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For D.E.C.E III Year (5th Semester)

N. Dhananjaya

G. Nageswara Rao

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P R E F A C E

This book **"INDUSTRIAL ELECTRONICS"** has been designed as per C-16 syllabus prescribed by **SBTET, Telangana** for Diploma in **Electronics and Communication Engineering**.

` This book uses plain, Simple diagrams and lucid language to explain fundamentals of this subject. The idea and scope for the book emerged from my own experience in attempting to acquire a good understanding of the rapidly evolving field of Electronics and Communication at a reasonable level of detail and breadth of coverage. The book is very useful for the students of ECE and EEE either diploma or B-Tech**.** Each chapter is well supported with necessary illustrations and practical examples**.** I hope that students will find the book very useful and the teachers will be able to use it with easy in the classroom to prepare their students to meet the expectations prevalent in Industry.

I am deeply indebted to our management & Principal **Sri. N.S.S.V. Ramanjaneyulu** (M.Tech, MISTE, MIETE) A.A.N.M. & V.V.R.S.R Polytechnic, Gudlavalleru for their words of advice and motivation have been of great support to me during preparation of this book.

I would like to express a coordial thanks to my HOD Sri.**Ch Srihari**, my colleagues and students for their suggestions. My heartful thanks to my wife **Suma** for her support to make it complete in time. I also feel happy to say thanks to my Sons **Sanay** and **Pranay** for not disturbing me during the preparation of this book.

Finally, I would like to express my sincere thanks to **MGB** PUBLISHERS, for bringing out this book in a very short time. I am confident that lecturers and students will welcome this book. Any suggestions for the improvement of this book are most welcome.

Author

G Nageswara Rao

DEDICATED

TO

My Brother in laws ***SHIVA & ASHOK***

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CHAPTER 1

Power Electronic Devices

OBJECTIVES

1.1 List different thyristor family devices.

1.2 Sketch the ISI circuit symbols SCR, SCS, SBS, SUS, DIAC, TRIAC.

1.3 Explain construction and working of SCR.

1.4 Explain Two-transistor model of SCR and its VI Characteristics

1.5 Mention the ratings of SCR.

1.6 Explain the construction and working of GTO SCR

1.7 Explain construction and working of DIAC & TRIAC.

1.8 Explain Volt-ampere characteristics of DIAC & TRIAC

1.9 State the different modes of TRIAC triggering.

1.10 Distinguish between SUS, SBS, SCS & LASCR

1.11 Explain the construction and working of UJT

1.12 Give the definition of intrinsic stand-off ratio of UJT

1.13 Explain negative resistance region of UJT

1.14 Explain SCR triggering using UJT

1.15 Explain the working principle of controlled rectifier.

1.16 Explain about speed control of DC motor using SCR

1.17 List the applications of DIAC, TRIAC & SCR

1.0. Introduction

In early 1950s, the semiconductor diode replaced the vacuum-tube rectifier and thus improved the efficiency by reducing on-state voltage drop from 30 V (vacuum tube) to 1-2 volts (semiconductor diode). The silicon controlled rectifier (SCR) was invented in 1956 and was commercially available in 1957. It was due to its invention, a new branch of engineering, i.e., power electronics has been created. Rating of both diode and SCR went to the highest level of all power semiconductor devices, viz, several kV, kA and MW. Both these devices (converter – grade) are most robust, reliable and have the highest transient withstand capability. Fast-recovery diodes and SCR (inverter-grade) are fast and their switching losses are small, but they are costly. TRIACs.

By mid-1960s, BJT based converters were used at high frequency (10-20 kHz). Thus a practical, efficiency lightweight dc regulator became available. However, a power BJT requires substantial and sustained base drive current (current gain, $h_{fc} = 3 - 10$). Both SCR and BJT are current controlled devices. In the late 1970s, the MOSFET was invented and high frequency (200 kHz – 1 MHz), highly-efficient low-power converters were realized. It is a voltage – controlled device, which requires negligible power for the gate – drive circuit. it further reduced the size of the converter. Moreover, parallel operation of MOSFET for increasing the current rating, became extremely simple. Development of 1GBT in 1980's further improved the converter efficiency (above 90%) by reducing on-state voltage drop and losses, which was present in MOSFET. The gate characteristics of 1GBT are same as MOSFET (low power, low voltage) and on-state characteristics are like SCR. Although operating frequency range is less than MOSFET, but power-handling capacity is more than MOSFET.

1.0.1. Concept of power electronics

Power electronics is the branch of Electrical Engineering which deals with conversion and control of electrical devices.

The filed of electrical engineering may be divided into three areas or specialization namely,

i) Electronics
ii) Power
iii) Control

Electronics basically deals with the study of semiconductor devices and circuits at low power levels. Power deals with the generation, transmission and distribution of electrical energy and static and rotating power equipments. Control deals with the steady state and dynamic characteristics of closed loop systems.

Power electronics is defined as the use of solid state electronics for the control and conversion of electronic power. Here control of electric power means, the output voltage can controlled and conversion of electric power means, ac to dc, dc to ac, dc to dc and ac to ac.

1.0.2. Applications

Power Electronics are now widely used in the industries. Examples of successful applications are as follows.

1. Control of ac and dc drives in rolling mills, papers and textile mills, traction vehicles, mine winders, cranes, ventilation fans, etc.
2. Uninterruptible power supplies (UPS) for critical loads such as computers and space applications.
3. Machine tool controls
4. Illumination controls for lighting in trains, homes and theatres.
5. Excitation systems for alternator and synchronous condenser.
6. Battery charging
7. Electric traction
8. Solid state controllers for home appliances

1.0.3. Advantages:

1. High efficiency due to low loss in power semiconductor devices.
2. Fast response of power electronic systems as compared to electro mechanical converter systems.
3. Long life and reduced maintenance due to absence of mechanical wear.
4. High reliability of power electronic converter systems.
5. Small size and low weight require less floor area.
6. Lower acoustic noise compared to electromagnetic controllers.
7. Mass production of power semiconductor devices has resulted in lower cost of the converter equipment.
8. Flexibility in operation due to digital controls.

1.0.4. Disadvantages

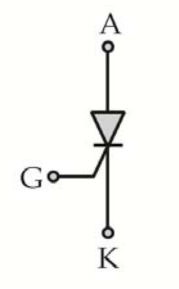
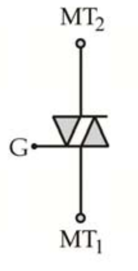
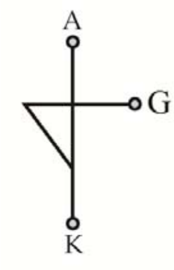
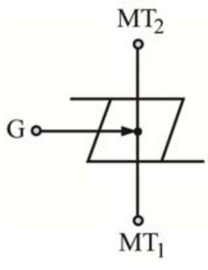
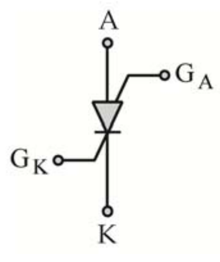
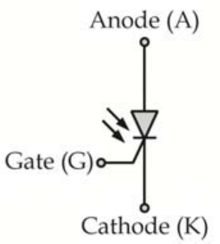
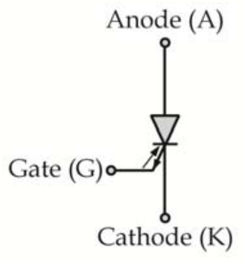
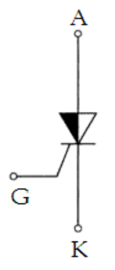
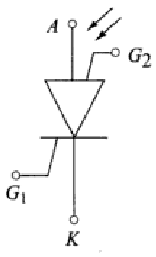
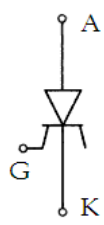
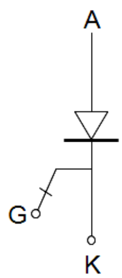
1. Power semiconductor converters have a tendency to introduce current and voltage harmonics into the supply systems and controlled systems.
2. Thyristor controllers have low overload capacity
3. Harmonics in the supply system causes interference with communication systems and distortion of supply system.
4. Some converters, such as controlled rectififer, cycloconverter and ac voltage controller suffer from a low power factor, particularly at low output voltages.

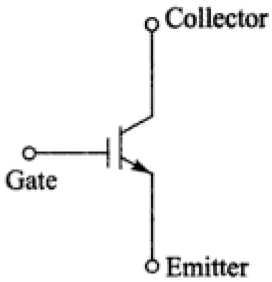
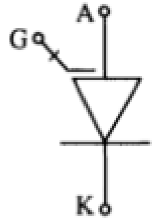
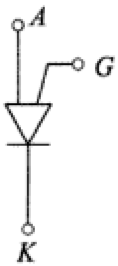
1.1. List different thyristor family devices

- The name "thyristor" is derived by a combination of the capital letters from **THY**ratron and trans**ISTOR**.
- International Electrotechnical Commission (IEC) in 1963 decided the definition of Thyristor as under.
  - It constitutes three or more P – N junctions.
  - It has two stable states, an ON – state and an OFF-state and can change its state from one to another. Thyristor is a four layer, three junction, P – N – P – N semiconductor switching device.
- There are several members in the thyristor family. Some of them are mentioned below:

1.	SCR	:	Silicon Controlled Rectifier
2.	DIAC	:	Bidirectional diode thyristor
3.	TRIAC	:	Bidirectional triode thyristor
4.	SUS	:	Silicon Unilateral Switch (or) complementary SCR (CSCR)
5.	SBS	:	Silicon Bilateral Switch
6.	SCS	:	Silicon Controlled Switch
7.	LASCS	:	Light Activated SCS
8.	LASCR	:	light activated SCR
9.	GTO SCR	:	Gate turn-off thyristor SCR
10.	ASCR	:	Asymmetrical SCR
11.	RCT	:	Reverse conducting thyristor
12.	SITH	:	Static induction thyristor
13.	GATT	:	Gate assisted turn-off thyristor
14.	MCT	:	MOS-controlled thyristor
15.	PUT	:	Programmable unijunction transistor
16.	IGBT	:	Insulated gate bipolar transistor
17.	ASBS	:	Asymmetrical Silicon Bilateral Switch

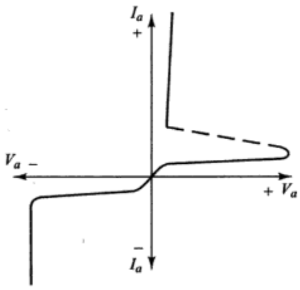
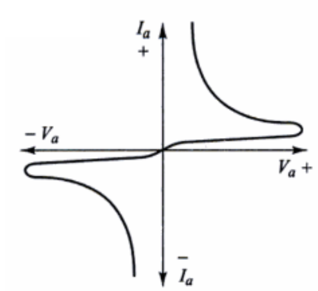
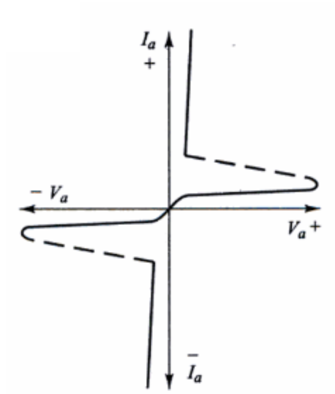
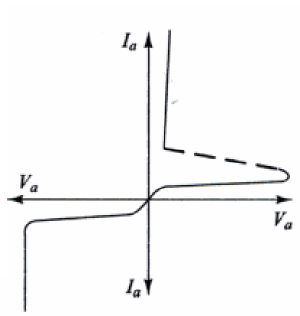
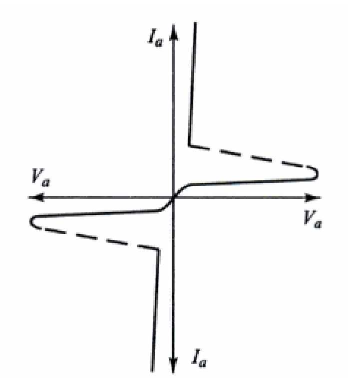
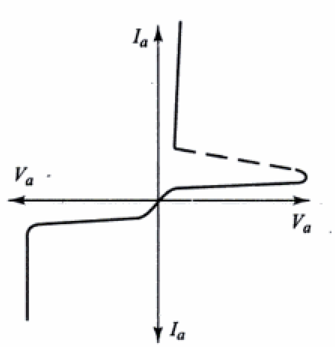
1.2. Sketch the circuit symbols for each device.

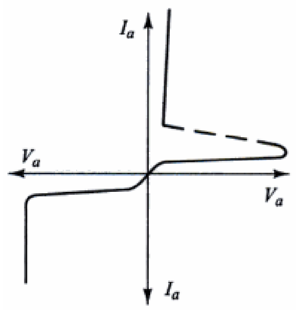
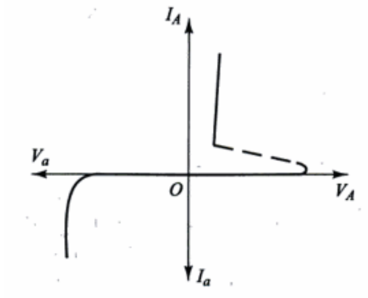
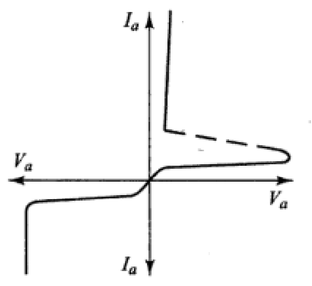
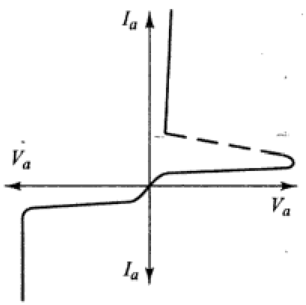
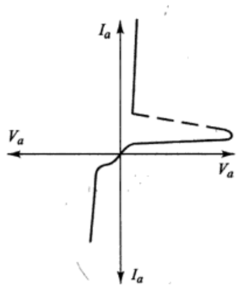
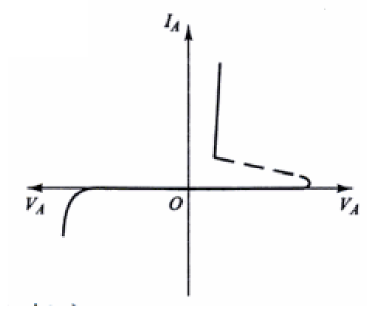
SCR	TRIAC	DIAC
		
SUS	**SBS**	**SCS**
		
LASCR	**GTO SCR**	**ASCR**
		
LASCS	**RCT**	**SITH**
		

IGBT	MCT	PUT
		

Additional Information

V-I Characteristics

SCR	TRIAC	DIAC
		
SUS	**SBS**	**SCS**
		

LASCR	GTO SCR	ASCR
		
LASCS	**RCT**	**SITH**
		

1.3. Explain constructional details of SCR.

- SCR is the oldest & first member of the thyristor family.
- SCR is a four layer, three-junction, PNPN semiconductor switching device. It has three terminals; anode, cathode and gate. Fig. (a) gives constructional details of a SCR.
- The three junctions J_1 J_2 and J_3 are formed from the four layers of alternate P-type and N-type silicon semiconductors.
- The threaded portion is provided for the purpose of tightening the thyristor to the frame or heat sink with the help of a nut. Gate terminal is kept near the cathode terminal.
- Schematic diagram and circuit symbol for a thyristor are shown respectively in fig. (b) and (c).
- The terminal connected to outer 'P' region is called Anode (A) The terminal connected to outer 'N' region is called cathode (K)
- The terminal connected to inner 'P' region is called the Gate(G)

- As SCRs are solid state devices, they are compact, possess high reliability and have low loss. Because of these useful features, SCR is almost universally employed for all high power-controlled devices.
- Like the diode, an SCR is an unidirectional device that blocks the current flow from cathode to anode.
- Unlike the diode, a thyristor also blocks the current flow from anode to cathode until it is triggered into conduction by a proper gate signal between gate and cathode terminals.
- But by proper triggering the gate terminal (i.e., by proper gate signal between gate and cathode terminal) the SCR will conduct the curent from anode to cathode. Hence, the SCR is used as a "controlled switch" to perform various functions such as rectification, inversion and regulation of power flow.

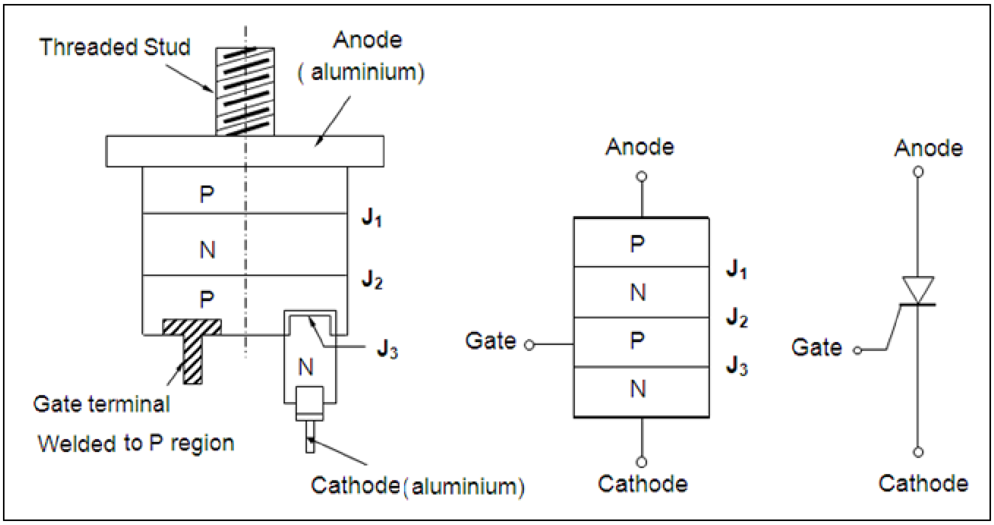


Fig. (a) Fig. (b) Fig. (c)

Do you Know?

1) SCR is a solid state equivalent of thyratron the gate, anode and cathode of SCR is corresponding to the grid, plate and cathode of the thyratron. For this reason SCR is sometimes called thyristor.
2) It is called SCR because; silicon is used for its construction and its operation as a rectifier (very low resistance in forward conduction and very high resistance in the reverse direction) and can be controlled.
3) For large current applications, thyrirstors need better cooling.
4) SCRs of voltage rating 10kV and an rms current rating of 3000A with corresponding power handling capacity of 30MW are available.
5) In the normal operating conditions of SCR, anode is held at high + ve potential w.r.t. cathode and gate at small +ve potential w.r.t cathode fig. shows the symbol of SCR.

1.4. Explain the working of SCR using two Transistor analogy

- When a PN junction is added to a junction transistor, the resulting three PN junction device is called a silicon controlled rectifier. Fig. (a) shows its construction.

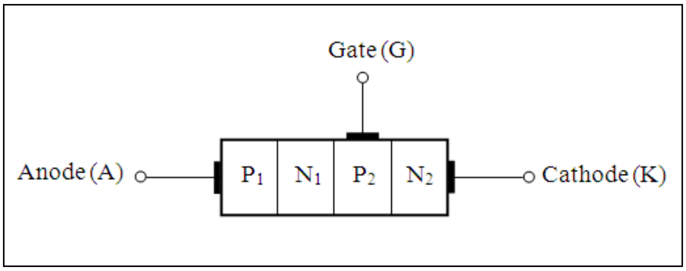


Fig. (a)

- The basic structure of SCR can be divided in to 3-layer structure as shown in fig. (b).
- It may be noted that the upper 3-layer structure is a PNP-transistor, where as the lower one is an NPN transistor. Thus SCR can be represented by two transistors Q_1 (i.e., PNP) and Q_2 (i.e., NPN) inter connected as shown in fig. (c).
- Sometimes, this circuit is also called as the two transistor analogy or an ideal latch of a SCR.

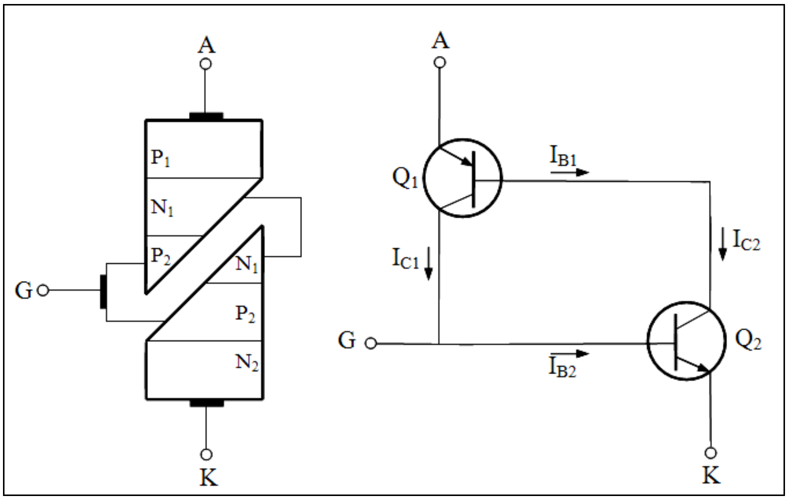


Fig. (b) Fig. (c)

- It is evident from the fig. (c) that the collector of each transistor is connected to the base of other transistor. Therefore the collector current of transistor Q_1 is the I_B of transistor Q_2 and the base current of transistor Q_1 is the collector current of transistor Q_2.
- For this circuit, we have an action of positive feedback or regeneration. It means that if there is a change in current, at any point in the loop (formed by transistors Q_1 & Q_2), it is amplified and returned to the starting point with the same phase.

- For Example, if the base current of transistor Q_2 increases, the collector current of transistor Q_2 will also increase.
- It causes more base current through transistors Q_1 due to which the collector current of transistor Q_1 increases.
- This action will continue till both the transistors switch and it will pass the current from anode to cathode.
- In the other hand, if the base current of transistor Q_2 decreases, the collector current of transistor Q_2 will also decreases.
- It causes the reduced base current through transistor Q_1 due to which the I_C of transistor Q_1 decreases.
- This action will continue till both the transistors are driven in to cut-off. In this case, the SCR acts like an OFF switch and hence it will block the current from anode to cathode.

Additional Information

- The principle of SCR operation can be explained with the use of its two transistor model (or two transistor analogy).
- Fig. (a) shows schematic diagran of a SCR. From this figure two-transistor model is obtained by bisecting the two middle layers, along the dotted line, in two separate halves as shown in fig. (b).
- Junctions $J_1 - J_2$ and $J_2 - J_3$ are form PNP and NPN transistors separately. The circuit representation of the two – transistor model of a thyristor is shown in fig. (c).

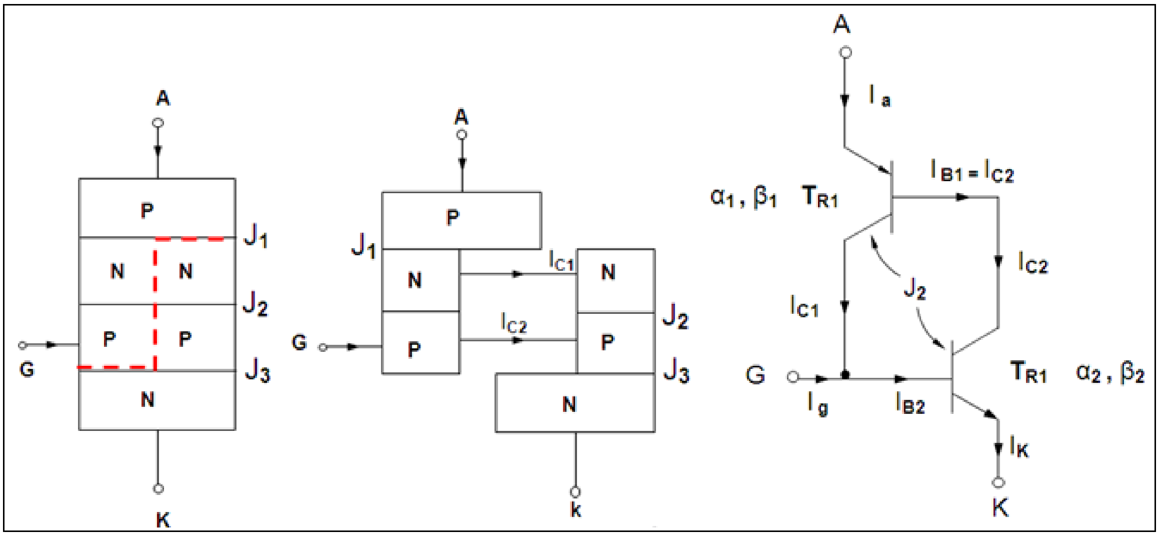


Fig. (a) Fig. (b) Fig. (c)

Mathematical Analysis:

- In the **off-state** of a transistor, collector current I_C is related to emitter current I_E as

  $\boxed{I_C = \alpha I_E + I_{CBO}}$.

  Where α = the common-base current gain

  I_{CBO} = the common – base leakage current of collector – base junction of a transistor.

- **For transistor** TR_1
  - Emitter current $I_E = \text{anode current } I_a$
  - $\text{Collector current} = I_C = I_{C1}$.

  $$\boxed{I_{C1} = \alpha_1 I_a + I_{CBO1}} \quad \ldots(1)$$

  Where α_1 = common-base current gain of TR_1

  I_{CBO1} = common base leakage current of TR_1

- **For transistor** TR_1
  - Similarly, for transistor TR_2, the collector current I_{C2} is given by

  $$\boxed{I_{C2} = \alpha_2 I_k + I_{CBO2}} \quad \ldots(2)$$

  Where α_2 = common-base current gain of TR_2

  I_{CBO2} = common base leakage current of TR_2

  I_k = emitter current of TR_2

- The sum of two collector currents gives by equations (1) and (2) is equal to the anode current I_a entering at anode terminal A.

  $$\boxed{I_a = I_{C1} + I_{C2}}$$

  Or $$\boxed{I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2}} \quad \ldots(3)$$

- When gate current is applied, then $\boxed{I_k = I_a + I_g}$. Substituting this value of I_k in equation (3) gives,

  $$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

  $$\boxed{I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}}$$

- For a silicon transistor, current gain α is very low at low emitter current. With an increase in current, α increase rapidly as shown in fig.
- With gate current $I_g = 0$ and with thyrisstor forward biased, $(\alpha_1 + \alpha_2)$ is very low and forward leakage current somewhat more than $(I_{CBO1} + I_{CBO2})$ flows.

- If, by some means, the emitter current of two component transistors can be increased so that $\alpha_1 + \alpha_2$ approaches unity, they I_a would tend to become infinity thereby turning on the device.

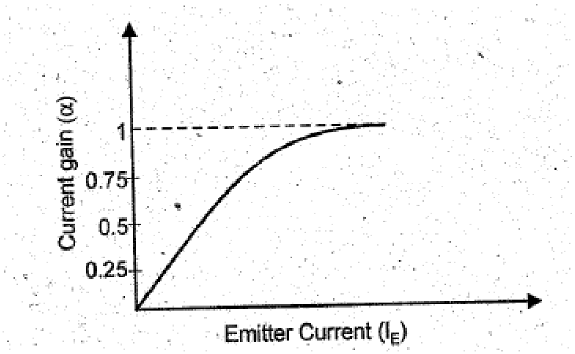


Fig. (d)

1.5. Explain the Volt-Ampere characteristics of SCR.

- An elementary circuit diagram for obtaining static V-I characteristics of a thryristor is shown in fig. (a).
- The anode and cathode are connected to main source through the load.
- The gate and cathode are fed from a source V_S which gives positive gate current from gate to cathode.

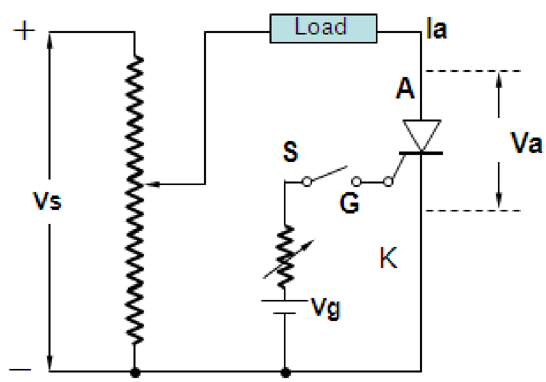


Fig. (a)

- Fig. (b) shows static V-I characteristics of a thyristor.
- The three basic modes of operations of SCR are:
    1. Forward Blocking mode.
    2. Forward Conduction mode.
    3. Reverse Blocking mode.

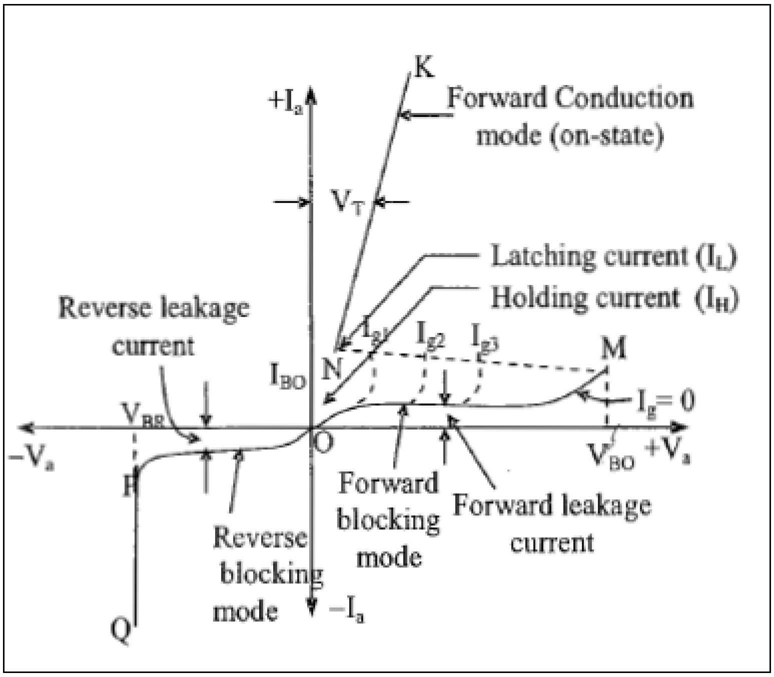


Fig. (b)

$I_{g1} > I_{g2} > I_{g3} > I_{g0}$

V_a = Anode voltage

I_a = Anode current.

V_{BO} = Forward break over voltage.

