SYNERGY INSTITUTE OF ENGINEERING & TECHNOLOGY
Department of Mechanical Engineering
LECTURE NOTE (Academic Session 2023-2024)

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ENGINEERING THERMODYNAMICS

What is Thermodynamics?

Thermodynamics is a science dealing with Energy and its transformation and its effect on the physical properties of substances.

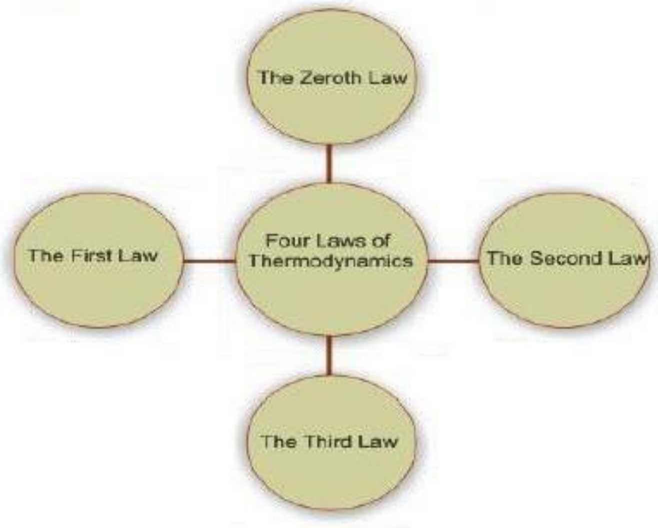
It deals with equilibrium and feasibility of a process.

Deals with the relationship between heat and work and the properties of systems in equilibrium.

Scope of Thermodynamics:

- Steam power plant
- Separation and Liquification Plant
- Refrigeration
- Air-conditioning and Heating Devices.
- Internal combustion engine
- Chemical power plants
- Turbines
- Compressors, etc

The principles of thermodynamics are summarized in the form of four thermodynamic laws:



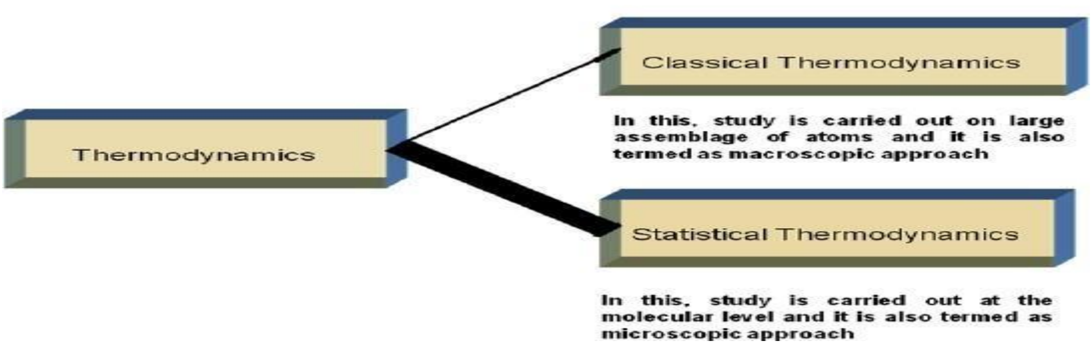
1. **The Zeroth Law** deals with thermal equilibrium and provides a means for measuringtemperatures.

2. **The First Law** deals with the conservation of energy and introduces the concept of internal energy.

3. **The Second Law** of thermodynamics provides with the guidelines on the conversion of internal energy of matter into work. It also introduces the concept of entropy.

4. **The Third Law** of thermodynamics defines the absolute zero of entropy. The entropy of a pure crystalline substance at absolute zero temperature is zero.

Different Approaches of Thermodynamics :



Write the difference between Macroscopic and Microscopic approach of Thermodynamics:

Macroscopic Approach	Microscopic Approach
1.Macroscopic approach is known as Classical Thermodynamics.	1. Microscopic approach is known as Statistical Thermodynamics
2. Attention is focussed on a certain quantity of matter without taking into account the events occuring at molecular level.	2. A knowledge of the structure of matter under consideration is essential.
3. Only a few variables are used to describe the state of the matter under consideration.	3. A large no. of variables are required for a complete specification of the state of matter under consideration.
4. The values of the variables used to describe the state of the matter are easily measurable.	4. The variables used to describe the state of matter cannot be measured easily and precisely

Define Thermodynamic System?

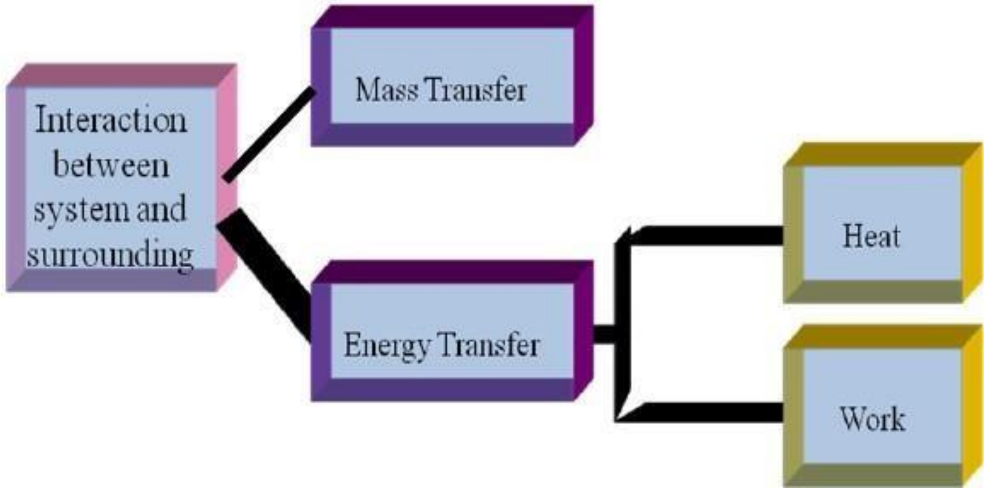
A thermodynamic system is defined as a definite quantity of matter or a region of space withina prescribed boundary upon which attention is focussed in the analysis of a problem.

Surrounding: Everything external to the system is Surroundings.

Boundary:

- The surface which separates the system from the surrounding.
- System and surrounding interact through boundary in the form of Heat and Work.
- Boundary can be real (or) imaginary.
- Boundary can be fixed (or) moving.
- System and Surrounding put together is known as **Universe**

Interaction Between System and Surrounding

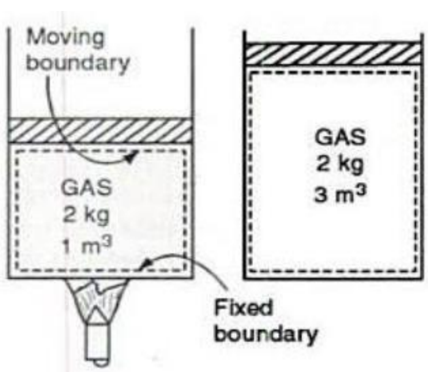


Based on the type of interaction, the systems are classified as

- **CLOSED SYSTEM**
- **OPEN SYSTEM**
- **ISOLATED SYSTEM**

CLOSED SYSTEM (Control Mass) : It is also termed as control mass or fixed mass analysis. There is no mass transfer across the system boundary but energy in the form of Heat or Work can cross the system boundary.

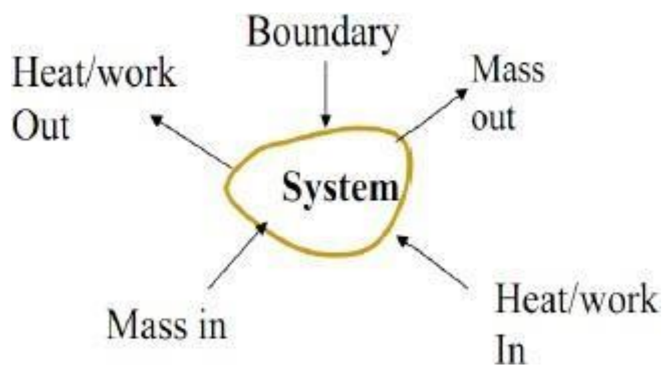
Eg.



Eg. A certain amount of gas enclosed in a cylinder piston arrangement.

Open System(Control Volume): The open system is one in which both mass and energy can cross the boundary of the system.

Open



Open system is also termed as control volume analysis

Write down the concept of Control Volume:

A large engineering problems involve mass flow in and out of a system and therefore, are modeled as control volumes.

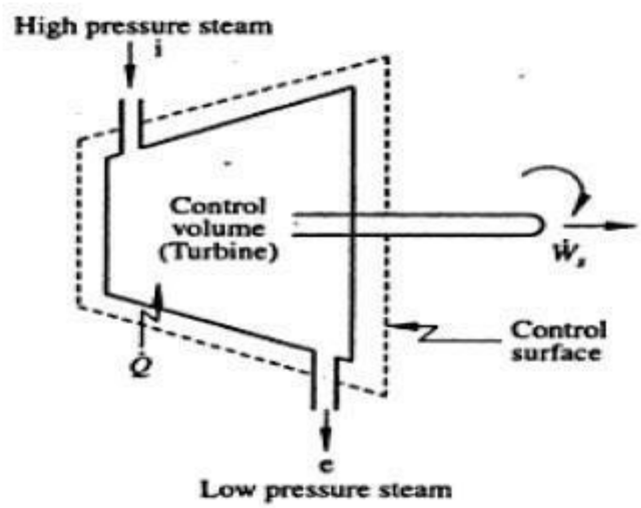
Control volume refers to a definite volume on which attention is focussed for energy analysis.

Examples: Nozzles, Diffusers, Turbines, Compressors,

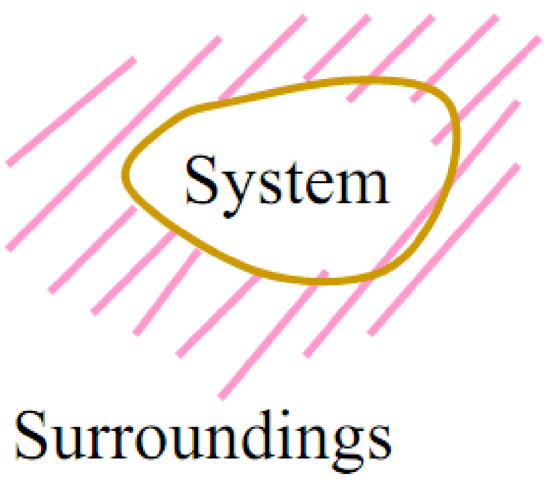
Heat Exchanger, De-superheater, Throttling valves,

I.C engine etc.

Control Surface: The closed surface that surrounds the control volume is called **CONTROL SURFACE.** Mass as well as energy crosses the control surface. Control surface can be real or imaginary.



Isolated System: The isolated system is one in which there is no interaction between the system and the surroundings that neither the mass nor the energy interactions. Therefore it isof fixed mass and energy.

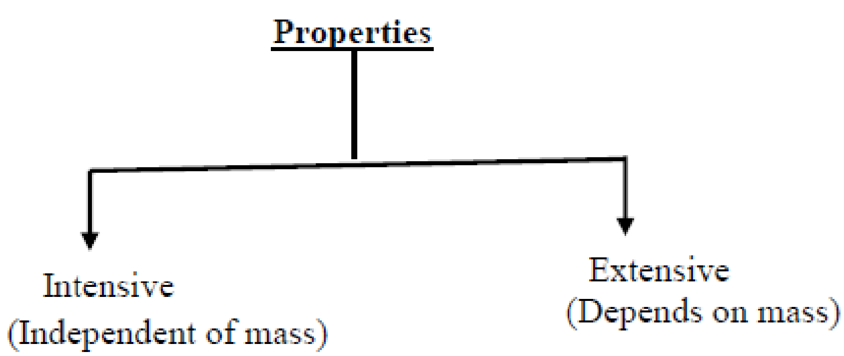


Note:

Mass Transfer	Energy Transfer	Type of System
No	Yes	Closed System
Yes	Yes	Open System
No	No	Isolated System
Yes	No	Impossible

What do you mean by Property?

Any observable characteristics required to describe the conditions or state of a system is knownas Thermodynamic property of a system.



Differentiate Intensive and Extensive Property?

Extensive Property	Intensive Property
1. Extensive properties are dependent on the mass of a system.	1. Intensive properties are independent of the mass of a system.
2.Extensive properties are additive.	2. Intensive properties are not additive.
3. Its value for an overall system is the sum of its values for the parts into which the system is divided.	3. Its value remains the same whether one considers the whole system or only a part of it.
4.Example:mass(m),volume(V),Energy(E),Enthalpy(H) etc.	4.Example:Pressure(P),Temperature(T),Density etc.
5. Uppercase letters are used for extensive properties except mass.	5. Lowercase letters are used for intensive properties except pressure(P) and temp.(T)

FIRST LAW OF THERMODYNAMICS

- This is based on Law of Conservation of Energy.
- This is also called as First Principle.

For a closed system, undergoing a cycle

Sum of all Work transfers = Sum of all Heat Transfers

$$(W_1+W_2+W_3+\ldots..) = \Sigma(Q_1 + Q_2+Q_3+\ldots\ldots\ldots)$$

$$\Sigma(W) = \Sigma(Q)$$

$$\oint dW = \oint dQ$$

For a closed system,undergoing a Process

Whenever heat is absorbed by a system it increases its internal energy and does some work.

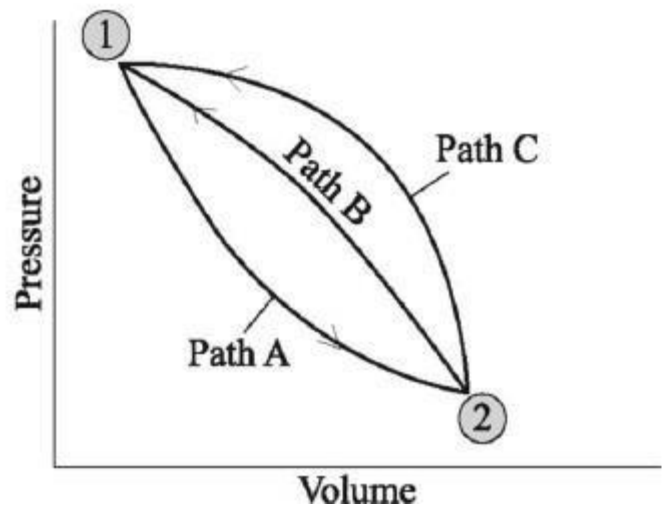
$$Q = \Delta E + W$$

Where Q – heat absorbed by the system

W – Work output from the system

ΔE – Change in Stored Energy of the system

Show that Energy is a property of the system



For path A,

$$Q_A = W_A + \Delta E_A \qquad (1)$$

For path B,

$$Q_B = W_B + \Delta E_B \qquad (2)$$

For path B,

$$Q_C = W_C + \Delta E_C \qquad (3)$$

For Cycle 1-A-2-B-1,

$$W_A + W_B = Q_A + Q_B \qquad (4)$$

$$Q_A - W_A = -(Q_B - W_B)$$

$$\Delta E_A = -\Delta E_B \qquad (A)$$

For Cycle 1-A-2-C-1,

$$W_A + W_C = Q_A + Q_C$$

$$Q_A - W_A = -(Q_C - W_C)$$

$$\Delta E_A = -\Delta E_C \qquad (C)$$

Comparing A and C

$$\Delta E_B = \Delta E_C$$

Enthalpy:

- It is the energy content of the flowing fluid.
- It is defined by the summation of internal energy and flow work.

H = U + PV

<u>Note:</u> For an ideal gas h = u + Pv.

= u + RT

So, h = f(T)

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

is also defined as the change of internal energy of the substance per unit change in temperature at constant volume. C

Define Cp with the help enthalpy and Temperature:

The amount of heat required to raise the temperature of unit mass of a substance by 1o C in a

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

reversible constant pressure process.

is also defined as the change of internal energy of the substance per unit change in temperature at constant volume. C

Define Cp with the help enthalpy and Temperature:

The amount of heat required to raise the temperature of unit mass of a substance by 1o C in a reversible constant pressure process.

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

C_p is also defined as the change of internal energy of the substance per unit change in temperature at constant pressure.

Application of First law to different Thermodynamic process:

Process	Index=n	Q	W= $\int PdV$	P-V-T Relation
Rev. Const.Vol.	∞	$Q = \Delta U$ $= mC_v(T_2 - T_1)$	W=0	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
Rev.Const.pressure	n=0	$Q = \Delta H$ $= mC_p(T_2 - T_1)$	$W = P(V_2 - V_1)$ $= mR(T_2 - T_1)$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Rev. Isothermal	n=1	$Q = W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$	$P_1V_1 = P_2V_2$
Rev.Adiabatic	n=γ	Q=0	$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$	$P_1V_1^{\gamma} = P_2V_2^{\gamma}$
Rev.Polytropic	n	$Q = \Delta U + W$	$W = \frac{P_1V_1 - P_2V_2}{n - 1}$	$P_1V_1^{n} = P_2V_2^{n}$

Carnot Cycle: Carnot cycle is a reversible cycle that is composed of four reversible processes,two isothermal and two adiabatic.

