.

Speed of sound through sea water is v

Total distance travelled by waves = 2d.

Then, $2d = v \times t$.

This method of measuring distance is also known as ‘echo-ranging’.

/

Ultrasonic Welding:

Practically, all metals and plastics can be welded using ultra�nic waves of suitable energy. The surfaces of the work pieces are cleaned and held together. They are subjected to ultrasonic oscillations at the spot where they are to be welded. The ultrasonic energy converts to heat at the contact area a result of friction arising between the surfaces. As the temperature of surface layers exceed the re-crystallization point, the layers melt and bond together to form a strong joint. The merits of this process are that it induces negligible stress at the spot of welding and that the structure of the materials remains unchanged.

.Ultrasonic Soldering:

Normally, surfaces are covered with contaminants grease and oxide films. Such films prevent formation of a good joint. Therefore, prior to soldering the surfaces are cleaned with active fluxes. The fluxes, when heated, dissolve the oxide film and uncover the clean metal surfaces which readily allow the molten solder to forma firm joint. This method is however not suitable for soldering aluminum. Active metals such as aluminum can be sol- dered without fluxes with the help of ultrasonic waves. In this case soldering is done by a special iron which vibrates at a frequency of tens ofkilohertz. Ultrasonic waves can also be used for drilling and cutting processes in metals. These waves can also be used for solder- ing, for example, aluminum canot be soldered by normal methods. To solder aluminum ultrasonic wave along with electricalsoldering iron is used. Ultrasonic welding can be done at room temperatures.

Ultrasonic Cleaning:

In the fabrication of electronic devices, it becomes highly essential to clean the sur- faces of parts and components at different stages of production. Cleaning of the surfaces is commonly carried out in either organic solvents or weakly alkaline acqueous solutions con- taining surface active agents. To make the scrubbing of surfaces more effective, the phe- nomenon of cavitation is utilized. Ultrasonic cleaning baths are used for the purpose. The hydraulic shock arising at the surface of a part due to cavitation destroys any layer of contaminants. Bubbles penetrate under the layer, tear it off and break it down into minute pieces. The surface active agent pulls them away into the solution.

Ultrasonicwavescanalsobeusedasacleaningagenttocleanclothes,utensils,removingdustandsootfrom chemney.

Chemicalreactions:

Thesewavesactasacatalysttostartandincreasetherateofreaction.

Signalingsystems:

Ultrasonicwavesaremoreenergeticandhavelessdiffractingproperty,sotheytravellongdistances in air and water even sea water.Hence, they can be used in signaling systems in air andseawater.

Medicalapplications:

Ultrasonicwavesareusedinvariousdiagnostic andtherapeutic applications.

Estimationofvelocityofbloodflowinveinsandarteries:

The Doppler shift in higher ultrasound frequencies is used to estimate the velocity of blood flow inveinsand arteries.

Ultrasonicscanningforheart,prostateenlargementdetectionandsonogram(echogram)ofpregnantwoman:

Lowenergyultrasoundfromthetransducerisusedtostudythemovementoftheheart,prostateenlargementin ultrasound scanning.

Asonogram(orechogram)ofapregnantwomancanalsobeobtainedusingultrasoundscanning,which shows the fetal growth and studyof thebodilyorgans in the womb.

Diagnosticuseof ultrasound:

Ultrasonicwaves areused indetectectingtumers oranyotherdefects inthe body.

Rheumaticand neuralgicpains:

Whentheultrasonicwavesareexposedonthepartwheretherheumaticorneuralgicpainsoccur,the massageaction of the waves relieves the pain.

Sterilization:

Ultrasonic waves sterilize water and milk.

Other application sultrasonic waves:

Ultrasonic wet-millingandgrinding

Ultrasonicsisanefficientmeansforthewet-millingandmicro-grindingofparticles.Inparticularforthemanufacturingofsuperfine-sizeslurries,ultrasoundhasmanyadvantages,whencomparedwith common size reduction equipment, such as: colloid mills (e.g. ball mills, bead mills), discmillsor jet mills.