V_{BR} = Re verse breakdown voltage

I_G = Gate current

1. Forward Blocking mode:

- When the anode voltage is made positive with respect to the cathode, with gate circuit open, SCR is said to be forward biased as shown in fig. (c).
- During this mode, junctions J_1, J_3 are forward biased but junction J_2 is reverse biased.
- In this mode, a small leakage current of the order of few milliamperes will flows from anode to cathode.
- OM in V-I characteristics represents the forward blocking mode of SCR.
- SCR is treated as an open switch in the forward blocking mode

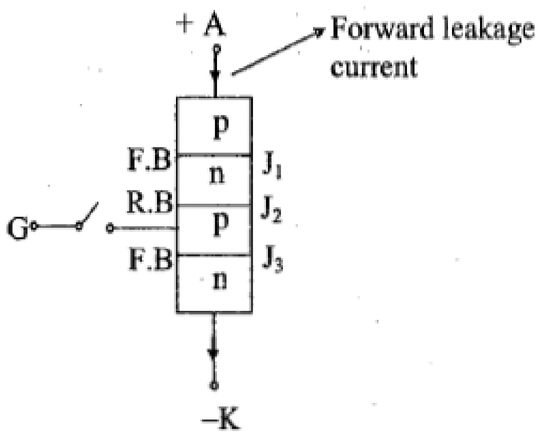


Fig. (c)

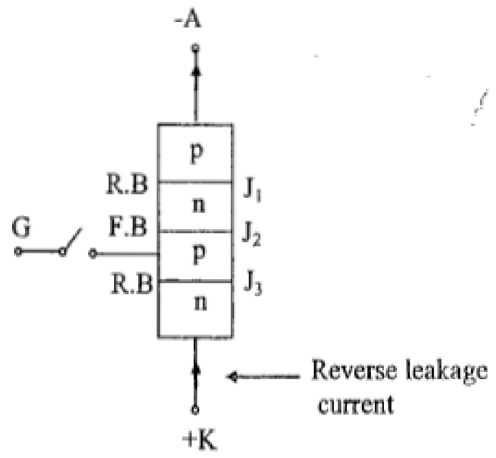


Fig. (d)

2. Forward Conduction mode:

- A thyristor can be brought from forward blocking mode to forward conducting mode by applying.
  - A positive gate pulse between gate and cathode

    (or)

  - A forward break over voltage (V_{BO}) across anode and cathode
- When anode to cathode forward voltage is increased with gate circuit open, reverse biased junction J_2 will have an avalanche breakdown at a voltage called forward break over voltage V_{BO}. After this breakdown, thyristor gets tuned ON.
- In V-I characteristics NK represents the forward conduction mode.
- In this mode, SCR is in on-state and behaves like a closed switch. Voltage drop across thyristor in the on state is of the order of 1 to 2V depending on the rating of thyristor.
- This small voltage drop V_T across the device is due to ohmic drop in the four layers.
- It is seen from fig. (b) that this voltage drop increases slightly with an increase in anode current.
- Once the thyristor conducts, it behaves like a conducting diode and there is no control over the device. The anode current of thyristor is limited by an external impedance (or) load.

a) Latching current (I_L):

- Latching current is the minimum forward current that flows through the SCR to keep it in forward conduction mode (i.e ON state) at the time of triggering. If forward current is less than latching current, SCR doesnot turn-on.

- The latching current is of the order of 10 to 15 milliamperes.
- The gate pulse width should be chosen to ensure that the anode current rises above the latching current (I_L)

b) Holding current (I_H):

- It is defined as the minimum value of anode current below which the SCR gets tuned OFF. Latching current (I_L) is more than holding current I_H.

Note:

- ❖ Latching current (I_L) is associated with turn on process.
- ❖ Holding current (I_H) is associated with turn off process

3. Reverse Blocking mode:

- When cathode is mode positive with respect to anode with switch S open, thyristor is reverse biased as shown in fig. (d). junctions J_1, J_3 are reverse biased whereas junction J_2 is forward biased.
- When cathode is made high potential with respect to anode with gate open, then the SCR is said to be reverse biased.
- J_1 and J_3 are reverse biased and J_2 is forward biased.
- The device behaves like a two diodes connected in series with reverse voltage applied across them.
- A small leakage current of the order of a few milliamperes or a few microamperes depending upon the SCR rating flows.
- This is reverse blocking mode, called the off-state, of the SCR.
- The SCR in the reverse blocking mode may therefore be treated as an open switch.
- If the reverse voltage increased, then at reverse breakdown voltage (V_{BR}), an avalanche breakdown occurs at J_1 and J_3 and the reverse current increases rapidly. (PQ)
- Due to this large reverse current and the losses will be increased hence it may lead to damage the thyristor. Hence when the thyristor is operating in reverse bias a voltage less then V_{BR} is to applied otherwise the thyristor may lead to damage.

Additional Information

General Thyristor Ratings

1. Anode Voltage ratings
2. Current ratings
3. Power ratings
4. Turn ON & Turn OFF times

5. Latching & holding currents
6. dv/dt rating
7. di/dt rating
8. Temperature ratings

Note: Above ratings will be specified by the manufacturer

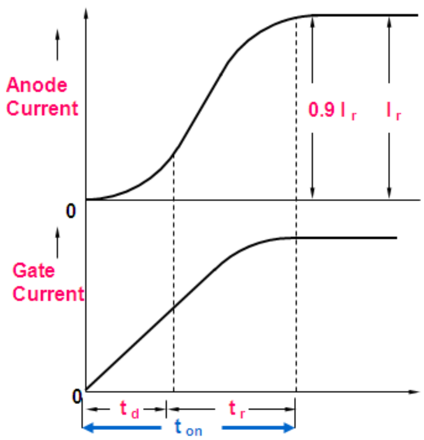
1. Anode Voltage Rating

It indicates the maximum voltage that can be applied across the device without causing any breakdown at junction area.

2. Current rating

- There are different current ratings established with repetitive and non-repetitive waveforms
- Currents should not rise the thyristor junction temperature even for short over loads of current
- If the junction temperature increases rapidly, the thyristor will be damaged.
- Hence the operating current should be within limits for safe working of the device

3. Turn on time

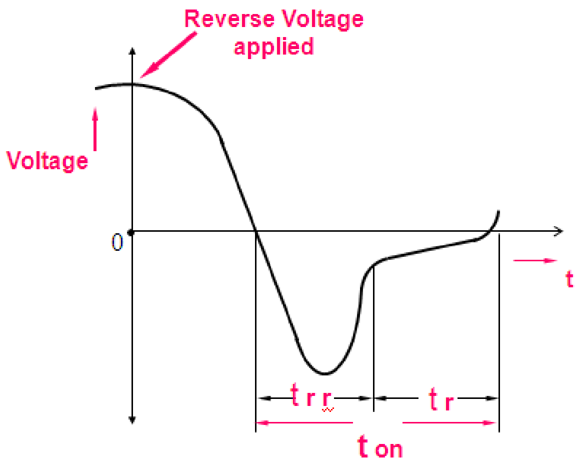


Turn ON characteristics

- Time taken by the thyristor to reach full conduction
- It consists of two parts
  - Delay time (td)
  - Rise time (tr)
- ton = td + tr = *Delay time (td) + Rise time (tr)*

4. TURN OFF Time

- When reverse voltage is applied to Thyristor the time taken from zero current point to time when Thyristor regains its full blocking voltage is called turn-off time
- Turn off time consists of
    - Reverse recovery current time , t rr
    - Recombination time, t r
- Turn off time = Reverse Recovery Time + Combination time
- t off = t rr + tr
- Circuit turn off time must be greater than device turn off time for safe turnoff.



Turn OFF characteristics

5. dv/dt rating

- It indicates the maximum rate of rise of voltage from anode to cathode without any harm to the device

6. di/dt rating

- It indicates the maximum rate of rise of current from anode to cathode without any harm to the device.

1.6. Mention the important ratings of SCR.

- For the reliable operation of the Thyristor, the device should be operated within specified limits. These safe limits are called Thyristor ratings
- The commercially available SCR’s are C20D, C22D, C220D type and its ratings are:

Voltage Rating

1)	Forward Break over Voltage (V_{FBO}):	:	50 – 1200V
2)	ON-state voltage	:	1 - 1.5 V
3)	Firing Voltage	:	More than 4 V
4)	Voltage safety factor	:	between 2 to 2.7
5)	Rate of Rise of Voltage $\left(\frac{dv}{dt}\right)$		
6)	Peak Inverse Voltage (V_{PIV})		

Current Rating

7)	Latching Current	:	I_L in mA(8-10mA)
8)	Holding Current	:	$I_H < I_L (3-5mA)$
9)	Gate Current	:	$I_g = 11mA$ to $18 mA$
10)	Rate of Rise of Current	:	$\frac{di}{dt} = 300 A/\mu sec$
11)	Gate Power Loss	:	P_g in mW
12)	Turn-ON time	:	$T_{ON} = 2 - 10\mu sec$
13)	Turn-OFF time	:	$T_{OFF} = 50 - 200\mu sec$

1.7. Define Forward Break over Voltage, Latching Current, Holding Current, Turn – ON Time, Turn – OFF Time of SCR.

1. **Forward Break over Voltage** (V_{FBO}): It is the voltage at which the SCR is switched from its OFF position to ON position. Its value is maximum for $I_G = 0$. Commercially available SCR's have V_{FBO} ranging from 50 to 1200 V.
2. **Latching Current** (I_L): It is minimum value of current which is required to latch the device from its OFF – state to its ON – state. It can also be defined as the minimum value of current required to trigger the device. Its value is normally in mA.

3. **Holding Current (I_H):** It is the value of anode current below which the SCR switches from its ON position to OFF position under the given conditions. Always I_H is less than I_L i.e., latching current.

   For example, if the latching current of a particular thyristor is in the range of 8 -10 mA, its holding current may be 3 to 5 mA.

4. **Turn – ON Time (T_{ON}):** The time for which the device waits before achieving its full conduction is known as Turn-ON time or response time. It can also be defined as the time taken by the device before getting latched from its OFF-state to its ON-state. The usual value of T_{ON} time lies between 2 to 10 μ secs.

5. **Turn – OFF Time (T_{OFF}):** A reverse voltage is required to be applied across the device for switching it OFF. After applying the reverse voltage, a finite time known as T_{OFF} to get switched OFF (commutated). Its value is around 200 μ secs.

1.8. Distinguish between SUS, SBS, SCS & LASCR

S.No.	SUS	SBS	SCS	LASCR
1.	It is available in ICs	It is available in ICs	It is a four layer device	It is a four layer device
2.	It is a three terminal device	It is a three terminal device	It is a four terminal device	It is a three terminal device
3.	It is a unidirectional switch	It is a bidirectional switch	It is a unidirectional switch	It is a unidirectional switch
4.	High switching stability	High switching stability	Low switching stability	Low switching stability
5.	Its cost is low	Its cost is low	Its cost is high	Its cost is high
6.	It has +ve turn ON characteristic	It has +ve ON characteristic	It has +ve turn OFF characteristics	It has +ve turn ON characteristics
7.	Used in high speed switching circuits, digital circuits, pulse generator etc.	Used in D.C. power supply static VAR, high speed switching circuits, digital circuits	Used in low power digital circuits	Used in HVDC electrical power transmission, static VAR compensation systems

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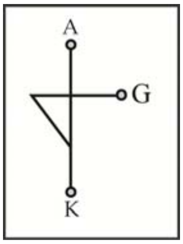
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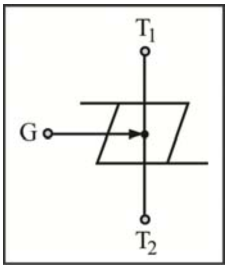
<td>
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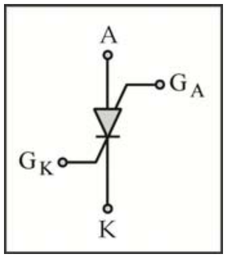
<td>
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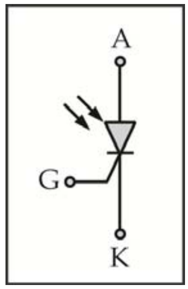
<td>
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1.9 Explain the construction and working of UJT

- A Uni-Junction Transistor is a three terminal semiconductor switching device.

a) Construction of UJT

- The basic construction of UJT is shown in the fig. (a).

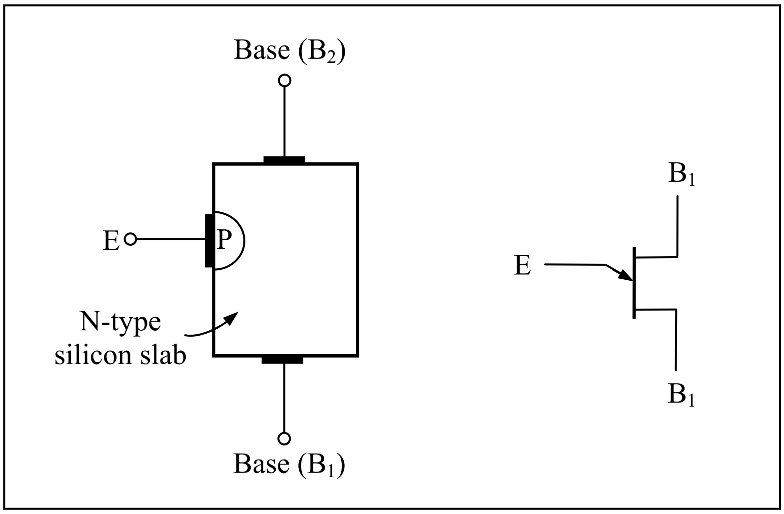


Fig. (a) Fig. (b)

- It consists of lightly doped N-type silicon bar.
- Two ohmic contacts are attached to this bar at the opposite ends. These are denoted as B_1 (Base 1) and B_2 (Base 2).
- A PN-junction is formed at a point closer to B_2 than to B_1. The terminal brought from this P-type material is called Emitter (E).
- Fig. (b) shows the circuit symbol of the UJT (The arrow indicates the direction of flow of conventional current when the UJT is forward biased).
- The following points are worth noting regarding the construction of the UJT.
  1. Since the device has one PN-junction and three leads, it is commonly known as a Uni-Junction Transistor (uni means single).

2. With one PN-junction, the device is really a form of diode. Since two base terminals are taken from one section of the diode, this device is also called Double-Based Diode.
3. The N-type region is lightly doped while P-type (emitter) is heavily doped. For this reason, the resistance between E and B_1 is more than that is between E and B_2.

Working Principle of UJT

The working principle of UJT can be easily understood with the help of an equivalent circuit of UJT.

The equivalent circuit of a UJT is shown in fig. (c). It consists of a diode D and the resistance RBB. The diode D, represents PN-junction and RBB represents the resistance between base B2 and base B1.

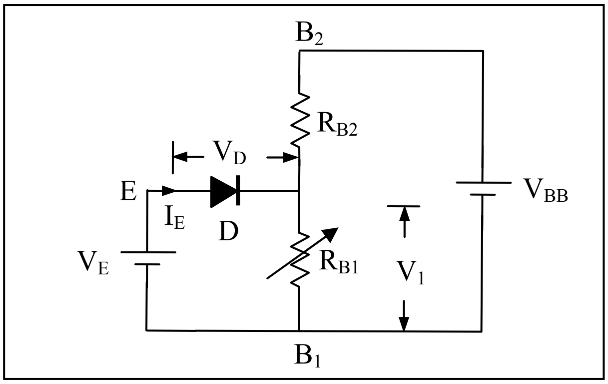


Fig. (c)

Case – 1:

With no voltage applied to the UJT, the inter-base resistance is given by;

$$R_{BB} = R_{B1} + R_{B2}$$

The value of R_{BB} generally lies between 4 kΩ and 10kΩ.

Case – 2:

If a voltage VBB is applied across the base terminals with emitter open $(V_E = 0V)$, the voltage will drop across RB1 and RB2.

∴ Voltage drop across R_{B1}, $V_1 = \dfrac{R_{B1}}{R_{B1}+R_{B2}} V_{BB}$

or $$\frac{V_1}{V_{BB}} = \frac{R_{B1}}{R_{B1}+R_{B2}}$$

Where V_{BB} = Inter base voltage

$R_{BB} = R_{B1} + R_{B2}$ = Inter base resistance

The ratio $\frac{V_1}{V_{BB}}$ is called intrinsic standoff ratio and is represented by Greek letter η (eta).

$$\therefore \quad \eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$$

$\therefore$ Voltage drop across $R_{B1} = \eta V_{BB}$

The voltage appearing across R_{B1} reverse bias the PN-junction diode. Therefore, small reverse leakage current flows from B_2 to emitter due to minority carriers. The device in this state is said to be in cutoff or in OFF state.

***Note:** The value of η usually lies between 0.51 and 0.82.

Case – 3:

If now a progressively rising positive voltage is applied to the emitter, the diode will becomes forward biased when the input voltage exceeds a critical voltage, known as Peak point voltage.

The Peak point voltage (V_P) is given by,

$$V_P = R_{B1} + V_D = \eta V_{BB} + V_D$$

Where, V_D = forward voltage drop across the diode

=0.7V for silicon diodes

=0.3V for germanium diodes

When the diode D starts conducting, holes are injected from P-type material into the N-type bar. These holes are repelled by a positive B2 terminal and they are attracted towards B1 terminal of the bar. This decreases the resistance RB1 from emitter to base 1 from several thousand ohms to a small value.

The result is that internal voltage drop from emitter to B1 is decreased and hence the emitter current IE increases. The device is now in the ON state. It may be noted that the emitter current is limited by emitter power supply only.

Case – 4:

If a negative pulse is applied to the emitter, the PN-junction is reverse biased and the emitter current is cut-off. In this condition, the device is said to be in the OFF state.

1.10 Give the definition of intrinsic stand-off ratio of UJT

The equivalent circuit of a UJT is shown in fig.

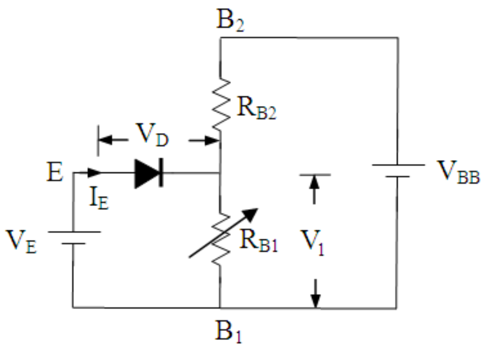
a) Inter base resistance

1. It consists of a diode and the resistance R_{BB}. The diode D represents PN junction and R_{BB} represents the resistance between base B_2 and base B_1 or the total resistance of

the silicon bar from one to other with emitter terminal opens, it is called as inter base resistance.

From the fig $R_{BB} = R_{B1} + R_{B2}$

2. Thus the inter base resistance is represented by two resistors in series viz.
   - R_{B2} is the resistance of the silicon bar between B_2 and the point at which the emitter junction lies.
   - R_{B1} is the resistance of the silicon bar between B_1 and emitter junction. This resistance is shown variable because its value depends up on the bias voltage across PN junction.
3. It is noted that at the point A, $R_{B1} > R_{B2}$ usually R_{B1} = 60% of R_{BB}. Resistance R_{B1} is variable because its value depends upon the bias voltage across PN junction.



b) Intrinsic stand off ratio

If a voltage V_{BB} is applied between the base with emitter open, the voltage will up across R_{B1} and R_{B2}.

Voltage across R_{B1}, $V_1 = \dfrac{R_{B1}}{R_{B2}+R_{B2}} V_{BB}$ or $\dfrac{V_1}{V_{BB}} = \dfrac{R_{B1}}{R_{B2}+R_{B2}}$

Where V_1 = voltage across R_{B1}

V_{BB} = inter base voltage

$R_{BB} = R_{B1} + R_{B2}$ = inter base resistance

R_{B1} = Base – 1 resistance R_{B2} = Base – 2 resistance

The ratio $\dfrac{V_1}{V_{BB}}$ (or) $\dfrac{R_{B1}}{R_{B1}+R_{B2}}$ is called intrinsic stand off ratio and is represented by Greek letter η (eta).

Note:

1. The value of η usually lies between 0.51 and 0.82.
2. The Voltage across R_{B1} is given by, $V_1 = \eta V_{BB.}$

c) Peak Point voltage

1. The voltage ηV_{BB} appearing across R_{B1} reverse bias the diode.
2. If V_γ is the cut in voltage of the PN junction, the total reverse bias voltage is given as,

$$V_P = \eta V_{BB} + V_\gamma$$

Where V_P = Peak point voltage

1.11 Explain negative resistance region of UJT

Fig. (d) shows the curve between emitter voltage (V_E) and emitter current (I_E) of UJT at a constant V_{BB} between the bases. This is known as emitter characteristic of UJT.

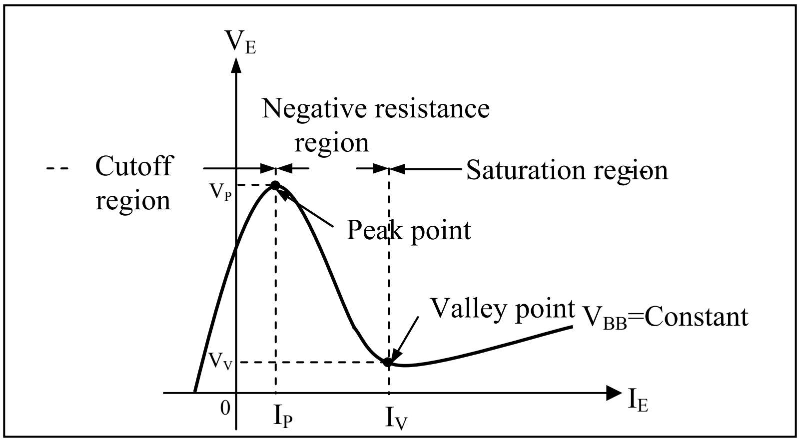


Fig. (d)

The following points may be noted from the characteristics.

1. Cut-off region

- The region to the left of peak-point, is called cut-off region.
- In this region, the emitter voltage is below the peak-point voltage (V_P) and the emitter current is approximately zero.
- The UJT is in its OFF position in this region.

2. Negative resistance region

- The region between the peak point and the valley-point is called negative-resistance region.
- In this region, the emitter voltage decreases from V_P to V_V and the emitter current increases from I_P to I_V. This is in fact, the very important feature of UJT.
- The increase in emitter current is due to the decrease in resistance R_{B1}.

3. Saturation region

- The region beyond the valley point, is called saturation region.
- In this region, the device is in its ON position.
- The emitter voltage (V_E) remains almost constant with the increasing emitter current in this region.

1.12. Explain SCR circuit triggering by UJT with a circuit diagram.

- Unijunction transistors are often used to trigger the SCR, TRIAC etc. It is the most common method of triggering the SCR because the pulses at the gate using R and RC triggering methods cause more power dissipation at the gate so by using UJT (Uni Junction Transistor) as triggering device the power loss is limited as it produce a train of pulses.
- The RC network is connected to the emitter terminal of the UJT which forms the timing circuit. The capacitor is fixed while the resistance is variable and hence the charging rate of the capacitor depends on the variable resistance means that the controlling of the RC time constant. The SCR triggering circuit is shown in the fig. 1.13(a).

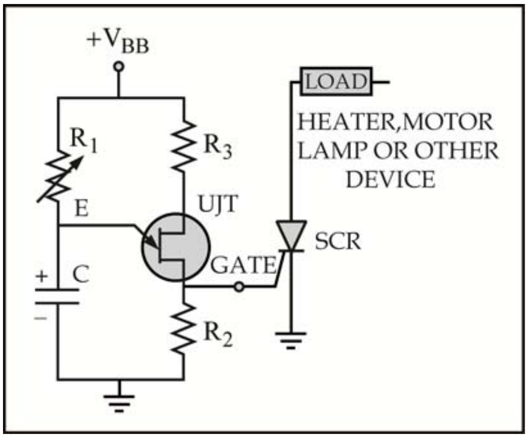


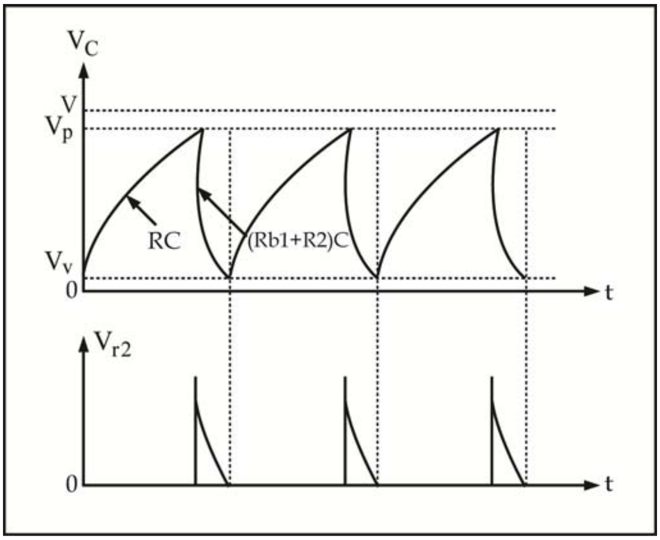
Fig. 1.13(a)

- When the UJT turns on, a pulse of gate current is provided to trigger the SCR on. In this power control circuit, the SCR switches off during the negative half of every cycle owing to the natural commutation i.e. whenever the current reduces below the holding value I_H, SCR cease conduction.
- When the voltage is applied, the capacitor starts charging through the variable resistance. By varying the resistance value voltage across the capacitor get varied. Once the capacitor voltage is equal to the peak value of the UJT, it starts conducting and hence produce a pulse output till the voltage across the capacitor

equal to the valley voltage Vv of the UJT. This process repeats and produces a train of pulses at base terminal 1.

- The time constant of the charging capacitor is controlled by the resistor R_1 and thus a small value of R_1 allows the capacitor to charge quickly. This causes the UJT and SCR to turn on early in the half cycle and allows the load current to flow for a significant portion of the positive half cycle. A large value of R_1 causes the capacitor to charge slowly which in turn causes a delay in the switching of both the UJT and SCR and allows load current to flow for a smaller time interval. Thus by varying the value of R_1 we can control the conduction angle of the SCR and power flow to the load. To ensure the turn on of UJT.
- The pulse output at the base terminal 1 is used to turn ON the SCR at predetermined time intervals.

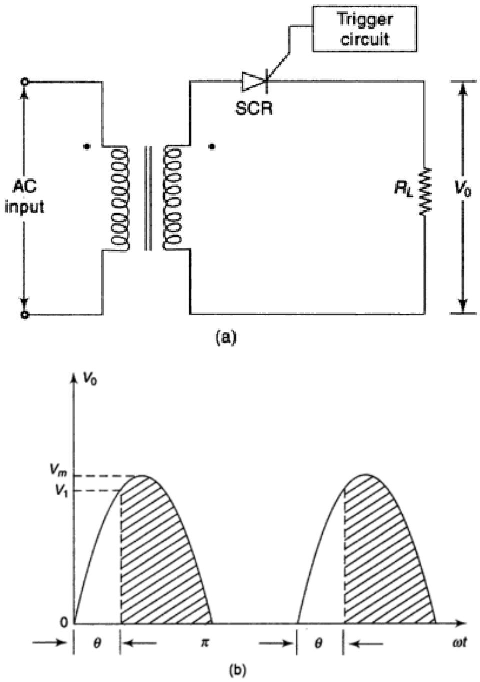
1.13. Draw input and output waveforms for the above circuit with resistive load.



1.14 Mention the use of SCR in single phase and three phase Power rectifiers.

1.14.1. SCR Half wave Rectifier

- Though the SCR is basically a switch, it can be used in linear applications like rectification. Fig 8.6 shows the circuit of an SCR half wave rectifier.
- During the negative half cycle, the SCR does not conduct irrespective of the gate current, as the anode is negative with respect to cathode and also PIV is less than the reverse breakdown voltage.



- During the positive half cycle of a.c voltage appearing across secondary, the SCR will conduct provided proper gate current is made to flow. The greater the gate current, the lesser the supply voltage at which the SCR is triggered ON. Referring to Fig. (b), the gate current is adjusted to such a value that SCR is turned ON at a positive voltage V_1 of a.c secondary voltage which is less than the peak voltage V_m. Beyond this , the SCR will be conducting till the applied voltage becomes zero. The angle at which the SCR starts conducting during the positive half cycle is called firing angle θ. Therefore , the conduction angle is $(180^0 - \theta)$.
- The SCR will block not only the negative part of the applied sinusoidal voltage but will also block the part of the positive waveform up to a point SCR is triggered ON. If the angle θ is zero, this will be an ordinary half wave rectification. Therefore by proper adjustment of gate current, the SCR can be made to conduct full or part of a positive half cycle, thereby controlling the power fed to the load.

Analysis:

- Let $V = V_m \sin \omega t$ be alternating voltage that appear across the secondary of the transformer. In SCR half wave rectifier θ is the firing angle and the rectifier conducts from θ to 180^0 (π radians) during the positive half cycle.
- Therefore, average or d.c output, $V_{av} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin \omega t d\omega t$

$$= \frac{1}{2\pi}\left[-V_m \cos\omega t\right]_\theta^\pi$$

$$= \frac{V_m}{2\pi}(1+\cos\theta)$$

- For $\theta = 0^0, V_{av} = \frac{V_m}{\pi}$ here the full positive half cycle will appear across the load this is the value of average voltage for ordinary half wave rectifier.
- When $\theta = 90^0, V_{av} = \frac{V_m}{2\pi}$ this shows that greater the firing angle θ, the smaller is the average voltage and vice-versa.

Similarly, $$V_m = \sqrt{\frac{1}{2\pi}\int_0^\pi (V_m \sin\omega t)^2 \, d\omega t}$$

$$= \sqrt{\frac{V^2}{4\pi}\int_0^\pi (1-\cos 2\omega t) d\omega t}$$

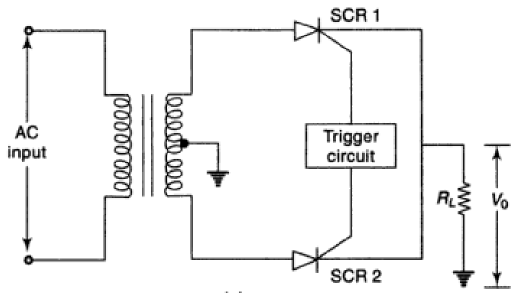
$$= \sqrt{\frac{V^2{}_m}{4\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^\pi}$$

$$= \frac{V_m}{2}\left[\frac{1}{\pi}(\pi - \theta + \sin 2\theta)\right]^{1/2}$$

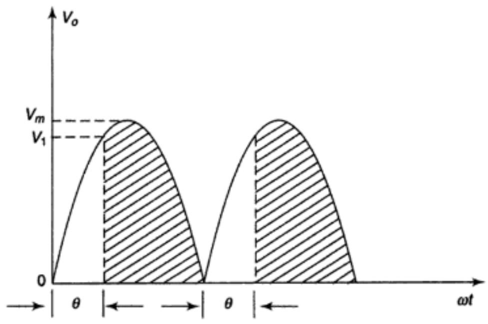
If $\theta = 0$, then $V_{rms} = \frac{V_m}{2}$

1.14.2. SCR Full Wave Rectifier

- The SCR full wave rectifier is shown in Fig.
- It is exactly similar to an ordinary full wave rectifier except that the two diodes have been replaced by two SCRs the angle of conduction can be changed by adjusting the gate currents.