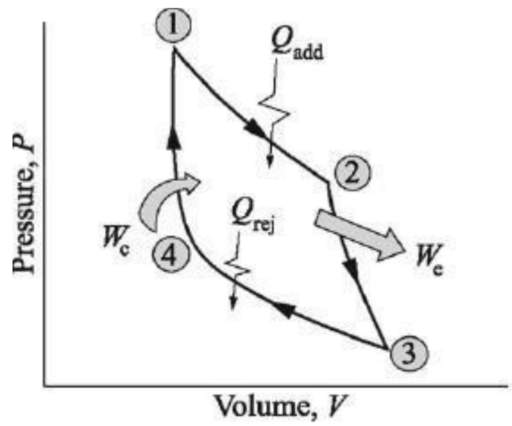
Process 1 - 2 (Reversible Isothermal Heat

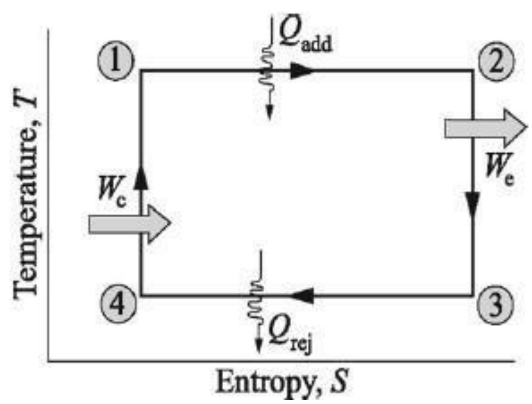
Addition) Process 2 – 3 (Reversible Adiabatic

Expansion) Process 3 – 4 (Reversible Isothermal

Heat Rejection)Process 4 – 1 (Revesible Adiabatic

Compression)





$$\Sigma(Q_{net})_{cycle} = \Sigma(W_{net})_{cycle}$$

$$Q_{add} - Q_{rej} = W_e - W_c$$

$$\eta = \frac{W_{net}}{Q_{add}} = \frac{Q_{add} - Q_{rej}}{Q_{add}}$$

$$\boxed{\eta = 1 - \frac{Q_{rej}}{Q_{add}}}$$

From T-S diagram

$$\eta = 1 - \frac{T_2 (\Delta S)}{T_1 (\Delta S)}$$

$$\boxed{\eta = 1 - \frac{T_2}{T_1}}$$

Carnot's Theorem:

1. The efficiency of an irreversible heat engine is always less than efficiency of a reversible one operating between the same two reservoirs.

2. The efficiencies of all reversible heat engines operating between the same reservoirs are the same.

Clausius Inequality

The cycle integral of $\frac{\delta Q}{T}$ is always less than or equal to zero.

Mathematically it can be expressed as $\oint \frac{\delta Q}{T} \leq 0$. The equality in the Clausius inequality holds for totally or just reversible cycle and the inequality for the irreversible ones.

Comparison between external combustion engine and internal combustion engine:

External combustion engine	Internal combustion engine
*Combustion of air-fuel is outside the engine cylinder (in a boiler)	* Combustion of air-fuel is inside the engine cylinder (in a boiler)
*The engines are running smoothly and silently due to outside combustion	* Very noisy operated engine
*Higher ratio of weight and bulk to output due to presence of auxiliary apparatus like boiler and condenser. Hence it is heavy and cumbersome.	* It is light and compact due to lower ratio of weight and bulk to output.
*Working pressure and temperature inside the engine cylinder is low; hence ordinary alloys are used for the manufacture of engine cylinder and its parts.	* Working pressure and temperature inside the engine cylinder is very much high; hence special alloys are used
*It can use cheaper fuels including solid fuels	*High grade fuels are used with proper filtration
*Lower efficiency about 15-20%	*Higher efficiency about 35-40%
* Higher requirement of water for dissipation of energy through cooling system	*Lesser requirement of water
*High starting torque	*IC engines are not self-starting

Main components of reciprocating IC engines:

Cylinder: It is the main part of the engine inside which piston reciprocates to and fro. It should have high strength to withstand high pressure above 50 bar and temperature above

2000 oC. The ordinary engine is made of cast iron and heavy duty engines are made of steel alloys or aluminum alloys. In the multi-cylinder engine, the cylinders are cast in one block known as cylinder block.

Cylinder head: The top end of the cylinder is covered by cylinder head over which inlet and exhaust valve, spark plug or injectors are mounted. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make an air tight joint.

Piston: Transmit the force exerted by the burning of charge to the connecting rod. Usually made of aluminium alloy which has good heat conducting property and greater strength at higher temperature.

Figure 1 shows the different components of IC engine.

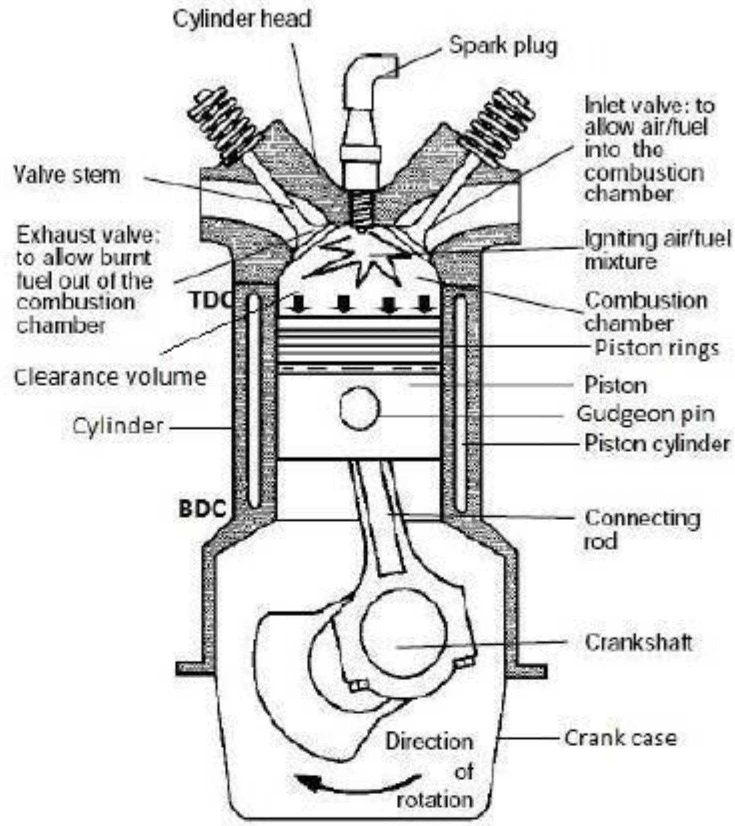


Fig. 1. Different parts of IC engine

Piston rings: These are housed in the circumferential grooves provided on the outer surface of the piston and made of steel alloys which retain elastic properties even at high temperature. 2 types of rings- compression and oil rings. Compression ring is upper ring of the piston which provides air tight seal to prevent leakage of the burnt gases into the lower portion. Oil ring is lower ring which provides effective seal to prevent leakage of the oil into the engine cylinder.

Connecting rod: It converts reciprocating motion of the piston into circular motion of the crank shaft, in the working stroke. The smaller end of the connecting rod is connected with the piston by gudgeon pin and bigger end of the connecting rod is connected with the crank. with crank pin. The special steel alloys or aluminium alloys are used for the manufacture of connecting rod.

Crankshaft: It converts the reciprocating motion of the piston into the rotary motion with the help of connecting rod. The special steel alloys are used for the manufacturing of the crankshaft. It consists of eccentric portion called crank.

Crank case: It houses cylinder and crankshaft of the IC engine and also serves as sump for the lubricating oil.

Flywheel: It is big wheel mounted on the crankshaft, whose function is to maintain its speed constant.It is done by storing excess energy during the power stroke, which is returned during other stroke.

Terminology used in IC engine:

1. Cylinder bore (D): The nominal inner diameter of the working cylinder.

2. Piston area (A): The area of circle of diameter equal to the cylinder bore.

3. Stroke (L): The nominal distance through which a working piston moves between two successive reversals of its direction of motion.

4. Dead centre: The position of the working piston and the moving parts which are mechanically connected to it at the moment when the direction of the piston motion is reversed (at either end point of the stroke).

(a) Bottom dead centre (BDC): Dead centre when the piston is nearest to the crankshaft.

(b) Top dead centre (TDC): Dead centre when the position is farthest from the crankshaft.

5. Displacement volume or swept volume (Vs): The nominal volume generated by the working piston when travelling from the one dead centre to next one and given as,

$$V_s = A \times L$$

6. Clearance volume (V_c): the nominal volume of the space on the combustion side of the piston at the top dead centre.

7. Cylinder volume (V): Total volume of the cylinder.

$$V = V_s + V_c$$

8. Compression ratio (r): $r = \frac{Vs}{Vc}$

Four stroke engine:

- Cycle of operation completed in four strokes of the piston or two revolution of the piston.

(i) Suction stroke (suction valve open, exhaust valve closed)-charge consisting of fresh air mixed with the fuel is drawn into the cylinder due to the vacuum pressure created by the movementof the piston from TDC to BDC.

(ii) Compression stroke (both valves closed)-fresh charge is compressed into clearance volume by the return stroke of the piston and ignited by the spark for combustion. Hence pressure and temperature is increased due to the combustion of fuel

(iii) Expansion stroke (both valves closed)-high pressure of the burnt gases force the piston towards BDC and hence power is obtained at the crankshaft.

(iv) Exhaust stroke (exhaust valve open, suction valve closed)- burned gases expel out due to the movement of piston from BDC to TDC.

Figure 2 show the cycle of operation of four stroke engine.

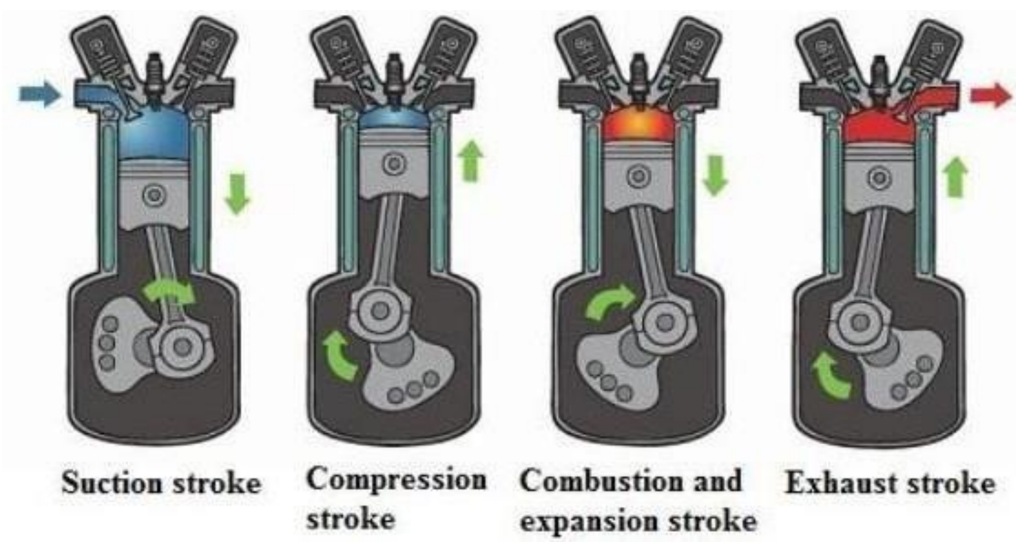


Fig. 2. Cycle of operation in four stroke engine

Two stroke engine:

-No piston stroke for suction and exhaust operations

-Suction is accomplished by air compressed in crankcase or by a blower

-Induction of compressed air removes the products of combustion through exhaust ports

-Transfer port is there to supply the fresh charge into combustion chamberFigure 3 represents operation of two stroke engine

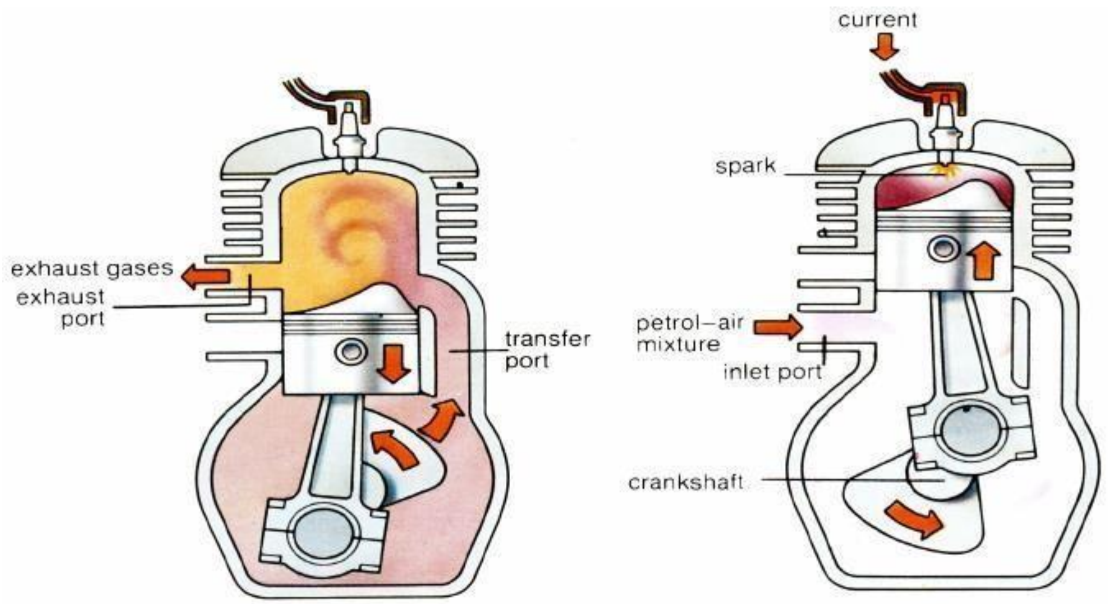


Fig. 3. Cycle of operation in two stroke engine

Comparison of Four-stroke and two-stroke engine:

	Four-stroke engine	Two-stroke engine
1.	Four stroke of the piston and two revolution of crankshaft	Two stroke of the piston and one revolution of crankshaft
2.	One power stroke in every two revolution of crankshaft	One power stroke in each revolution of crankshaft
3.	Heavier flywheel due to non-uniform turning movement	Lighter flywheel due to more uniform turning movement
4.	Power produce is less	Theoretically power produce is twice than the four stroke engine for same size
5.	Heavy and bulky	Light and compact
6.	Lesser cooling and lubrication requirements	Greater cooling and lubrication requirements
7.	Lesser rate of wear and tear	Higher rate of wear and tear
8.	Contains valve and valve mechanism	Contains ports arrangement
9.	Higher initial cost	Cheaper initial cost
10.	Volumetric efficiency is more due to greater time of induction	Volumetric efficiency less due to lesser time of induction
11.	Thermal efficiency is high and also part load efficiency better	Thermal efficiency is low, part load efficiency lesser
12.	It is used where efficiency is important.	It is used where low cost, compactness and light weight are important.
	Ex-cars, buses, trucks, tractors, industrial engines, aero planes, power generation etc.	Ex-lawn mowers, scooters, motor cycles, mopeds, propulsion ship etc.

Comparison of SI and CI engine:

SI engine	CI engine
Working cycle is Otto cycle.	Working cycle is diesel cycle.
Petrol or gasoline or high octane fuel is used.	Diesel or high cetane fuel is used.
High self-ignition temperature.	Low self-ignition temperature.
Fuel and air introduced as a gaseous mixture in the suction stroke.	Fuel is injected directly into the combustion chamber at high pressure at the end of compression stroke.
Carburettor used to provide the mixture. Throttle controls the quantity of mixture introduced.	Injector and high pressure pump used to supply of fuel. Quantity of fuel regulated in pump.
Use of spark plug for ignition system	Self-ignition by the compression of air which increased the temperature required for combustion
Compression ratio is 6 to 10.5	Compression ratio is 14 to 22
Higher maximum RPM due to lower weight	Lower maximum RPM
Maximum efficiency lower due to lower compression ratio	Higher maximum efficiency due to higher compression ratio
Lighter	Heavier due to higher pressures

AN INTRODUCTION TO REFRIGERATION

Introduction

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning. Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space. The subject of refrigeration and air conditioning has evolved out of human need for food and comfort, and its history dates back to centuries. The history of refrigeration is very interesting since every aspect of it, the availability of refrigerants,the prime movers and the developments in compressors and the methods of refrigeration all are a part of it. The French scientist Roger ThÝvenot has written an excellent book on the history of refrigeration throughout the world. Here we present only a brief history of the subject with special mention of the pioneers in the field and some important events.

Natural Refrigeration

In olden days refrigeration was achieved by natural means such as the use of ice or evaporative cooling. In earlier times, ice was either:

1. Transported from colder regions,

2. Harvested in winter and stored in ice houses for summer use or,

3. Made during night by cooling of water by radiation to stratosphere.

In Europe, America and Iran a number of icehouses were built to store ice. Materials like sawdust or wood shavings were used as insulating materials in these icehouses. Later on, cork was used as insulating material. Literature reveals that ice has always been available to aristocracy who could afford it. In India, the Mogul emperors were very fond of ice during the harsh summer in Delhi and Agra, and it appears that the ice used to be made by nocturnal cooling.