Ultrasonic cellextraction

Ultrasonics isused in the extraction of enzymes and proteins stored in cells and subcellularparticles. The extraction of organic compounds contained within the body of plants and seeds by asolventcan bedoneusingultrasound.

Ultrasonicdegassingofliquids

In this case the ultrasound removes small suspended gas-bubbles from the liquid and reduces thelevelof dissolved gas below the natural equilibrium level.

Ultrasonicleakdetectionofbottlesandcans:

Ultrasoundisbeingusedinbottlingand fillingmachinesto checkcansandbottlesforleakage.

Ultrasonicwire,cableand strip cleaning:

Ultrasonic cleaning is an environmentally friendly. The cleaning of continuous materials, such aswire and cable, tape or tubes can be done with ultrasonic cleaning process. The ultrasonic powerremoveslubrication residues likeoil orgrease,

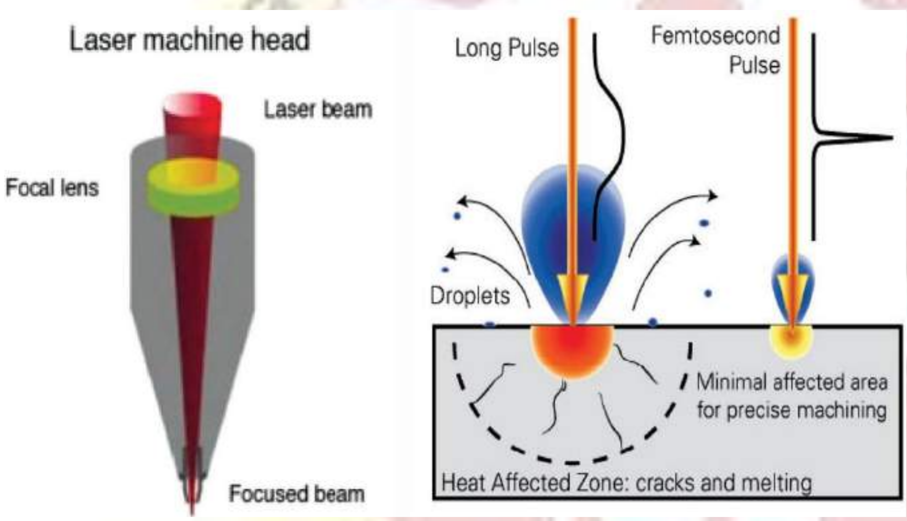
Application of LASER in industry.

Lasers in Industries

1. Lasers are used to cut glass and quartz.
2. Lasers are used in electronic industries for trimming the components of Integrated Circuits (ICs).
3. Lasers are used for heat treatment in the automotive industry.

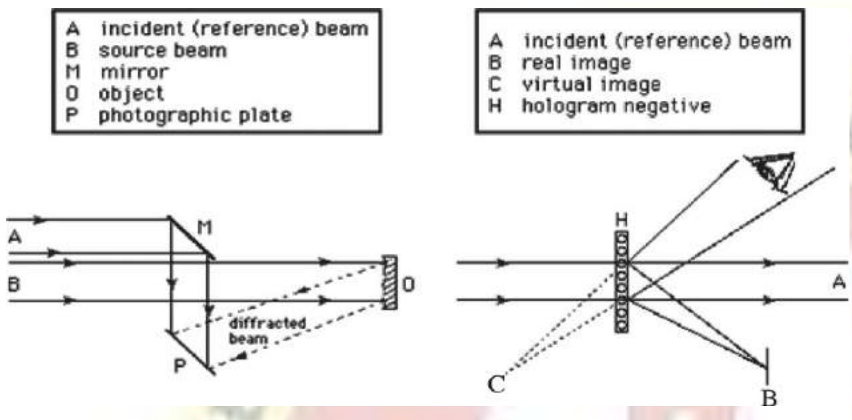
4. Laser light is used to collect the information about the prefixed prices of various products in shops and business establishments from the bar code printed on the product.
5. Ultraviolet lasers are used in the semiconductor industries for photolithography. Photolithography is the method used for manufacturing printed circuit board (PCB) and microprocessor by using ultraviolet light.
6. Lasers are used to drill aerosol nozzles and control orifices within the required precision