(a)



(b)

- During the positive half cycle of the input signal, anode of SCR1 becomes positive and at the same time the anode of SCR2 becomes negative. When the input voltage reaches V_1 as shown in Fig(b), SCR1 starts conducting and therefore only the shaded portion of positive half cycle will pass through the load.
- During the positive half cycle of the input signal, the anode of SCR1 becomes negative and the anode of SCR2 becomes positive. Hence, SCR1 does not conduct and SCR2 conducts when the input voltage becomes V_1.
- The main advantage of this circuit over ordinary full wave rectifier circuit is that any voltage can be made available at the output by simply changing the firing angle of the SCRs.

Analysis:

- Referring to Fig., let $V = V_m \sin \omega t$ be the alternating voltage that appears between center tap and either end of secondary and θ be the firing angle.

$$V_{av} = \frac{1}{\pi}\int_{\theta}^{\pi} V_m \sin \omega t \; d\omega t = \frac{V_m}{\pi}\left[-\cos \omega t\right]_{\theta}^{\pi} = \frac{V_m}{\pi}\left[1 + \cos \theta\right]$$

This is double that of a half wave rectifier, as negative half cycle is also rectified.

1.15 Explain about speed control of DC motor using SCR

The speed of the motor is given by the following relation

$$\boxed{N = \frac{E_{dc} - I_{dc}R_a}{K\phi} \text{R.P.M}}$$

Where

E_{dc}	is the armature terminal voltage
I_{dc}	is the armature current
R_a	is the armature resistance
ϕ	is the operating magnetic flux
K	is the constant

- The product $K\phi$ depends on the field current.
- The flux ϕ increases with the increase of the field current.
- '$K\phi N$' is called the back voltage or back e.m.f of the motor.
- The armature terminal voltage exceeds the back e.m.f, by the armature voltage drop in the armature.

Methods of speed control:

1. **Variation of the armature resistance:**
    - This can be accomplished by inserting series resistance in the armature circuit either in series with armature or across the armature terminals(called as series motors or shunt motors).
2. **Variation of the operating magnetic flux:**
    - $\text{Speed } \alpha \ \dfrac{1}{\text{operating flux}}$
    - The variation of flux can be obtained by means of shunt regulator in case of shunt motor by diverter in case of a series motor.
3. **Variation of the terminal voltage:**
    - $N \ \alpha \ E_{dc}$, so by varying the terminal voltage speed can varied.
4. **Electronic control method:**
    - Rheostatic control
    - Field control method

1.16. Explain the construction of Diac

$$\boxed{\text{DIAC} = \text{DIode} + \text{AC}}$$

- The term Diac is obtained from capital letters, Diode that can work on AC.
- Diac is a five layer four junction semiconductor device.
- DIAC is two terminal bidirectional device without gate.
- A Diac can be switched from the off-state to the on-state for either polarity of applied voltage.
- DIAC is one of the most important devices used to trigger the TRIAC.
- The symbol of DIAC is shown in fig. (b).
- The word diac can be split into DI and AC.
- DI stands for two electrodes namely M_{T1} and M_{T2}.
- AC indicates its ability to conduct in both the directions.
- From the structure, the equivalent circuit can be drawn with two PNPN devices connected back to back.

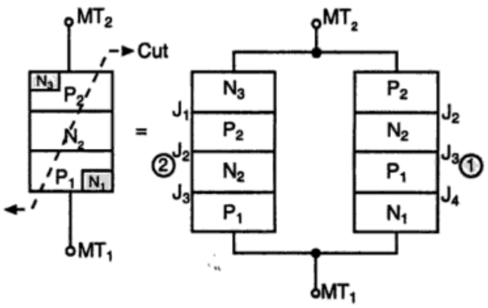


Fig. (a)

Fig. (b)

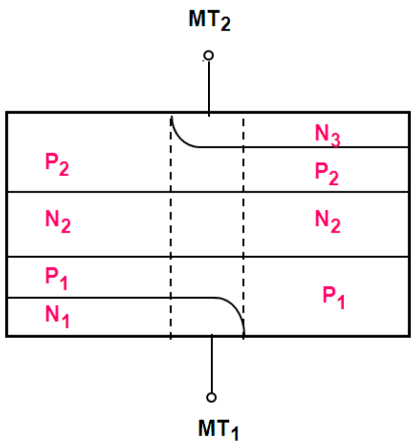


Fig. (c)

- When M_{T2} is made positive with respect to M_{T1}. the device 1 is forward biased. Junctions J_2 and J_4 are forward biased and J_3 is reverse biased.
- When the voltage is increased beyond the break over voltage the junciton J_3 break dwon and the device 1 goes from high impedance state to low impedacne state.
- The characteristic is similar to that of SCR forward characteristic without gate facility.
- When MT_1 is made positive with respect to M_{T2}, the device 2 is forward biased. The junctions J_1 and J_3 are forward biased and J_2 is reverse biased. J_2 breaks down when the voltage is increased beyond break over voltage and the current flows from M_{T1} to M_{T2}.
- The characteristic in the third quardrant is similar to that of first quardrant. The diac is used in the triggering circuit of triac.

- In both cases the currents during blocking regions are very small and are called as leakage currents. The behaviour in both directions are similar because doping level is same in all the layers in two directions and is shown in Fig.

Note:

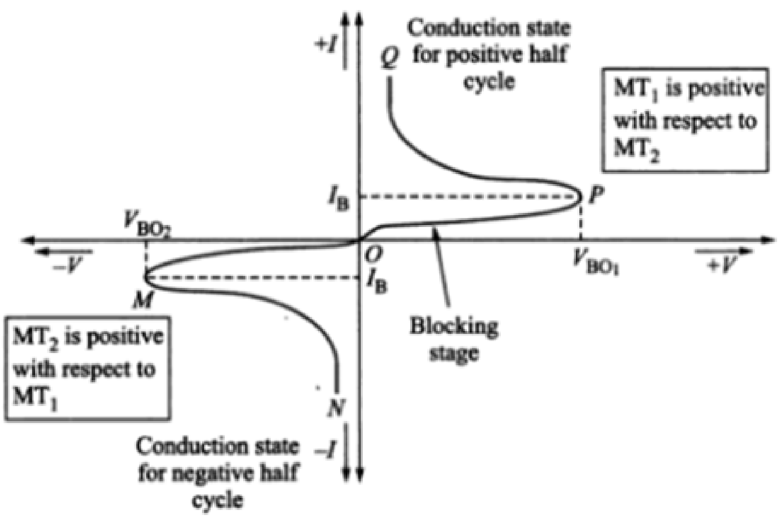
1. Generally the breakover voltage of DIAC is about 30 – 50 volt and voltage drop is across the device is about 3 – 5 volt.
2. As compared to TRIAC the operating characteristics of DIAC is similar but it has no gate terminal. Hence, it is also called as GATE LESS TRIAC.

a) Disadvantages of DIAC

1. It is a low power device.
2. It does not have a control terminal.

1.17. Explain the volt-ampere characteristics of DIAC

- Figure 5.15 shows the V-I characteristics of a diac.
- As discussed earlier, a diac conducts in either direction, depending on the polarity of the applied voltage across its main terminals.
- This characteristic is divided into two parts- conduit on in positive half cycle and conduction in negative half cycle.



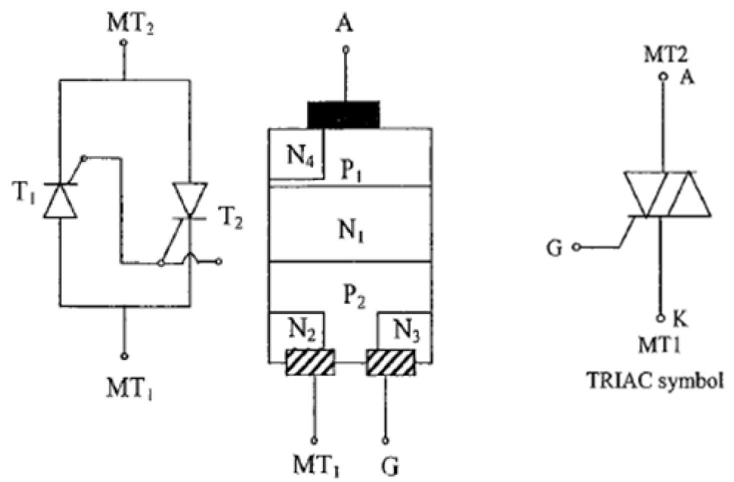
- When the terminal MT_1 is positive with respect to the terminal MT_2, i.e. during the positive half cycle at voltage less than the break over voltage (V_{BO1}), a very small amount of current, called leakage current, flows through the device.
- This leakage current is produced due to the drift of the electrons and the holes at depletion layer which are not sufficient to cause conduction in the device. Hence

the device remains non-conducting. This portion is indicated by the region OP in the characteristics, i.e. the blocking stage.

- At the point P, as the voltage level reaches the break over voltage, the device starts to conduct. During this region, the device exhibits negative resistance characteristics.
- The flow of current in the device is increasing and the voltage starts to decreases as indicated by the region PQ in Figure 5.15. This state is known as conducting stage. The current corresponding to the point P is called breakover current.
- During the negative half cycle of the diac, the working is indicated by the region OMN.
- In this region, the terminal MT_2 is positive with respect to the terminal MT_1. this characteristic in the third quadrant is similar to that in the first quadrant because the doping level is same at the two junctions of the device.
- When the diac starts to conduct, very high amount of current flows through it. External resistance can limit this current.

1.18. Explain the construction of TRIAC

$\boxed{\text{Triode} + \text{AC} \rightarrow \text{TRIAC}}$



- In the SCR family, after the SCR, TRIAC is the most widely used device for power control.
- The major drawback of an SCR is that, it can conduct current in one direction only.
- It has reverse blocking characteristics and current cannot flow from cathode-to-anode direction.

- Hence, SCR can control D.C power (or) forward biased half cycles of AC. However, in an A.C. system it is very necessary to control over both positive and negative half cycles.
- For this, two thyristors are connected back to back or two anti-parallel thyristors can be integrated into a single chip as depicted in Fig. this device is called a TRIAC (triode ac switch). TRIAC can conduct in both directions. Hence, TRIAC is a bidirectional thyristor and it is extensively used for ac controller circuits.
- TRIAC is derived by combining the capital letters from the words TRIODE and AC.

Construction:

- The constructional view of TRIAC is shown in fig.
- TRIAC has four layers and three terminals such as MT_1, MT_2 and gate G.
- The terminal MT_1 makes contact with the layers N2 and P2.
- The terminal MT_2 makes contact with the layers P1 and N4.
- The gate terminal G makes contact with layers N3 and P2.
- MT_1 is as the reference point to measure voltages and currents at gate terminal and MT_2. the gate G is present near MT_1.

  Note: The anode and cathode terminals are not used to represent a TRIAC.
- The triac is equivalent to two SCRs connected back to back with their gate terminals tied up.
- When M_{T2} is positive with respect to M_{T1}.the SCR 1 is forward biased. If the gate is made positive with respect to M_{T1}, the SCR conducts and the device goes from high impedance state to low impedance state.
- When M_{T1} is made positive with respect to M_{T2}, SCR 2 is forward biased and it conducts when the gate is made positive. Thus the triac can conduct in both the directions.
- A positive voltage between gate and cathode. But the triac can conduct with either positive or negative voltage at the gate.
- SCR conducts only in the forward directions, whereas the TRIAC conducts in both the directions.

a) Advantages of TRIAC

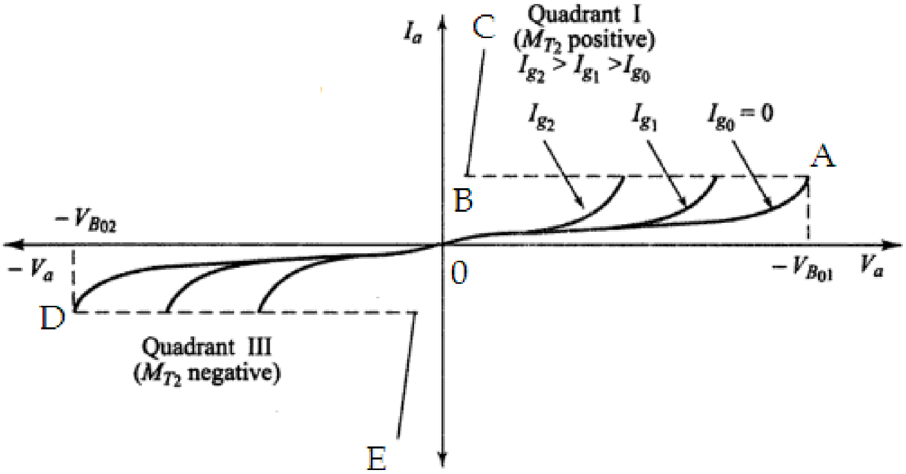
1. It is a bidirectional device
2. It is more suitable for resistive loads.
3. It is not necessary to use a protection diode across the triac.

b) Disadvantages of TRIAC

1. We cannot use it as a controlled rectifier
2. Not suitable for controlling power to highly inductive loads.
3. Power rating is lower than that of SCR.

1.19. Volt-ampere characteristics of TRIAC

- It gives the relationship between the triac current and the voltage applied across its two main terminals.
- When the voltage applied is less than breakover voltages V_{BO1}, V_{BO2} and gate signal is not applied, then triac is in blocking state for both the directions.
- We know that a triac is operated usually in two ways.
  1. Main terminal 2 (i.e., MT2) and gate (G) both are positive with respect to main terminal 1 (i.e., MT1) and
  2. Main terminal 2 (i.e., MT2) and gate (G) both are negative with respect to main terminal 1 (i.e., MT1)
- In the first case, the triac current flows from the main terminal 2 to the main terminal 1. And in the second case, the triac current flows from the main terminal 1 to the main terminal 2.



- When the triac is operated, with its main terminal 2 and gate both positive with respect to main terminal 1, the V-I characteristic obtained is as shown in fig. by the curve method OABC.
- Similarly, when the triac is operated with its main terminal 2 and gate both negative with respect to main terminal 1, the V-I characteristic obtained is shown in fig. by the curve method ODEF.
- The V-I characteristic of the triac gives the following information:

1. The curves OABC and ODEF are symmetrical and identical to the forward characteristic of SCR.
2. The triac is OFF until the applied voltage of either polarity (i.e., whether MT2 is positive with respect to MT1 or MT2 is negative with respect to M.T.1) exceeds the breakover voltage.
3. As the applied voltage of either polarity exceeds the breakover voltage, the triac turns ON and the voltage drop across the triac decreases a low value (indicated by V_H). The triac current increases to a value determined by the supply voltage and load resistance.
4. As the value of gate current is increased above zero, the breakover voltage is lowered (indicated by points A^1 and D^1). Like SCR, the triac is never operated with the zero gate current. When the gate current of a suitable value is applied, the triac turns ON at much lower breakover voltage.

1.20. Explain different mode of TRIAC triggering:

- Triac can be turned on with positive or negative gate current keeping the MT_2 terminal at positive or negative potential.
- There are 4 triggering modes

Mode	Potential of T_2	Potential of gate with respect to T_1
I^+	Positive	Positive
I^-	Positive	Negative
III^+	Negative	Positive
III^-	Negative	Negative

- The device with MT_2 positive but gate current negative is less sensitive and therefore, more gate current is required.
- If the voltage applied is less than breakover voltage and gate signal is not applied, the Triac is in blocking state for both the directions.

Mode 1: MT_2 is positive and gate G is positive (with respect to terminal T_1):

- The junctions $P_1 - N_1$ and $P_2 - N_2$ are forward biased but the junction $N_1 - P_2$ is reverse biased.
- When the gate current is positive with respect to MT_1, gate current flows mainly from the gate lead to the terminal MT_1 through the $P_2 - N_2$ junction, as shown in fig. The device turns on in the conventional manner as in the case of an SCR.

- However, in case of a Triac, the gate current requirement is higher for turn on at a particular voltage
- When gate current is able to inject sufficient number of charge carries in P_2 layer, the junction $N_1 - P_2$ breaks down.
- As a result, triac starts conducting through $P_1, N_1P_2N_2$ layers.
- Triac operates in first –quadrant in this mode of operation.

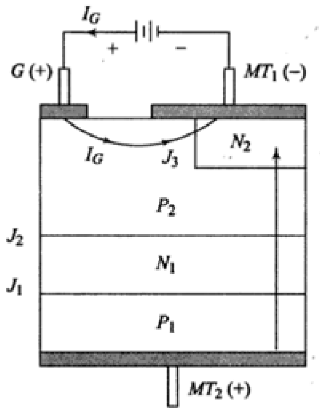


Fig. (a)

Mode 2: MT_2 is positive and gate G is negative

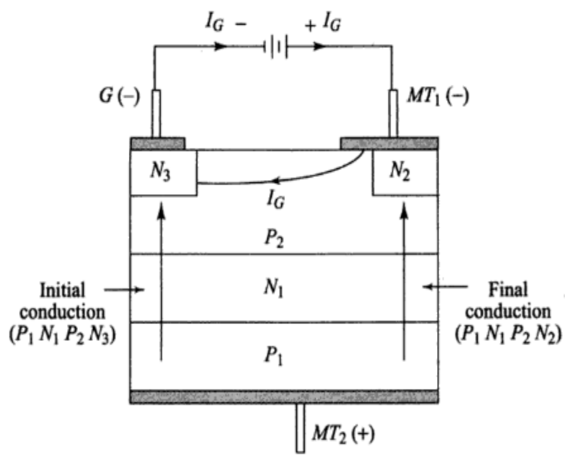


Fig. (b)

- The junctions $P_1 - N_1$ and $P_2 - N_2$ are forward biased but the junction $N_1 - P_2$ is reverse biased. The gate current flows through $P_2 - N_3$ junction as shown in fig..
- Initially, the triac conduction current flows through the layers $P_1 - N_1 - P_2 - N_3$. Due to this the potential of the left part of layer P_2 in contact with n_3 increases.

- This potential gradient across the P_2 layer causes flow of current flow left to right through layer P_2. This current is similar to conventional gate current of thyristor.
- Therefore, the right hand portion $P_1 - N_1 - P_2 - N_2$ starts conducting. The device operates in the first quadrant. In this mode of operation a higher gate current is required for triggering.

Mode 3: MT_2 is negative and gate G is positive

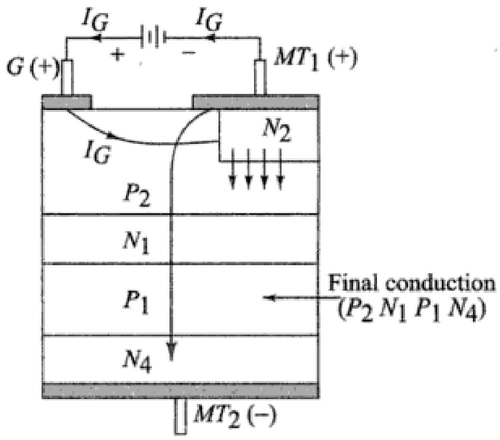
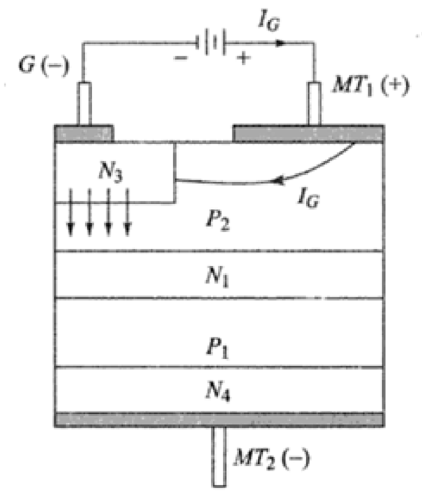


Fig. (c)

The four layers used in this mode of operation are $p_2 - n_1 - p_1 - n_4$. The junction of $n_1 - p_1$ layer is reverse biased. Since the gate terminal is positive, the gate current forward biases $p_2 - n_2$ junction. Layer n_2 injects electrons into p_2 layer (as shown by arrows) and the reverse biased junction $n_1 - p_1$ breakdown. Finally, the layers $p_2 - n_1 - p_1 - n_4$ start conducting and the current increases. As in a thyristor the current is limited only by the external resistance in the circuit. The device operates in the third quadrant. In this mode also triac is less sensitive and a higher gate current is required for turning ON. Operation is shown in fig. 1.10(c).

Mode 4: MT_2 is negative and gate G is negative

- Fig. (d) shows the operation.
- The gate current flows from P_2 to N_3 and electrons are injected as shown by arrows. The reverse biased junction $N_1 - P_1$ breaks down. The current flow through layers $P_2 - N_1 - P_1 - N_4$. The device is more sensitive in this mode of operation and the gate current required is less. It operates in the third quadrant.



Additional Information

Quadrant	Element polarities			Required I_c
I+	T_2 **+**	T_1 **-**	**G+**	**5-10mA**
I-	T_2 **+**	T_1 **-**	**G-**	**10-20mA**
III-	T_2 **-**	T_1 **+**	**G-**	**7-15mA**
III+	T_2 **-**	T_1 **+**	**G+**	**>40mA**

- From the above four operating modes of triac, it becomes clear that the sensitivity of the triac is greatest in the first quadrant when turned ON with negative gate current .
- The sensitivity of the triac is slightly lower in the first – quadrant when turned ON with negative gate current . Further, the Triac is much less sensitive in the third – quadrant with the positive gate current .
- Thus , the Triac is rarely operated in the first – quarant with negative gate current and in the third – quadrant with positive gate current

1.21. List the applications of DIAC, TRIAC & SCR

a) Applications of SCR

Common areas of applications of SCRs are as follows:

1. Relay controls
2. Series static switch
3. Phase control systems

4. Battery charger
5. Temperature controller
6. Single source emergency lighting system
7. Regulated power supplies
8. Speed control of DC shunt motor
9. Choppers
10. Inverters
11. Cycloconverters
12. Protective circuits
13. Heater controls

b) Applications of TRIAC

1. As a static switch
2. For speed regulator
3. Lamp dimmer
4. Temperature Control.
5. In the AC voltage stabilizers
6. Speed control of single phase Induction Motors as well as Series motors.
7. Phase level circuits.
8. Illumination level control.

c) Applications of DIAC

1. As a triggering device for TRIAC
2. Lamp dimmer
3. Fan speed regulator
4. Temperature controller
5. Universal Motor Speed Control
6. Proximity detector
7. In industrial circuits for phase and heat control with triac

CHAPTER 2

Inverters, SMPS and UPS

OBJECTIVES

2.1 Explain the need of inverters

2.2 Explain the principle of operation of inverter

2.3 Explain the working of MOSFET based Inverter circuit.

2.4 Explain PWM Voltage control of inverter

2.5 List the applications of inverters

2.6 Explain the working of SMPS with block diagram

2.7 List the applications of SMPS

2.8 Explain the working of Off Line UPS and Online UPS

2.9 Explain the working of MOSFET based UPS

2.10 List the applications of UPS

2.1 Introduction

- The inverters are DC to AC converters. The DC source is normally a battery or output of the controlled rectifier. Inverters are used in induction motor drives, UPS, standby power supplies, induction heating etc.
- The output voltage waveform of the inverter can be square wave, quasi-square wave or low distorted sine wave.
- The output voltage can be controlled (i.e. adjustable) with the help of drives of the switches.
- The pulse width modulation (PWM) techniques are most commonly used to control the output voltage of inverters. Such inverters are called PWM converters. The output voltage of the inverter contain harmonics whenever it is non sinusoidal. These harmonics can be reduced by using proper control schemes.
- The inverters can be classified as voltage source inverters or current source inverters. When input DC voltage remains constant, then it is called voltage source inverter (VSI) or voltage fed inverter (VFI). When input current is maintained constant, then it is called current source inverter (CSI) or current fed inverter (CFI).
- Some times, the DC input voltage to the inverter is controlled to adjust the output. Such inverters are called variable DC link inverters.
- The inverters can have single phase or three phase output.

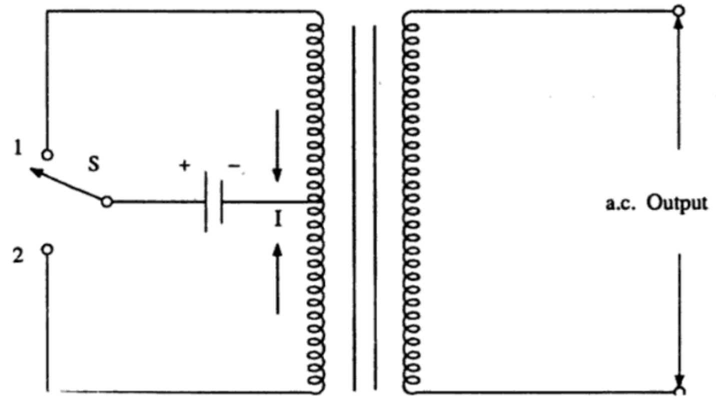
2.1 Explain the need of inverters

- A device that converts dc power into ac power at desired output voltage and frequency is called in inverter.
- Some industrial applications of inverters are for adjustable-speed ac drives, induction heating, stand by air-craft power supplies, UPS(uninterruptable power supplies) for computers, HVDC transmission lines etc.
- Phase-controlled converters, when operated in the inverter mode, are called line-commutated inverters,
- But line-commutated inverters require at the output terminals an existing ac supply which is used for their commutation. This means that line-commutated inverters can’t function as isolated ac voltage sources or as variable frequency generators with dc power at the input.
- Therefore, voltage level, frequency and waveform on the ac side of line-commutated inverters cannot be changed.

- On the other hand, force commutated inverters provide an independent ac output voltage of adjustable voltage and adjustable frequency and have therefore much wider applications.

2.2 Explain the principle of operation of inverter

- The process of converting d.c. into a.c. is known as inversion. In other words, we may defined it as the reverse process of rectification. The device which performs this process is known as an inverter.
- The basic principle of an inverter can be explained with the help of a simple circuit, as shown in Fig.5.1.
- If switch S is connected alternately to positions 1 and 2 at a rapid speed and if S is not kept closed to any of the two positions (1 and 2) for too long, then an alternating voltage will appear across the primary winding. This can be explained by the direction of the current flow in the primary winding.
- Although the voltage applied d.c. in nature, the direction of current flow in the primary winding when S is connected to position 1, is from top to bottom whereas when S is connected at position 2, the current flows from bottom to top. This change in the direction of current flow in the primary winding gives rise to an alternating voltage in it.
- The frequency of this alternating voltage will depend on how rapidly the switch (S) positions are interchanged. This alternating voltage in the primary winding will induce an alternating emf in the secondary winding which will act as the a.c. output.



Note:

1. With the development of semiconductor devices, a lot of improvements took place in the design of inverter circuits. Transistor being a fast-switching device was used as a switch for developing low and medium power inverters.

2. Later, with the arrival of SCRs, SCR inverters (in general, thyristor inverters) were developed. These usually have more power ratings as compared to the transistor inverters.
3. SCRs are normally triggered by means of gate pulses.
4. Efficiency of an inverter increases as its input voltage is raised because the voltage drop in the device becomes insignificant when compared to the high input voltage.

2.3 Explain the working of MOSFET based Inverter circuit.

Fig. 1.23(a) shows the circuit diagram of NMOS inverter and fig. 1.23(b) shows for PMOS inverter. The working operation of the circuits is same. The MOSFET T_1 in both the circuits work as resistors since T_1 is conducting as gate is connected to drain.

In fig. 1.23(a) when input A is at logic 0, the MOSFET T_2 will be OFF giving the high voltage at the output. So the output is at logic 1. If on the other hand input A is at logic 1, the MOSFET T_2 will be ON and output will be at logic 0. This verifies the operation of inverter. The operation of PMOS will be discussed in similar fashion with the only difference that it works for negative logic.

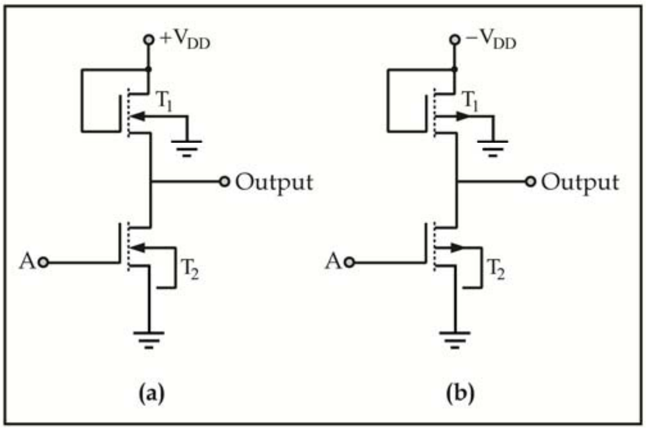


Fig. 1.23

2.4 Explain PWM Voltage control of inverter

- The output voltage of the inverter needs to be varied as per load requirement. Whenever the input DC varies, the output voltage can change. Hence these variations need to be compensated.
- In case of motor drives the ratio of voltage to frequency $\left(\frac{V}{f}\right)$ is maintained constant.
- The output voltage and frequency of the inverter is adjusted to keep $\frac{V}{f}$ constant.

- Similarly, in UPS the output voltage of inverter is to be regulated. These all the reasons indicate that the output voltage of inverter is to be controlled. The pulse width modulation(PWM) techniques are mainly used for voltage control. These techniques are most efficient and they control the drives of the switching devices.
- Following are the PWM techniques:
  - Single pulse width modulation
  - Multiple pulse width modulation
  - Sinusoidal pulse width modulation
  - Modified sinusoidal pulse width modulation
  - Phase displacement control
- Out of the above techniques, sinusoidal PWM techniques are most widely used. They control the output voltage as well as reduce the harmonics.

2.5 List the applications of inverters

Inverters are used in

1. Induction motor drives,
2. UPS,
3. Standby power supplies,
4. Induction heating etc.

2.6 Explain the working of SMPS with block diagram

SMPS means Switch Mode Power Supply. This is used for D.C to D.C conversion. This works on the principle of switching regulation. The SMPS system is highly reliable, efficient, noiseless and compact because the switching is done at very high rate in the order of several kHz to MHZ.

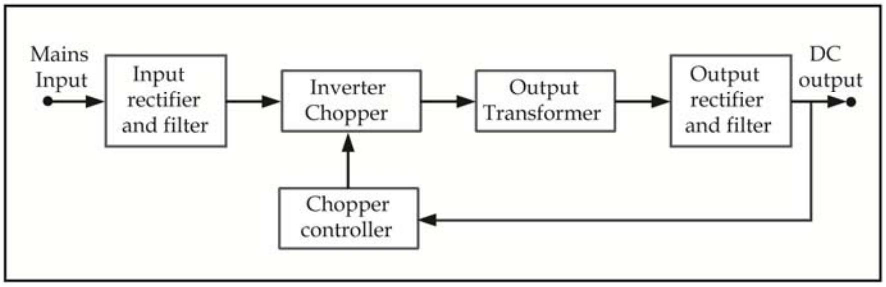


Fig. 1.29(a)

1. **Input Rectifier Stage:** It is used to convert an ac input to dc. A SMPS with dc input does not require this stage. The rectifier produces unregulated dc which is then passed through the filter circuit.
2. **Inverter Stage:** The inverter stage converts DC, whether directly from the input or from the rectifier stage described above, to AC by running it through a power oscillator, whose output transformer is very small with few windings at a frequency of tens or hundreds of kilohertz.
3. **Output Transformer:** If the output required is to be isolated from input, the inverted AC is used to draw the primary windings of a high frequency transformer. This converts the voltage up or down to the required output level on its secondary winding.
4. **Output Rectifier:** If the dc output is required, the ac output from the transformer is rectified.
5. **Regulation:** Feedback circuit monitors the output voltage and compares it with the reference voltage.