In 1806, Frederic Tudor, (who was later called as the "ice king") began the trade in ice by cutting it from the Hudson River and ponds of Massachusetts and exporting it to various countries including India. In India Tudor's ice was cheaper than the locally manufactured ice by nocturnal cooling. The ice trade in North America was a flourishing business. Ice was transported to southern states of America in train compartments insulated by 0.3m of cork insulation. Trading in ice was also popular in several other countries such as Great Britain, Russia, Canada, Norway and France. In these countries ice was either transported from colder regions or was harvested in winter and stored in icehouses for use in summer. The ice trade reached its peak in 1872 when America alone exported 225000 tonnes of ice to various countries as far as China and Australia. However, with the advent of artificial refrigeration the ice trade gradually declined.

Introduction To air-condition

Design and analysis of air conditioning systems involves selection of suitable inside and outside design conditions, estimation of the required capacity of cooling or heating equipment, selection of suitable cooling/heating system, selecting supply conditions, design of air transmission and distribution systems etc. Generally, the inputs are the building specifications and its usage pattern and any other special requirements. Figure 29.1 shows the schematic of a basic summer air conditioning system. As shown in the figure, under a typical summer condition, the building gains sensible and latent heats from the surroundings and also due to internal heat sources (RSH and RLH). The supply air to the building extracts the building heat gains from the conditioned space. These heat gains along with other heat gains due to ventilation, return ducts etc. have to be extracted from the air stream by the cooling coil, so that air at required cold and dry condition can be supplied to the building to complete the cycle. In general, the sensible and latent heat transfer rates (GSH and GLH) on the cooling coil are larger than the building heat gains due to the need for ventilation and return duct losses. To estimate the required cooling capacity of the cooling coil (GTH), it is essential to estimate the building and other heat gains. The building heat gains depend on the type of the building, outside conditions and the required inside conditions. Hence selection of suitable inside and outside design conditions is an important step in the design and analysis of air conditioning systems.

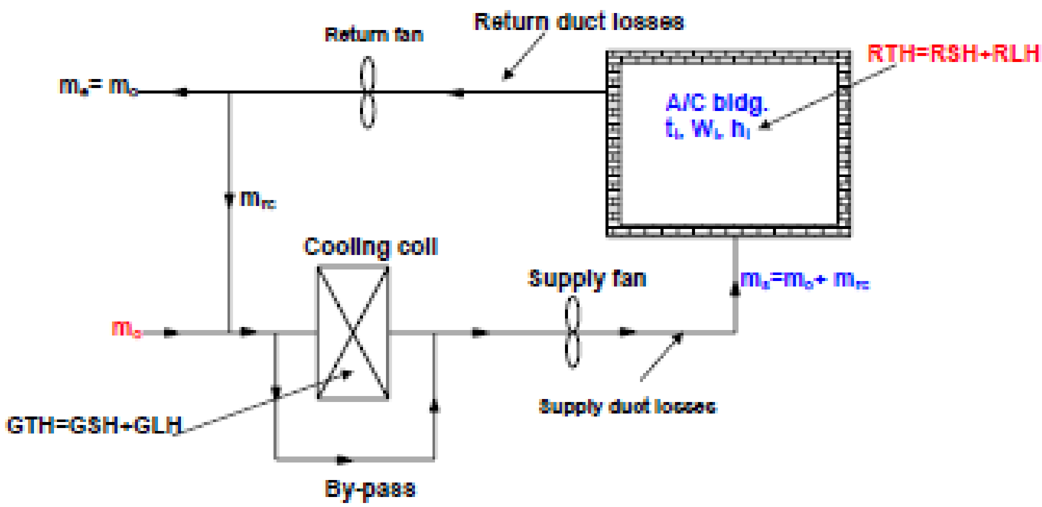


Fig.29.1: Schematic of a basic summer air conditioning system

BASIC REFRIGERATION PRINCIPLES

If you were to place a hot cup of coffee on a table and leave it for a while, the heat in the coffee would be transferred to the materials in contact with the coffee, i.e. the cup, the table and the surrounding air. As the heat is transferred, the coffee in time cools. Using the same principle, refrigeration works by removing heat from a product and transferring that heat to the outside air.

REFRIGERATION SYSTEM COMPONENTS

- There are five basic components of a refrigeration system, these are:
    - Evaporator
    - Compressor

- Condenser
- Expansion Valve
- Refrigerant; to conduct the heat from the product

In order for the refrigeration cycle to operate successfully each component must be present within the refrigeration system.

The Evaporator

The purpose of the evaporator is to remove unwanted heat from the product, via the liquid refrigerant. The liquid refrigerant contained within the evaporator is boiling at a low-pressure. The level of this pressure is determined by two factors:

- The rate at which the heat is absorbed from the product to the liquid refrigerant in the evaporator

- The rate at which the low-pressure vapour is removed from the evaporator by the compressor.

To enable the transfer of heat, the temperature of the liquid refrigerant must be lower than the temperature of the product being cooled. Once transferred, the liquid refrigerant is drawn from the evaporator by the compressor via the suction line. When leaving the evaporator coil the liquid refrigerant is in vapour form.

The Compressor

The purpose of the compressor is to draw the low-temperature, low-pressure vapour from the evaporator via the suction line. Once drawn, the vapour is compressed. When vapour is compressed it rises in temperature. Therefore, the compressor transforms the vapour from a low-temperature vapour to a high-temperature vapour, in turn increasing the pressure. The vapour is then released from the compressor in to the discharge line.

The Condenser

The purpose of the condenser is to extract heat from the refrigerant to the outside air. The condenser is usually installed on the reinforced roof of the building, which enables the transfer of heat. Fans mounted above the condenser unit are used to draw air through the condenser coils. The temperature of the high-pressure vapour determines the temperature at which the condensation begins. As heat has to flow from the condenser to the air, the condensation temperature must be higher than that of the air; usually between -12°C and -1°C. The high-pressure vapour within the condenser is then cooled to the point where it becomes a liquid refrigerant once more, whilst retaining some heat. The liquid refrigerant then flows from the condenser in to the liquid line.

The Expansion Valve

Within the refrigeration system, the expansion valve is located at the end of the liquid line, before the evaporator. The high-pressure liquid reaches the expansion valve, having come from the condenser. The valve then reduces the pressure of the refrigerant as it passes through the orifice, which is located inside the valve. On reducing the pressure, the temperature of the refrigerant also decreases to a level below the surrounding air. This low-pressure, low-temperature liquid is then pumped in to the evaporator.

The Refrigerant

The type of refrigerant used will depend on the pressure capabilities of the system and the temperatures that have to be achieved during refrigeration. The following brief table shows the relationship between temperature and pressure, given in bar, for two common refrigerants.

This gas cycle refrigeration systems based on air, namely

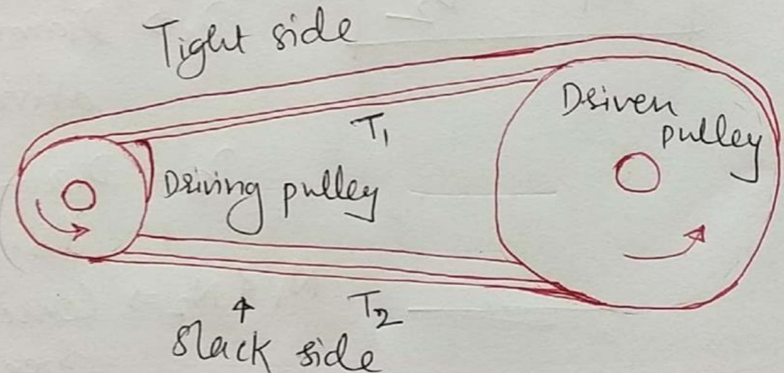
1. Reverse Carnot cycle & its limitations
2. Reverse Brayton cycle – Ideal & Actual
3. Aircraft refrigeration cycles, namely Simple system, Bootstrap system, Regenerative system.

* Belt drive :-

> When the motion is transmitted from one shaft to another by using belt as a connection between them it is known as belt drive.

> There is relative velocity between shaft and belt ~~which is~~ due to slip.

> Generally, belt, rope drives are used when the distance between shafts is large.



> In belt drive, belt is mounted on pulley.
> Pulley which is ~~driven~~ used to drive the other pulley using belt is known as driving pulley.
~~and~~

> In belt drive, the velocity of two shafts can be varied by variation in diameter of pulley.

> ~~Eg~~ Outer and inner faces of belt are subjected to tension and compression respectively.

> There are two types of cross sections of belts i.e. (a) Flat belt (b) V-belt.

> Velocity ratio is the ratio of speed of the driven pulley to that of the driving pulley.

$$\frac{N_2}{N_1} = \frac{D_1}{D_2}$$

where -

$D_1 \Rightarrow$ Diameter of driving pulley.

D_2 = Diameter of driven pulley.

N_1 & $N_2 \Rightarrow$ Corresponding speeds.

~~* Creep:~~

~~When belt passes from~~

> Open-belt drive is used to provide same direction of rotation to driven shaft as the direction of rotation of driving shaft.

> Crossed-belt drive is used to provide reverse direction of rotation to driven shaft as the direction of rotation of driving shaft as shown in figure.

Crossed- belt drive

—x—

Creep:-

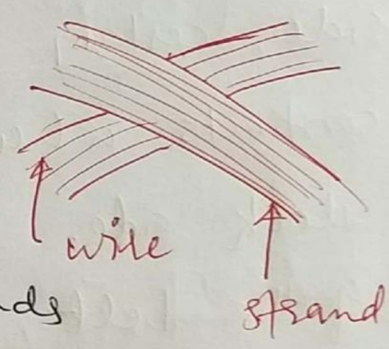
> When belt passes from slack to tight side, certain portion of belt extends and again contracts when belt passes through tight to slack side. Due to fluctuation in length of the belt, there is relative motion between belt and pulley surface.
This relative motion is known as creep.

Rope drive :-

Rope drive is very similar to belt drive. It is classified as —

1. Fibre ropes
2. Wire ropes.

- Fiber ropes are made of manilaa or cotton.
- Wire ropes are made of steel wires.
- A number of wires make a strand and strands make a rope
- Each strand is twisted with other strands.



- Rope may have three strands or nine strands and each strand may have 7-19 wires, depending on its application.

* Coupling :-

> Coupling is a device used to connect two shafts together at their ends for transmitting the power.

> There are two general types of couplings -

1. Rigid
2. Flexible.

① Rigid Coupling :-

> Rigid coupling keeps two shafts together tightly to prevent relative motion between them.

> It is used where precise alignment ~~is required~~. between two shafts is required.

> If misalignment occurs during operation, it leads to failure ~~of~~ due to fatigue.

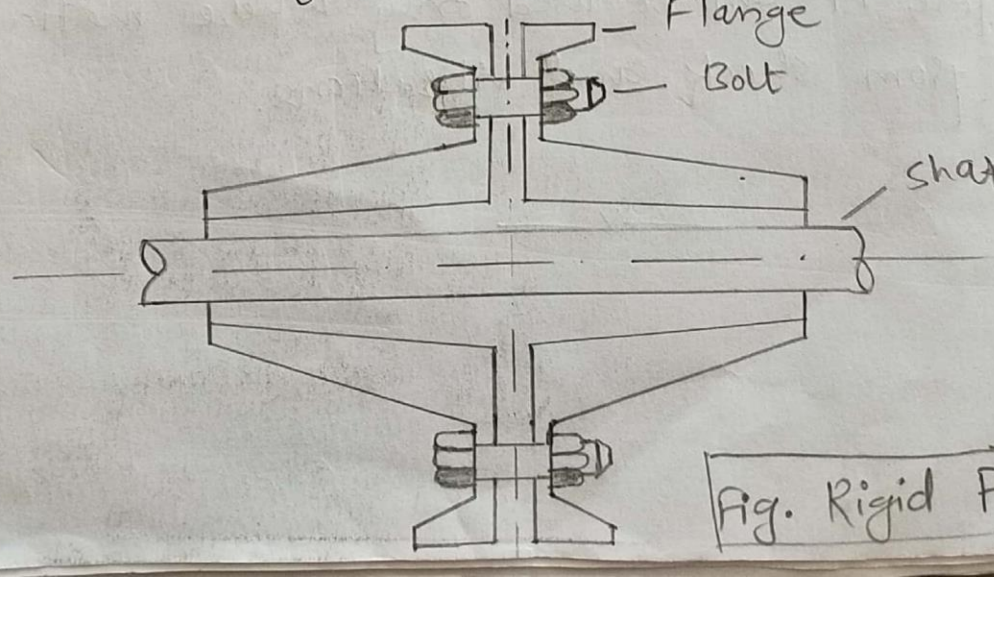


Fig. Rigid Flange Coupling *

> It consists of two flanges which are keyed to the shafts.

> Flanges are attached together and bolted in annular space.

> Bolts are placed equispaced on bolt circle diameter, torque transmitted through bolts.

> Number of bolts depend on diameter of shafts.

> Advantages of rigid flange couplings are high torque transmission, easy to assemble and ~~dissamble~~ disassemble, simple design and these are easy to manufacture.

> Main disadvantages are, it requires more space, it can fail if misalignent between shafts occur, therefore it can be used only where motion is free from shock and vibrations.

—x—

(2) Flexible bushed coupling :-

> In bushed coupling the rubber bushings over pins are provided to accomodate some misalignment due to flexibility of bushings.

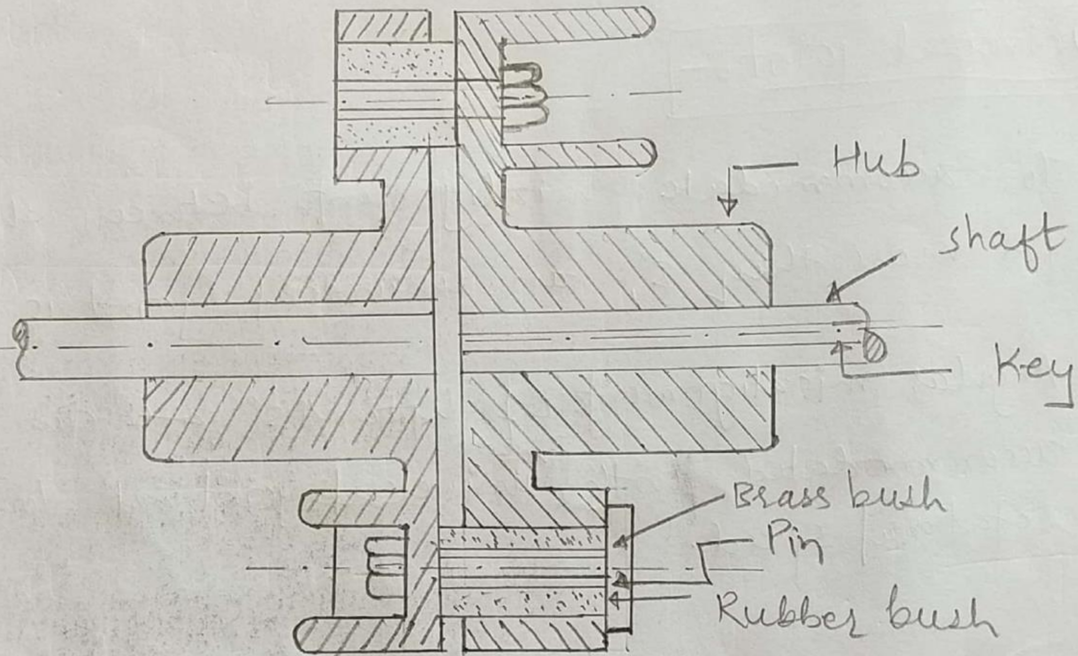


Fig. Flexible bushed coupling.

> It is similar to rigid flange coupling but the only difference is pins (bolts) are covered with rubber bush.

> Advantages of this coupling are that it can bear 0.5 mm and 1.5° lateral and angular misalignment.

> It absorbs shock and vibrations.

> It is used for transmission of high torque.

- It is easy to assemble and disassemble.
- Simple design
- It is costly and requires more space than rigid flange coupling.

—x—

③ Universal joint:-

- To accommodate mialignment between shafts for more than 3°, an universal joint is used.
- Angular misalignments of upto 45° ~~are~~ can be accommodated with single universal joint at low ~~spee~~ rotational speed.

—x—

* Clutches :-

Clutch is a device which is used to engage and disengage the driven shaft from driving shaft- ~~withou~~ during the motion to change the gears meshing without stopping the driving shaft.

Its operation is based on the friction between two surfaces.