2 Laser Machining and Cutting Laser energy can be focused in space and concentrated in time so that it heats, burns away, or vaporizes many materials. Although the total energy in a laser beam may be small, the concentrated power on small spots or during short intervals can be enormous. Although lasers cost much more than mechanical drills or blades, their different properties allow them to perform otherwise difficult tasks. A laser beam does not deform flexible materials as a mechanical drill would, so it can drill holes in materials such as soft rubber nipples for baby bottles. Likewise, laser beams can drill or cut into extremely hard materials without dulling bits or blades. Laser machining is not dependent on the material hardness but on the optical properties of the laser and the optical and thermo-physical properties of the material. For example, lasers have drilled holes in diamond dies used for drawing wire.Several recent research have shown that laser cutting is best achieved with ultrafast lasers (Fig. 2), as the material only ablates and does not get a chance to melt under such ultrafast time scale interactions.



3.2 Laser Imaging and Holography

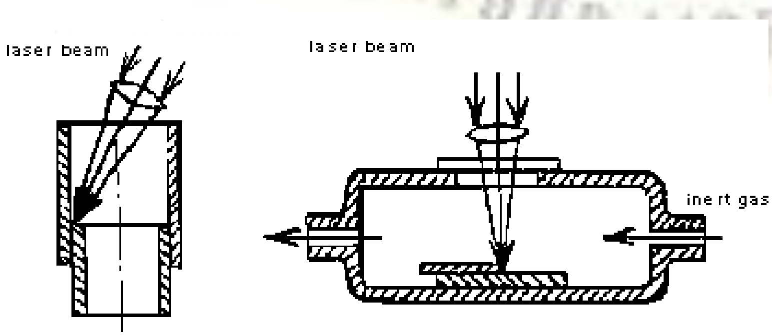
The coherence of laser light is crucial for interferometry and holography, which depend on interactions between light waves to make extremely precise measurements and to record three- dimensional images. The result of adding light waves together depends on their relative phases. If the peaks of one align with the valleys of the other, they will interfere destructively to cancel each other out; if their peaks align, they will interfere constructively to produce a bright spot. This effect can be used for measurement by splitting a beam into two identical halves that follow different paths. Changing one path just half a wavelength from the other will shift the two out of phase, producing a dark spot. This technique has proved invaluable for precise measurements of very small distances. Holograms are made by splitting a laser beam into two identical halves, using one beam to illuminate an object. This object beam then is combined with the other half— the reference beam—in the plane of a photographic plate, producing a random-looking pattern of light and dark zones that record the wave front of light from the object (Fig. 4). Later, when laser light illuminates that pattern from the same angle as the reference beam, it is scattered to reconstruct an identical wave front of light, which appears to the viewer as a three-dimensional image of the object. Holograms now can be mass-produced by an embossing process, as used on credit cards, and do not have to be viewed in laser light.



WELDING

Laser welding makes use of optical radiation to melt the material to a desired depth, minimizing at the same time the surface vaporization. In practice, this process utilizes mostly the continuous lasers of the infrared

CO_2 spectrum and the Nd:YAG lasers, of a wavelength of 10.6 nm and 1.06 nm, respectively. Welding, as against some other processes, uses a lower intensity optical beam and a longer laser pulse [of the order of ms]. The advantage of laser welding rests in the absence of physical contact with the electrode, in localised heating and cooling, in welding parts in a pro- tective atmosphere or sealed into optically transparent material (see Fig. 20). Lasers can weld, e.g., air-tight shields of miniature relays, pacemakers, contacts in microelectronics, and metal sheets in car or aircraft industry.