(or)

Working of SMPS with Block Diagram

D.C to d.c converts and d.c. to a.c. converters belong to the category of Switched Mode Power Supplies (SMPS). The SMPS operating from mains, without using an input transformer at line frequency 50 Hz is called "off-line switching supply". In off-line switching supply, the a.c. mains is directly rectified and filtered and the d.c. voltage so obtained is then used as an input to a switching type d.c. to d.c. converter.

Fig. 1.29(b) shows the block diagram of off-line high frequency SMPS. As the name implies the input rectification in a switching power supply is done directly off-the line, without the use of low frequency power transformer.

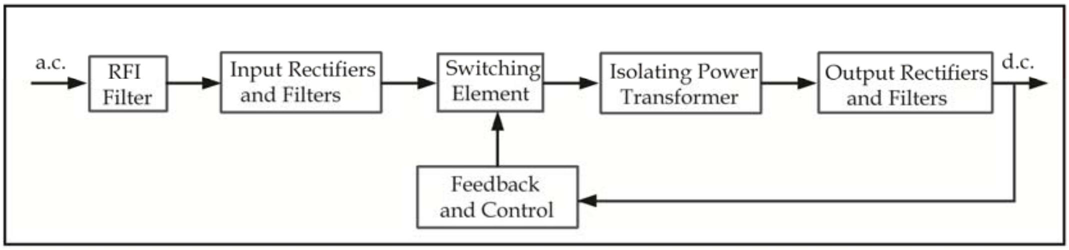


Fig. 1.29(b) Block diagram of Off-Line High Frequency SMPS

A typical SMPS consists of 6 blocks as given below:

1. **RFI Filter:** It is the input filter used to reduce the radio frequency interference of the input a.c. supply.
2. **Input Rectifier and Filter:** Input rectifier and filter produces an unregulated d.c. voltage, which inturn is fed into a switching element.

3. **Switching Element:** SMPS utilizes a low loss switching elements namely BJT or MOSFET. A power BJT is used when the chopping frequency is limited to 40 KHz. Whereas Power MOSFETs are used if higher chopping frequencies of the order of 200 KHz is required. The switching element converts the d.c. voltage in to a high frequency square wave (a.c).
4. **Isolation Power Transformer:** This transformer produces a predetermined a.c. output voltage.
5. **Output Rectifier and Filter:** This stage converts the input a.c. voltage to required d.c output.
6. **Feedback and Control:** A portion of this output is monitored and compared against the fixed reference voltage, and the error signal is used to control the on-off times of the switching element, thus regulating the output.

2.7 List the applications of SMPS

Switched Mode Power Supplies have applications in various areas. A switched mode supply is chosen for an application when its weight, efficiency, size or wide input range tolerance make it preferable to linear power supplies. Initially the cost of semiconductors made switch mode supplies a premium cost alternative, but current production switch mode supplies are nearly always lower in cost than the equivalent linear power supply.

1. Personal computer
2. Mobile chargers
3. Battery chargers
4. Vehicles
5. Televisions
6. Lightning
7. Space stations

Additional Information

General UPS System

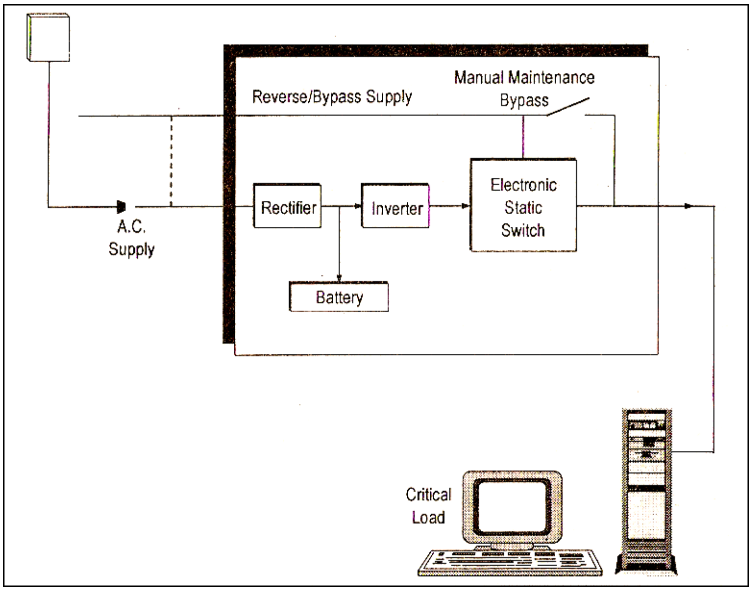
UPS is a device used to provide continuous supply of power to the a.c load. There are only three major components that make up a UPS.

1. Electronic Circuitry
2. Power Supply Unit (PSU)
3. Battery

The circuitry is responsible for filtering and detecting the power loss. At the same time another part of the circuitry charges the battery. The circuitry is not high.

The PSU converts a.c. voltage to d.c. voltage, as all the components inside the computer use d.c.

The battery is the heart of the UPS system. It powers the computer for those crucial minutes after a power failure. The lead-acid battery used in typical UPS devices.



2.8 Explain the working of Off Line UPS and Online UPS

The UPS is classified into three categories:

1. An off-line UPS (stand by UPS)
2. An on-line UPS (continuous duty UPS)
3. Hybrid UPS

1.25.1. OFF-Line UPS (Standby UPS)

An off line UPS is also known as Stand by UPS or Backup UPS and supplies emergency power when mains AC fail. The capacity of an off line UPS is generally below 1kVA.

In off-line UPS, the inverter is OFF, when the mains power is ON and the output voltage derived directly from the mains is the same as the mains supply voltage. The inverter turns ON only when the mains supply goes OFF. Its switching time is less than 5ms.

Working

The transfer switch is used to connect the mains supply and inverter. When AC mains Supply is ON, the inverter is OFF and the transfer switch is directly connected to AC main supply and provides power to required systems and at the same time the battery is charged through the rectifier/charger as shown in fig. 1.25.1.

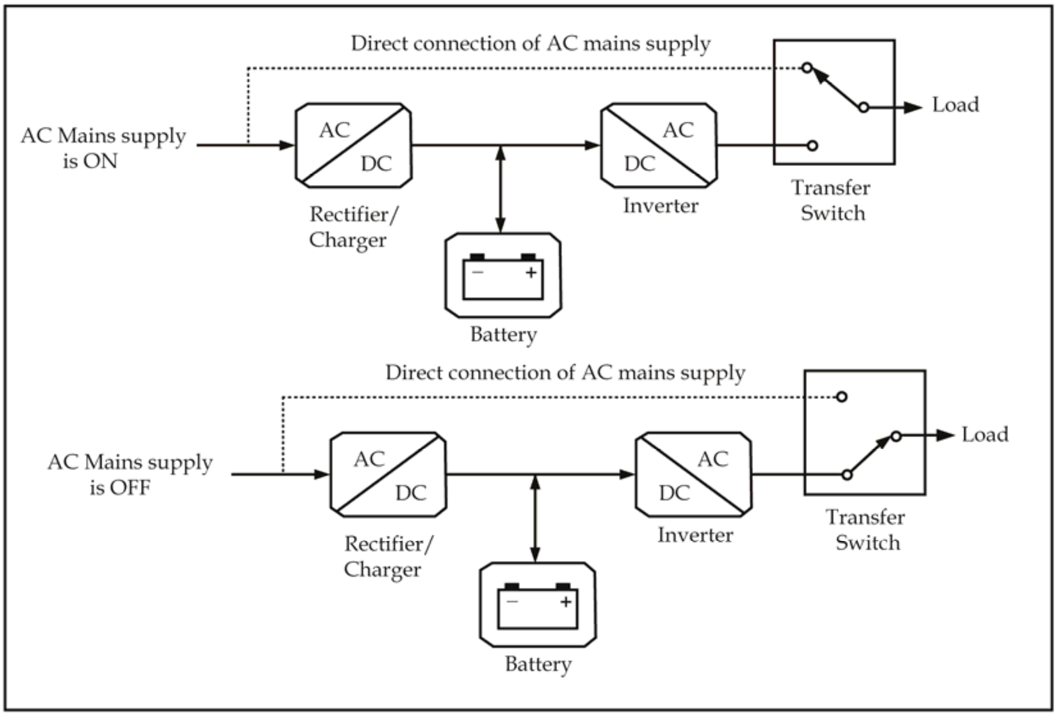


Fig. 1.25.1 OFF-line UPS

When AC mains supply fails, the inverter turns ON. Already charged batteries supply DC voltage to the inverter. Inverter converts the DC to AC and transfer switch connects this AC to the output as shown in fig. 1.25.1.

Again when mains AC comes, the transfer switch connects mains AC to output. Thus the transfer switch keeps on changing connection of output to between mains AC supply and inverter. When mains AC are available, the charger unit recharges the battery.

The Block diagram of OFF line UPS consists of the following blocks.

1. **Rectifier/Charger:** The AC mains supply is given to the battery charger. It converts AC voltage into DC voltage. This DC voltage is given to the battery.
2. **Battery:** It stores the DC voltage. The output of battery is connected to the inverter.
3. **Inverter:** It converts the DC voltage into AC voltage. It is also the output of UPS.
4. **Transfer Switch:** It normally connects the main supply. When the mains supply fails, then the switch automatically connects to the inverter circuit.

Advantages of Off-line UPS

1. Low cost
2. Silent operation
3. Efficient

Disadvantages of Off-line UPS

1. Minimal power protection – not suitable for places where voltage fluctuation is severe.
2. Poor output voltage regulation.
3. Break-transfer to battery mode because of switch over delay.
4. UPS will drop the load if there is overload current and or inverter failure.

Applications

1. These UPS are generally used with PCs or computers or other appliances where a small duration (5 ms or less) interruption. Usually, sealed batteries or lead-acid batteries are used. The running time of these supplies is also low (about 10 to 30 minutes).
2. Office and home PC's.
3. Business centers

1.25.2. On-Line UPS

The on-line UPS is also called as true UPS. The UPS converts the 230V input AC mains supply to DC power which is then used to charge the battery. The dc output of the battery is then converted into ac by using an inverter. The battery continues to drive the inverter without any break and supplies power to output devices. That's why it is called "true UPS".

In the on-line UPS, whether the AC mains supply is ON or OFF, the battery operated inverter is ON all the time and supplies the ac output voltage. When the mains power supply goes OFF, the UPS will be ON only until the battery gets discharged. When the AC mains supply is turns ON, the battery will get charged again through the rectifier/charger.

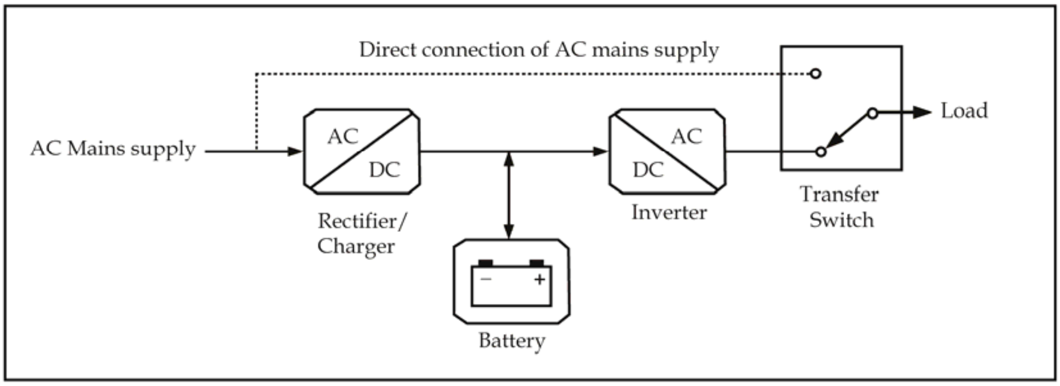


Fig. 1.25.2 On-line UPS

The block diagram of ON line UPS consists of the following blocks.

1. **Rectifier/Charger:** The AC mains supply is given to the battery charger. It converts AC voltage into DC voltage. This DC voltage is given to the battery.

2. **Battery:** It stores the DC voltage. The output of battery is connected to the inverter.
3. **Inverter:** It converts the DC voltage into AC voltage. It is also the output of UPS.
4. **Transfer Switch:** It normally connects the inverter output.

The switching times of these supplies is considered to be zero. The main benefit of the online system is its isolation of source and load. The main feature of this UPS is that it uses the battery as primary source and the load is connected to the inverter. On line UPS models generally have capacity more than 5 kVA.

Advantages of On-line UPS

1. This provides fail safe/overload protection
2. This is a true No-break power supply
3. This is mainly used for large servers

Disadvantages of on-line UPS

1. Size and cost of on-line UPS is more than other types of UPS
2. The power dissipation is very high due to conversion from ac to dc and dc to ac.
3. The heat generated is very high hence it reduces the life of the battery

1.25.3. Differences between OFF-line and ON-line UPS

S.No.	ON-LINE UPS	OFF-LINE UPS
1.	It is also called as true UPS	It is also called as stand by UPS
2.	The primary source of power is battery	The primary source of power is the input AC mains supply
3.	Cost is high	Cost is low
4.	switching time is zero	switching time is less than 5 ms
5.	These have capacity more than 5 kVA	These have capacity less than 1 kVA
6.	In an On-line UPS the power flows continuously through the inverter. High heat is produced. Then reduces the battery life	In an Off-line UPS the power does not flow continuously through the inverter. So very less heat is produced. Then the life of battery is high
7.	Power loss will occur	No power loss will occur
8.	In this the output power is independent of input mains supply	In this the output power is dependent input mains supply
9.	In this UPS isolation of AC mains supply and load	In this UPS is not isolation of AC mains supply and load

10.	Size is high because capacity is high	Size is less because capacity is less
11.	Efficiency is high	Efficiency is low
12.	These are used in Telecommunication systems, Network servers, Email systems, medical applications etc.	These are used in Office and home PC's and also Business centers

2.9. List the applications of UPS

1. Telecommunication systems
2. Voice mail and Email systems
3. Network servers
4. Electronic equipments
5. Test and diagnostic equipments

CHAPTER 3

Transducers & Ultrasonics

OBJECTIVES

Upon completion of the chapter the student should be able to Understand the working of Transmission Lines

3.1 Explain the term transducer, mechanical transducers and electrical/electronic transducers
3.2 Give the classification of electrical/electronic transducers on the basis of principle of operation and applications.
3.3 Give the list of different Resistive, Inductive and Capacitive transducers
3.4 Explain the working principle, construction and applications of resistance straingauge.
3.5 Explain the working principle, construction and applications of potentio-metric transducer.
3.6 Explain the construction and working of LVDT.
3.7 Explain piezo-electric effect
3.8 Explain the construction and working of Piezo-electric transducer.
3.9 Explain the construction and working of Thermocouple transducer.
3.10 Explain the working principle of Accelerometer, servomotor, and Tacho-generator.
3.11 Explain the term Ultrasonic.
3.12 Explain magnetostriction effect
3.13 Explain the construction and working of magnetostriction oscillator and how ultrasonics are generated.
3.14 Explain the construction and working of piezoelectric ultrasonic generator
3.15 Give the list of applications of ultrasonics
3.16 Explain the construction and working of pulsed-echo ultrasonic flaw detector

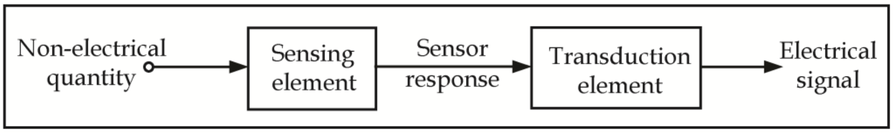
3.0. Introduction

A transducer is a device that converts one form of energy to another. The input quantity for most instrumentation systems is non electrical. In order to use electrical methods and techniques for measurement, the non electrical quantity is converted into a proportional electrical signals.

Any device which converts non-electrical quantities (mechanical, chemical, optical, thermal, etc) into an electrical signal is called a transducer. Many other physical input parameters like heat, light, humidity, etc. can also be converted into electrical form by means of transducers.

Actually, electrical transducer consists of two parts which are very closely related to each other. These two parts are sensing or detecting element and transduction element. The sensing or detecting element is commonly known as sensor.

1. Sensing Element: It is the part of the transducer which senses or responds to a physical quantity or a change in a physical quantity.
2. Transduction Element: It is that part of the transducer which transforms the response of the sensing element into an electrical signal.



3.0.1. Advantages & Disadvantages of Electrical transducers:

The various advantages of electrical transducers are,

1. Electrical signals can be easily attenuated or amplified.
2. The power requirement of transducers is very small. The electrical systems can be controlled with a small level of power.
3. The electrical output of the transducer can be easily used, transmitted and processed for the purpose of measurement.
4. The reduced effects of friction and other mechanical nonlinearities.
5. Due to the integrated circuit technology, the electrical and electronic systems are compact, having less weight and portable.
6. The data transmission through mechanical menas is eliminated. Thus no mechanical wear and tear and no possibility of mechanical failures exist.
7. The reduced effects of mass interia problems.

The main disadvantage of an electrical transducers is its cost. And while designing the circuit the effects fo ageing and drifts of parameters of active components must be considered. This makes the design complicated.

3.0.2. Types of Electrical Transducers

S.No	Electrical Parameter & class of transducer	Principle of Operation	Typical Applications
		Passive Transducers	**(Externally powered)**
		Resistance	
1.	Potentiometer device	Positioning of the slider by an external force varies the resistance in a potentiometer or a bridge circuit.	Pressure, displacement
2.	Resistance strain gauge	Resistance of a wire or semiconductor is changed by elongation or compression due to externally applied stress.	Force, torque (pressure, displacement, acceleration, temperature)
3.	Pirani gauge or hot wire meter	Resistance of a heating element is varied by convection cooling of a stream of gas.	Gas flow, gas pressure
4.	Resistance thermometer	Resistance of pure metal wire with a large positive temperature coefficient of resistance varies with temperature.	Temperature, radiant, heat
5.	Thermistor	Resistance of certain metal oxides with negative temperature coefficient of resistance varies with temperature.	Temperature, flow
6.	Resistance hygrometer	Resistance of a conductive strip changes with moisture content.	Relative humidity
7.	Photoconductive cell	Resistance of the cell as the circuit element varies with incident light.	Photosensitive relay
		Capacitance	
1.	Variable capacitance pressure gauge	Distance between two parallel plates is varied by an externally applied force.	Displacement, pressure
2.	Capacitor	Sound pressure varies the	Speech, music, noise

	microphone	capacitance between a fixed plate and a movable diaphgram.	
3.	Dielectric gauge	Variation in capacitance by changes in the dielectric or dielectric constant	Liquid level, thickness
Inductance			
1.	Magnetic circuit transducer	Self–inductance or mutual inductance of a.c. excited coil is varied by changes in the magnetic circuit.	Pressure, displacement
2.	Reluctance pick up	Reluctance of the magnetic circuits is varied by changing the position of the iron core of coil.	Pressure, displacement, vibrations, position
3.	Differential transformer	The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic core through an externally applied force.	Pressure, force, displacement, position
4.	Eddy current gauge	Inductance of a coil is varied by the proximity of an eddy current plate.	Displacement, thickness
5.	Magnetostriction gauge	Magnetic properties are varied by pressure and stress.	Force, pressure sound
Voltage and Current			
1.	Hall effect pickup	A potential difference is generated across a semiconductor plate (germanium) when magnetic flux interacts with an applied current.	Magnetic flux, current, power
2.	Ionization chamber	Electron flow induced by ionization of gas due to radio-active radiation	Particle counting, radiation
3.	Photoemissive cell	Electron emission due to incident radiation upon photoemissive surface	Light and radiation

4.	Photomultiplier tube	Secondary electron emission due to incident radiation on photosensitive cathode	Light and radiation, photosensitive relays
Self Generating Transducers (No external power)			
1.	Thermocouple and thermopile	An emf is generated across the junction of two dissimilar metals or semiconductors when that junction is heated	Temperature, heat flow, radiation
2.	Moving coil generator	Motion of a coil in a magnetic field generates a voltage	Velocity, vibrations
3.	Piezoelectric pickup	An emf is generated when an external force is applied to certain crystalline materials	Sound vibrations, acceleration
4.	Photovoltaic	A voltage is generated in a semiconductor junction device when radiant energy stimulates the cell	Light meter, solar cell

3.1. Classify transducers on the basis of principle of operation and applications.

3.1.1. Classification based on the operating principle

1. Capacitive transducer
2. Inductive transducer
3. Piezo electric transducer
4. Photo voltaic transducer
5. Photo conductive transducer
6. Resistive transducer

3.1.2. Classification based on applications:

1. Pressure transducer
   Used for measurement of pressure
   Ex: Bourdon Gauge
2. Temperature transducer
   Used for the measurement of temperature
   Ex: Thermocouple

3. Flow transducer
   Used for the measurement of air flow, liquid flow etc.,
   Ex: Electromagnetic flow meter
4. Level transducer
   Used for the measurement of level
   Ex: Displacer and torque tube
5. Displacement transducer
   Used for measurement of displacement
   Ex: LVDT (Linear variable differential transformer)
6. Acceleration transducer
   Used for the measurement of acceleration
   Ex: Potentiometric accelerometer
7. Force/Torque transducer
   Used for the measurement of force (or) torque
   Ex: Piezoelectric dynamometer

Note:

1. The above transducers convert the corresponding variable to measure into the electrical signal. But the output is calibrated in terms of input to be measured.
2. The name is given to transducer based on the measuring variable.

3.2. Explain the working principle, construction and applications of strain gauge

3.2.1. Strain Gauge

Strain gauge is a passive transducer which converts a mechanical displacement into change of resistance of the strain wire. These are used for experiment determination of strain for the purpose of stress analysis.

Strain gauge is a passive transducer that converts a mechanical elongation or displacement produced due to a force into its corresponding change in resistance R, inductance L or capacitance C.

A strain gauge is basically used to measure the strain in a work piece. If a metal piece is subjected to a tensile stress, the metal length will increase and thus will increase the electrical resistance of the material. Similarly, if the metal is subjected to compressive stress, the length will decrease, but the breadth will increase. This will also change the electrical resistance of the conductor.

The device finds its wide application as a strain gauge transducer/sensor as it is very accurate in measuring the change in displacement occurred and converting it into its corresponding value of resistance, inductance or capacitance.

3.2.2. Gauge factor of a Strain Gauge:

Gauge factor or sensitivity factor of a strain gauge is defined as the change in resistance of the gauge per unit of strain. Gauge factor, G_F is expressed as,

$$\text{Gauge factor, } G_F = \frac{dR/R}{dl/l} = 1 + 2\mu$$

Where μ is the poison's ratio.

For most metals and their alloys, the average value of gauge factor is 2. For example, constantan, an alloy of nickel and copper has a gauge factor of nearly 2. Nichrome (Nickel-chromium alloy) also has similar gauge factor.

For a gauge factor of 2, the value of Poisson's ratio, μ should be nearly equal to 0.5.

3.2.3. Types of Strain Gauges

Most commonly used strain gauges are electrical strain gauges. Mechanical and optical strain gauges are also made for special applications. Mechanical gauges are bulky requiring levers or gears. They also require sufficient area for their installation. Optical gauges are similar to mechanical gauges. The magnification of strain is achieved using mirrors and prisms.

Electrical strain gauges measure the changes that occur in resistance, capacitance or inductance due to strain transferred from the test object to the gauge.

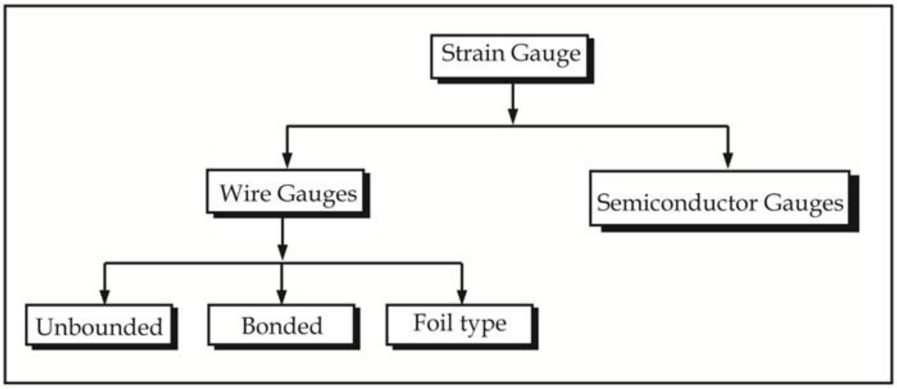


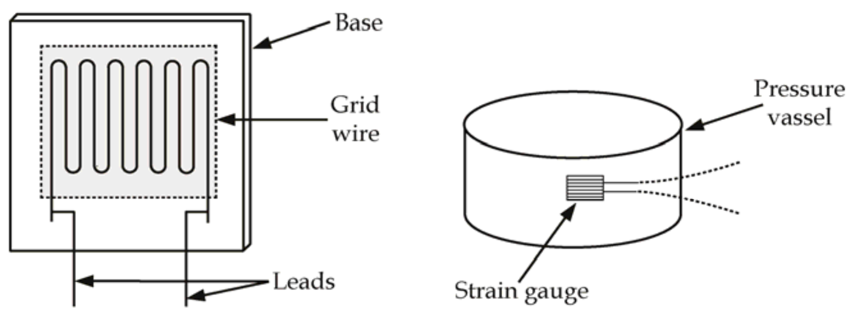
Fig. 3.2.2

3.2.4. Principle of operation and construction of strain gauge (bonded strain gauge transducer)

Resistance of a wire changes when it is subjected to stress (application of a force). The resistance element may be fixed on the body which is under stress. The stress on the body will therefore be transferred to the resistance wire. The resistance wire will be strained. Its length will increase. The increase in length will result in increase in resistance of the wire. This change in resistance can be measured with the help of a standard Wheatstone bridge. The bridge is kept normally balanced with the strain gauge resistance as one of the four arms of the bridge. The galvanometer that is used as null detector will give zero deflection indicating balanced condition of the bridge.

Any change in resistance of the strain gauge will make the bridge unbalanced and an unbalance voltage will appear across the bridge terminals. This unbalance voltage will be proportional to the stress (input force) or the pressure.

The resistance may be in the form of wire, foil or film. The most common type is in the form of a wire resistance grid. The wire is looped back and forth to form a grid as shown in fig. 3.2.3.



(a) Schematic view of a bonded strain gauge transducer
(b) A starin gauge mounted on the surface of a pressure vessel.

Fig. 3.2.3

The gauge is bonded directly on the surface of the vessel or any structure whose strain is to be measured. Measurement will be accurate when the strain gauge becomes integral with the structure. The area of measurement of strain where the gauge has to be mounted should be polished and properly cleaned. All traces of grease, dirt etc., should be removed using cotton swabs dipped in acetone. Similarly, one of the surfaces of the strain gauge must be cleaned properly before mounting on the structure with a thin layer of adhesive cement.

Strain from the structure is transmitted to the strain gauge wire whose resistance change becomes a measure of the strain. The diameter of the resistance wire used to form a gauge is about 0.025 mm or even less.

3.2.5. Semiconductor Strain Gauge

Semiconductor strain gauges are used when a high value of gauge factor is desired. Their gauge factor is 50 times as high as that of wire gauges.

Basic principle of operation of the semiconductor strain gauge is the Piezo-resistive effect; i.e. the change in the value of resistance due to change in resistivity of the semiconductor because of strain applied. However, in metallic gauges, the change in resistance is mainly due to change in dimension when strained. Semiconductor materials used are germanium and silicon.

A typical strain gauge is shown in the fig. 3.2.4.

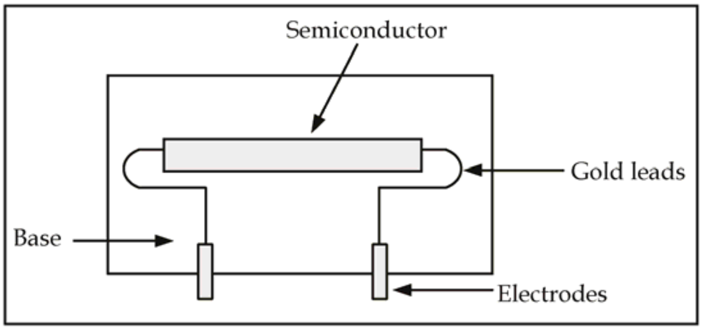


Fig. 3.2.4 Typical Semiconductor Strain Gauge

The semiconductor wafer or filament used has a thickness of 0.05 mm. They are bonded on suitable insulating substrates, such as Teflon. Gold leads are used for making contacts.

The gauge factor of this type of strain gauge is about $130 \pm 10\%$ for a unit of $350\,\Omega$. This gauge factor is measured at room temperature. The gauge is stable and can be operated with conventional indicating and recording systems. It can measure small strains from 0.1 to 500 micro strain.

a) Advantages of Semiconductor Strain Gauge

1. It has a high gauge factor of about 130, which allows measurement of very small strains, of the order of 0.01 microstrain.
2. Hysteresis characteristics of semiconductor strain gauge is excellent i.e., less than 0.05%.
3. Life of the semiconductor strain gauge is long, more than 10^7 operations. It has also excellent frequency response.
4. Semiconductor strain gauge is very small in size.

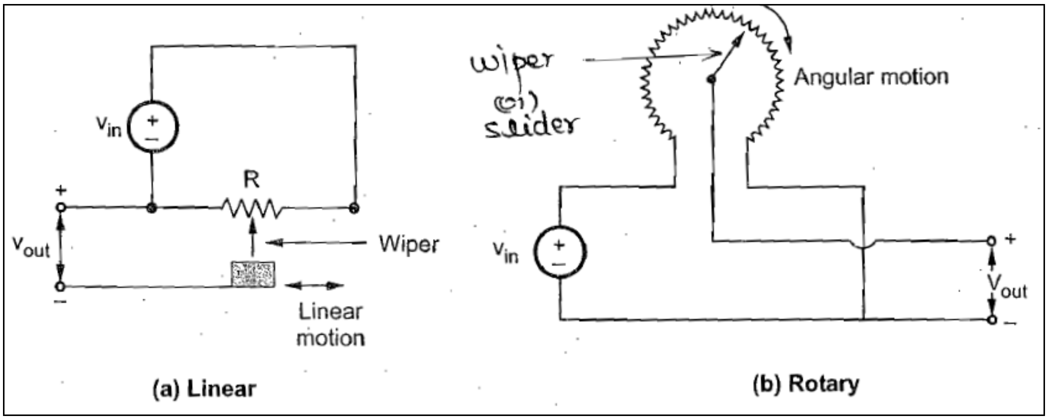
b) Disadvantages

1. The semiconductor strain gauge is sensitive to changes in temperature.
2. The linearity of the gauge is poor.

3. The gauge is more expensive.
4. The gauge factor varies with strain. Suppose the gauge factor is 130 at 0.2% strain, then it is 112 at 0.4% strain.