Clutches may be classified as follows -

1. Single plate clutch or disc clutch.
2. Multi-plate disc clutch.
3. Conical clutch.
4. Centrifugal clutch.

1 Single plate Clutch :-

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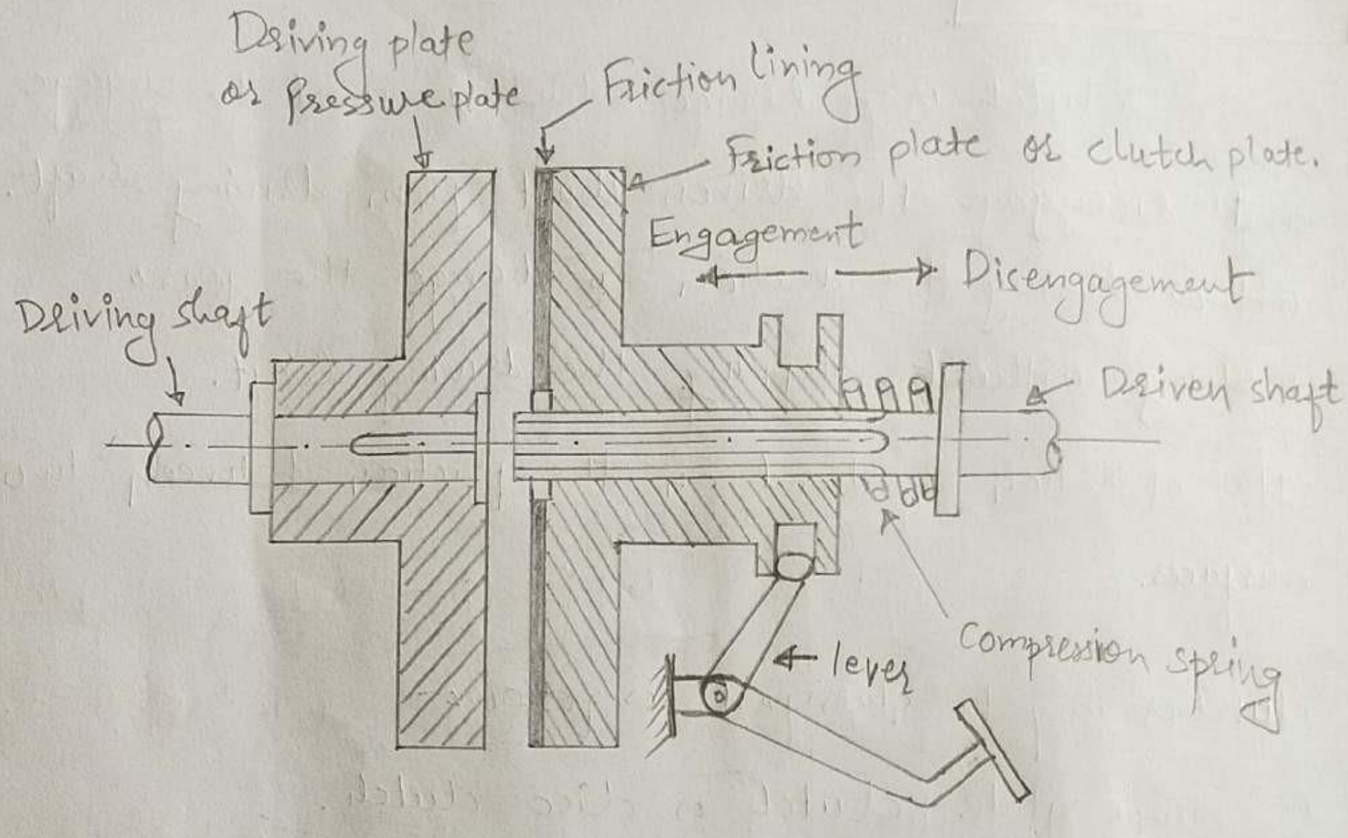


Fig. Single plate clutch.

> It operates on the principle of friction.

> When two surfaces are brought together and held against each other, due to friction between them, they can use to transmit power.
If one surface is rotated then other also rotates.

> In single plate clutch one surface is connected to engine and other to the transmission system.
It consist of (a) Driving member (b) Driven member (c) Operating member

> The driving member has a flywheel which is mounted on the engine crankshaft.

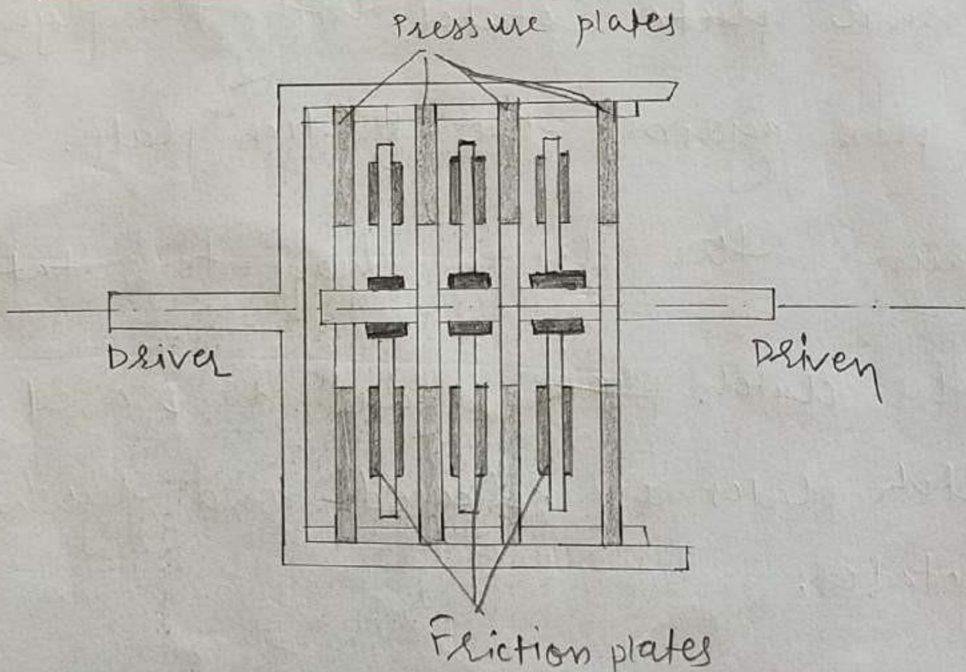
> A disc is bolted to ~~flywheel~~ flywheel which is known as pressure plate.

> The driven member is a disc called clutch plate. This plate can slide freely to and fro on the clutch shaft.

> The operating member consists of a pedal or lever which can be pressed to disengage the driving and driven plate.

—x—

* **Multiplate clutch:-**



> A multiplate clutch consists of a number of clutch plates, instead of only one clutch plate

as in the case of single clutch plate.

> The increased number of friction surfaces increases the capacity of the clutch to transmit torque.

> The plates are alternately fitted to the engine shaft and gear box shaft. They are firmly pressed by springs.

> The working of multiplate clutch is the same as a single plate clutch by operating the clutch pedal.

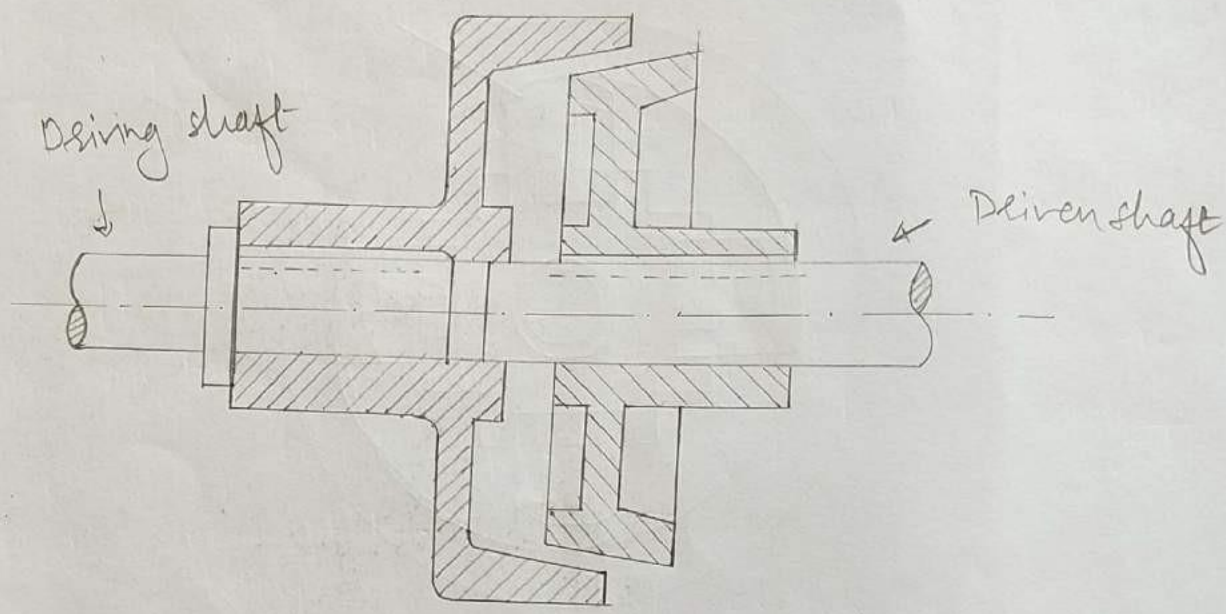
> The pressure plate rotates with the flywheel and it press against the friction plate.

> This causes the driven shaft to rotate.

> When the clutch ~~plate~~ pedal is pressed, the clutch plates are released and flywheel still rotates.

—x—

* Cone clutch :-



> A cone clutch serves the same purpose as a disc or plate clutch.

> Instead of mating two spinning disks, the clutch uses two conical surfaces to transmit torque by friction.

> The cone clutch transfers a higher torque than plate or disc clutches of same size due to increased surface area of contact.

> They are used in racing or extreme off-road vehicles.

* Centrifugal clutch :-

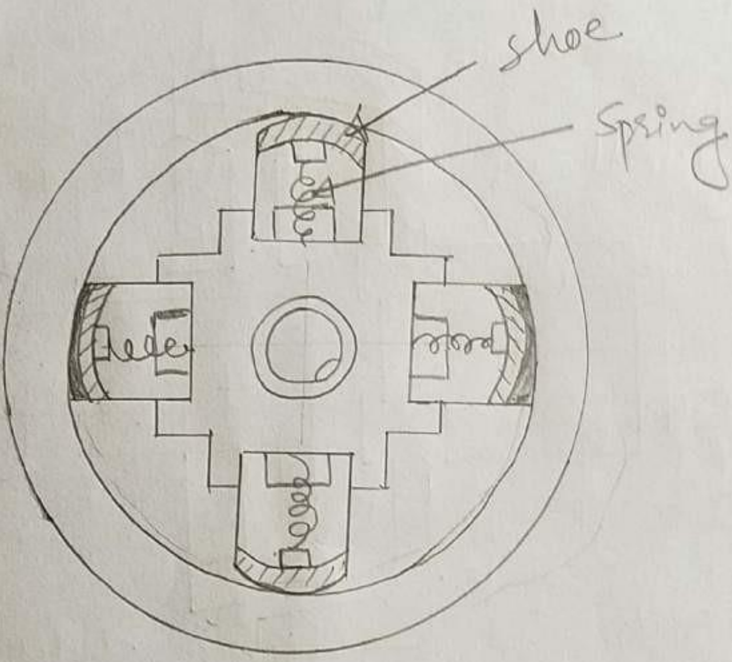


Fig. Centrifugal clutch.

> Centrifugal clutch works on the principle of centrifugal force.

> When driving shaft rotates at high speed, the shoes move radially outward.

> The outer surfaces of the shoes are covered with friction material which engages the pulley. Thus pulley rotates with driving shaft.

> This type of clutch is generally used in motor pulley.

> The spring force resists the centrifugal force, thus prevents the engagement at lower speed.

* Brakes :-

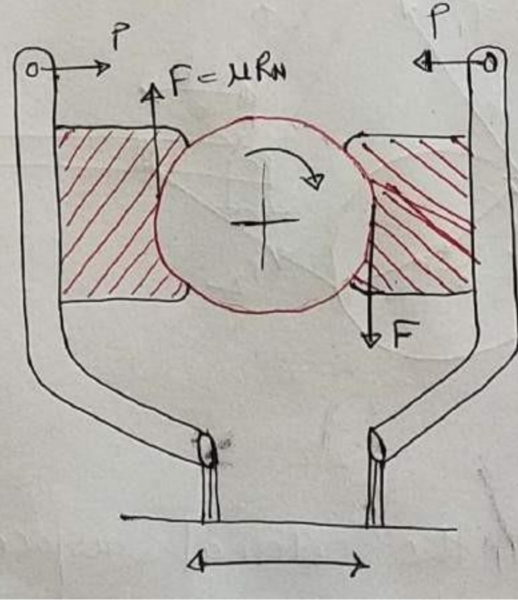
Brake is a device which is used to bring the body into rest while it is in motion.

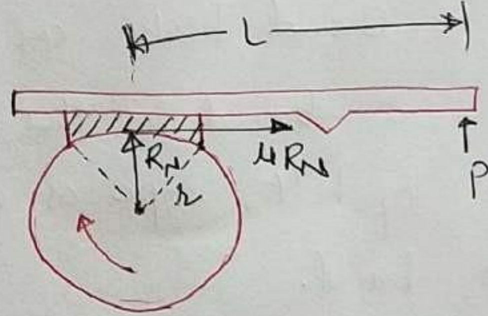
There are four types of brakes –

1. Block brake or shoe brake
2. Band brake.
3. Band and block brake.
4. Internal expanding shoe brake.

* Block or shoe brake :–

- In this brake, a shoe or block is pressed against the drum.
- The force can be increased by using a lever as shown in figure.





r = Radius of drum

μ = Coefficient of friction.

R_N = Normal reaction on the shoes.

P = Force applied on lever.

F = Frictional force.

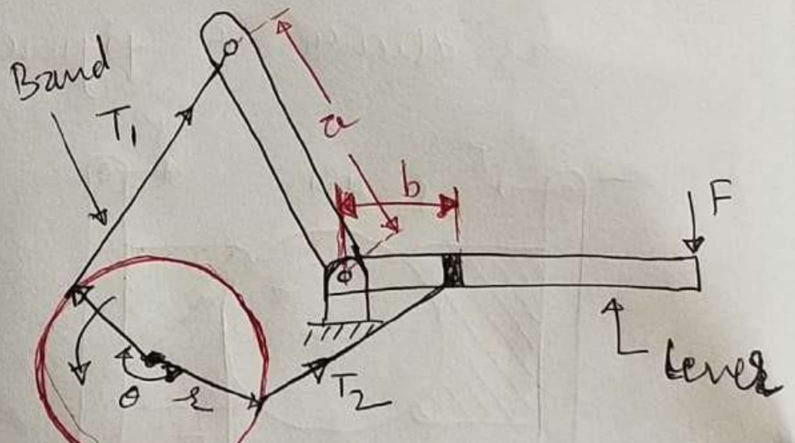
> Due to pressure applied by single shoe, there is a side thrust on the shaft of drum.

> To counter balance the side thrust, two shoes may be used opposite to each other.

> In this case, braking torque becomes double,

—— x ——

* **Band brake :-**



> Band brake consists of a band in the form of belt, rope or steel band.

> When force is applied at the free end of lever, the band is pressed against the external surface of drum

Braking torque,

$$T = (T_1 - T_2) \times r$$

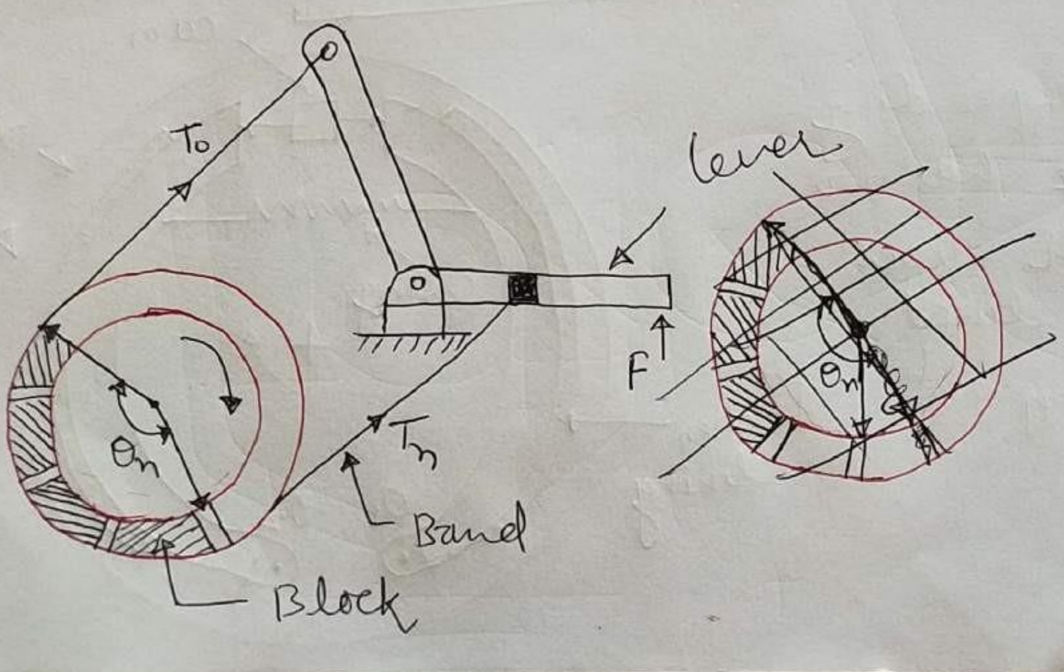
& $$\frac{T_1}{T_2} = e^{\mu\theta}$$

where, T_1 is tension in tight side.
T_2 is tension in slack side.

> The effectiveness of braking force varies according to the direction of rotation of drum, ratio of length a and b, and the direction of force applied at the ~~end~~ of lever.

— x —

* **Band and Block Brake :-**



> This brake is combination of band and block brake.