Laserdrillingisbasedonremovingmaterialbyvaporization.Thebeam intensity should be higher than for welding, and so drilling preferspulse lasers of pulse length less than 1 nm. The first laser drilling goes backto1965.Then,arubylaserwasemployedtodrilldrawingdiamonddieholes.Atpresent,laserdrillingmakesus emainlyoftheNd:YAGpulselaser,itsadvantageconsistinginitsabilitytodrillminiatureholes10to100 nm in diameter at spots where other techniques prove difficult or even impossible.

Laser cuttingis utilised when some low thermal conductivity materialis to be removed. With cutting, the material is to be vaporized as qiuckly aspossible, while keeping the area thermally affected as small as possible. ThelasersusedforthispurposeareagainthecontinuousCO_2lasersofupto15 kW. In industrial laser cutting, some gas is transported to the cutting spotcoaxially with the laser beam; in case of metals, a reactive gas, as, e.g.,oxygen.What follows, is an isothermical reaction to speed up cutting. This ishowsuchmaterialsastitanium,low-carbonsteels,andstainlesssteelsarecut.Tocutnon metallicmaterials,forinstance,ceramics,plastics,and wood, inert gas is transported to the spot only to remove the material thatmelteddownorvaporized.Thesametechniqueisapplicabletotextile,paper, and glass. The advantge of laser cutting rests in its great speed, incuttingvariousshapes(seeFig.21),initspossibleautomation,innon-contact approach, in the good quality of the cut, and, last but not least, in thelimited area of thermal effect.

Laser glass decoration is a modification of laser cutting. At the spotfocused laser beam impinges upon the glass surface, the melted glass willevaporate and cracks will appear on its surface. They will diffuse light,producing thus a shiny effect of the lasered ornament. Glass is decorated bylasers whose radiation is easily absorbed by the glass, e.g., by the continousCO_2 laser.

Lasermarking is based onlocalsurfaceevaporationoftheobjectmaterial. In this case, the laser beam passes through a template with thedesiredpattern(e.g.lettersornumbers).Whenthelaserbeamimpingesupon the surface of the object, the pattern of the template will show up.Another way to perform this operation is to move the laser beam along thematerial to be marked, or to move the object. The marks identifying theobjectscanbelaseredontosemiconductor,ceramic,andmetallicsurfaces,aswellasonpaper,glass,plastics, ferriteelements, etc. The depth of the markingusuallyrangesbetweenfractionsandunitsofmillimetres,thethickness being of the order of micrometres. This technique is performed bythe powerful pulse laser of pulse energy up to tens of joules, or by thecontinuous laser, i.e., the Nd:YAG or excimer laser. The advantage of lasermarking is the non-contact process, eliminating any possible stresses andstrains in the lasered material.

Laser quenching can be defined as thermal treatment of metals makinguse of laser radiation to obtain speedy heating. Compared to other ways ofheating, lasers are able to localise thermal treatment even to spots inacces-sible by other methods, as well as to secure non-deforming treatment. Thisprocedure is preferred mainly in industry for the so called **transformationstrengthening** of some stressed car and aircraft parts. Also in this case, thesourceofradiationisthecontinousCO_2laser;thistime,however,ofapower of several thousand watts.

Laserradarinegology-LIDAR

Ground laser radars (see Fig. 24) are used in *ecology* to measure airpollution.Theyarealsousedin*meteorology*.Inthiscaseitis**bothreflection and scattering** that **are made use of in measurements**. Passingthrough the atmosphere, the laser pulse is scattered by the molecules andaerosolspresentthere,causingMie,Raleigh,orRamanscattering.Partofthe radiation scattered backwards is concentrated by a telescope, and pas-sing through a filter detected by a photodetector. The received signal, whoseamplitude at any moment is proportional to the intensity of the scatteredradiation is recorded as a function of time, due to which it is possible toobtain also the distance of the scattering body, while the filter width and/orthe attached spectrometer determine the spectrum of the received signal.LIDAR serves to monitor the distribution and direction of smoke trails; tomeasure the bottom level and profile of clouds, of atmospheric turbulence,distributionandareasofvariousimissionsintheatmosphere,etc.