3.3. Explain the working, principle, construction and applications of potentiometer

- It is also called resistive tranducer.
- A potentiometric resistance transducer (or simply potentiometer) is generally used to measure linear or angular displacement.
- A resistance potentiometer consists a wire wound resistive element along with a sliding contact which is called as wiper. A wire is made up of platinum or nickel alloy with diameter as small as 0.01 mm. The resistive element is made up of cement, hot moulded carbon or carbon film. The wire is wound on an insulting former. The linear and rotary potentiometers are as shown in the fig.
- Using resistance potentiometers mechanical displacement is converted into an electrical output. Linear or angular displacement is applied to the sliding contact and then the corresponding change in resistance is converted into voltage or current. Note that the resistance potentiometers shown in the Fig. may be excited by either a.c voltage or d.c voltage.



- A potentiometer (simply called POT) consists of a resistive elements provided with a sliding contact. Let us consider a translational pot as shown in the fig.
- In above transducer, the measured is converted into a change in position of wiper which causes the change in ratio of resistance i.e. the ratio between one fixed end and wiper contact divided by the total resistance of the potentiometer. The potentiometer is excited by d.c or a.c voltage. The output of the potentiometer is given by,

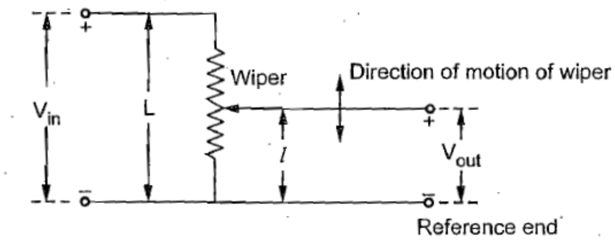
$$V_{out} = \left(\frac{l}{L}\right)V_{in}$$

Where V_{out} = voltage between wiper contact and fixed reference end

V_{in} = Total applied voltage to potentiometer wire

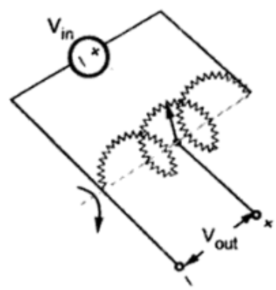
l = Length of wire between wiper contact and reference end

L = Total length of the potentiometer wire



Note:

- To measure combination of linear (translational) and angular (rotational) motion, the heliports are used. As the resistive element in such potentiometer is in the form of helix, it is called helipot.



3.3.1. Advantages of Potentiometric Transducer

The advantages of resistance potentiometers are as follows:

1. Simple in construction and operation.
2. Best suitable for measurements in the systems with least requirements.
3. High electrical efficiency.
4. Useful for displacement measurement of large amplitudes
5. Inexpensive.

3.3.2. Disadvantages of Potentiometric Transducer

The disadvantages of resistance potentiometers are as follows:

1. In linear potentiometers, large force is required to move wiper.
2. Suffer from mechanical wear and misalignment of wiper.
3. Limited resolution and high electronic noise in output.
4. The output of potentiometer is insensitive to the variations in displacement to wiper between two consecutive turns of wire.

3.4. Explain the working, principle, construction of capacitive and inductive transducers

- Capacitive transducers are passive transducers. These are used to measure displacement, force and pressure in most of the cases. Sometimes these are used in the measurement of liquids (or) gas levels.
- **Principle:** The principle of operation of capacitive transducers is based upon the familiar equation for capacitance (parallel plate capacitance fig. 3.4.1(a)).

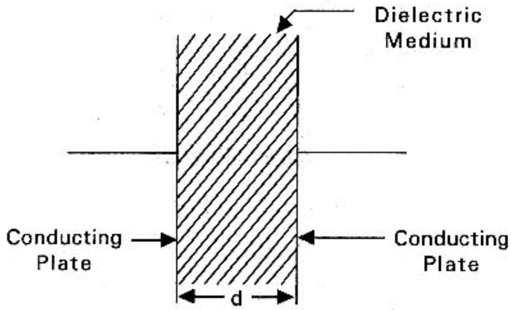


Fig. 3.4.1(a) Parallel Plate Capacitor

$$C = \frac{\in A}{d} = \frac{\in_0 \in_r A}{d} \text{ Farads}$$

Where, C = Capacitance Farad

$\in = \in_0 \in_r$ = Permittivity of medium (F/m)

$\in_0$ = Absolute permittivity of air

$= 8.85 \times 10^{-12}$ F/m

$\in_r$ = Relative permittivity of medium

A = Area of plates (m^2)

d = Distance between two plates (m)

- The capacitive transducer work on the principle of change of capacitance which may be caused by:
  1. Change in area of plates; A
  2. Change in distance between the plates; d and
  3. Change in dielectric constant
- Depending on these parameters, there are three types of capacitive transducers are available:
  1. Variable dielectric type
  2. Variable area type

3. Variable distance capacitor type

3.4.1. Variable Dielectric Type Capacitive Transducer:

- Two concentric cylindrical electrodes are fixed and made stationary. A sleeve is inserted between the inner and outer electrodes, and has different dielectric constant than air.
- This arrangement is shown in fig. 3.4(a).
- The sleeve moves between the electrodes and varies the capacitance depending upon the input measurand. Variable permittivity type capacitive transducers are used in liquid-level measurements.

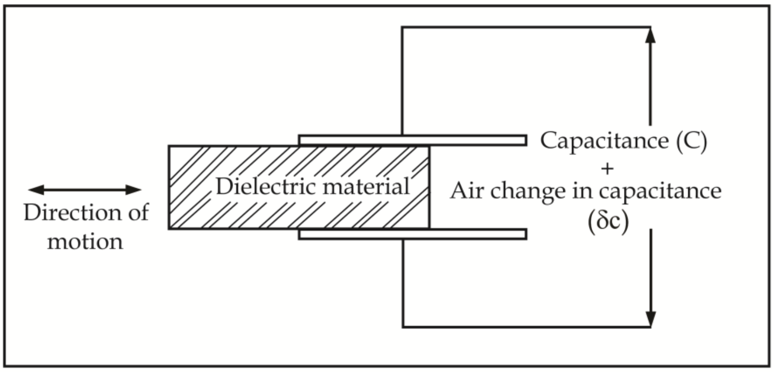


Fig. 3.4(a)

3.4.2. Variable Area Type Capacitive Transducer:

- If one plate of a parallel plate capacitor is displaced with respect to the other plate, the effective area between the plates changes, as shown in fig. 3.4(b).
- This consequently changes the capacitance value between the plates.
- The practical application of a variable – area capacitive transducer is found in a typical torque meter for induction motors.

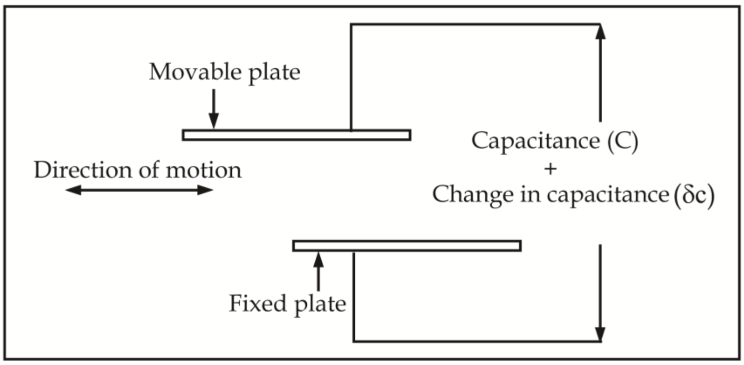


Fig. 3.4(b)

3.4.3. Variable Distance Capacitor:

- Fig. 3.4(c) shows the variable distance capacitance.
- It consists of a static plate and a flexible diaphragm with dielectric between them.

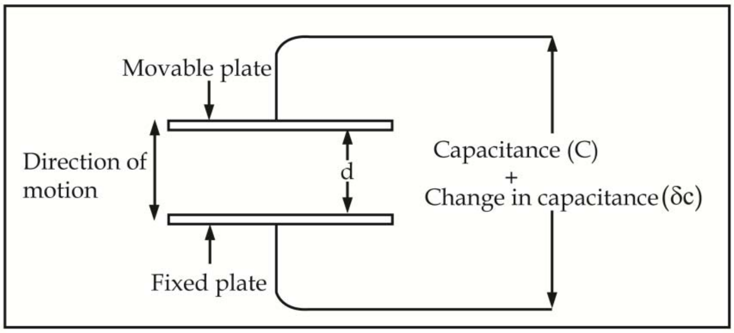
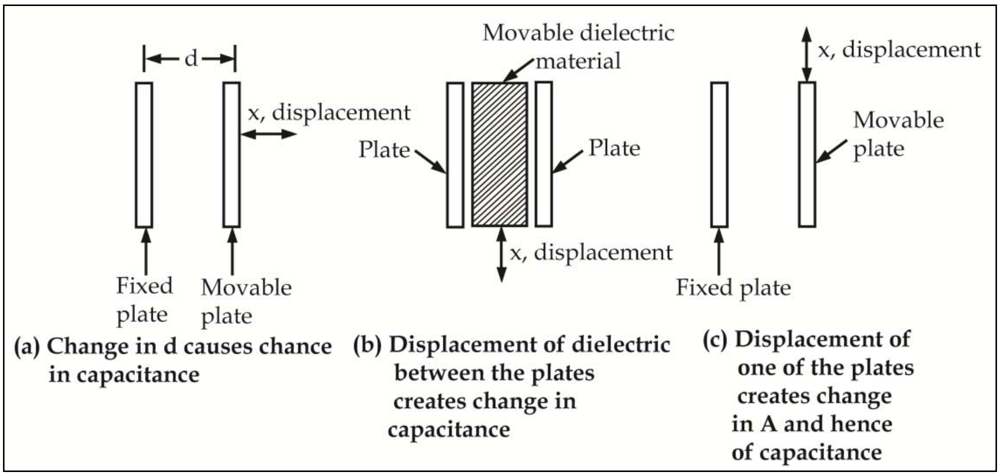


Fig. 3.4(c)



- Any force applied to the diaphragm changes the distance between the diaphragm and the static plates. Hence, the capacitance value is changed. The change in the capacitance may be measured on an a.c. bridge.
- The change in displacement of the diaphragm causes change in capacitance C and hence changes in the frequency of the oscillating circuit. Thus this change in the oscillator frequency is a measure of the displacement and a measure of the magnitude of the applied force.

3.4.4. Advantages

The major advantages are:

1. Capacitive transducers require extremely small forces to operate them and hence are very useful for use in small systems.
2. They are inexpensive and easy to construct.

3. They are extremely sensitive.
4. They have a good high frequency response.
5. They have high input impedance and therefore the loading effects are minimum.
6. A resolution of the order of 2.5×10^{-3}mm can be obtained with these transducers.
7. The force requirements of capacitive transducers is very small and therefore they require small power to operate them.

3.4.5. Disadvantages

1. Sensitivity to temperature variations.
2. Possibility of erratic or distorted signals due to long leads.
3. Low frequency response is poor.
4. The capacitive transducers show non-linear behavior many a times on account of edge effects.

3.5. Mention the 6 important applications of above transducers.

3.5.1. Applications of Strain Gauge

1. For the measurement of strain and stress in experimental stress analysis
2. To investigate strain in many structural materials over a wide range of environmental conditions
3. For the measurement of temperature
4. For the measurement of pressure
5. For the measurement of acceleration
6. In medical field of investigation

3.5.2. Applications of Potentiometric Transducer

Resistive transducers have many and varied applications in the transduction of measurands such as

1. Displacements
2. Mechanical strain
3. Pressure
4. Force and load
5. Temperature, and fluid velocity into electrical outputs
6. Control applications

3.5.3. Applications of Capacitive Transducer

1. Capacitive transducers can be used for measurement of both linear and angular displacements.

2. These can be used for the measurement of force and pressure.
3. These can also be used directly as pressure transducers in all those cases where $\in$ of a medium changes with pressure.
4. These are used for the measurement of humidity in gases.
5. Capacitive transducers are commonly used in conjunction with mechanical modifiers for measurement of volume, density, liquid level, weight etc.

3.5.4. Applications of Inductive Transducer

In general inductive transducers are used for the measurement of physical quantities such as

- Displacement,
- Force,
- Pressure,
- Velocity,
- Position,
- Vibration etc.

3.6. Explain the working principle, construction and applications of LVDT

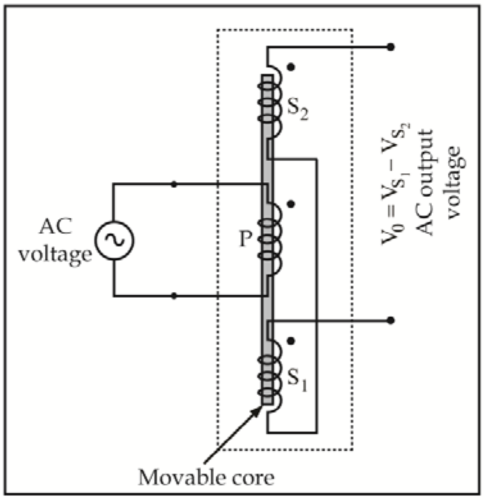


Fig. 3.6(a)

- Linear variable differential transformer (LVDT) also known as differential transformer is a passive inductive transducer.
- It is the most widely used inductive transducer to measure force (or weight, pressure and acceleration etc. which depends on force) in terms of the amount and direction of displacement of the ferro–magnetic core of a transformer.

- LVDT transducer is primarily used to measure the linear displacement.
- It comprises a transformer with one primary and two secondary coils with a movable core between them.
- The schematic diagram of LVDT is shown in fig. 3.6(a).
- This device is a transformer. It has a single primary winding with external source of AC voltage, and two secondary windings connected in series. It is variable because the core is free to move between the windings.
- It is differential because of the way the two secondary windings are connected. Being arranged to oppose each other (180^0 out of phase) means that the output of this device will be the difference between the voltage output of the two secondary windings.

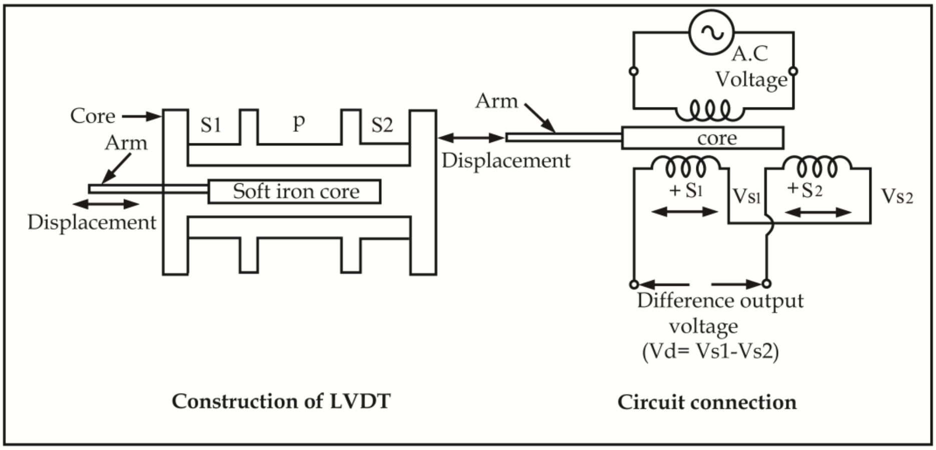


Fig. 3.6(b) Construction and Circuit Connection of LVDT

3.6.1. Working

- As shown in fig. above (fig. 3.6(b)), an ac voltage with a frequency between (50 – 400) Hz is supplied to the primary winding. Thus, two voltages V_{s1} and V_{s2} are obtained at the two secondary windings S_1 and S_2 respectively. The output voltage will be the difference between the two voltages $(V_{S1} - V_{S2})$ as they are combined in series.
- The AC voltage output by an LVDT indicates the position of the movable core. Zero volts means that the core is centered. The further away the core is from center position, the greater percentage of input ("excitation") voltage will be seen at the output. The phase of the output voltage relative to the excitation voltage indicates which direction from center the core is offset.
  - **Null Position:** This is also called the central position as the soft iron core will remain in the exact center of the former. Thus the linking magnetic flux produced in the two secondary windings will be equal. When the core is

centered and both windings are outputting the same voltage, the net result at the output terminals will be zero volts. The voltage induced because of them will also be equal. Thus the resulting voltage $V_{S1} - V_{S2} = 0$. It is called linear because the cores freedom of motion is straight line.

- **When core is moved to left side towards B:** In this position, the linking flux at the winding S_2 has a value more than the linking flux at the winding S_1. V_{S2} is greater than V_{S1} and hence output voltage is negative. Therefore the output voltage is 180^0 out of phase with the voltage which is obtained when the core is moved to left side.
- **When core is moved to right side towards B:** In this position, the linking flux at the winding S_2 has a value less than the linking flux at the winding S_1. V_{S2} is greater than V_{S1} and hence output voltage is positive. This movement represents the positive value and therefore phase angle is zero.

- From the working it is clear that the difference in voltage, $V_{S1} - V_{S2}$ will depend on the right or left shift of the core from the null position. Also, the resulting voltage is in phase with the primary winding voltage for the change of the arm in one direction, and is 180^0 out of phase for the change of the arm position in the other direction.

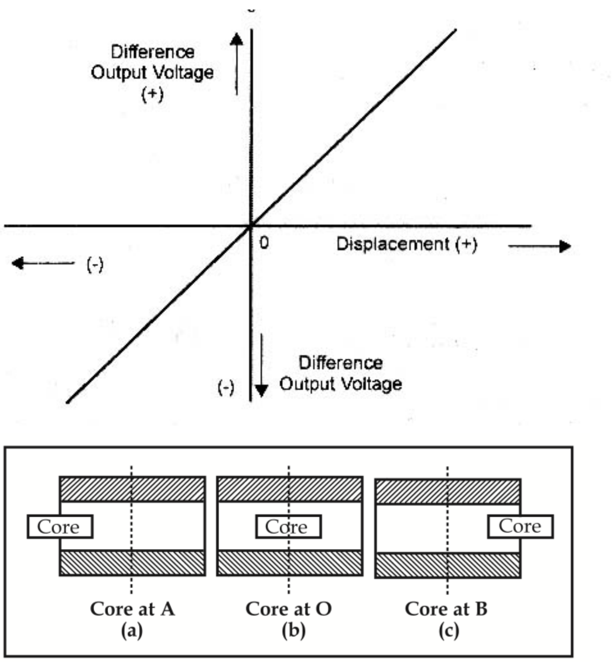


Fig. 3.6(c)

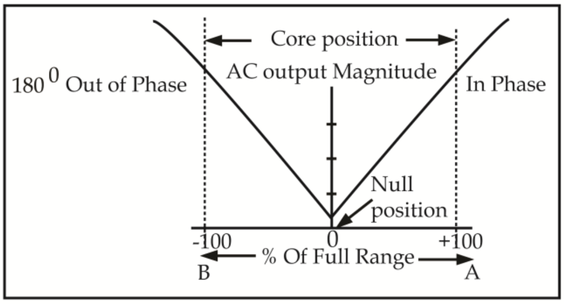


Fig. 3.6(d) Characteristics of LVDT

3.6.2. Advantages

1. Maintains a linear relationship between the voltage difference output and displacement from each position of the core for a displacement of about 4 millimeter.
2. Produces a high resolution of more than 10 millimeter.
3. Produces a high sensitivity of more than 40 volts/millimeter.
4. Small in size.
5. Weight is less.
6. Rugged in design.
7. Produces low hysteresis and thus has easy repeatability.
8. Low power consumption.
9. Very good linearity.

3.6.3. Disadvantages

1. The whole circuit is to be shielded as the accuracy can be affected by external magnetic field.
2. The displacement may produce vibrations which may affect the performance of the device.
3. Produces output with less power.
4. The efficiency of the device is easily affected by temperature.
5. A demodulator will be needed to obtain a d.c. output.

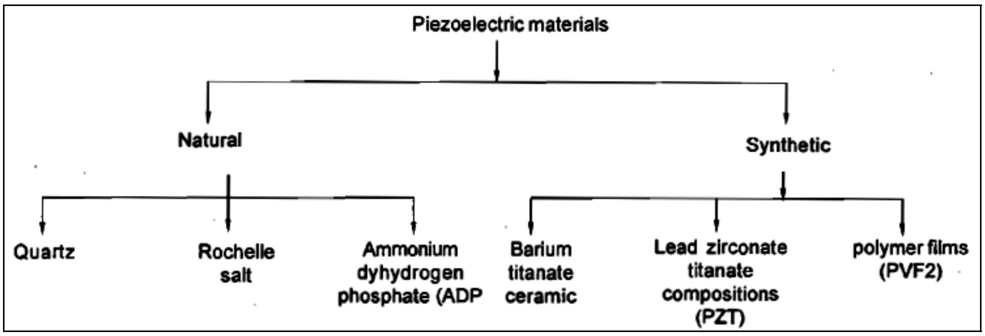
3.6.4. Applications of LVDT

1. LVDT is used to measure displacement ranging from fraction millimeter to centimeter.
2. Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure etc.
3. Jet engine controls in close proximity to exhaust gases.
4. Measurement of material thickness in hot strip or slab steel mills.

5. In accelerometers.
6. Measurement of roll position.
7. For the measurement of low frequency vibrations.
8. For the measurement of long duration shock motions.

3.7. Explain the working principle and construction of Piezo electric transducers.

- Piezoelectric transducer is an active transducer which utilizes the piezoelectric effect.
- These transducers are used in measurement of force, pressure and acceleration (by properly calibrating the voltage scale in terms of force, pressure or acceleration).
- Certain solid materials, when deformed, generate electric charge within them. This effect is reversible, i.e., if a charge is applied, the material mechanically deforms. This is known as piezoelectric effect.
- Thus piezoelectric materials are of the self-generating type. The piezoelectric effect arises because when asymmetric crystal lattice is distorted, an internal charge re-orientation takes place, and causes a relative displacement of positive and negative charge to opposite outer surfaces of the crystal.
- Piezo electric materials can be classified as follows.



1. Natural piezoelectric materials exhibit the property in their natural form without further processing. They are dense, brittle, stiff, and difficult to produce in large sizes.

   Fabrication into complex shapes is impractical.
2. Lead zorconate titanate compositions exhibit a stronger piezo-electric and offer much higher operating temperatures than barium titanate ceramics.
3. Synthetic piezoelectric polymer films have been developed recently; out of which polymers based on vinylidene fluoride (PVF2) have the highest piezo electric effect. They are plaint, flexible, tough, and light weight.

The main principle of a piezoelectric transducer is that a force, when applied on the quartz crystal, produces electric charges on the crystal surface. The charge thus produced can be called as piezoelectricity. Piezo electricity can be defined as the electrical polarization produced by mechanical strain on certain class of crystals. The rate of charge produced will be proportional to the rate of change of force applied as input. As the charge produced is very small, a charge amplifier is needed so as to produce an output voltage big enough to be measured. Quartz, tourmaline, and several other naturally occurring crystals generate an electrical charge when strained.

3.7.1. Piezo electric transducers

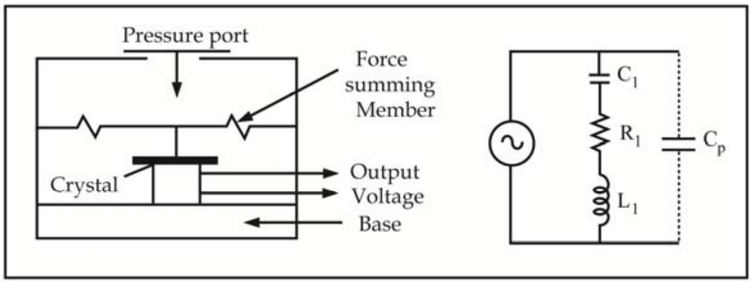


Fig. 3.7(b)

- The figure shows a conventional piezoelectric transducer with a piezoelectric crystal inserted between a solid base and the force summing member.
- If a force is applied on the pressure port, the same force will fall on the force summing member. Thus a potential difference will be generated on the crystal due to its property.
- The voltage produced will be proportional to the magnitude of the applied force.
- Piezoelectric transducer can measure pressure in the same way a force or an acceleration can be measured.

3.7.2. Advantages

1. Very high frequency response
2. Self generating, so no need of external source
3. Simple to use as they have small dimensions and large measuring range
4. Barium titanate and quartz can be made in any desired shape and form. It also has a large dielectric constant. The crystal axis is selectable by orienting the direction of orientation.

3.7.3. Disadvantages

1. It is not suitable for measurement in static condition
2. Since the device operates with the small electric charges, they need high impedance cable for electrical interface
3. The output may vary according to the temperature variation of the crystal

4. The relative humidity rises above 85% or fall below 35%, its output will be affected. If so, it has to be coated with wax or polymer material.

List any 3 uses the Piezo electric transducer

1. Piezoelectric transducers can be used for the dynamic measurement of force in the range 1 N to 200 kN with an accuracy of 1%.
2. Transient measurement of fluid pressures in the ranges $3\times10^{3}\,N/m^{2}$ to $6\times10^{8}\,N/m^{2}$ with 1% accuracy can be carried out by piezoelectric transducers.
3. They are widely used in record – player pickup and electronic watches.
4. Piezoelectric transducers are used in high frequency accelerometers.
5. These are used for measurement and recording of variation of gas pressure within cylinder of a gasoline engine, compressors etc.

3.9. Explain the working principle of RTD and Thermocouple transducer.

3.9.1. Working principle of RTD transducer

A resistance thermometer or resistance temperature detector (RTD) is a device which used to determine the temperature by measuring the resistance of pure electrical wire. This wire is referred to as a temperature sensor. If we want to measure temperature with high accuracy, RTD is the only one solution in industries. It has good linear characteristics over a wide range of temperature. The variation of resistance of the metal with the variation of the temperature is given as,

$$R_t = R_0\left[1 + (t - t_0) + \beta(t - t_0)^2 + \ldots\ldots\ldots\ldots\ldots\ldots\right]$$

Where, R_t and R_0 are the resistance values at t^0C and $t_0{}^0C$ temperatures, α and β are the constant depends on the metals.

Generally, electrical resistance of any metallic conductor varies according to temperature changes. The sensor for measurement of temperature by utilizing this phenomenon is called **Resistance Thermometer**. It is a basic element of resistance temperature detector, RTD.

1. Principle of Operation

The resistance of a conductor changes when its temperature changes. This property is used for the measurement of temperature. The resistance thermometer determines the change in the electrical resistance of the conductor to determine the temperature.

The temperature sensing element used in this thermometer should exhibit a relatively large change in resistance for a given change in temperature. Also the sensing element should not undergo permanent change with use or age. Another desirable characteristic for the sensing element is the linear change in resistance with change in temperature. When the sensing element is smaller in size, less heat is required to raise its temperature. This is suitable for measurement of rapid variations in temperature. Platinum, nickel, and copper are the metals most commonly used to measure temperature. The relationship between temperature and resistance of conductor is given by equation:

$$R_t = R_{ref}\left[1 + \alpha \Delta t\right]$$

Where, R_t = Resistance of the conductor at temperature t^0C

R_{ref} = Resistance of the conductor at the reference temperature, usually 0^0C

α = Temperature coefficient of the resistance

Δt = Difference between the temperature to be measured and reference Temperature

Almost all metallic conductors have a positive temperature coefficient so that their resistance increases with an increase in temperature. A high value of α is desirable in a temperature sensing element so that a substantial change in resistance occurs for a relatively small change in temperature. This change in resistance (ΔR) can be measured with a Wheatstone bridge, the output of which can be directly calibrated to indicate the temperature which caused the change in resistance.

2. Construction of RTD

The construction is typically such that the wire is wound on a form (in a coil) on notched mica cross frame to achieve small size, improving the thermal conductivity to decrease the response time and a high rate of heat transfer is obtained. In the industrial RTD's, the coil is protected by a stainless steel sheath or a protective tube.

So that, the physical strain is negligible as the wire expands and increases the length of the wire with the temperature change. If the strain on the wire is increasing, then the tension increases. Due to that, the resistance of the wire will change which is undesirable. So, we don't want to change the resistance of wire by any other unwanted changes except the temperature changes.

This is also useful to RTD maintenance while the plant is in operation. Mica is placed in between the steel sheath and resistance wire for better electrical insulation. Due less strain in resistance wire, it should be carefully wound over mica sheet. The fig. 2 shows the structural view of an industrial resistance temperature detector (RTD).

As shown in the fig. 3.8, the resistance temperature detector is composed of a resistance element, internal conductors, insulated tube, protection tube, reinforcing tube, terminal head and other necessary mounting attachments.

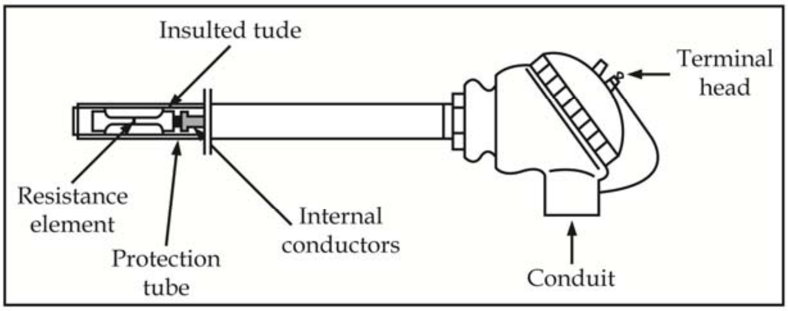


Fig. 3.8

1. **Resistance Element:** RTD uses platinum, nickel or copper as a resistance element. Generally, platinum wire is wound as bifilar on either ceramic bobbin or glass bobbin to form a resistance element. This resistance element is provided with a stainless steel fin having excellent heat transfer, which is secured within the protection tube, providing excellent resistance to vibration.
2. **Internal Lead Wire:** The internal lead wire is used to connect a resistance element and terminal. The standard nickel lead wire is of the 3-wire type. But 2-wire and 4-wire types are also available.
3. **Insulated Tube:** This insulated tube is used for internal lead wire insulation and short-circuit prevention; fiber glass sleeving is used for low and medium temperature, and a ceramic insulator for high temperature.
4. **Protection Tube:** Protection tube is used to protect a resistance element, internal lead wires, etc. from ambient conditions, and is also fitted with mounting attachments and terminal heads, etc. for easy installation. Protection tube may be subjected to extremely severe operating conditions. It is therefore necessary to select materials and shape suitable to the operating temperature, atmosphere, applications etc.
5. **Terminal Head:** This terminal head is used to connect the resistance temperature detector with external lead wire.
6. **Mounting Attachment:** This mounting attachment is provided for a protection tube to install the resistance temperature detector to a measuring point.