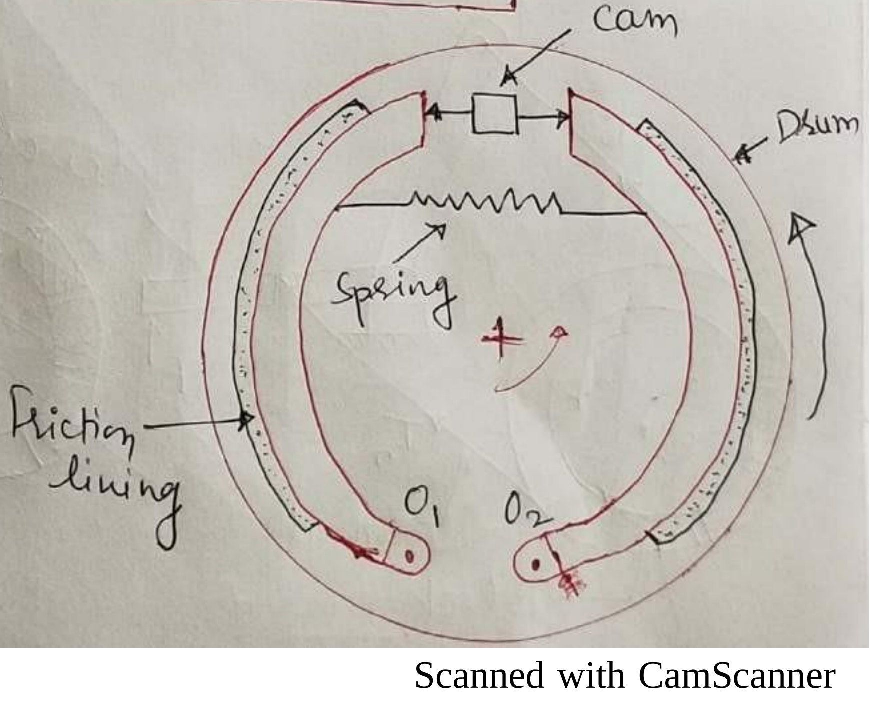
> A number of blocks are mounted on the drum and inside the band.

> Brake is applied by pressing the blocks against the drum with the help of band.

> Blocks are used under the band since blocks have higher coefficient of friction. This ~~incre~~ arrangement increases the effectiveness of brake.

* Internal expanding shoe brake :-

> Internal expanding shoe brake has two semicircular shoes which are lined with friction material.



> The outer diameter of shoe is less than inner diameter of drum, so that the drum can rotate freely.

> When brake is applied, the shoes expand and press the inner surface of the drum and resist the motion.

> It is used in automobile.

> It is self-energizing and good heat dissipative.

———x———

Power transmission is a process to transmit motion from one shaft to another by using some connections between them like belt, rope chain and gears.

There are various types of power transmission devices –

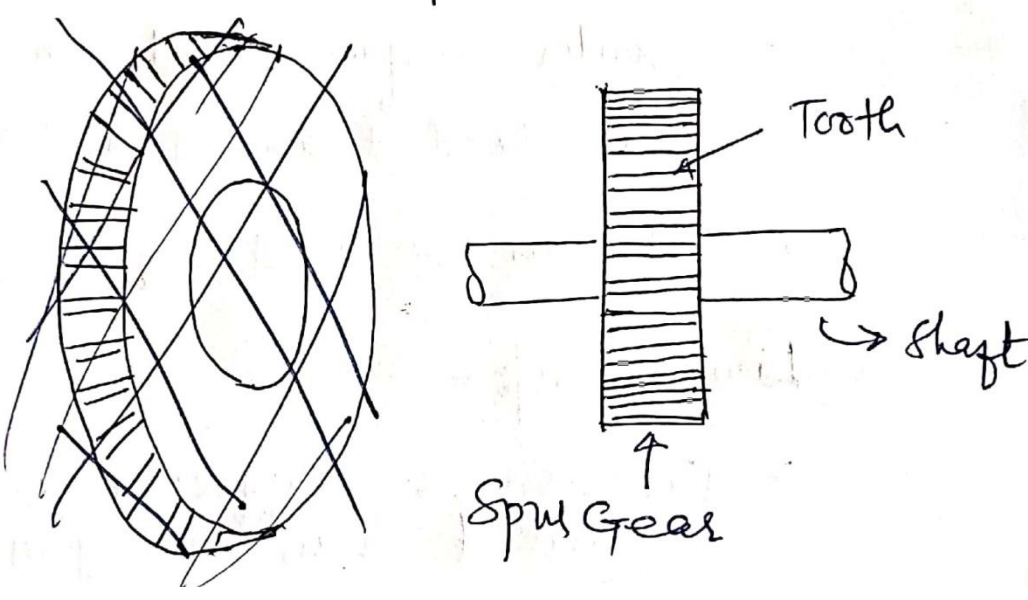
1. Gear drive / Gear train.
2. Belt drive
3. Chain drive.

* **Classification of gears :-**

Gears are classified according to position of shafts -

(A) **Parallel shafts :-**

1. **Spur gear :-**
   > Teeth on gear are parallel to the shaft.
   > These are most commonly used gears.



* Advantages of spur gears:-

> Easy to find, inexpensive and efficient.

Limitations:-

> It is used for smaller speeds only.

> Noise and vibration.

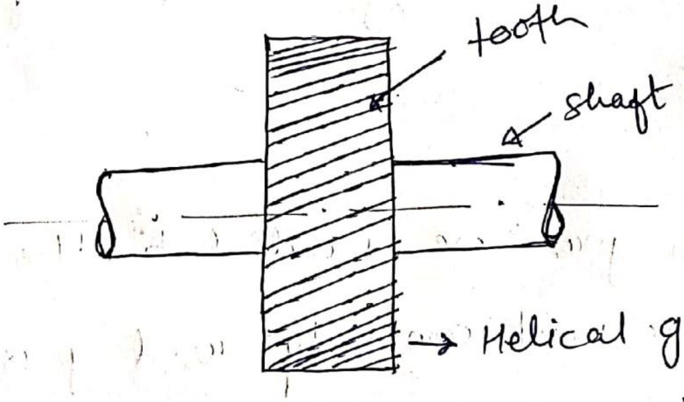
② Helical gears:-

> Teeth of helical gear are inclind to the axis of shaft.

> Teeth are longer than the teeth on a spur gear of equivalent pitch diameter.

Advantages:-

> Tooth strength is greater than spur gear.



> Greater surface contact on the teeth which carry more load than spur gear.

> It can be used for non-parallel shafts also.

* Limitations:-

> Expensive, difficult to manufacture and less efficient than spur gear.

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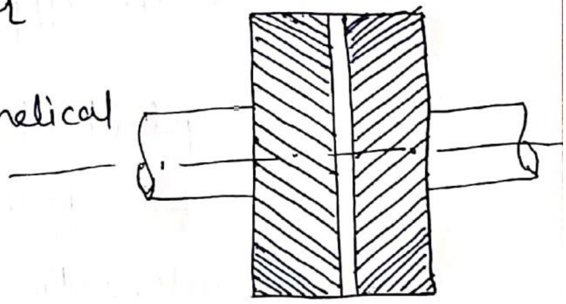
> Helical gears create axial thrust on the shaft.

③ Herringbone gears :- / Double helical gear :-

> To eliminate axial thrust heringbone or double helical gears are used.

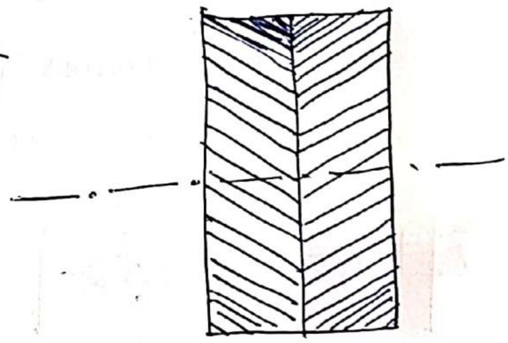
> ~~Herringbone~~ Double helical gears have one right-hand helix and the other a left-hand helix.

> The teeth of two rows of double helical are ~~Sp~~ seperated by a groove.



ⓐ Double helical

> Herringbone gears are joined in the middle of the gear circumference. This arrangement makes it compact.



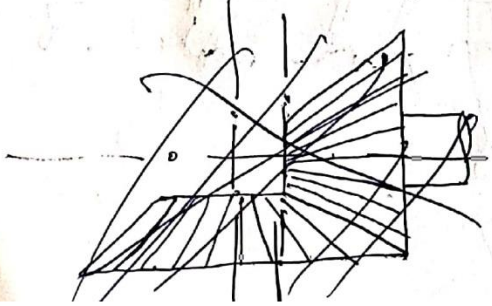
ⓑ Herringbone gear

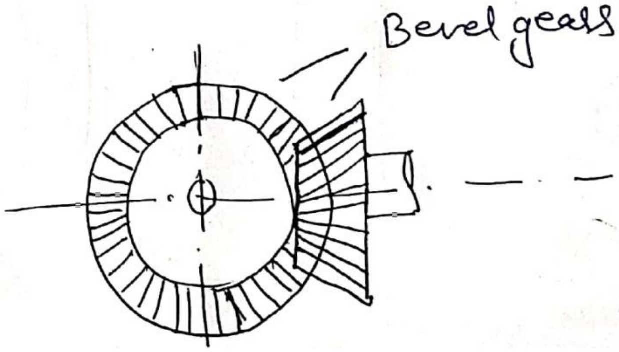
Ⓑ Intersecting shafts :-

① Bevel gears :-

> It is used to transfer power between intersecting shafts. Mostly for the shafts which are perpendicular to each other.

> The teeth of these gears are formed on a conical surface.





Bevel gears.

> Standard bevel gears have teeth which are cut straight and parallel to the line pointing the apex of cone.

> Spiral bevel gears are also available with teeth form arcs.

> Uesed in differentials of automobiles.

> Hypocycloid bevel gears are ~~generally considered the best~~ special type of spiral gear that allow non-intersecting, non-parallel shafts to mesh.

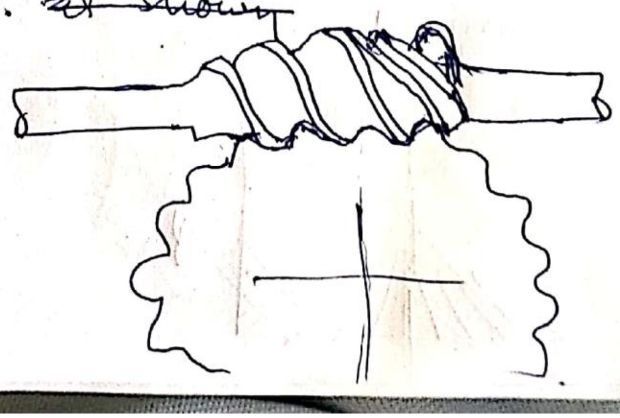
> It can not be used for parallel shafts.

> It becomes noisy at high speeds.

* ~~Hypoid gears:~~

* **Worm gears:-**

> If a tooth of a helical gear makes complete revolutions on the pitch cylinder, the resulting gear is known as worm. The mating gear is called worm wheel. ~~as shown~~



* **Gear trains :-**

Sometimes, two or more gears are made to mesh with each other to transmit power from one shaft to another, such a combination is called as gear train.

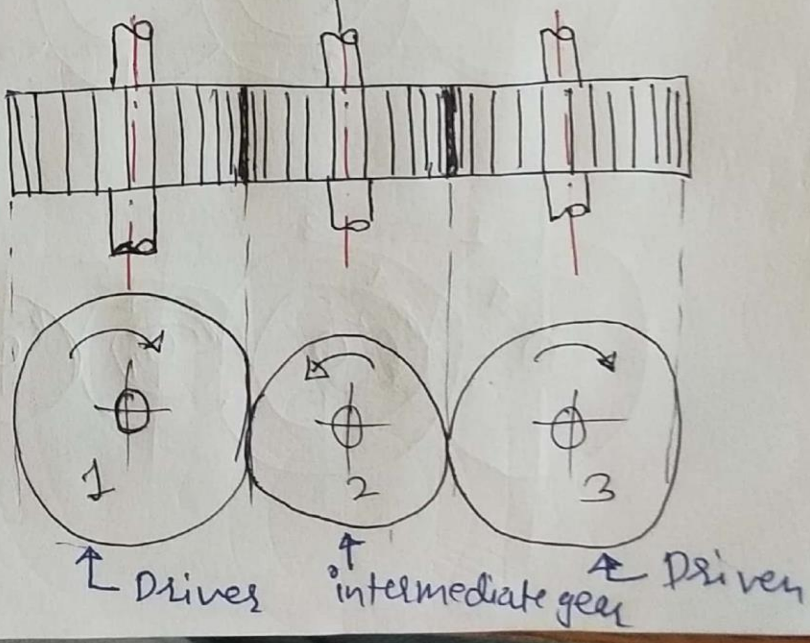
Types of gear trains :- Depending upon arrangement of wheels

1. Simple gear train.
2. Compound gear train
3. Reverted gear train
4. Epicyclic gear train.

① Simple gear train :-

When there is only one gear on each shaft, the gear train is known as simple gear train.

> Motion is transferred from Gear 1 to gear 3. Gear 1 is known as driver and gear 3 is known as driven or follower.



> When number of intermediate gear are odd, the the motion of driver and driven gear is like ~~and~~ vice-versa.

> ~~speed ratio~~ $= \dfrac{\text{Speed of driver}}{\text{Speed of driven}} = \dfrac{\text{Number of teeth of driven}}{\text{Number of teeth on driver}}$

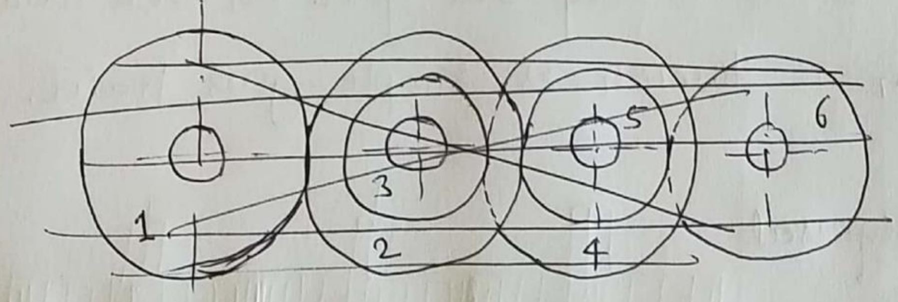
> $\text{Speed ratio} = \dfrac{\text{Speed of driver}}{\text{Speed of driven}} = \dfrac{\text{Product of number of teeth on drivens}}{\text{Product of number of teeth on drivers}}$

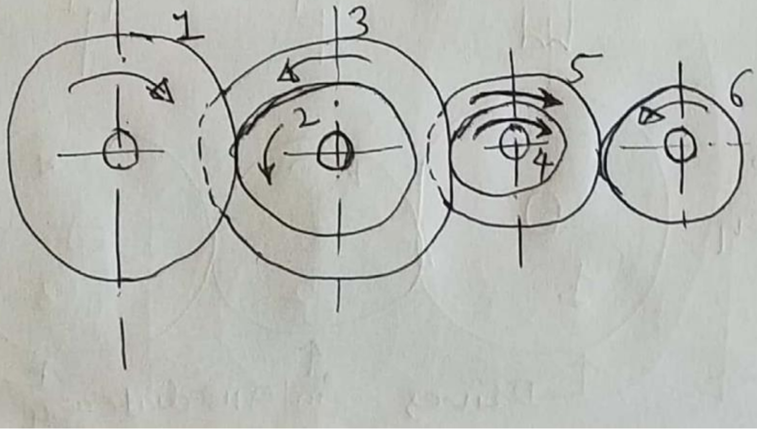
> In simple gear train, speed ratio is independent of numbers of intermediate gears.

> ~~Train value is recipr~~

② Compound gear train :-

When there is more than one gear on a shaft, it is known as compound gear train.





> Whenever, the distance between driver and driven shaft has to be ~~brigd~~ bridged and at the same time great (or much less) speed ratio is required, then the ~~advantage of~~ compound gear train is used.

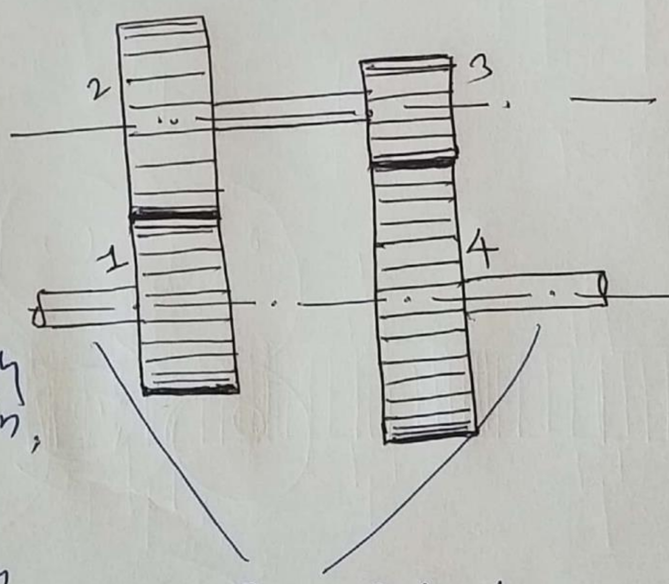
>

∴ Speed ratio of compound gear train is —

$$\frac{N_1}{N_6} = \frac{T_2 \times T_4 \times T_6}{T_1 \times T_3 \times T_5}$$

③ Reverted gear train :-

> When the axes of the first gear (driver) and the last gear are co-axial, then the gear train is known as reverted gear train, as shown in figure.



Co-axial shafts

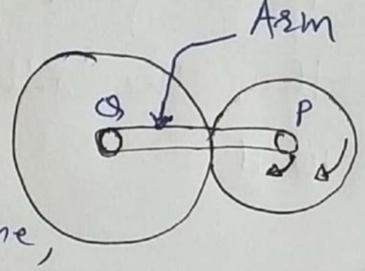
> In reverted gear train, the motio of first gear and las gear is like.

~~Speed ratio~~

> Reverted gear train is used in clocks, automotive transmition.

(4) Epicyclic gear train:-

> If the axis of at least one gear in gear train moves relative to fixed axis or frame, such type of gear train is known as epicyclic gear train.



> In this one gear rotate upon and around other gear.

> If gear Q is fixed, then arm can rotate about the axes of Q & gear P would also ~~move~~ rotate around Q.

———X———

ENGINEERING MATERIALS AND THEIR PROPERTIES

MATERIAL:-

- Material is something consist of matter.
- Materials comprise a wide range of metals and non-metals and other.

MATERIAL CLASSIFICATION:-

- Normally materials are 5 type.

(A)Metals (Ferrous and Nom-ferrous)

(B)Ceramics

(C) Organic

(D)Composites

(E)Semiconductors

PROPERTIES OF MATERIALS

- **Physical Properties**
- Dimension:-
  - Dimension of a material implies it's size(breadth, width, length, dimeter) and shape (section, circular,channel,angle).
- Appearance:-
  - Different materials have different looks.
  - Some materials got specific colour and some materials got some specific porperty which make them different from others
- Density:-
  - The density is the weight of unit volume of a material.
    - Density=weight/volume
- Melting point:-
  - Melting point of a material is that temperature at which the solid metals changes into the molten state.
- Porosity:-
  - A material is said to be porous if it has pores within it.
  - Pores can absorb lubricant as in a sintered self-lubricating bearing.
    - True porosity=Total pore volume/Total volume

- **Chemical Properties:-**
- Corrosion resistance:-
  - It is the deterioration of material by chemical reaction with it's environment.
- Chemical composition
- Acidity or Alkalinity
- **Mechanical Properties:-**
- Elasticity
  - The tendency of a deformed solid to seek it's original dimensions upon withdrawing force is known as elasticity.
  - Stress=Load/Area
  - Strain=Change in dimension/Original dimension
  - Young's Modulus of Elasticity=Stress/Strain
- Plasticity
  - Plasticity is that property of a material by virtue of which it may be permanently deformed when it has been subjected to an external force great enough to exceed the elastic limits.
- Toughness
  - Toughness is the ability of the material to absorb energy during plastic deformation up to fracture.
- Resilience
  - Resilience is the capacity of a material to absorb energy when it is elastically deformed and then upon unloading, to have this energy recovered.
- Tensile Strength
  - Tensile strength is the maximum force needed to fracture the material.
- Yield Strength
  - Yield strength is that value of stress at which a material exhibits a specified deviation from proportionality of stress and strain.
  - Yield strength of a material represents the stress below which the deformation is almost entirely elastic.
- Impact Strength
  - The capacity of a material to resist shock energy before it fracture is called it's impact strength.
- Ductility
  - Ductility refers to the capacity of a material to undergo deformation under tension without rupture.
- Malleability
  - Malleability is the capacity of a material to withstand deformation under compression without rupture.

- Brittleness

    - Brittleness is defined as a tendency to fracture without appreciable deformation and is therefore the opposite of ductility
- Hardness
    - Hardness is the resistance of a material to plastic deformation.
- Fatigue
    - When subjected to repeated loads, material tends to develop a characteristic behavior which is different from under steady loads.
    - Fracture takes place under stresses whose maximum value is less than the tensile strengthof the material.
- Creep
    - Creep is the time-dependent permanent deformation that occurs under constant stress at elevated temperature.
- Wear Resistance
    - Wear is the unintentional removal of solid material from rubbing surface.

PERFORMACE REQUIREMENTS:-

- Fabrication requirements:-
    - It means that the material should be able to get shaped and joined easily.
- Service requirements:-
    - It imply that the material selected for the purpose must stand up to service demand.
- Economic requirements:-
    - It demand that the engineering part should be made with minimum overall cost.

MATERIAL RELIABILITY AND SAFETY:-

- The final product should be reliable(e.g.,should last for desired time period in a particular conditions) and safe for user(e.g., shouldn't harm the user in anyway possible)

FERROUS AND NON-FERROUS CATEGORYAND ALLOY:-

- Ferrous metals are any metal that contains iron, such as stainless steel. They are known for their tensile strength, which makes them ideal for architectural and structural uses such as the tallest skyscrapers, as well as bridges, railways and more.
- Ferrous metals are also have magnetic properties, which is why you can use magnets to pin things to your refrigerator door, although their high carbon content means that many ferrous metals are prone to rusting. The exceptions to this are stainless steel, which doesn't rust because of the chromium, and wrought iron which doesn't rust due to the high pure iron content.
- Example:-
    - Steel
    - Stainless Steel
    - Cast Iron
    - Wrought Iron

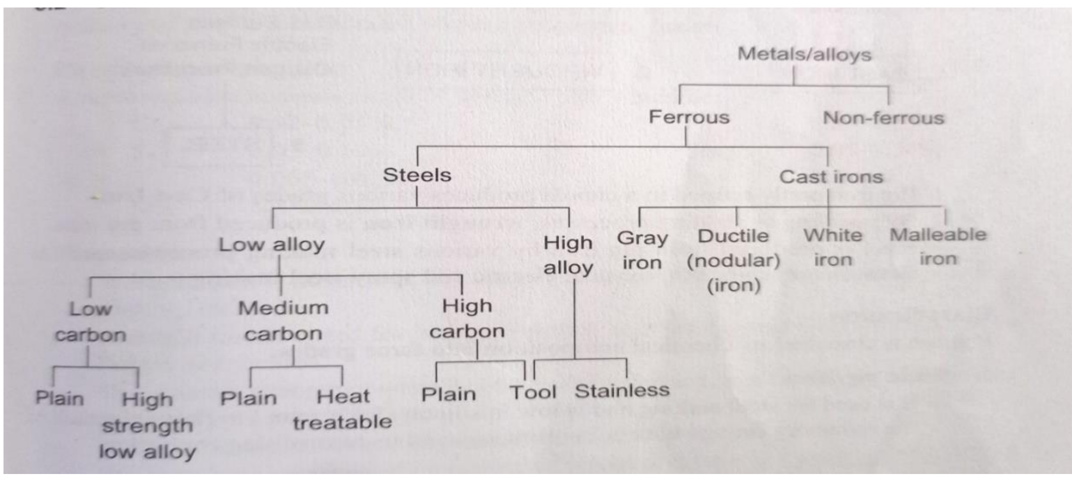
    - Carbon Steel
- Non-ferrous metals don’t contain iron. They are lighter and more malleable than ferrous metals, making them ideal for applications where strength is required but weight is a consideration, such as with the aerospace industry.
- Non-ferrous metals are not magnetic but do offer good resistance to corrosion and can conduct heat and electricity. They are used in for items including industrial piping, gutters, roofing and electrical applications.
- Example:-
    - Aluminium
    - Cupper
    - Lead
    - Tin
    - Silver
    - Brass
    - Gold
    - Zinc

Ferrous Materials and Alloys

Introduction:-

- Ferrous materials contain iron, and the one elements people use more than all other is Iron .
- Ferrous materials are the most important metals/alloy in the metallurgical and mechanical industries because of their very extensive use.
- Iron containing compounds exist in abundant quantities within the earth's crust.
- Metallic iron and steel alloys may be produced using relatively economical extraction, refining, alloying and fabrication technique.
- Ferrous alloys are extremely versatile in that they may be tailored to have a wide range of mechanical and physical properties.

Classification:-



Composition and Application of different steel:-

Steel is an alloy of iron and carbon. Carbon steel can be classified as

i. Low carbon steel
ii. Medium carbon steel
iii. High carbon steel

Low carbon steel(Mild steel):-

Mild steels may be classified as follows

- Dead mild steel(C 0.05-0.15%)

It is used for making steel wire, sheet and chain
It has tensile strength of 390 N/mm^2 and hardness of about 115 BHN

- Low mild steel(C 0.15-0.2%)
  It is used for camshaft, welding tube
  It has a tensile strength of 420 N/mm^2 and hardness of about 125 BHN
- Mild steel(C 0.2-0.3%)
  It is used for valves, gears, connecting rod
  It has a tensile strength of 555 N/mm^2 and hardness of about 140BHN

Medium carbon steel:-

- Steel containing carbon from 0.35 to 0.45%
  - They are used for key stock, wires and rods
  - They have a tensile strength of about 750 N/mm^2
- Steel containing carbon from 0.45 to 0.55%
  - They are used for axle, crankshaft
  - They have a tensile strength of 1000 N/mm^2
- Steel containing carbon from 0.6 to 0.7%
  - They are used for clutch disc, valve spring
  - They have a tensile strength of 1230 N/mm^2

High carbon steel:-

- Steel containing carbon from 0.7 to 0.8%
  - It is used for jaws for vises, cold chisel
  - It has a tensile strength of 1400 N/mm^2
- Steel containing carbon from 0.8 to 0.9%
  - It is used for Leaf spring, clutch discs
  - It has a tensile strength of 660 N/mm^2
- Steel containing carbon 0.9 to 1%
  - It is used for Pins, keys
  - It has a tensile strength of 580 N/mm^2
- Steel containing carbon 1 to 1.1%
  - It is used for Railway spring machine tool
- Steel containing carbon 1.1 to 1.2%
  - It is used for knives, twist drill
- Steel containing carbon 1.2 to 1.3%
  - It is used for files, metal cutting tools
- Steel containing carbon 1.3 to 1.5%
  - It is used for wire drawing dies, paper knives

Alloy Steel:-

- Steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits;
    - Mn = 1.65%
    - Si = 0.6%
    - Cu = 0.6%
- Given below is the composition of typical alloy steel

  C=0.2-0.4%   Mn=0.3-1%

  Si=0.3-0.6%   Ni=0.4-0.7%

  Cr=0.4-0.6%   Mo=0.15-0.3%

Advantages and disadvantages of alloy steel

Advantages that may be attained	**Disadvantages that may be encountered**
Greater hardenability	Cost
Less distortion and cracking	Special handling
Greater stress relief at given hardness	Tendency toward austenite retention
Less grain growth	Temper brittleness in certain grades
Higher elastic ratio and endurance strength	
Greater high temperature strength	
Better machinability at high hardness	
Greater ductility at high strength	

Tool steel:-

- Tool steels may be defined as special steel which have been developed to form cut or otherwise change the shape of a material into a finished or semi finished product.

Properties:-

i. Slightly change of form during hardening
ii. Little risk of cracking during hardening
iii. Good toughness
iv. Good wear resistance
v. Very good machinability
vi. A definite cooling rate during hardening
vii. A definite hardening temperature
viii. A good degree of through hardening
ix. Resistance to decarburization
x. Resistance to softening on heating

Composition:-

1.	W-High speed steels (T)					
	$T_1 \rightarrow$ C 0.7,	Cr 4,	V 1,	W 18		
	$T_4 \rightarrow$ C 0.75,	Cr 4,	V 1,	W 18,	Co 5	
	$T_6 \rightarrow$ C 0.8,	Cr 4.5,	V 1.5	W 20,	Co 12	
2.	Mo-High speed steels (M)					
	$M_1 \rightarrow$ C 0.8,	Cr 4,	V 1	W 1.5,	Mo 8	
	$M_6 \rightarrow$ C 0.8,	Cr 4,	V 1.5,	W 4,	Mo 5,	Co 12
3.	High C, high Cr steels (D)					
	$D_2 \rightarrow$ C 1.5,	Cr 12,	Mo 1,			
	$D_5 \rightarrow$ C 1.5,	Cr 12,	Mo 1,	Co 3		
	$D_7 \rightarrow$ C 2.35,	Cr 12,	V 4,	Mo 1		
4.	Air hardening steels (A)					
	$A_2 \rightarrow$ C 1,	Cr 5,	Mo 1			
	$A_7 \rightarrow$ C 2.25,	Cr 5.25,	V 4.75	W 1,	Mo 1	
	$A_9 \rightarrow$ C 0.5,	Cr 5,	Ni 1.5,	V 1,	Mo 1.4	
5.	Oil hardening steels (O)					
	$O_1 \rightarrow$ C 0.9,	Mn 1,	Cr 0.5,	W 0.5		
	$O_6 \rightarrow$ C 1.45,	Si 1,	Mo 0.25			
6.	Water hardening steels (W)					
	$W_2 \rightarrow$ C 0.6/1.4,	V 0.25				
	$W_5 \rightarrow$ C 1.1,	Cr 0.5				
7.	Hot work steel (H)					
	$H_{10} \rightarrow$ C 0.4,	Cr 3.25,	V 0.4,	Mo 2.5		
	$H_{12} \rightarrow$ C 0.35,	Cr 5,	V 0.4,	W 1.5,	Mo 1.5	
8.	Shock resisting steel (S)					
	$S_1 \rightarrow$ C 0.5,	Cr 1.5,	W 2.5			
	$S_2 \rightarrow$ C 0.5,	Si 1,		Mo 0.5		
	$S_5 \rightarrow$ C 0.55,	Mn 0.8,	Si 2,	Mo 0.4		
	$S_7 \rightarrow$ C 0.5,	Cr 3.25,	Mo 1.4			

Stainless steel:-

- When 11.5% or more chromium is added to iron, a film of chromium oxide forms spontaneously on the surface exposed to air. The film acts as a barrier to retard further oxidation, rust or corrosion.
- As the steel cannot be stained easily, it is called stainless steel.
- All stainless steel can be grouped into 3 classes;
    1. Austenitic
    2. Ferritic
    3. Martensitic

Austenitic:-

Composition:-

C=0.03 to 0.25%　　Mn=2 to 10%

Si=1 to 2%　　　　　Cr=16 to 26%

Ni=3.5 to 22%

- They possess the highest corrosion resistance of all the stainless steel
- They possess the greatest strength and scale resistance at high temperature
- They are non-magnetic so that they can be easily identified with a magnet
- They may uses in Aircraft industry, Food processing, Dairy industry

Ferritic:-

Composition:-

C=0.08 to 0.2%　　　　　Si=1%

Mn=1 to 1.5%　　　　　Cr=11 to 27%

- It has low carbon to chromium ratio which eliminates the effects of thermal transformation and prevents hardening by heat treatment
- These steels are magnetic and good ductile
- These steels developed their maximum softness, ductility and corrosion resistance in the annealed condition
- These are uses in Lining for petroleum industry, Interior decorative work, Oil burner parts

Martensitic:-

Composition:-

C=0.15 to 1.2%　　　　　Si=1%

Mn=1%　　　　　Cr=15 to 18%

- Because of higher carbon to chromium ratio, these are the only types hardenable by heat treatment
- These steel are magnetic and possess the best thermal conductivity of the stainless types
- Hardness, ductility and ability to hold an edge are characteristic of martensitic steel
- These type of steel uses in pumps and valve parts, Turbine bucket

Tool steel: Effect of various alloying elements

Carbon: Carbon content in steel affects

- Hardness
- Tensile strength
- Machinability
- Melting point.

✓**Nickel:** Nickel

- Increases toughness and resistance to impact
- Lessens distortion in quenching
- Lowers the critical temperatures of steel and widens the range of successful heat treatment

- Strengthens steels
- Renders high-chromium iron alloys austenitic
- Does not unite with carbon.

✓**Chromium:** Chromium

- Joins with carbon to form chromium carbide, thus adds to depth hardenability with unproved resistance to abrasion and wear,

Silicon: Silicon

- Improves oxidation resistance
- Strengthens low alloy steels
- Acts as a deoxidizer.

Titanium: Titanium

- Prevents localized depletion of chromium in stainless steels during long heating
- Prevents formation of austenite in high chromium steels
- Reduces martensitic hardness and hardenability in medium chromium steels.

✓**Molybdenum:** Molybdenum

- Promotes hardenability of steel
- Makes steel fine grained
- Makes steel unusually tough at various hardness levels
- Counteracts tendency towards temper brittleness
- Raises tensile and creep strength at high temperatures
- Enhances corrosion resistance in stainless steels
- Forms abrasion resisting particles.

✓**Vanadium:** Vanadium

- Promotes fine grains in steel
- Increases hardenability (when dissolved)
- Imparts strength and toughness to heat-treated steel
- Causes marked secondary hardening.

Tungsten: Tungsten

- Increases hardness (and also red-hardness)
- Promotes fine grain
- Resists heat
- Promotes strength at elevated temperatures.

✓**Manganese:** Manganese

- Contributes markedly to strength and hardness (but to a lesser degree than carbon)
- Counteracts brittleness from sulphur
- Lowers both ductility and weldability if it is present in high percentage with high carbon content in steel.