3. *Advantages of RTD*

1. Linear over wide operating range
2. Wide temperature operating range
3. High temperature operating range
4. Interchageability over wide range
5. Good stability at high temperature

4. Disadvantages of RTD

1. Low sensitivity
2. Higher cost than thermocouples
3. No point sensing
4. Affected by shock and vibration
5. Requires three or four wire operation
1. Air, gas and liquid temperature measurement

3.9.2. Working principle of Thermocouple transducer

Thermocouple comes under the category of active transducer. It works on the principle of seebeck effect or thermoelectric effect discovered by German physicist Thomas seebeck.

1. Seebeck Effect:

- When two dissimilar metals were in contact, a voltage was generated where the voltage was a function of
    - o Temperature difference
    - o The type of wire material used

2. Principle of Thermocouple

- A thermocouple consists of a pair of dissimilar metal wires joined together at one end, called the sensing junction and terminated at the other end, called the reference junction which is maintained at a known constant temperature called the reference temperature.
- When the sensing junction and the reference junction are at different temperatures, a potential difference gets produced which causes a current in the circuit. A micro ammeter or recording instrument is connected across the reference end as shown in fig. 3.9(a).
- Then the meter current is proportional to the temperature difference between the hot junction and the reference junction.

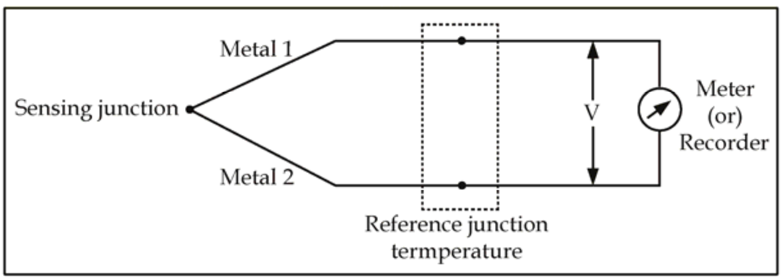


Fig. 3.9(a) Circuit for measuring temperature by using thermocouple

3. Thermocouple Transducer

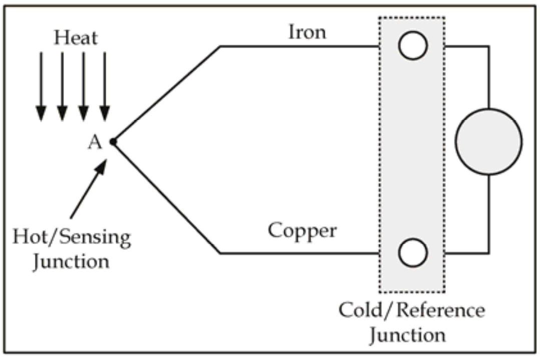


Fig. 3.9(b)

- The thermocouple transducer consists of two dissimilar metal wires joined at one end as shown in the given diagram, the end "A" is known as "sensing junction", the other end known as "Cold" or "Reference" junction because it is kept at a low but a constant temperature (Reference Temperature).
- When end "A" is heated an e.m.f. called thermo electric e.m.f in the milli volt is produce between sensing junction and reference junction.
- The magnitude of this e.m.f. depends on the temperature difference between the hot and cold junctions and the type of wire material used, the thermocouples are made from a number of different materials covering a wide range of temperature from -270^0C to 2700^0C.
- **Advantages of Thermocouples:**
  1. Rugged construction.
  2. Temperature range – 270^0C to 2700^0C
  3. Comparatively cheaper in cost
  4. Good measurement accuracy
  5. High speed of response
  6. Offers good reproducibility
  7. Calibration checks can be easily performed
  8. Bridge circuits are not needed for temperature measurement
  9. Using extension leads and compensating cables, long transmission distances for temperature measurement are possible
- **Limitations of Thermocouples:**
  1. They exhibit non-linearity in the emfVs temperature characteristics
  2. Cold junction and other compensation is essential for accurate temperature measurements

3. To ensure long life thermocouples in their operating environment, they should be protected in an open or closed end metal protecting tube or well.
4. Sometimes when the measuring device is placed remote from the thermocouple the circuitry becomes very complex.

3.10. Mention the 6 important applications of above transducers.

3.10.1. Applications of RTD

1. Air conditioning and refrigeration servicing
2. Food processing
3. Stoves and grills
4. Textile productions
5. Plastics processing
6. Petrochemical processing
7. Micro electronics

3.10.2. Applications of Thermocouple

1. In industry, thermocouples are used for measuring temperatures of industrial furnaces.
2. They are suitable for very low temperature measurement i.e. in the cryogenic range required in industry, scientific research and medical instrumentation.
3. For monitoring the temperature of liquids and gases in storage and while flowing in pipes and ducts.

3.11. Explain the application of transducer in accelerometer, servomotors and tachogenerators.

3.11.1. Accelerometer

- Accelerometer is an passive/active transducer which is generally used for measurement of acceleration (rate of change in velocity).
- It is measured in units of displacement per time per time. They consists of suspended spring mass damper system such that the mass is free to move in one direction only and against a restraining spring as shown in fig. 3.11.1(a).
- Movement of the mass may be sensed by some form of position transducer such as Potentiometric type, variable inductance type, variable capacitance type, bonded strain gauge type, piezoelectric type etc.
- Potentiometric type accelerometer is shown in fig. 3.11.1(b).
- It is generally contained in a housing. The mass supported by a spring and a damper is connected to the housing frame.

- The frame is rigidly attached to the machine or system whose acceleration characteristics are to be determined.
- When an acceleration is imparted by the system to the housing frame, the mass would move relative to the frame, and this relative displacement is sensed by any one of the electrical transducer; in this case by the Potentiometric transducer.
- The output signal from the Potentiometric transducer will be proportional to acceleration.

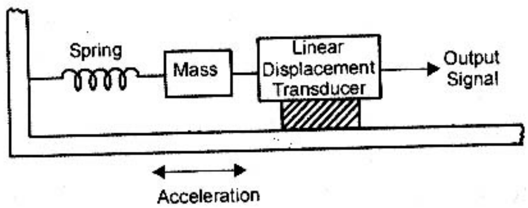


Fig. 3.11.1(a) Basic Accelerometer

3.11.1. Servo meter

- A servomotor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller.
- There are some special types of application of electrical motor where rotation of the motor is required for just a certain angle not continuously for long period of time for a given electrical input (signal). For this purpose of Servo Motor is used.
- **Definition of a Servo Motor:** This is normally a simple DC motor which is controlled for specific angular rotation with help of additional servomechanism (a typical closed loop feedback control system). It has a rotary actuator that allows for precise control of angular position, velocity and acceleration with great precision.
- In modern usage the term servo or servo – mechanism is restricted to a feedback control system in which the controlled variable is mechanical position or time derivates of position such as velocity and acceleration.
- A servo is a device, electrical, mechanical or electro mechanical that upon receipt of a stimulus or input, will employ feedback for velocity and/or position control, creating a closed loop.
- A feedback system is a control system which tends to maintain a prescribed relationship between a controlled quantity and a reference quantity by comparing their functions and using the difference as a means of control.
- Servo motor is a device which converts the input electrical quantity into displacement velocity or torque as output.

- There are mainly of two types,
  1. DC servo motors
  2. AC servo motors

1. d.c servo motors:

- D.c. servo motors are d.c. motors driven by current from d.c. electronic amplifiers or a.c. amplifiers with internal or external demodulators, saturable reactors or SCRs.
- The basic characteristics of such servo motors are that the torque developed is proportional to the applied control voltage developed by the amplifier in response to the error signal, and the direction of torque is determined by the control voltage polarity.
- There are two types of d.c. servo motors viz.,
  a. The field controlled shunt motor and
  b. The armature controlled shunt motor

a. Field controlled d.c. shunt motor:

Fig. 3.11.2(a) shows diagrammatically a field controlled d.c. servomotor.

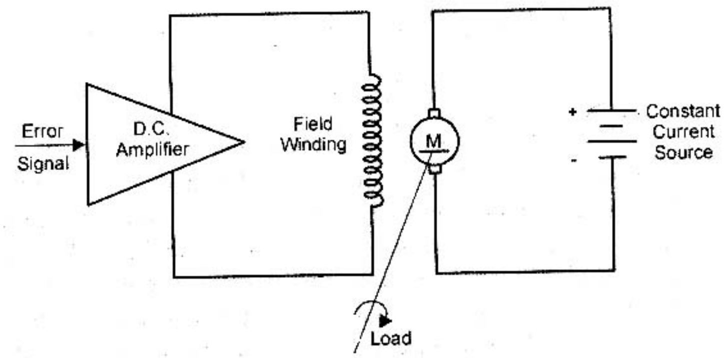


Fig. 3.11.2(a) DC Servo motor, field controlled type

- When the error signal is zero, there would be no field current and hence torque developed would be zero (as torque, $R = K\phi I_a$ and $\phi \alpha I_f$).
- The armature being supplied from a constant current source, the torque developed would be directly proportional to the field flux, i.e. field current up to the saturation point.
- The direction of rotation of the motor would depends on the polarity of the field, i.e. if the field polarity is reversed, the motor would develop torque in the opposite direction.

b. Armature controlled d.c. shunt motor:

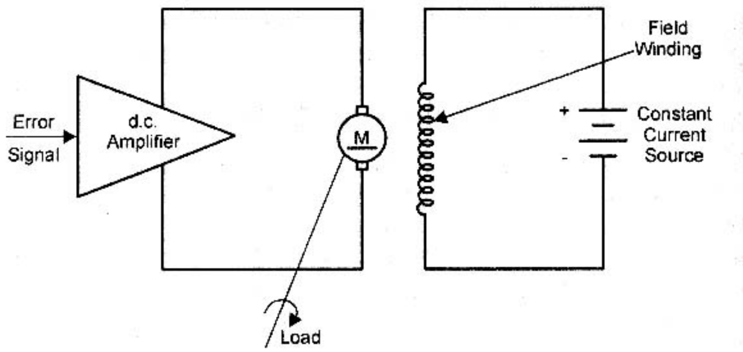


Fig. 3.11.2(b) DC servomotor, armature controlled type

- In servomotor of this type a fixed d.c. excitation is provided to the field winding by a constant – current source.
- The error signal after amplification through a dc amplifier is applied across the armature terminals as shown in fig. 3.11.2(b).
- The field magnets are excited beyond the knee of the saturation curve, i.e. the field is over excited to well beyond the knee of the saturation point. By doing so, the effect of variation of torque due to slight change in the voltage of the constant current source is avoided. That is for slight variation of excitation the field flux does not change and hence the torque developed is not affected.
- Armature controlled servomotors will have certain dynamic advantages as compared to the field controlled d.c. servomotor.
- A sudden change in armature voltage, large or small, produced by the error signal will cause an almost immediate response in torque, as the armature circuit is essentially a resistive one as compared to the field circuit.
- The field circuit being inductive will cause a delayed response to the output voltage. Large capacity d.c. servomotors are essentially armature controlled.
- For small low torque armature controlled d.c. servomotors, instead of providing constant field excitation, use is made of permanent magnets as filed magnets. Such servomotors are generally manufactured in 6V and 24V ratings.

2. a.c servo motors:

- The a.c. servomotors are mainly squirrel cage or drag cup induction motors. They are essentially two phase induction motors.
- However, a three phase construction is made where larger power is necessary.

a. Squirrel cage a.c. servomotor:

- Fig. 3.11.2(c) shows a schematic representation of squirrel cage a.c. servomotors.

- The stator has two separate windings displaced in space by 90^0 from each other. The rotor has squirrel cage construction.
- One of the stator windings, called the reference winding, is usually excited through a capacitor by a fixed a.c. supply. In the absence of any error signal the rotor would be stationary.
- A small error signal of some instantaneous polarity with respect to the reference winding would be amplified and fed to the control winding.
- A torque would be produced causing rotation of the rotor. The rotor would rotate in such a direction so as to reduce the error signal, and the rotor would stop rotating when the error signal is zero.

3. Applications of Servo Motors

Servo motors are small and efficient but critical for use in applications requiring precise position control. The servo motor is controlled by a signal (Data) better known as a pulse-width modulator (PWM). Here are several of the more common servo motor applications in use today.

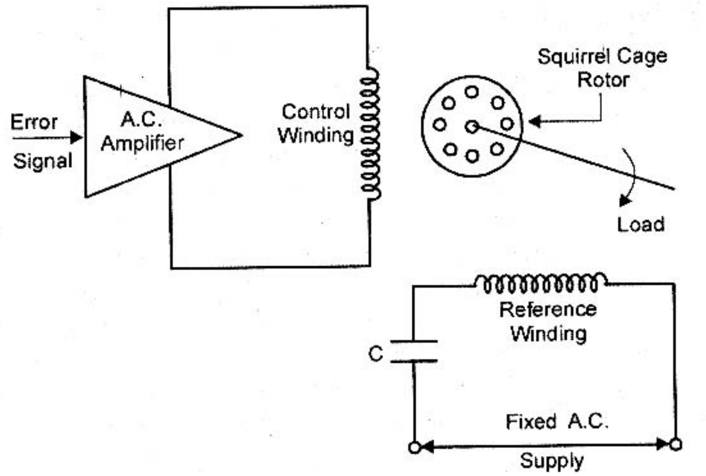


Fig. 3.11.2(c) Squirrel Cage a.c. servomotor

Servo motor applications are also commonly seen in remote controlled toy cars for controlling the direction of motion and it is also very commonly used as the motor which moves the tray of a CD or DVD player.

1. Robotics
2. Conveyor Belts
3. Camera Auto Focus
4. Robotic Vehicle
5. Solar Tracking System
6. Metal Cutting and Metal Forming Machines

7. Antenna Positioning
8. Wood Working / CNC
9. Textiles Printing Presses/ Printers
10. Automatic Door Openers

3.11.3. Tachogenerator:

- An active transducer that converts speed of rotation directly in to electrical signal is called a tachogenerator.
- The purpose of tachogenerator is to convert angular speed into a directly dependent voltage signal.
- Tachogenerators are of two types namely,
    1. D.C tachogenerator and
    2. A.C tachogenerator

1. D.C. Tachogenerator

- This instrument shown in fig. 3.10.3 essentially consists of two units, viz.,
    1. A miniature d.c. generator (a dynamo) serving as a transducer and
    2. A voltmeter serving as a display unit
- The armature of the dynamo rotates in an alnico permanent magnet field. Its electrical output is given by the relation.

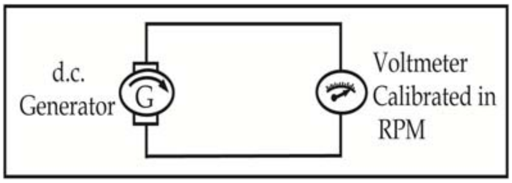


Fig. 3.10.3 D.C. Tachogenerator

$$E = \frac{\phi ZNP}{60A}$$

Where, E = emf of the dynamo

ϕ = Magnetic flux

P = Number of poles

A = Number of parallel paths in armature windings and

N = Revolutions per minute

Z = Number of armature conductors

- Since, P, Z and A are constants, it follows that E is proportional to N.
- Since the output of the dynamo is connected to a voltmeter graduated in revolutions per minute, when very little current is drawn, the d.c. tachogenerator system, shown in fig. 3.10.4 can be used as RPM counter.

- The d.c. tachogenerator is used in automatic speed control system. In such an application, the output voltage of the tachogenerator is fed back and compared with a reference voltages. The difference (i.e., error voltage) between the two readings causes the speed to be regulated to the reference voltage.

2. A.C. Tachogenerator

- Constructionally, the a.c. tachogenerator is similar to a two-phase induction motor, having stator and rotor as main components.
- The stator has two uniformly distributed windings placed in quadrature in space, as shown in fig. 3.10.4(a).
- The rotor can be of any one of the following types:
    1. High resistance squirrel cage type or
    2. Drag cup type
- The drag – cup rotor made of aluminium, has two air – gaps, as shown in fig. 3.10.4(b).

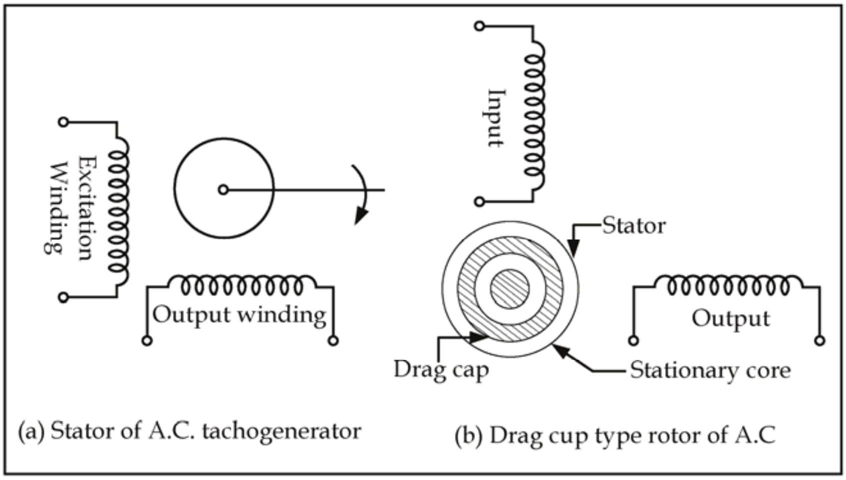


Fig. 3.10.4 A.C Tachogenerator

- Excitation winding produces a flux along the rotor axis.
- The rotor flux is developed by included eddy currents, when the rotor is stationary. Since the combined flux has no component along the axis of output winding, the output voltage is zero when rotor is stationary, and increases with increase in rotor speed.

3.12. Explain the term ultrasonic.

- Ultrasonic waves are sound waves transmitted above the human detectable frequency range, usually above 20,000 Hz. They are used by some animals and in medical or industrial technological devices.

- Ultrasonic is basically a sound which is not audible because its frequency is beyond the audible range of 20 kHz.
- The energy of ultrasonic sound has proved to be an important source of energy with a wide range of applications. It is extensively used in the modern metal working and manufacturing processes.
- The electrical energy is converted into ultrasonic vibrations (or energy) by means of transducers. These vibrations are utilized in various types of industrial processes such as machining, wire drawing, welding, soldering etc.
- The other applications of ultrasonic vibrations are found in cleaning of machines, medical field measurement of speed, testing etc.

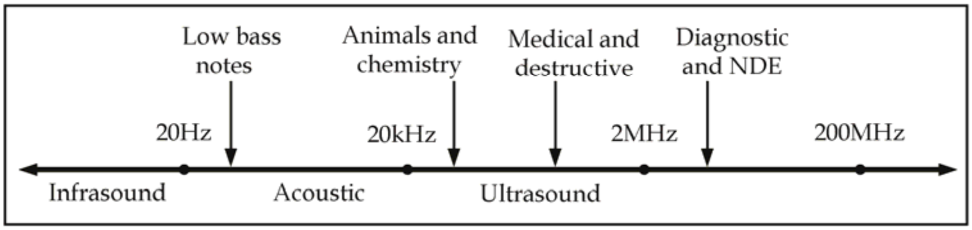


Fig. 3.11

- When an explosion takes place, various types of sounds are associated with it. One has a very low frequency even below the audible limit (20 Hz to 20 kHz). Such sounds are called **Infra Sounds** (or) **Infrasonics**. The other is the ordinary audible sounds.
- There is a third type in which the frequencies are beyond the limits of audible range and these sounds are called "**Ultrasonics**" (beyond 20 kHz).

3.12.1. Applications of Ultrasonics

Ultrasonic has found numerous applications in industry and communication system. A few of these are listed below:

1. Ultrasonic stroboscope
2. Ultrasonic as means of communication
3. Testing of materials by Ultrasonics
4. Dispersive and Colloidal effect of Ultrasonics
5. Coagulating action of Ultrasonics
6. Separation of mixtures by Ultrasonics
7. Cutting and Machining of Hard Materials
8. Degassing of liquids by Ultrasonic Waves
9. Physico-chemical effects of Ultrasonics
10. Chemical effect of Ultrasonics
11. Thermal effects of Ultrasonics

12. Biological effects of Ultrasonics

The main applications of ultrasonic vibrations are in the following:

1. Machining
2. Non – destructive testing (NDT) and flaw detection
3. Soldering, welding and bonding of leads
4. Medical testing
5. Cleaning

- **Machining:** This is one of the most important applications of ultrasonic vibrations. It includes drilling, cutting, grinding, fabricating complicated shaped work pieces etc. This is a very accurate process and is specially meant for precision operations.
- Ultrasonic drilling is preferred for making holes of different shapes and of very small dimensions, specially on hard and brittle materials like glass, tungsten, porcelain etc.
- **Non – Destructive Testing (NDT) and Flaw Detection:** This technique, employing Ultrasonics is used for detecting cracks in metals and concrete slabs. It is most often
- used in situations where no fault can be tolerated and every piece is to be tested separately.
- **Soldering, Welding and Bonding of Leads:** Ultrasonic welding is useful particularly for plastic sheets and aluminium foils. Similarly, Ultrasonic soldering is preferred for aluminium. It is also used to bond leads of electronic circuits, specially in d.c. circuit fabrication.
- **Medical Testing:** Ultrasonic vibrations are these days used for diagonising heart and stomach diseases. An echogram is employed for obtaining the output waves which are analyzed for the diagnostic purposes.
- **Cleaning:** The objects to be cleaned are kept in liquid which is then subjected to Ultrasonic vibrations. The vibrations cause formation of small bubbles which collapse, thus sending shock waves through the liquid. These shock waves cause the cleaning action. The formation of bubbles and their collapsing is called cantation.
- Apart from the above applications ultrasonics can also be used for measurement purposes. For instances it is used by the police to measure the speed of vehicles.

3.13. Mention methods of generating ultrasonic waves.

- Ultrasonic vibrations are produced by exciting a transducer by either mechanical or electrical energy. The basic process of ultrasonic generation can be explained by the simple block diagram shown in fig. 3.13.

- Depending on the type of transducer used, the excitation can be of two types, viz., (i) mechanical and (ii) electrical.
- The first type is called the mechanical generation of ultrasonics while the second type is known as the electrical generation of ultrasonics.
- Electrical methods of ultrasonic generation are universally preferred over the mechanical methods because of their convenience, compactness, and ease of handling.

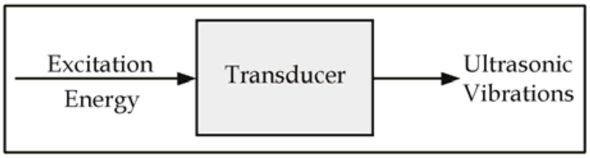


Fig. 3.13 Basic Principle of Generation of Ultrasonic Vibrations

- In the electrical methods of ultrasonic generation, generally an oscillator circuit is used to drive the transducer for producing the ultrasonics. The two main types of electrical ultrasonic generators are (i) the piezoelectric generator and the (ii) the magnetostriction generator.

1. Mechanical Generators:

a. **Tuning Forks:** In air, ultrasonic waves up to 90 kc/s may be produced by small tuning forks with prongs only a few millimeter long. These waves are, however, strongly damped and not useful in practical applications

b. **The Galton Whistle:** This produces constant amplitude, constant frequency ultrasonic waves upto about 100 kHz.

c. **Gas Current Generator:** This produces ultrasonic waves of frequencies of about 60 kc/sec in air. It is useful for producing greater power upto about 50 watts of sound.

d. **Holtzmann's Generator:** In this ultrasonic waves are produced by clamping a glass rod at one end and vibrating it length wire. This produces frequencies of about 33 kc/sec for a glass tube length of 7.5 cm.

2. Electrical Generators:

a. **Piezo-Electric Generator:** This is the only generator which produces higher frequency ultrasonic waves. It utilizes the Piezo-electric effect.

b. **Magneto Striction Generator:** It utilizes the magneto striction effect (whenever a ferro magnetic material is subjected to an alternating supply source, causes changes in its dimensions either in length wise (or) breadth wise alternatively hence generates ultrasonic waves in the material).

3. Thermal Generators: Heating of certain metals and non metals can give rise to mechanical vibrations in the ultrasonic range. These are not of any practical importance, since several electronic oscillators have appeared.

3.14. Draw and explain pulsed-echo ultrasonic flaw detector

This is the equipment most widely used and is basically a pulsed flaw detector operating of the principle of reflected signal indication. The ultrasonic pulse uses high frequencies of 0.8 to 2.5 MHz for inspection of steel, aluminium and brass articles but uses lower frequencies for inspection of coarse grain materials such as cast iron, plastic goods, porcelain, concrete, timber etc.

The pulsed echo method currently in use is very sensitive since echo pulse of energy as small as one per cent of the transmitted energy is sufficient for recording an echo. Generally a single probe or transducer is used. The transducer first acts as a transmitter sending out a pulse of high frequency ultrasonic waves into the article to be inspected and then acts as a receiver to receive the ultrasonic echo pulses reflected from the flaw and from the far end of the material.

The received ultrasonic echo pulses are transformed by the transducer into corresponding electric echo pulses of the same frequency as the sound waves. These are then amplified and displayed in the form of a series of pips and pulses on the screen of a C.R. tube. The first pulse corresponds to the transmitted pulse. This is followed by pulse corresponding to the flaws and lastly comes the pulse from the far end of the materials shown in fig. 3.13(c). The distance of the flaw echo pulse from the transmitted pulse gives the location of the flaw from the near end. Thus the process of inspection is very simple. The equipment can be used for detection of flaws as deep as 10 meters from the front surface. However, the drawback of the pulse – echo detector is that there exists dead zone.

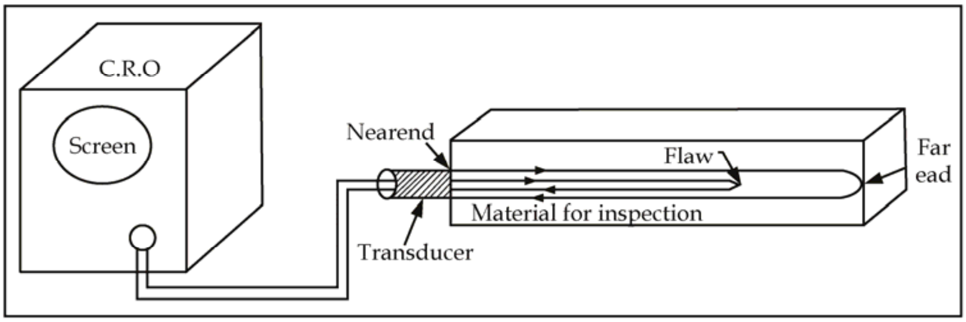


Fig. 3.13(a) Block diagram illustrating the working of pulsed – echo ultrasonic flaw detector

The portion of the material close to the front surface, which cannot be inspected. This dead zone extends upto 2 to 5 mm. Flaws within the dead zone are not detectable since the echos obtained from them return to the transmitter while it is still transmitting the pulses and is not switched to receiving.

For testing sheet material, there are used several pairs of transducers which are consecutively connected to a high frequency oscillator and amplifier through a distribution board. The flaws are recorded on electrically sensitive paper.

(or)

This method is normally used to detect manufacturing flaws in metals and concrete slabs. It is also known as the reflection method of flaw detection. A block diagram representation of such a scheme has been shown in fig.

The transmitter is basically an ultrasonic generator which when excited by a proper exciter for a short duration produces a sharp train of ultrasonic vibrations in the form of an energy pulse. These vibrations are sent through the job which is being tested for the flaw. The receiver is similar to a transmitter and is capable of receiving the ultrasonic vibration pulses.

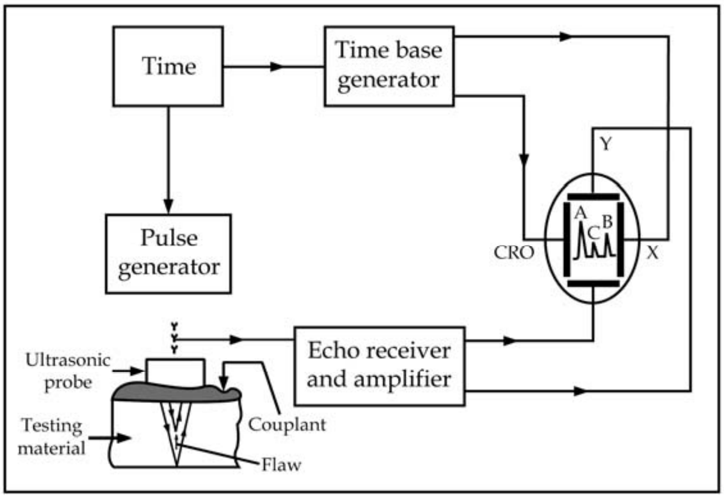


Fig. 3.13(b): Block diagram of Pulsed echo ultrasonic flaw detector

The transmitter can also be used as a receiver or a separate receiver can be used. When the vibrations are applied to the job and the transmitter and the receiver is moved gradually along the side we receive two pulses, besides the one transmitted. One corresponding to the second surface and the other corresponding to the surface where the flaw occurs. Reflections of the pulses occur whenever the medium changes due to the change in impedance.

If there is no flaw in the job the middle pulse obviously would not appear. This has been explained in fig. A job of length l having a flaw at a distance d from the first end surface of the job has been shown in fig. The pulses received by the receiver of a pulse echo-ultrasonic flaw detector have been shown in fig. Pulse one is the transmitted pulse, pulse two is obtained due to reflection at a distance d due to flaw reflection and third corresponding to the surface where the flaw occurs.

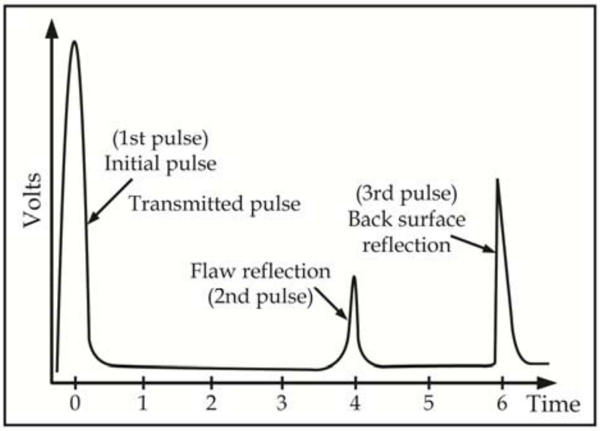

Volts
(1st pulse)
Initial pulse
Transmitted pulse
(3rd pulse)
Back surface
reflection
Flaw reflection
(2nd pulse)
0
1
2
3
4
5
6
Time

Fig. 3.13(c)

CHAPTER 4

Industrial heating

OBJECTIVES

Upon completion of the chapter the student should be able to Understand the working of Transmission Lines

4.1 Give the classification of industrial heating methods.
4.2 Explain the principle of induction heating.
4.3 Give the list of applications of induction heating.
4.4 Explain about HF power source for induction heating.
4.5 Explain the principle of dielectric heating.
4.6 Explain about the electrodes used in dielectric heating & method of coupling to RF generator.
4.7 Give the list of dielectric heating applications.
4.8 Give the definition of welding.
4.9 Give the list of different types of Electrical welding
4.10 Explain the principle of resistance welding.
4.11 Explain the basic circuit of AC resistance welding and explain its working.
4.12 Explain about the electrodes used in resistance welding system
4.13 Give the list of resistance welding applications.
4.14 Draw the block diagram of a resistance welding system that uses sequence timer.

4.0. Introduction

Most electrical load produces a certain amount of heat. Heating is caused when current flows through a resistive device. In some equipment, heat causes a power loss. Lamps, for example, produce heat energy as well as light energy. There are several types of loads that are mainly heating loads. Their main purpose is to convert electrical energy into heat energy. These load devices include resistive heating, inductive heating, and dielectric (capacitive) heating.

Electric heating is extensively used both for domestic and industrial applications. Domestic applications include

1. Room heaters
2. Immersion heaters for water heating
3. Hot plates for cooking
4. Electric kettles
5. Electric irons
6. Pop-corn plants
7. Electric ovens for bakeries and
8. Electric toasters etc.

Industrial applications of electric heating include

1. Melting of metals
2. Heat treatment of metals like annealing, tempering, soldering and brazing etc.
3. Moulding of glass
4. Baking of insulators
5. Enamelling of copper wires etc.

The basic circuit is shown in fig. 4.0 and can be used with d.c. as well as a.c. supply. When direct current is used, the electrode is mostly negative (DCSP). The process is started by adjusting the amperage on the d.c. welder, turning welder ON and bringing the electrode into contact with the work piece. After the arc column starts, electrode is withdrawn 25 – 40 mm away and the arc is maintained at this distance. The arc can be extinguished by simply removing the electrode from the work piece completely. The only function of the carbon arc is to supply heat to the base metal. This heat is used to melt the base metal or filler rod for obtaining fusion weld depending on the type and size of electrodes, maximum current values range from 15A to 600A for single-electrode carbon arc welding.

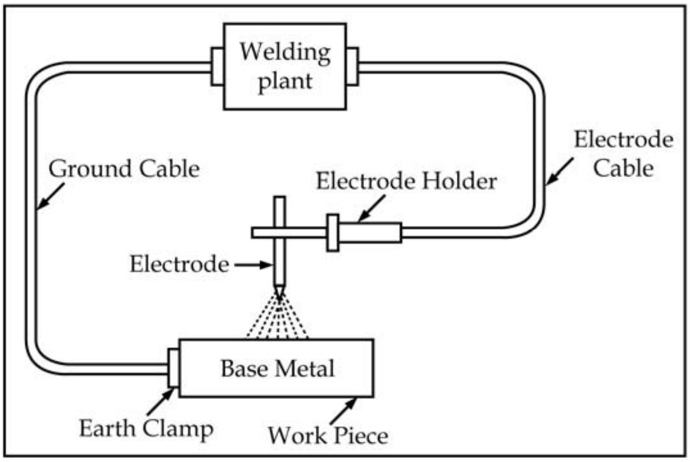
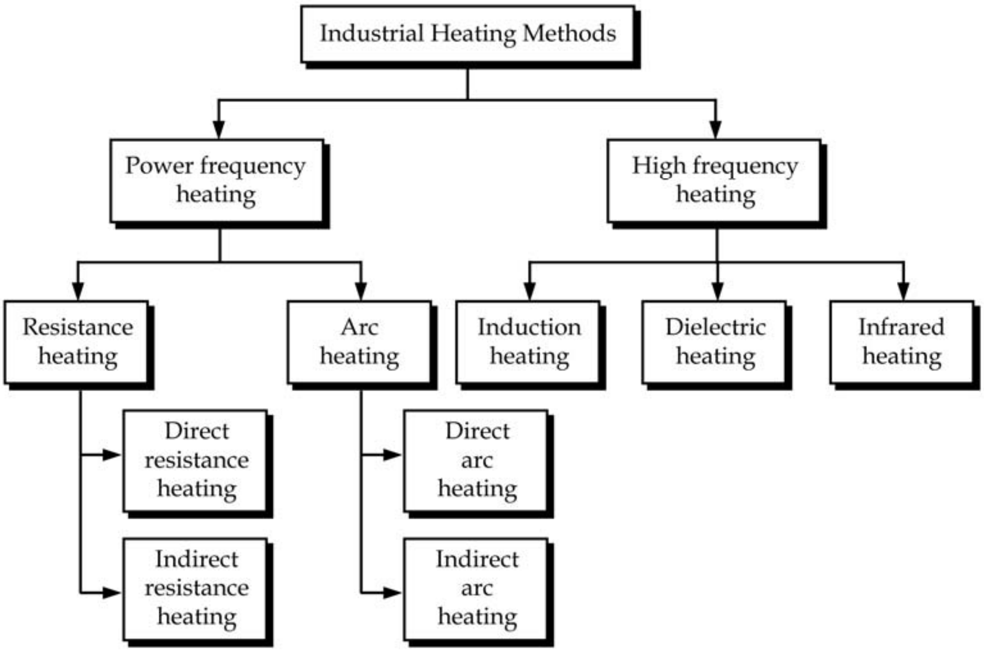


Fig. 4.0

4.1. Classify Industrial Heating Methods



Heating methods are broadly classified into:

1. High Frequency Heating
2. Power Frequency Heating

In high frequency heating, heat transfer takes place inside the material. Here, the heat transfer rate is as much as $10{,}000\,\mathrm{W/cm^2}$ which is very useful for high-speed production. High frequency heating can be applied to

(i) Ferro magnetic or non magnetic materials and

(ii) Insulating materials

High frequency heating is divided into:

1. Induction Heating
2. Dielectric Heating

4.2. Principle of Induction Heating

- When AC current i is made to flow through the work coil, AC magnetic field will be produced.
- Since current reverses or alternates, flux will also change and change in flux will induce a voltage within the work piece and voltage induced is given by,

$$e = -\frac{d\phi}{dt}$$

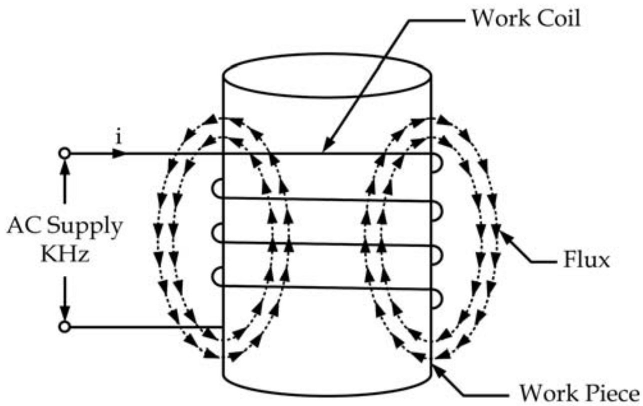


Fig. 4.2 Basic setup for induction heating

- This induced voltage will cause large eddy current to flow through metal. When this eddy current passes through resistance of metal job, it will generate heat. In this way eddy currents produce heat through induction.
- If work piece is a magnetic material along with heat generated by eddy currents, heat is produced through hysteresis loss also. But heat produced due to hysteresis loss is very less and can be neglected in most of the cases.
- Induction heating can be used to heat only conducting material.

Additional Information

∗ Advantages of Induction Heating∗

The advantages of induction heating are as follows:

1. The heat is concentrated near the surface of the work piece. This characteristic is useful in surface hardening of steel.
2. The rate of heating the work piece is very high. It is of the order of $0.5\,W/m^2$.
3. The extent of the heating surface can be controlled rigidly, resulting in less wastage of heat.
4. The heat transferred to the work piece can be controlled by electronic timers.
5. Induction heating of metals can be satisfactorily done in vacuum, or in an inert gas or any other gas.
6. The temperature of the work piece can be controlled accurately by automatic means.
7. Relatively unskilled personnel may be used for operation of the induction heating equipment.

∗ Disadvantages of Induction Heating∗

The disadvantages of induction heating are as follows:

1. High cost of operation and equipment.
2. Overall of efficiency is poor $(< 50\%)$.

4.3 Applications of Induction Heating

1. Surface hardening of steel
2. Soldering and brazing
3. Annealing of brass and bronze items
4. Induction cooking using metal pans and pots
5. Drying points on metals, sintering powdered metals
6. Sterilizing surgical instruments
7. Welding and bonding clutch facing

4.4. HF Power Source for Induction Heating

4.4.1. Introduction

- The type of power source used for induction heating depends upon the nature of application and on the amount of power needed. Thus for large size objects made of magnetic materials, alternators generating frequencies in the range of 1 to 10 KHz may be used.

- For small size objects, for non – magnetic materials for application needing small depths of penetration, and jobs requiring precise and automatic control of heating power, electronic oscillator generating frequencies in the vicinity of 450 KHz are used.
- The electronic oscillators are more compact, sturdy, portable and almost automatic when compared to alternators. As the high frequency power source is subjected to frequent overloads, dust, vibration and rough handling by relatively unskilled operators in induction heating, so they must be specially designed for these conditions.
- Fig.4.4.1 shows the block diagram representation of high frequency induction heating (electronic heater).

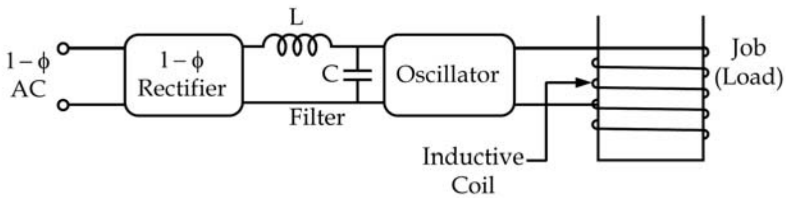


Fig. 4.4.1

4.4.2. Working

- The ac supply voltage is stepped up by means of a step-up transformer and further rectified by a bridge rectifier as shown in fig. 4.4.2.
- The ripple components are minimized by the use of an LC filter. This ripple-free high voltage dc is fed to a Colpitt's oscillator.
- The oscillator circuit produces high frequency power and feeds it to the input of an inductive coil which is the primary of the work coil. The work piece acts like a short circuited secondary.
- The oscillator circuit produces a high frequency – high voltage supply which leads to a large amount of heat loss. This results in the reduction of conversion efficiency of the system.
- To minimize the heat loss, the system has to be designed properly for absorbing the heat within the oscillator circuit.
- The induction coils are made in the form of hollow tubes through which cold water is circulated to absorb heat. The frequency used in the case of the non-magnetic is about 50 kHz.

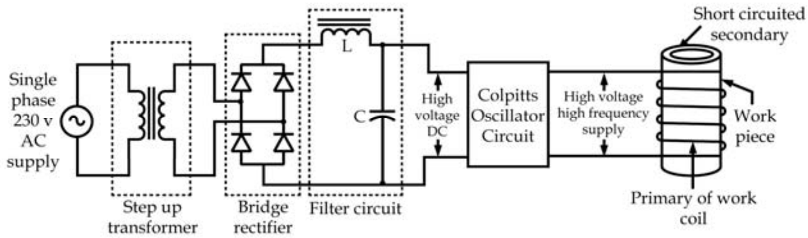


Fig. 4.4.2 Source of high frequency power supply for induction heating

Additional Information

∗ Dielectric Heating∗

A non – conducting material generates heat when subjected to an alternating electric field. This process wherein heating takes place due to dielectric loss is known as **dielectric heating**. The amount of heat produced depends on the value of the dielectric strength of the material. The non-conducting material acts as the job which is to be heated. This method is extensively used in plastic and wood industries. It is specially of immense utility where multiply woods are to be heated and glued. The heat supplied by this method is applied evenly throughout the whole body. This method is also employed in the textile, rubber, chemical and food industries.

4.5. Principle of Dielectric Heating

- In case of a capacitor, if sinusoidal voltage is applied, current leads the voltage by 90^0. But in practical capacitor there is a small component of current in phase with voltage and will lead to I^2R heat I the dielectric of the capacitor. This is referred as dielectric loss of capacitor. Dielectric loss is nothing but waste of energy in capacitor in the form of heat.

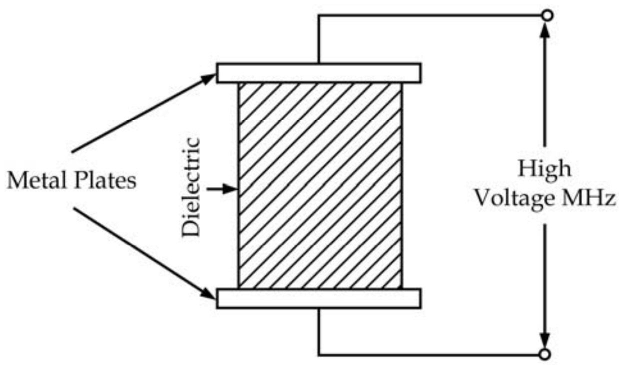


Fig. 4.5 Dielectric Heating Principle

- Dielectric loss can be effectively utilized so as to produce heat in poorly conducting material. Some heat is always produced when any dielectric is placed under alternating voltage.
- This happens because rapid change of electrostatic field distorts molecular structure of material and inter molecular friction generates heat uniformly throughout all parts of the material.
- To heat non-conducting materials, they should be placed under parallel metal plates and HF or VHF AC supply should be applied.
- Fig.4.5 shows the dielectric heating setup. As shown in this setup, the dielectric work piece is held between the two electrodes.
- A high frequency, high voltage AC supply is given to the electrodes. This causes some current to flow through dielectric work piece.
- The current flow in the dielectric material causes losses and the material heats up due to losses.
- Fig. 4.5.1(b) shows an equivalent circuit of dielectric heating. The losses take place due to internal resistance of dielectric material and 'C' is an internal capacitance of the material.

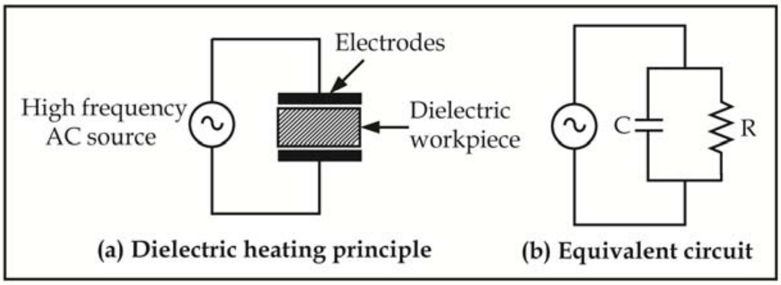


Fig. 4.5.1 Dielectric Heating

4.5.1. Advantages and Disadvantages of Dielectric Heating

Advantages of Dielectric Heating

1. Heating is very quick
2. The efficiency is higher
3. Heating is uniform
4. Being free from smoke, dust, process is very clean
5. There are no flue gases, no risk of pollution
6. Heat is produced due to dielectric loss occurs in the material itself

Disadvantages of Dielectric Heating

1. Enclosures to reduce high sound levels
2. Dust collector for furnace off-gas

3. Slag production
4. Cooling water demand
5. Heavy truck traffic for scrap, materials handling and products
6. Environmental effects of electricity generation

4.6. Electrodes used in Dielectric Heating

4.6.1 Electrodes used in Dielectric Heating

In order to establish the required high electrostatic field intensity in the region of the material to be heated, it is necessary to apply HF or VHF voltage of desired high magnitude to the two metallic electrodes. The dielectric to be heated is placed between the electrodes.

For optimum results, proper selection and placement of electrodes is important for the required application. The heat produced in any section of the dielectric is proportional to the square of the voltage gradient and if the gradient is not constant heating will not be uniform.

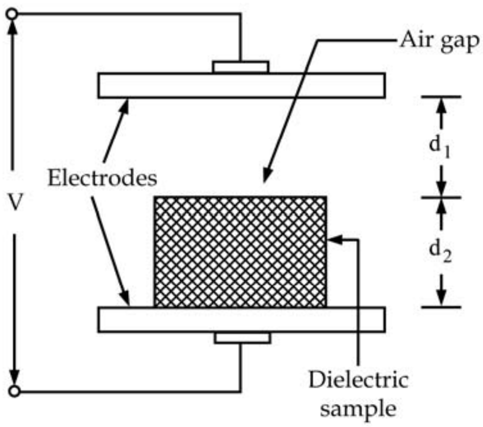


Fig. 4.6.1 General circuit of dielectric heating

In case the material to be heated travels between the electrode or on a conveyor belt, or the material is non-uniform in dimensions or when different parts of the material required to be heated at different rates, then the air clearance is permitted between the dielectric material of one or both the electrodes.

Fig. 4.6.1. shows the general circuit of dielectric heating with an air gap between one electrode and the dielectric.

The shape and size of the electrodes between which the material to be heated is placed depends upon the fact that a uniform voltage gradient has to be provided. Electrodes slightly larger than the material are used where regular field cannot be created on account of the peculiar shape of the charge. The electrodes may be made of simple shape and the charge may be rotated in the space between the electrodes or the gap should be kept at an optimum value. In case of irregularly shaped dielectrics, uniform voltage gradient is produced by using specially shaped electrodes to obtain uniform heating throughout the material.

4.7. Method of Coupling of Electrodes to RF Generator

Following are the common methods of coupling the lead to the tank circuit of RF oscillator.

a. **Electrode directly across the tank coil:** In this case the load with the electrodes constitutes a capacitor comes in shunt with the variable capacitor shown in fig. 4.6.2(a) and becomes a part of it. Thus the load voltage is nothing but the tank circuit voltage.

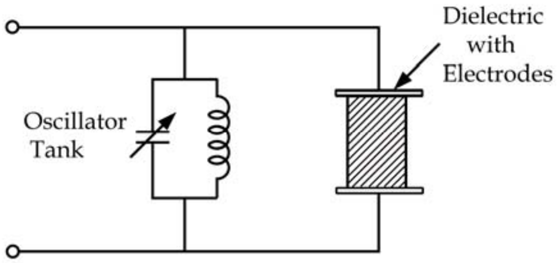


Fig. 4.6.2(a) Directly across the coil

b. **Load across a part of the tank coil:** The below arrangement reduces the load voltage to a desired value below the tank circuit voltage.

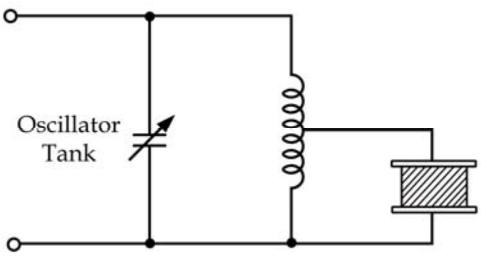


Fig. 4.6.2(b) Load across a part of tank coil

c. **Auxiliary inductor in series with load:** The load which is shown in fig. 4.6.2(c), itself constitutes a capacitor and this capacitor along with inductor L forms a series resonant circuit. As the value of L is increased, this series circuit comes more and more in resonance at the frequency of oscillator, then the load voltage increases above the oscillator voltage.

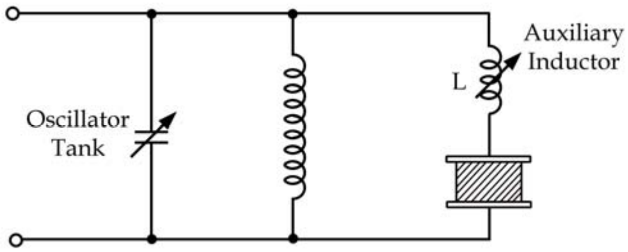


Fig. 4.6.2(c) Use of Auxiliary series inductor

d. **Load connected through transmission lines:** Sometimes it becomes necessary to keep the load away from the R.F. generator. In such a case, the energy from R.F. oscillator is sent over transmission line to the load. For impedance matching, reactive T or π sections may be used.

4.8. Applications of Dielectric Heating

Plywood industry	Plastic welding
Sand core baking	Vulcanization of rubber
Plastic industry	Gluing of wood
Tobacco industry	Electronic sewing
Bakeries	Heating of raw plastic
Sand core baking	Food processing
Electronic sawing	Pasteurizing milk
Dehydration of food	Dehydrating fruits
Electromedical application	Defrosting frozen food
Book binding	

Additional Information

∗ Comparison between Dielectric Heating and Induction Heating∗

The differences between induction heating and dielectric heating are as follows:

S.No.	Induction Heating	Dielectric Heating
1.	Induction heating is caused by eddy currents in imperfect dielectrics.	Dielectric heating depends on the electrostatic effect.
2.	The operating frequencies are of the order of 200 kHz to 500 kHz.	The operating frequencies range from 1 MHz to 50 MHz.
3.	The cost of equipment required is low.	The cost of equipment required is comparatively high.

4.9. Definition of Welding

Welding:

It is the process of joining two pieces of metal or non-metal at faces rendered plastic or liquid by the application of heat or pressure or both. Filler material may be used to effect the union.

(or)

Welding is a metallurgical process by which metals are joined together by the application of heat and pressure.

(or)

Welding is the process in which metals are heated to melting point and adhere on solidification.

(or)

Welding is a process of making permanent joint by establishing inter atomic bonds between two (or) more pieces of metals by using heat or heat and pressure.

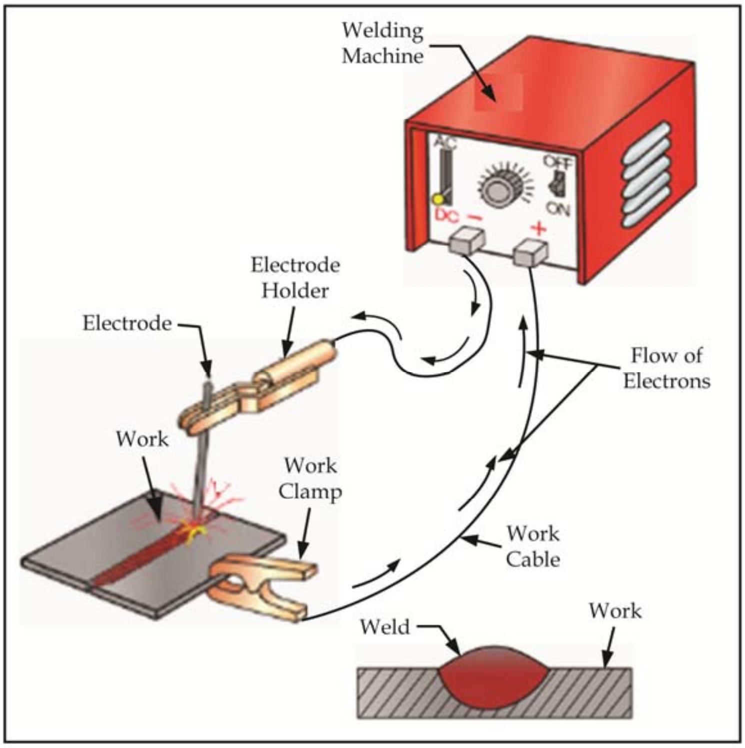


Fig. 4.9 Welding Machine

All welding processes fall into two distinct categories:

1. **Fusion Welding:** It involves melting of the parent metal. Examples are:
   a. Carbon arc welding, metal arc welding, electron beam welding, electroslag welding and electrogas welding which utilize electric energy and

   b. Gas welding and thermit welding which utilize chemical energy for the melting purpose.

2. **Non-fusion Welding:** It does not involve melting of the parent metal. Examples are:
   a. Forge welding and gas non-fusion welding which use chemical energy.
   b. Explosive welding, friction welding and ultrasonic welding etc., which use mechanical energy.
   c. Resistance welding which uses electrical energy.

4.10. Types of Electrical Welding

Electrical welding is another common type of a heat – producing power conversion system. The types of electrical welding systems include

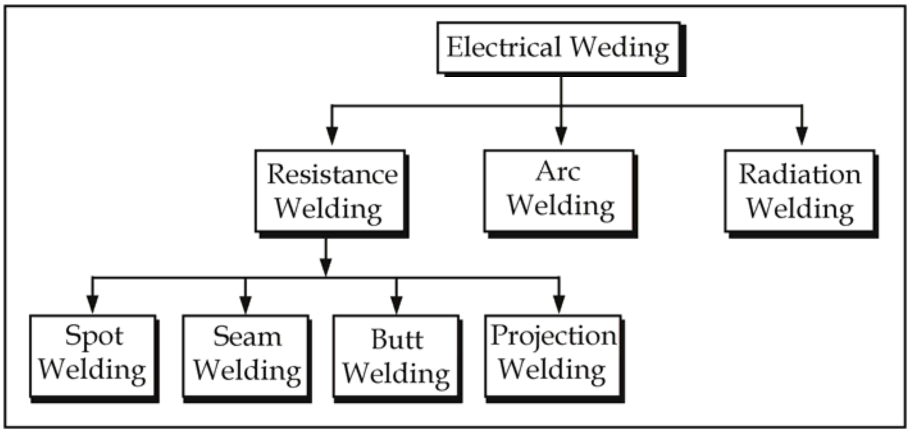


Fig. 4.10

4.11. Principle of Resistive Welding

Two metallic pieces to be welded together as pressed against each other by applying pressure by the two electrodes of the resistance welding unit. After this, a high current is made to flow between the two electrodes. This current, while flowing through the metallic plates produces large heat due to I^2R loss where R is the contact resistance between the metal plates.

As a result, localized melting occurs and the two pieces are fused together at that point. Now the current is stopped but the pressure is still retained. As there is no heating effect now, the fused portions cool down and get welded to each other. After this the pressure is removed and the next weld begins. This is the basic principle of resistance welding.

Due to the enormous heat produced during welding, the electrodes may get welded to the job. This must be evidently prevented. To prevent such occurrence, the electrodes are hollow and are water cooled in big units. The electrode material is hard copper alloy.

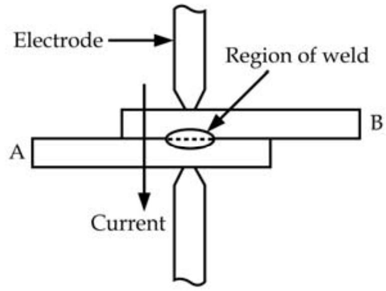


Fig. 4.10 Principle of resistance welding

Advantages

Some of the advantages of resistance welding are as under:

1. Heat is localized where required
2. Welding action is rapid
3. No filler material is needed
4. Requires comparatively lesser skill
5. Is suitable for large quantity production
6. Both similar and dissimilar metals can be welded
7. Parent metal is not harmed
8. Difficult shapes and sections can be welded

Only disadvantages are with regard to high initial as well as maintenance cost. It is a form of resistance welding in which the two surfaces are joined by spots of fused metal caused by fused metal between suitable electrodes under pressure.

4.13. Types of Resistance Welding

The various types of resistance welding processes may be divided into the following four main groups:

1. Spot welding
2. Seam welding
3. Projection welding
4. Butt welding

Which could be further subdivided into flash welding, upset welding and stud welding etc.

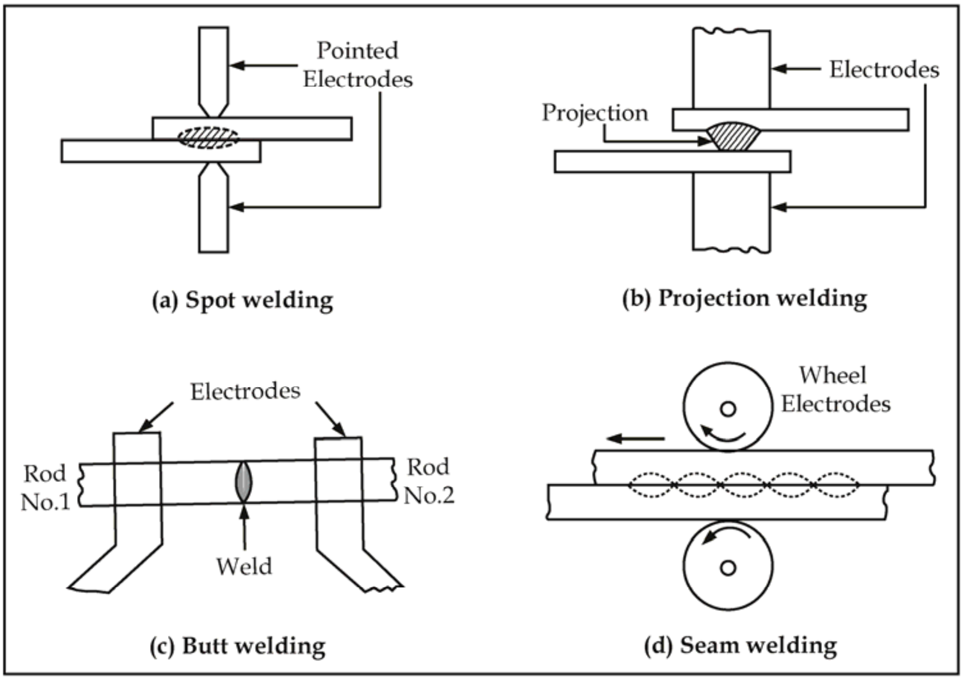


Fig. 4.13 Important types of resistance welding arrangements

1. **Spot Welding:** Spot welding is done by clamping together between two pointed electrodes, two or more pieces of metal usually in the form of sheets. The pointed electrodes ensure proper localization of current. Fig. shows the basic arrangement.
2. **Projection Welding:** In projection welding, instead of using point electrodes, for concentration of heat, use is made of either an embossing or raised pump, on one or both of the pieces at a location where welding is desired. Fig shows the general arrangement.
3. **Butt Welding:** In butt welding, the ends of two bars, rods or tubes to be welded are firmly butted together as shown in fig. Current flowing through the butt raises the temperature. When the desired temperature is reached, the two pieces are rammed together either manually or automatically resulting in a weld. Butt welding can be used to weld together bars of diameter upto several centimeter.
4. **Seam Welding:** In seam welding, two over lapped sheets of metals are welded together along a continuous line by moving them between two wheel shaped electrodes through which the welding current flows at short intervals. Fig. shows the general principle.

4.14. Working of Basic Circuit of AC Resistive Welding

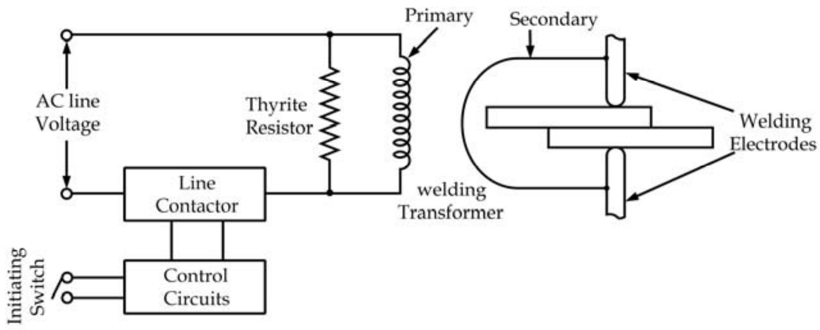


Fig. 4.11 Basic circuit for AC resistance welding

Fig. 4.11 gives the basic circuit for AC resistance welding. The line contactor (magnetically controlled contactor or a manual switch or tube contactor) which depends on the nature of job, connects the primary of the welding transformer to the AC supply during the interval of welding. The welding transformer which produces high voltage and large current depending upon the nature of weld at its secondary. In order to handle the large secondary current, a thick conductor is used for secondary winding and it is connected to the electrodes of the unit for welding.