Copper: Copper (0.2 to 0.5%) added to steel
- Increases resistance to atmospheric corrosion
- Acts as a strengthening agent.

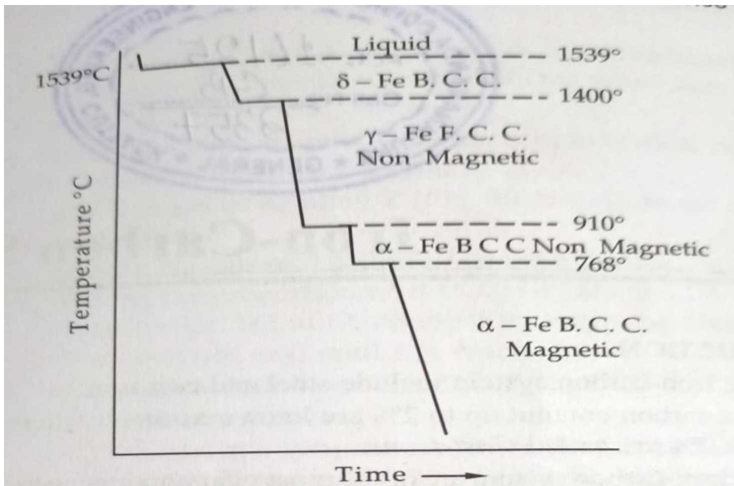
Boron: Boron
- Increases hardenability or depth to which steel will harden when quenched.

Aluminium: Aluminium
- Acts as a deoxidizer
- Produces fine austenitic grain size
- If present in an amount of about 1%, it helps promoting nitriding.

Cobalt: Cobalt
- Contributes to red-hardness by hardening ferrite
- Improves mechanical properties such as tensile strengths, fatigue strength and hardness
- Refines the graphite and pearlite
- Is a mild stabilizer of carbides
- Improves heat resistance
- Retards the transformation of austenite and thus increases hardenability and freedom from cracking and distortion.

Vanadium: Vanadium (0.15 to 0.5%)
- Is a powerful carbide former
- Stabilizes cementite and improves the structure of the chill.

- Alloys of Iron-Carbon system include steel and cast iron
- Alloys with a carbon content up to 2% are known as steels whereas those having carbon above 2% are called cast irons
- The iron carbon system provides the most prominent example of heat treatment and property alteration based on polymorphic transformation and eutectoid decomposition
- The primary constituent of iron carbon system is the metal iron



- Iron is a relatively soft and ductile metal
- Iron has a melting point of 1539°C
- Iron is a allotropic metal, which means that it exists in more than one type of lattice structure depending upon temperature
- In normal room temperature state, iron is B.C.C. in lattice arrangement, whereas at 908°C it changes to F.C.C. and then at 1403°C back to B.C.C.
- One another change occurs at about 770°C (called the curie point) at which the room temperature magnetic property of iron disappear and becomes non magnetic
- Iron is molten above 1539°C. It solidifies in the B.C.C. Delta form
- On further cooling at 1400°C, a phase change occurs and it take Gamma F.C.C. nonmagnetic form
- On further cooling at 910°C another phase change occurs and it change to Alpha B.C.C nonmagnetic
- Finally at 768°C it again change to magnetic Alpha B.C.C.

Micro-Constituents of Iron and Steel

- When steel is heated above the austenitic temperature and is allowed to cool under different conditions, the austenite in steel transforms into a variety of micro-constituents
- Various micro-constituents are:-
    - Austenite
        - Austenite is the solid solution of carbon and other alloying elements in Gamma iron

- Austenite can dissolved maximum 2% carbon at 2066°F
- It has tensile strength of 10500 Kg/cm^2
- It is non-magnetic and soft

- Ferrite
  - The maximum solubility is 0.025% carbon at 1333°F and it dissolves only 0.008% carbon at room temperature
  - It is the softest structure that appears on the Fe-C equilibrium diagram
  - Tensile strength is $2800kg/cm^2$

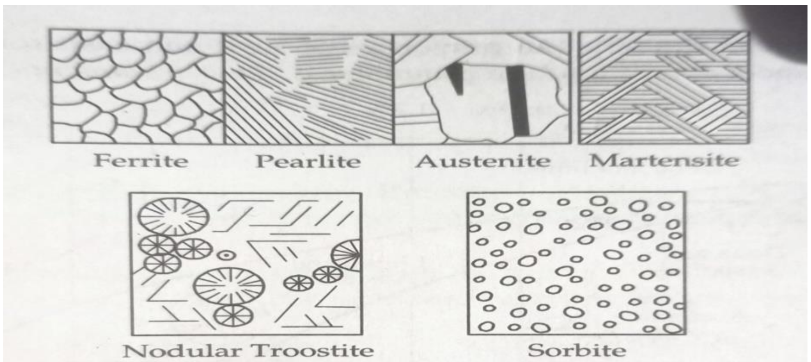


Fig. 40.3

- Cementite
  - It contain 6.67% of carbon by weight

        - It is the hardest structure in Fe-C equilibrium diagram. It's crystal structure is orthorhombic
        - Tensile strength is 350 kg/cm^2
    - Ledeburite
        - Ledeburite is the eutectic mixture of austenite and cementite
        - It contains 4.3% carbon
        - It is formed at about 1130^o C
    - Pearlite
        - Pearlite is an eutectoid mixture generate by austenite decomposition
        - It contains 0.8% carbon
        - It formed at 723^o C
    - Bainite
        - Bainite is produced by Aiistempering
        - It formed below the temperature of pearlite and above the temperature of martensite
        - If bainite is formed in the upper part of the temperature range it's appearance is feathery and it is called Feathery Bainite
        - If it is formed in lower part of the temperature range it's known as Acicular Bainite
    - Martensite
        - Martensite is an interstitial supersaturated solid solution of carbon in Alpha iron and has a body centered tetragonal lattice
        - Martensite possess an acicular or needle-like structure
    - Troostite
        - Troostite is a mixture of ferrite and cementite
        - It is produced on tempering mastensite below approximately 450^{o}C
    - Sorbite
        - It is the microstructure consisting of ferrite and finely divided cementite
        - It produced on tempering martensite above approximately 450^{o}C

Iron-Carbon Diagram

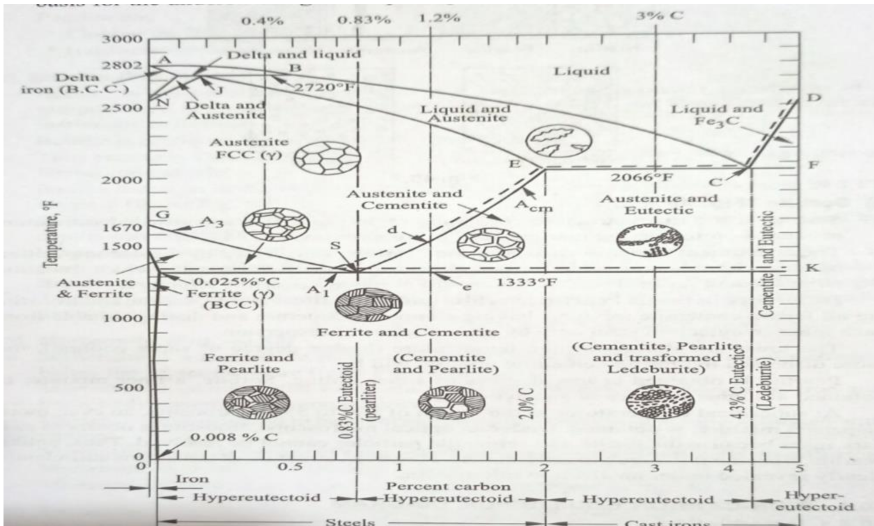


Fig. 40.4 Iron carbon equilibrium diagram

- Iron-Carbon diagram indicates the phase changes that occur during heating and cooling and the nature and amount of the structural component that exist at any temperature
- It establish a correlation between the microstructure and properties of steel and cast iron and provides a basis for the understanding of the principles of heat treatment
- This diagram has a peritectic point “J” , an eutectoid point “S” , eutectic point “C”
- Peritectic equation
    - Delta+ Liquid = Austensite
- Eutectic equation
    - Liqiud = Austenite + Cementite
- Eutectoid equation
    - Solid = Ferrite + Cementite

Introduction:

- A crystal is a solid composed of atoms, ions, or molecules arranged in a pattern which is repetitive in three dimensions.
- In an ideal crystal the atomic arrangement is perfectly regular and continuous throughout. An ideal crystal is perfect.
- But real crystals are as in cast or welded objects are never perfect; lattice distortion and various imperfections, irregularities or defects are generally present in them.
- All defects and imperfections in crystals can be conveniently classed under four main divisions, namely:
    - Point Defects
        - Vacancies
        - Interstitialcies
        - Impurities
        - Electronic defects
    - Line Defects
        - Edge dislocation
        - Screw dislocation
    - Surface Defects
        - Grain boundaries
        - Tilt boundaries
        - Twin boundaries
    - Volume Defects

Point Defects:

- In a crystal lattice, point defect is one which is completely local in its effect, e.g. a vacant lattice site
- The number of defects at equilibrium at a certain temperature can be determined from equation

$$n_d = Ne^{-E_d/kT}$$

where, n_d is the number of defects.
N is the total number of atomic sites per cubic metre or per mole.
E_d is the energy of activation necessary to form the defect.
k is the Boltzmann constant, and
T is the absolute temperature.
The possible point defects have been explained as under:

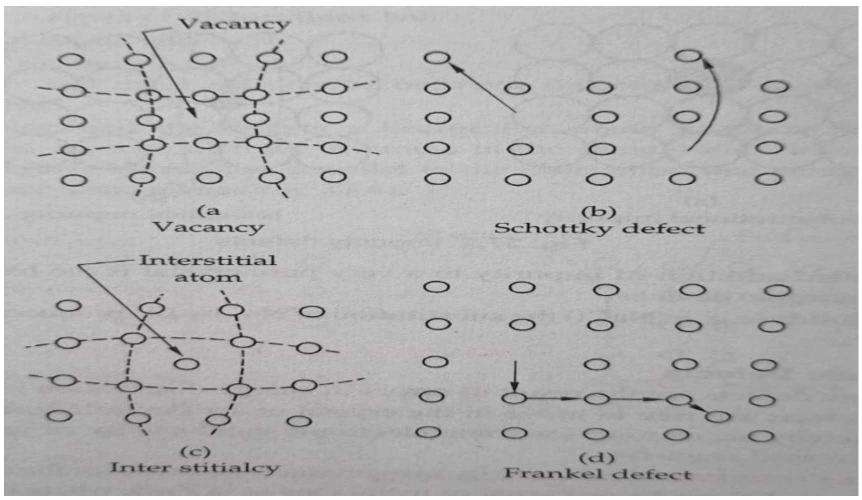
Vacancies:

- A vacancy implies an unoccupied atom position within a crystal lattice. In other word, vacancies are simply empty atom sites.

- Vacancies may occur as a result of imperfect packing during the original crystallization or they may arise from thermal vibrations of atoms at elevated temperatures
- Schottky defect is closely related to vacancies an is formed when an atom or an ion is removed from a normal lattice site and replaced in an average position on the surface of the crystal

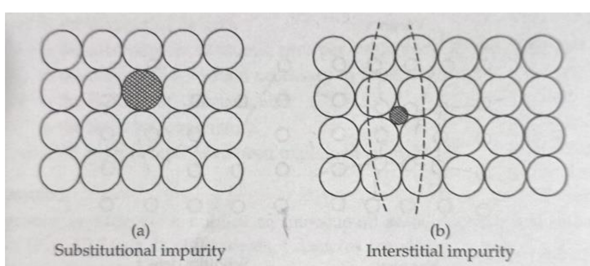
Interstitialcies:

- An interstitial defect arises when an atom occupied a definite petition in the lattice that is not normally occupied in the perfect lattice
- The interstitial atom maybe either a normal atom or a foreign atom
- Frankel defect closely related to interstitialcies. An displaced from the lattice into an interstitial site is called a Frankel defect



Impurities:

- Impurities give rise to compositional defects
- Foreign atoms generally have atomic radii and electronic structure differing from those of the host atoms and therefore act as center of distortion
- Impurity atoms are introduced into crystal structure as a substitutional or interstitial atoms



Line Defects:

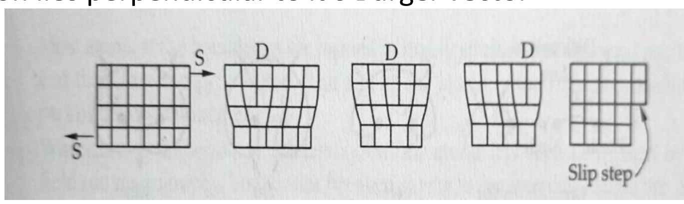
- The most important 2 dimensional defect is dislocation
- A dislocation may be defined as a disturbed region between two substantially perfect parts of a

crystal

- Two type of line defects are Edge dislocation and Screw dislocation
- The main difference between them is that In edge dislocation the Burger's vector lies in same plane in right angle whereas in screw dislocation the Burger's vector lies parallel in same plane

Edge Dislocation:

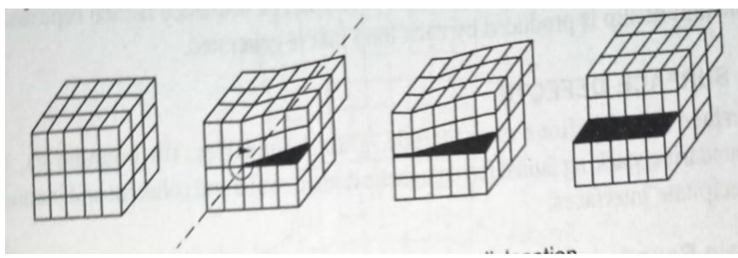
- An edge dislocation lies perpendicular to it's Burger vector



- Edge dislocation is particularly useful in explaining slip in plastic flow during mechanical working

Screw Dislocation:

- A screw dislocation lies parallel to its Burger's vector



- The force required to form and move a screw dislocation, although probably somewhat greater than those required to initiate an edge dislocation, are markedly less than those required to exceed the elastic limit of a perfect crystal
- Dislocation arises in crystals as a result of
  - Growth accident
  - Thermal stress
  - External stress causing plastic flow
  - Phase transformation
  - Segregation of solute atoms causing mismatch

Definition:-

- Heat treatment may be define as an combination of operation involving heating and cooling of a metal/alloy in solid state to obtain desirable condition(i.e. relieved stresses) and properties (i.e. better machinability, improved ductility, homogeneous structure etc)

Classification of heat-treatment processes:-

1. Annealing
    a. Stress-relief annealing
    b. Process annealing
    c. Spheroidising
    d. Full annealing
2. Normalizing
3. Hardening
4. Tempering
5. Martempering
6. Austempering
7. Maraging

Purpose of heat treatment:-

1. Cause relief of internal stresses developed during cold working, welding, casting, forging etc
2. Harden and strengthen metals
3. Improve machinability
4. Change grain size
5. Soften metal for further working as in wire drawing or cold rolling
6. Improve ductility and toughness
7. Increase heat, wear and corrosion resistance of material
8. Improve electrical and magnetic properties
9. Homogenise the structure; to remove coring or segregation
10. Spheroidize tiny particle such as those of Fe_2C in steel by diffusion

Annealing:-

- Annealing is the process of heating a metal which is in a metastable state, to a temperature which will remove the instability or distortion and then cooling is so that the room temperature structure is stable and strain free

Purpose:-

1. Including a completely stable structure

2. Refining and homogenizing the structure
3. Reducing hardness
4. Improving machinability
5. Improving cold working, characteristics for facilitating further cold work
6. Producing desired microstructure
7. Removing residual stresses
8. Removing gases
9. Improving mechanical, physical, electrical and magnetic properties

- In case of ferrous alloy annealing known as full annealing and in case of non-ferrous alloy annealing known as to soften the alloy
- If any process of annealing has a sole purpose to reduce stress, then it known as stress relief

Stress Relief:-

- It relieves stresses produced by casting, quenching, machining, cold working, welding
- Stress relief is often desirable when a casting is liable to change dimensions to a harmful degree during machining or use

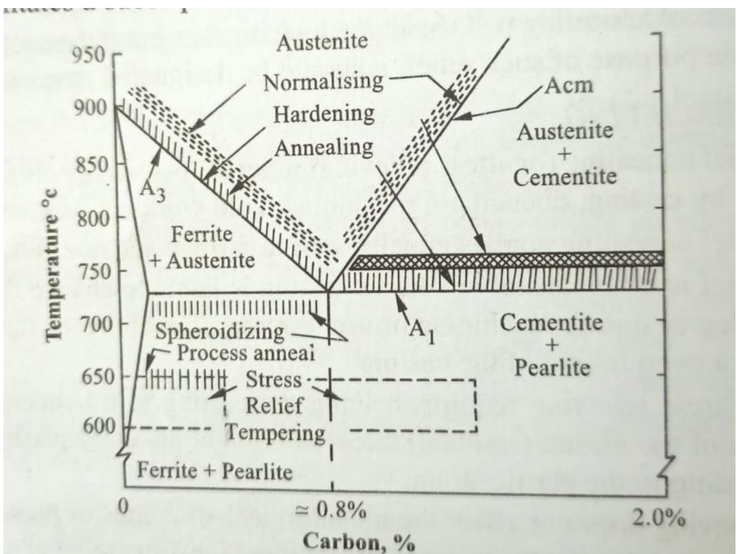


Fig. 43.1 Heat treating temperatures for carbon steels

Normalizing:-

- Normalizing consists in heating steel to about 40-50ºC above it's upper critical temperature and if necessary holding it at that temperature for a short time and then cooling in still air at room temperature
- Normalizing produces microstructures consisting of ferrite and pearlite for hypoeutectoid steel