Sometimes, a difficulty is created by the high transient voltage across the transformer caused by very rapid rate of change of current in the primary of the transformer. Such a high voltage may endanger the insulation of the transformer. To overcome this difficulty, a properly designed thyrite resistor is connected across the primary as shown in fig. 4.11.

The control circuit shown in fig. 4.11 may be extremely varied in form depending upon the nature and precision welding. The control operation it its simplest form may consist in manually operating a push button switch thereby exciting the ignitron circuit of the line contactor. As soon as the button is pressed, the conduction starts. The initiation of conduction may result at any phase angle in the AC cycle of line voltage. Further in this button mode operation, the duration of welding cannot be accurately controlled particularly when the period is short. On the other hand, highly elaborate and precise circuits use electronic control.

Note: During the process of welding a low voltage of several hundreds of amperes to several thousand amperes flow through the electrodes. The duration of the flow of current and magnitude are controlled.

4.15. Applications of Resistive Welding

1. Used for fabricating pressure tight and leak proof tanks.
2. Used for fabricating barrels.
3. Exhaust systems.
4. Used for welding rail ends.
5. Used for welding rolled sections.
6. Used for shaft axles.
7. Used for welding rods, pipes and wires.
8. Used for production works.
9. Used for making lap and butt joins.
10. Used for welding thin high nickel alloys.
11. Monel metal can be easily welded for this process.
12. The joint designs that can be used with carbon arc welding are butt joints, bevel joints, flange joints, lap joints and fillet joints.

4.16. Applications of other Welding Techniques

1. We can observe the welding process in industries and in constructions areas like pressure vessels, water pipelines, tankers, submarines, bridges, press frames, storages, water turbines, ships etc.
2. Fabrication or fixtures, jigs, clamps, oil machinery, boilers, railway coaches and kitchen cabin etc.
3. In the household equipments also the welding process is used.
4. To assemble rods, bars, tubings, sheets and most ferrous metals.
5. In the production of wheel rims for automobiles and bicycles.
6. For welding tubular parts such as automobile break cross-shafts.
7. For welding tube coils for refrigeration plants etc.

CHAPTER 5

Control Systems

OBJECTIVES

Upon completion of the chapter the student should be able to Understand the working of Transmission Lines

5.1 Give the definition of system and Control system.
5.2 Give the classification of control systems
5.3 Explain an open loop control system with some examples
5.4 Give the list of merits and demerits of open loop control.
5.5 Explain closed loop system with the help of a block diagram.
5.6 Give some examples for closed loop system
5.7 Give the comparison between open loop and closed loop control systems.
5.8 Give the definition of Transfer function
5.9 State the need for industrial automation
5.10 State the need for PLC
5.11 Explain the PLC system with block diagram
5.12 Mention some applications of PLCs in the industry

5.0. Introduction

Development of technology has seen a wide range use of automatic control systems to improve the quantity and quality of manufactured products in many domestic, industrial, and defence applications.

A control system is, in general, a combination of elements or sub-systems which tends to maintain a quantity or a set of quantities termed output suitably related to another quantity or a set of quantities termed input.

Automatic control systems are used in almost every sphere of our life. Domestically they are used for heating and airconditioning. Their industrial use comprises automatic control of machine operations, quality control, inventory control, and so on. Automatic control systems are also used in space technology and defence applications such as nuclear power weapons, guided missiles, etc. Robots, (mechanical bodies programmed to move and perform certain tasks) are also created by using automatic control systems.

Any control system can be represented by a basic block diagram, as shown in fig. 5.0(a).

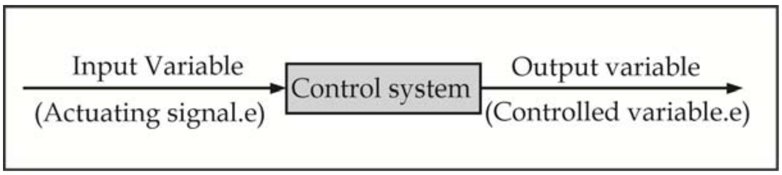


Fig. 5.0(a) Block diagram of a basic control system

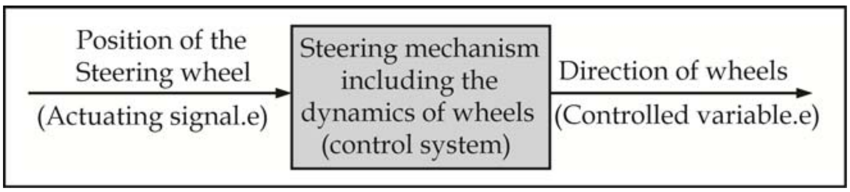


Fig. 5.0(b) Block diagram of the basic control system of an automobile

Here, variable c is to be controlled by an actuating signal e through the elements of the control system. This can be best understood through an example. Let us take the example of a motor car. The direction of the car can be changed by rotating the steering wheel which is connected to the wheels by some sort of control mechanism. This control system can be represented by a block diagram (as shown in fig. 5.0(b)).

5.1. Definition of System and Control System

A system is defined as a set (collection) of interconnected objects with a definite relationship between the objects and attributes. The interconnected components provide the desired function.

Objects are the parts or components of a system. For example, switches, spring, masses, dash-pots, transistors, transformers, generators, inductors, capacitors, resistors etc. are the objects. Attributes are the characteristics of objects. Given below are some of the objects and their attributes.

S.No.	Objects	Attributes
1.	Inductor	Voltage across and current through inductor
2.	Mechanical spring	Spring tension and displacement
3.	Switches	Speed of operation and state
4.	Motor	Speed and torque

Control System: A control system is a system of devices or set of devices, that manages, commands, directs or regulates the behavior of other device or system to achieve desire results. Industrial control systems are used in industrial production for controlling equipment or machines.

(or)

A control system is a system, which controls other system.

Note: The word control means,

- To regulate
- To direct
- To command or govern

Hence a control system is an arrangement of different physical elements connected in such a manner so as to regulate, direct or command itself or some other system.

For example, if lamp is switched ON or OFF using a switch, the entire system can be called a control system. The concept of physical system and a control system is shown in the fig. 5.2(a).

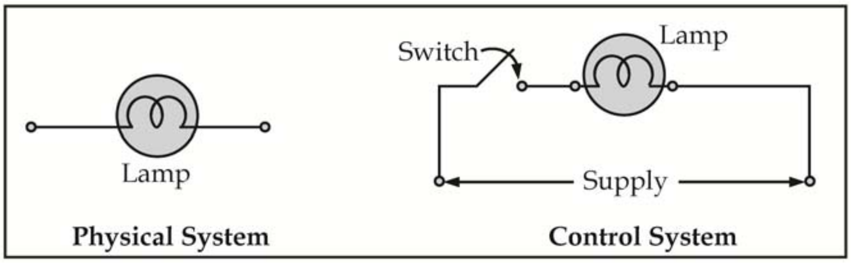


Fig. 5.2

5.2. Basic Block Diagram of Control System

Figure is a block diagram of an elementary feedback control system. The solid lines with arrows indicate the flow of signals between the components.

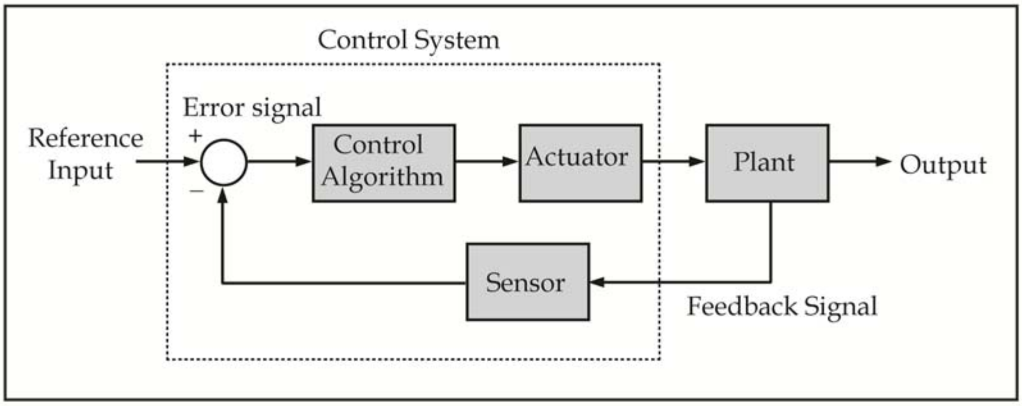


Fig. 5.2(c) Block diagram of a feedback control system

The circle in the figure represents a summing junction, which combines its input by addition or subtraction depending on the + and – signs next to each input.

The contents of the dashed box in fig. are the control system components. The controller inputs are the reference input (also called a set point) and the plant output signal (measured by the sensor), which is used as feedback. The controller output is the actuator signal that drives the plant.

5.3. Requirements of Good Control System

Accuracy: Accuracy is the measurement tolerance of the instrument and defines the limits of the errors made when the instrument is used in normal operating conditions. Accuracy can be improved by using feedback elements. To increase accuracy of any control system error detector should be present in control system.

Sensitivity: The parameters of control system are always changing with change in surrounding conditions, internal disturbance or any other parameters. This change can be expressed in terms of sensitivity. Any control system should be insensitive to such parameters but sensitive to input signals only.

Stability: It is an important characteristic of control system. For the bounded input signal, the output must be bounded and if input is zero then output must be zero then such a control system is said to be stable system.

Bandwidth: An operating frequency range decides the bandwidth of control system. Bandwidth should be large as possible for frequency response of good control system.

Speed: It is the time taken by control system to achieve its stable output. A good control system possesses high speed. The transient period for such system is very small.

Oscillation: A small numbers of oscillation or constant oscillation of output tend to system to be stable.

5.4. Classify Control Systems

Control systems may be classified into two types depending upon whether the controlled variable (i.e., the output) affects the actuating signal or not.

The two types of control systems are:

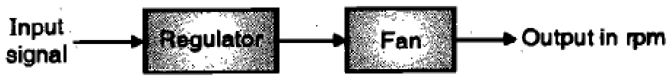
1. Open-loop Control Systems and
2. Closed-loop Control Systems

5.5. Open Loop Control System

An open loop system is one which does not automatically correct the change in output by adjusting the input signal.

Definition: A system in which the control action is totally independent of the output of the system is called as open loop system .

In open loop systems, the output remains constant for a given input provided the external conditions are the same. There is no correcting action taking place in an signal open loop system.



A very common example of a open loop system is the Fan.

In this case, when we switch on the fan, it starts moving at a speed depending on the position of the regulator. It continues to rotate at the same speed without taking into account the surrounding environment. The only way to change the speed of the fan would be to physically adjust the regulator.

This is an open loop system.

In this human-system interface, the system (fan in this case)is unable to complete its task (controlling the temperature of the room)without the contribution from a human operator.

5.5.1. Advantages and Disadvantages of Open Loop Control System

Advantages of Open Loop Control System

1. Simple in construction and design
2. Economical
3. Easy to maintain
4. Generally stable
5. Convenient to use as output is difficult to measure

Disadvantages of Open Loop Control System

1. They are inaccurate
2. They are unreliable
3. Any change in output cannot be corrected automatically

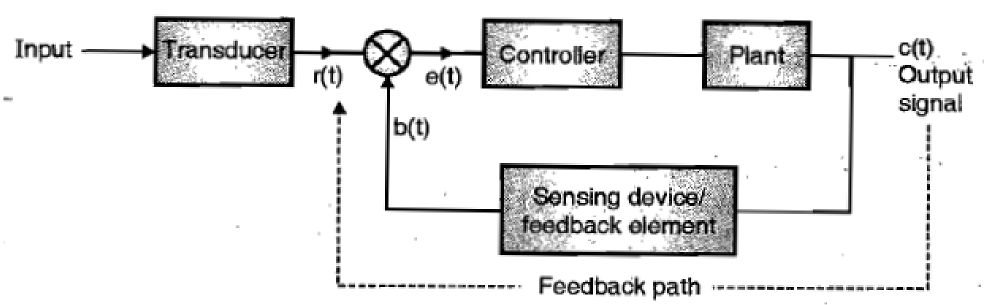
5.6. Examples for Open Loop Control System

All control systems operate on the basis of present timing mechanism are open loop control systems.

1. **Automatic Washing Machine:** This machine runs according to the pre-set time irrespective of washing is completed or not.
2. **Traffic Light Controller:** Lamps glow whenever light switch is on irrespective of light is required or not.
3. **Electric Hand Drier:** Hot air (output) comes out as long as you keep your hand under the machine, irrespective of how much your hand is dried.
4. **Automatic Tea/Coffee Maker:** These machines also function for pre adjusted time only.
5. **Timer Based Clothes Drier:** This machine dries wet clothes for pre adjusted time, it does not matter how much the clothes are dried.
6. **Volume on Stereo System:** Volume is adjusted manually irrespective of output volume level.

5.7. Closed Loop System with the help of a Block Diagram

A system in which the control action is dependent on the output is called a closed loop system. In closed loop systems, the output is constantly monitored and adjusted to the required value by the system. A generalized block diagram of a closed loop system is shown in Fig.



As is evident from the block diagram, the output signal is fed back and compared to the reference input. Dependong on the difference between the output signal and the reference input, corrective action is taken by the controller to adjust the output. The general notations used are as follows

$r(t) \rightarrow$ reference input $e(t) \rightarrow$ error signal

$b(t) \rightarrow$ feedback signal $c(t) \rightarrow$ controlled output signal

The main difference between a closed loop system and an open loop system is that in a closed loop system, there is a constant comparison between the output and the reference input. This is absent in open loop systems.

A common example of a closed loop system is an Air-Conditioning (A.C) unit.

In an A.C . we adjust the temperature to a particular value (say 24^0 C).

The A.C. gives out cool air which cools the room. As soon as the temperature of the room drops below 24^0 C, it shuts off its compressor till the temperature of the room rises above 24^0 C. It then once again switches on the compressor. This action ensures that the temperature of the room is maintained at a fixed temperature.

The A.C. is constantly checking the temperature of the room and based on the temperature, it seitches on or switches off the compressor.

Note: Open loop control system can be converted into closed loop control system by providing a feedback. This feedback automatically makes the suitable changes in the output due to external disturbance. In this way closed loop control system is called automatic control system.

5.7.1. Advantages and Disadvantages of Closed Loop Control System

Advantages of Closed Loop Control System

1. Closed loop control systems are more accurate even in the presence of non linearity.
2. Highly accurate as any error arising is corrected due to presence of feedback signal.
3. Bandwidth range is large.
4. Facilitates automation.
5. The sensitivity of system may be made small to make system more stable.
6. This system is less affected by noise.

Disadvantages of Closed Loop Control System

1. They are costlier
2. They are complicated to design
3. Required more maintenance
4. Feedback leads to oscillatory response
5. Overall gain is reduced due to presence of feedback
6. Stability is the major problem and more care is needed to design a stable closed loop system.

5.8. Examples for Closed Loop System

1. **Automatic Electric Iron:** Heating elements are controlled by output temperature of the iron.
2. **Servo Voltage Stabilizer:** Voltage controller operates depending upon output voltage of the system.
3. **An Air Conditioner:** An air conditioner functions depending upon the temperature of the room.
4. **Water Level Controller:** Input water is controlled by water level of the reservoir.
5. **Missile Launched and Auto Tracked by Radar:** The direction of missile is controlled by comparing the target and position of the missile.
6. **Cooling System in Car:** It operates depending upon the temperature which it controls.

5.9. Compare Open Loop and Closed Loop Control Systems

S.No.	Open Loop Control System	Closed Loop Control System
1.	The feedback element is absent	The feedback element is always present
2.	An error detector is not present	An error detector is always present
3.	It is stable one	It may become unstable
4.	Easy to construct	Complicated construction
5.	It is an economical	It is costly
6.	Having small bandwidth	Having large bandwidth
7.	It is inaccurate	It is accurate
8.	Less maintenance	More maintenance
9.	It is unreliable	It is reliable

10.	**Examples:** Hand drier, tea maker	**Examples:** Servo Voltage Stabilizer, perspiration

5.10. Define Transfer Function

Control system deals with representing physical devices as mathematical equations and analysing them.

The transfer function of a system is defined as the ratio of Laplace transform of output to the Laplace transform of input with zero initial conditions.

$$\text{Transfer function} = \left.\frac{\text{Laplace Transform of output}}{\text{Laplace Transform of input}}\right|_{\text{with zero initial conditions}} \qquad \ldots(1.1)$$

The transfer function can be obtained by taking Laplace transform of the differential equations governing the system with zero initial conditions and rearranging the resulting algebraic equations to get the ratio of output to input .

$$\text{i.e., T.F.} = G(s) = \left.\frac{C(s)}{R(s)}\right|_{\text{initial conditions}=0}$$

Since initial conditions are made equal to zero, the output is also known as the zero-state response.

By using the concept of transfer function, it is possible to represent the system equations in s. If the highest power of s in the denominator of the transfer function is equal to n, the system is called the n^{th} - order system.

Example -1:
Find the transfer function of the given physical system.

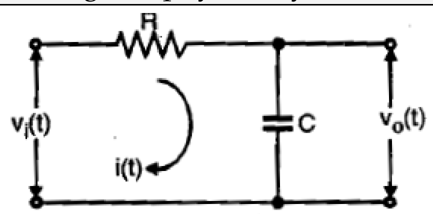


Fig. P. 2.2.2

Solution : We apply KVL to this circuit.

$$v_i(t) = Ri(t) + \frac{1}{c}\int i(t)dt \qquad (1)$$

$$v_o(t) = \frac{1}{C}\int i(t)dt \qquad (2)$$

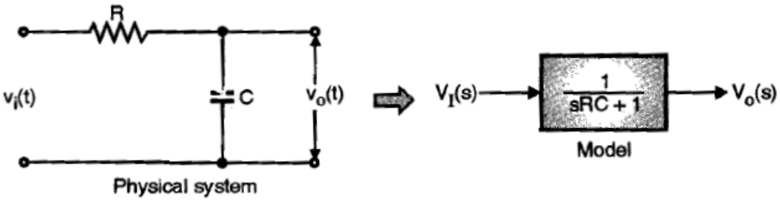
Instead of working in the time domain, we move to the s-domain by applying the Laplace transform on Equation (1) and Equation (2) . Assumong zero initial conditions we obtain,

$$V_I(s) = RI(s) + \frac{1}{sC}I(s) \qquad V_o(s) = \frac{1}{sC}I(s)$$

$$\therefore \text{Transfer function} = \frac{v_o(s)}{v_I(s)} \qquad\qquad \therefore \frac{V_o(s)}{V_I(s)} = \frac{\frac{1}{sC}I(s)}{\left(R + \frac{1}{sC}\right)I(s)}$$

$$\frac{V_o(s)}{V_I(s)} = \frac{1}{sRC+1}$$

The transfer function represents the mathematical model of the physical RC circuit.



Example -2:
Compute the transfer function of the given circuit.

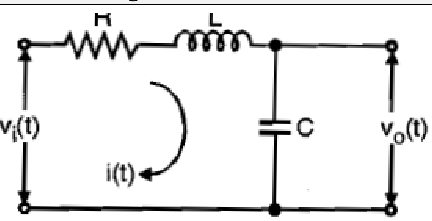


Fig. P. 2.2.3

Soln : Applying KVL to this circuit we get,

$$v_i(t) = Ri(t) + L\frac{di(t)}{dt} + \frac{1}{C}\int i(t)dt \qquad \ldots(1)$$

$$v_0(t) = \frac{1}{C}\int i(t)dt \qquad \ldots.(2)$$

We take the Laplace transform of equation (1)and (2) assuming zero initial conditions

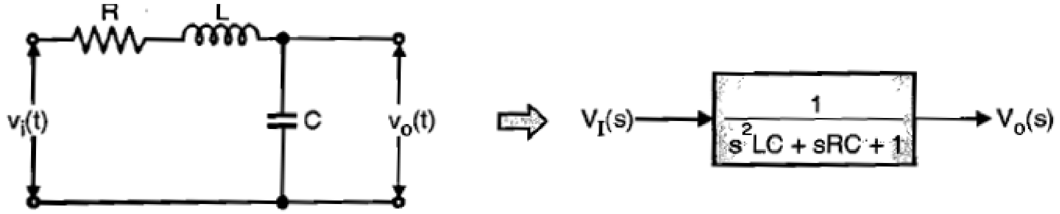
$$\therefore V_I(s) = RI(s) + sLI(s) + \frac{1}{sC}I(s) = \left[R + sL + \frac{1}{sC}\right]I(s)$$

$$v_o(s) = \frac{1}{sC}I(s)$$

$$\text{Transfer function} = \frac{V_o(s)}{V_I(s)} = \frac{\frac{1}{sC} I(s)}{\left(R + sL + \frac{1}{sC}\right) I(s)}$$

$$\frac{V_o(s)}{V_1(s)} = \frac{1}{s^2 LC + sRC + 1}$$

This is the transfer function of the physical RLC circuit



Characteristics of a Transfer Function

1. The transfer function is a property of the system elements only.
2. It is independent of the input functions.
3. It does not provide any information concerning the internal structure of the system.
4. It is not defined for a non linear system.

Additional Information

Introduction

The Programmable Logic Controller (PLC) was introduced in the early 1970s. Before that humans were the main method for controlling a system. It replaced the relay-based control systems, which permitted electrical power to be turned ON and OFF without using a mechanical switch. Relays were also being used to make simple logical control decisions. The PLC is today the most common choice for controlling systems, machines and processes. The PLC is a digital based electronic control devices with a programmable memory for storing instructions specific to a control function, such as logic, sequencing, timing, counting and arithmetic.

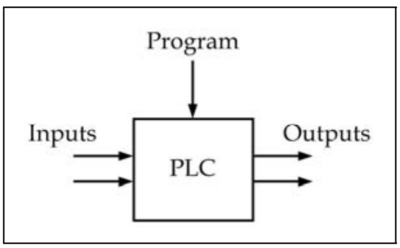


Fig. 4.1 A programmable logic controller

A Programmable Logic Controller, PLC, or Programmable Controller is a digital computer used for automation of typically industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides or light fixtures. PLCs are used in many machines, in many industries. PLCs are designed for multiple arrangements of digital and analog inputs and outputs, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed-up or non-volatile memory.

The PLC operates any system which has output (load) devices that turn ON and OFF (known as discrete or digital outputs). A program is be needed to process the inputs and decide the means of turning OFF and ON load devices. The PLC can also operate any system with variable (i.e. analog) outputs.

5.11. Need for PLC

In industries automation is required,

1. To increase the quality and lower the cost of production
2. To enhance the production rate
3. To achieve optimum performance
4. To minimize the labor of several routine, repetitive manual operations

Early automation systems are designed using electrical devices, which are controlled by relays. The electromagnetic relays have provided control mechanism for a long period of time. But there use is limited due to the following reasons:

Relays are “hard-wired” that means relays are interconnected by wires to perform specific functions. The interconnection of the relays limits switches, timers and counters.

The initial wiring is very complex, when hundreds of relays are involved.

Trouble shooting is tedious when lots of relays are included.

When changes occur in the requirements of production, it is essential to make modifications to the existing system. To modify the existing system, it is necessary to physically move the wires from the relays, which is a time consuming process. Therefore, modifications to the system cause delayed production and rise in production cost.

The lifetime of relays is limited hence strict maintenance is needed.

To overcome the above limitations Programmable Logic Controllers (PLCs) are developed, which offer the same functionality as the relay logic systems.

A Programmable Logic Controller (PLC) is a user-friendly, microprocessor based dedicated computer that performs several sorts of control functions with different levels of complexity. Its intent is to keep track of critical process parameters and regulate process operations correctly. PLC is used widely because,

1. It is easy to set up and program
2. It performs predictably
3. It is ruggedized

Additional Information

∗ Advantages and Disadvantages of PLCs ∗

Advantages of PLC

1. PLCs are highly flexible
2. They have compact size and reduced cost
3. PLCs are accurate, high speed and reliable
4. PLCs can be reprogrammed easily and quickly
5. Data storage and logging is easier since PLCs can be easily interfaced to computers
6. PLCs can handle large number of inputs and outputs
7. Programming of PLCs is easier

Disadvantages of PLC

1. For small operations or one or two functions, PLCs are not cost effective.
2. PLCs use electronic devices and microprocessors. They fail some times in adverse environmental conditions.
3. PLCs are not fail safe.
4. If the operation is never altered, PLCs prove to be costly.

5.12. Basic Principle of PLCs

A PLC works by continuously scanning a program. The scan cycle contains three steps.

Step 1: Check input status

Step 2: Execute program

Step 3: Update output status

At start, the PLC scans the state of all the connected inputs and stores their states in the PLC memory. When PLC program accesses an input, it reads the input state as it was at the start of the program scan. A zone of PLC memory corresponding to the outputs is changed by the execution of the program, and then, all the outputs are updated simultaneously at the end of the scan. The action is thus read inputs, execute program, and update outputs. Therefore, a PLC does not communicate continuously with the outside world.

Once the third step is completed the PLC returns to step one and repeats the step continuously. One scan time is defined as the time it takes to execute the three steps illustrated as shown in the fig.

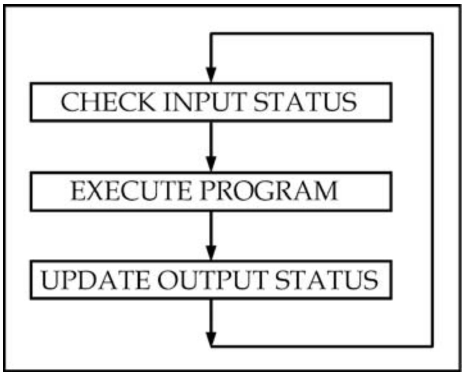


Fig. Three steps in PLCs

5.13. Advantages of PLCs

1. Less wiring
2. Wiring between devices and relay contacts are done in the PLC program
3. Easier and faster to make changes
4. Trouble shooting aids make programming easier and reduce downtime
5. Reliable components make these likely to operate for years before failure
6. They are cost-effective
7. They are flexible
8. Reliable
9. Compact

5.14. Comparison between PLC and Relay

S.No.	Description	PLC	Relay Control
1.	Floor area required	Less	More
2.	Physical size	Less	More
3.	Reliability	More	Less
4.	Programming (or) construction	It can be done easily	Wiring of relay controls is not easy
5.	Expandability	Easy i.e., it is easy to modify the system	Difficult
6.	Maintenance cost	Less	More
7.	Programming/replacement	Easy	Difficult

8.	Power consumption	Low	More
9.	Construction	It has eliminated much of hard wiring associated with conventional relay control circuits	Relay have to be hand-wired to perform a specific function
10.	Special function	It is easy to perform for following functions - Time day action - Counters	It is not possible to perform the special functions like - Time delay action - Counters

5.15. Block diagram of PLC

Programmable Logic Controller (PLC) is a digital computer used for the automation of various electro-mechanical processes in industries. These controllers are specially designed to survive in harsh situations and shielded from heat, cold, dust, and moisture etc. PLC consists of a microprocessor which is programmed using the computer language.

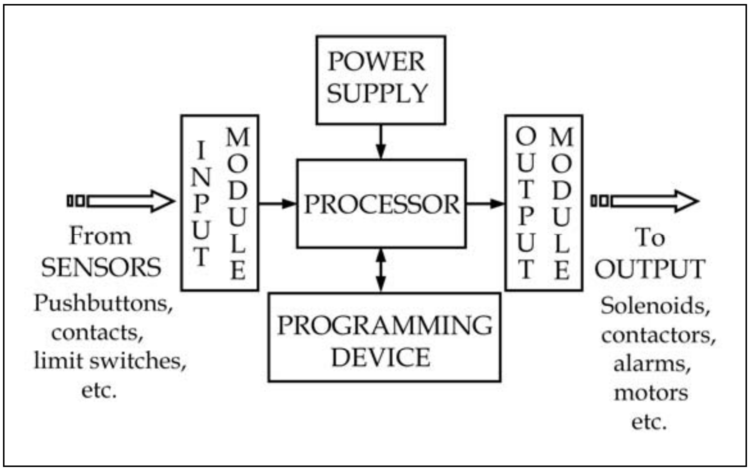


Fig.

1. **Power Supply:** Provides the voltage needed to run the primary PLC components. The power supply unit is needed to convert the mains AC voltage to the low DC voltage necessary for the processor and the circuits in the input and output interface modules.
2. **I/O Modules:** Provides signal conversion and isolation between the internal logic-level signals inside the PLC and the fields high level signal.

   a. The I/O interface section of a PLC connects it to external field devices.
   b. The main purpose of the I/O interface is to condition the various signals received from or sent to the external input and output devices.
   c. Input modules converts signals from discrete or analog input devices to logic levels acceptable to PLC's processor.
   d. Output modules converts signal from the processor to levels capable of driving the connected discrete or analog output devices.
3. **Processor:** Provides intelligence to command and govern the activities of the entire PLC systems. Major components of a common PLC of the entire PLC systems.
4. **Programming Device:** Used to enter the desired program that will determine the sequence of operation and control of process equipment or driven machine.
   a. The input and output sections are where the processor receives information from external devices and communicates information to external devices. The inputs might be sensors push button switches, contacts etc. The outputs might be motor, solenoid, contactors , alarms, etc. Input and output devices can be classified as giving signals that are discrete, digital or analog. Devices giving discrete or digital signals are ones where the signals are either off or on. Thus a switch is a device giving a discrete signal, either no voltage or a voltage. Digital devices can be considered essentially as discrete devices that give a sequence of on/off signals. Analog devices give signals of which the size is proportional to the size of the variable being monitored. For example, a temperature sensor may give a voltage proportional to the temperature.
5. **CPU:** Keeps checking the PLC controller to avoid errors. They perform functions including logic operations, arithmetic operations, computer interface and many more.
6. **Memory:** Fixed data is used by the CPU. System (ROM) stores the data permanently for the operating system. RAM stores the information of the status of input and output devices, and the values of timers, counters, and other internal devices.

5.16. Applications of PLCs in the Industry

1. Manufacturing / Machining
2. Food / Beverages
3. Metals
4. Power
5. Mining
6. Petrochemical / chemical
7. PLC is used in machine tool industry where Computer Numerical Controls (CNC) have been used in the past.
8. Processes like
    a. Filling and capping of bottles
    b. Printing of newspapers
    c. Assembly of automobiles, etc are carried out by PLCs.
9. PLC is used in process control, e.g. a petroleum refinery.
10. PCLs are used in annunciators for the working of the plant that could be monitoring pressure, temperature, motor and valve status.
11. PLCs are also used in controlling electrical and mechanical machines within a sequence of values of time, pressure, temperature, level etc.