Purpose:-

1. Produces a uniform structure

2. Refines the grain size of steel, which may have been unduly coarsened at the forging or rolling temperature
3. May achieve the required strength and ductility in a steel that is too soft and ductile for machining
4. Reduces internal stresses
5. Improves structures in welds
6. Produces a harder and stronger steel than full annealing
7. Eliminates the carbide network at the grain boundaries of hypereutectoid steel

Hardening:-

- Hardening is that heat treatment of steel which increase it's hardness by quenching
- The hardening of steel requires the formation of martensite
- In steel, the maximum % increase of hardness by quenching is obtained if they contain between 0.35 and 0.6% carbon

Purpose

1. Hardens steel to resist wear
2. Enable steel to cut other metals
3. Improves strength, toughness and ductility
4. Develops best combination of strength and notch-ductility

Tempering:-

- Tempering produces structure martensite and retained austenite
- It requires
  - Heating hardened steel below the lower critical temperature
  - Holding it at that temperature for 3 to 5 minutes for each mm of thickness
  - Cooling the steel either rapidly or slowly except in case of steels susceptible to temper brittleness

Purpose:-

1. Relieve residual stresses
2. Improve ductility
3. Improve toughness
4. Reduce hardness
5. Increase % elongation

Surface Hardening:-

- Numerous industrial applications such as cams, gears require a hard wear resistant surface called the case and a relatively soft, tough and shock resistant inside, called the core

- Both these requirements may be met by employing a low carbon steel with suitable core properties and then adding Carbon, Nitrogen or both to the surface of the steel part in order to provide a hardened case of a definite depth
- These treatments are known as case hardening

Purpose

1. Improve corrosion, heat or wear resistant
2. Rebuild worn or undersized parts
3. Serve as an ornamental finish
4. Lengthen the useful life of a part manufactured from a low cost material having surface characteristics unsuited for a given installation

Carburizing:-

- Carburizing is a method of intruding, carbon into solid iron-base alloys such as low carbon steels in order to produce a hard case
- Low carbon steel is heated at 870 925^{o}C in contact with gaseous, solid or liquid carbon containing substances for several hours

Characteristics

1. Case depth is about 0.05 inch
2. Hardness after heat treatment is Re 65
3. Carburizing causes negligible change in dimensions
4. Distortion may occur during heat treatment

- There are three general methods of carburizing, depending upon the form of the carburizing medium, namely
    - Pack Carburizing
    - Gas Carburizing
    - Liquid Carburizing

Nitriding:-

- Nitriding accompanies the introduction of nitrogen into the surface of certain types of steels by heating it and holding it at a suitable temperature in contact with partially dissociated ammonia or other suitable medium

Characteristics

1. Case depth is about 0.381mm
2. Extreme hardness
3. Growth of 0.025-0.050mm occurs during nitriding
4. Case has improved corrosion resistance

Advantages	Disadvantages
Very high surface hardness of the order of 1150 VPN may be obtained	Long cycle times (40 to 100 hrs)
Since nitride parts are not quenched, this minimizes distortion	The brittle case
Good fatigue resistance	Only special alloy steels can be satisfactorily treated
Good corrosion and wear resistance	High cost of the nitriding process
Whereas in a carburized part, hardness begins to fall at about 200°C, a nitride part retains hardness up to 500°C	Technical control required
No machining is required after nitriding	If a nitride component is accidentally overheated, the surface hardness will be lost completely and the component must be nitride again
Some complex parts which are not carburized satisfactorily, can be nitride without difficulty	
The process is economical when large number of parts are to be treated	

Effect of heat treatment on properties of steel:-

- When steel with a medium to high carbon content is subjected to heat treatment, it can be hardened
- Annealing changes a metal's properties by altering and realigning the grain structure using heat, making the metal softer and more ductile
- When heating the metal to a point higher than that of the annealing process and allowing it to air cool, the grain structure stresses can be removed. Normalizing steel gives the structure more stability and the metal can be prepared for other processes
- Steel can be made more malleable by “tempering” it. This involves heating the metal to a predetermined temperature which depends on the level of malleability required
- Quenching refers to the rapid cooling of hot metal using oil or water. This sets the steel, making it hard but brittle

Hardenability of steel:-

- The hardenability is defined as the ability of the steel to partially transform from austenite to martensite at a given depth below the end surface, when cooled under a given condition
- In the absence of adequate hardenability of steel even the most drastic quench is incapable of producing martensite in a steel bar of a given size.

INTRODUCTION:

- Aluminium is a silvery white metal.
- It is a light metal, with a density about a third that of a steel.
- Aluminium is a very good conductor of electricity
- It has a higher resistance to corrosion than many other metals.
- It is also a good conductor of heat
- It is very ductile
- It is non-magnetic
- Melting point of aluminium is 650^0C

ALUMINIUM ALLOYS:

- Although pure aluminium is not particularly strong, it forms high strength alloys in conjunction with other metals such as Cu, Cr, Ni, Zn, Mo, Si and Mg
- They are malleable and ductile
- Aluminium and its alloys can be
  - Cast
  - Forged
  - Welded
  - Extruded
  - Rolled

Use of Aluminium Alloy:

- Transportation industry
- Overhead conductors and heat exchanger parts
- Food industry
- Architectural
- As heavy duty structures such as dragline booms, travelling cranes, hoists, conveyor supports, bridges etc

CLASSIFICATION:

- Aluminium alloys can be classified as follows
  - Wrought alloys
    - 4.4 Cu, 0.6 Mn, 1.5 Mg, balance Al
    - 0.12 Cu, 1.2 Mn, balance Al
    - 2.5 Mg, 0.25 Cr, balance Al
    - 0.6 Si, 0.27 Cu, 1.0 Mg, 0.2 Cr, balance Al
  - Cast alloys
    - 12 Si, balance Al

        - 4 Cu, 3 Si, rest Al
        - 4.5 Cu, 5.5 Si, rest Al
        - 3.8 Mg, 1.8 Zn, rest Al
    - Heat treatable alloys
        - 3.9-5.0 Cu, 0.2-0.8 Mg,0.5-1.0 Si, 0.3-1.2 Mn, rest Al
        - 0.5-1.2 Mg, 0.7-1.3 Si, 0.4-1.0 Mn, rest Al
        - 0.4-0.9 Mg, 0.3-0.7 Si, rest Al
- Non heat treatable alloys
    - 0.8-1.5 Mn, rest Al
    - 1.7-2.4 Mg, rest Al
    - 10-13 Si, rest Al
    - 5.0-5.5 Mg, 0.6-1.0 Mn, 0.05-0.2 Cr, rest Al

Duralumin:

- It contains:
    - Cu 3.5-4.5 %
    - Mn 0.4-0.7 %
    - Mg 0.4-0.7 %
    - Al Balance
- It possesses:
    - High machinability
    - High tensile strength after heat treatment
    - Strength as high as steel but has only about one third of its weight
    - Excellent casting and forging properties
- Uses of Duralumin:
    - Aircraft and automobile parts
    - As bar, sheet, tubes and rivets
    - As light structure and extruded section

Y Alloy:

- Y alloy is a nickel containing aluminium alloy.
- It contained:
    - Cu 4.0 %
    - Mn 1.5 %
    - Ni 2.0 %
    - Al Balance
- Uses of Y alloy:
    - Piston
    - Forging components which require high strength at very high temperature

COPPER ALLOY:

- Copper possesses following properties
  - Excellent resistance to corrosion
  - Non-magnetic properties
  - It is ductile and malleable
  - High thermal and electrical conductivity
  - High resistance to fatigue
  - Very good machinability
- Copper used for following
  - Electrical parts
  - Heat exchanger
  - Household utensils
- Copper alloys may be classified as
  - High copper alloy
  - Brass
  - Bronze
  - Copper-Nickel
  - Leaded copper
  - Special alloy
  - Copper-Nickel-Zinc

BRASS:

- Brass contain zinc as principle alloying element
- It subdivided into three groups
  - Cu-Zn
  - Cu-Pb-Zn
  - Cu-Zn-Sn
- Zinc in the brass increase ductility along with strength
- Brass possesses greater strength than copper, however, it has a Lower thermal and electrical conductivity

BRONZE:

- Bronze is basically an alloy of copper and tin
- It possesses superior mechanical properties and corrosion resistance than brass
- It is comparatively hard and it resist surface wear
- These are subdivided into three group
  - Phosphor Bronze
  - Aluminium Bronze
  - Silicon Bronze

PHOSPHOR BRONZE:

- The most important copper-tin alloys are those which have been deoxidized with phosphorus during the refining process and hence are known as phosphor bronze
- Existence of phosphorus increase hardness and strength of the alloy, in exchange of ductility
- A phosphor bronze containing approximately 4 % each of tin, lead and zinc has excellent free cutting characteristics
- Standard Phosphor bronze contain
  - Cu 90%
  - Sn 10%
  - P 0.5%
- In sand cast condition it has a tensile strength of 220-280 N/mm^2 and %elongation 3-8%
- In general phosphor bronze
  - Has high strength and toughness
  - Is resistance to corrosion
  - Has good load bearing capacity
  - Has low coefficient of friction
- Phosphor bronze is used for
  - Bearing application
  - Making pump parts, lining, springs, diaphragms, gears, clutch discs, bellows

LEAD ALLOY:

- Lead alloy containing 8% to 10% Pb are used as bearing, cable sheaths, accumulation plates
- Lead glass refracts light strongly
- Bearing metals are lead and tin alloys for friction bearings. When antimony is added, they are known as babbit metals
- Lead-tin alloy containing 10 to 25% tin and rest lead is used as metallic coating for sheet iron for manufacturing containers

NICKEL ALLOYS:

- Various nickel alloys are:
  - Nickel-iron alloy
  - Nickel-copper alloy
  - Nickel-chromium alloy
  - Nickel-molybdenum alloy
  - Super alloy
- Invar is one of the nickel-iron alloy containing 40-50% nickel is characterized by an extremely low coefficient of thermal expansion
- Monel which is a nickel-copper alloy has a brighter appearance than nickel, is stronger and tougher than mild steel

- Super alloys are atleast five times as strong as steel. They withstand enormous strain and exhibit remarkable resistance to fatigue

ZINC ALLOY:

- It has slightly low melting point
- It has good resistance to corrosion
- It is soluble in copper
- It inherent ductility and malleability

P-22 AND P-91:

- P-22 contain:
    - C 0.05-0.15%
    - Mn 0.3-0.6%
    - P 0.025%
    - S 0.025%
    - Si 0.5%
    - Cr 1.9-2.6%
    - Mo 0.8-1%
- P-22 has
    - Yield strength 30ksi
    - Tensile strength 60ksi
    - Elongation 30%
- P-91 contain:
    - C 0.08-0.12%
    - Mn 0.3-0.6%
    - P 0.02%
    - S 0.01%
    - Si 0.2-0.5%
    - Cr 8-9%
    - Mo 0.85-1%
- P-91 has
    - Yield strength 60ksi
    - Tensile strength 85ksi
    - Elongation 20%

DUPLEX AND SUPER DUPLEX STAINLESS STEEL:

Duplex stainless steel	Super duplex stainless steel
It has around 22% chromium	It has around 25% chromium
It has pitting resistance equivalent number of 22 to 45	It has pitting resistance equivalent number of 38 to 45

INTRODUCTION:

- Bearing support moving parts, such as shafts and spindles, of a machine or mechanism
- It may be classified as
  - Rolling contact bearing
  - Plain bearing
- Rolling contact bearings are almost invariable made of steel that can be hardened after machining

PROPERTIES:

- A bearing material should:
  - Possess low coefficient of friction
  - Provide hard, wear resistant surface with tough core
  - Have high compressive and fatigue strength
  - Be able to bear shocks and vibration
  - Possess high thermal conductivity
  - Possess resistance to corrosion
  - Possess anti-seizure characteristics
  - Have be cheap and easily available

TYPES OF BEARING MATERIAL:

- They are
  - Copper based alloy
  - Lead based alloy
  - Tin based alloy
  - Cadmium based alloy

Copper based alloy:

- Bronze is one of the oldest known bearing material
- Typical composition of bronze bearing are
  - Cu 80%
  - Sn 10%
  - Pb 10%
- Bronze
  - Is easily worked
  - Has good corrosion resistance
  - Is reasonably hard

- Copper based bearing used in machine and engine industry for bearing bushes made from thin walled drawn tube
- These are employed for making bearing required to resist heavier pressures such as in railway

Lead based alloy:

- Lead based alloy contain 80% of lead and 1-10% of tin
- Composition:
    - Pb 75%
    - Sb 15%
    - Sn 10%
- Lead based alloy are softer and brittle than the tin based alloy
- It is cheaper
- It possess good corrosion resistance and good conformability to journal
- Lead based alloys are suitable for light and medium loads
- It is used in rail roads and speed

Tin based alloy:

- Tin based alloy contain 80% of tin and little or no copper
- Composition:
    - Sn 88%
    - Sb 8%
    - Cu 4%
- Tin based alloys have low coefficient of friction as compared to copper based alloy
- These alloy possess good ability to embed dirt and very good seizure resistance
- Tin base alloys are preferred for higher loads and speed
- These are used in high speed engines, steam turbines

Cadmium based alloy:

- Composition:
    - Cd 95%
    - Ni 2%
    - Ag 1%
    - Cu 1.25%
    - Zn 0.75%
- These alloys are not popular because of high price
- These bearing possess greater compressive strength
- It also possess:
    - Low coefficient of friction
    - High fatigue strength
    - Low wear
    - Good seizure resistance

- High load carrying capacity
- Fair ability to embed dirt
- Poor corrosion resistance

- These alloys are tired in automobile sector and aircraft industry and good results were obtained

INTRODUCTION:

- Spring store mechanical energy. Therefore the spring material remains under high tension stress
- In ideal spring the deviation from the rest position is directly proportional to the load it carries, even for high loads. After the load is removed, no matter after a long time, the ideal spring returns to its original position

TYPES:

- These are some commonly used spring material:
    - Iron based spring material
    - Copper based spring material
    - Nickel based spring material
    - Special spring material

Iron based spring material:

- Steel is usually the best choice as spring material
- A good steel spring possesses high
    - Modulus of elasticity
    - Elastic limit
    - Fatigue strength
    - Creep strength
    - Notch toughness
- Steel is used for making
    - Helical spring
    - Plate spring
    - Leaf spring
    - Torsional spring
    - Cone spring
- Steel piano wire
    - Composition:
        - C 0.7-1.0%
        - Fe 98.5%
        - Mn 0.3-0.6%
    - Uses:
        - Small sized helical spring
- Cr-V spring steel
    - Composition:
        - C 0.5%

        - Mn 0.8-1.1%
        - Cr 0.2-0.9%
        - V 0.07-0.12%
        - Fe 97.8%
    - Uses:
        - Engine
        - Railway carriages
        - Automotive valves
- Stainless steel:
    - Composition:
        - Cr 18%
        - Ni 8%
        - C 0.1-0.2%
        - Fe 73.8%
    - Uses:
        - Valve springs in flow meters

Copper based spring material:

- They possess
    - High electrical conductivity
    - Good resistance to corrosion
    - Lack of magnetic properties
- Phosphor bronze:
    - Composition:
        - Cu 92%
        - Sn 8%
    - Uses:
        - High quality springs for switches, relays, contacts
- Brass:
    - Composition:
        - Cu 67%
        - Zn 33%
    - Uses:
        - Switches and contacts
- Nickel silver:
    - Composition:
        - Cu 56%
        - Ni 18%
        - Zn 25%
    - Uses:
        - Better switches and contacts than brass

Introduction:-

- A polymer is a large molecule or macromolecule which essentially is a combination of many smaller units of molecule
- Normally we can get two types of polymer such as naturally occurring polymers and synthetic organic polymer
- Characteristics:-
  - Low density
  - Good corrosion resistance
  - Low coefficient of friction
  - Poor tensile strength
  - Poor temperature resistance
  - Low mechanical resistance
  - Can be produced with close dimensional tolerance
  - Excellent surface finish can be obtained
- Classification:-
  - Thermoplasts
  - Thermosets

Thermoplast:-

- It soften when heated and harden when cooled
- So it can be remolded
- On molecular level, as the temperature is raised, secondary bonding forces are diminished so that the relative movement of adjacent chains is facilitated when a stress is applied
- Irreversible degradation results when the temperature of a molten thermoplastic polymer is raised to a point at which molecular vibrations become violent enough to break the primary covalent bonds
- Properties:-
  - Low melting point
  - Soft
  - Ductile
  - Economical
- Example:-
  - Polyvinyl chloride(plastic wall and floor tile)
  - Polystyrene(fluorescent light reflector)
  - Polymethyl methacrylate(plastic lences)

Thermoset:-

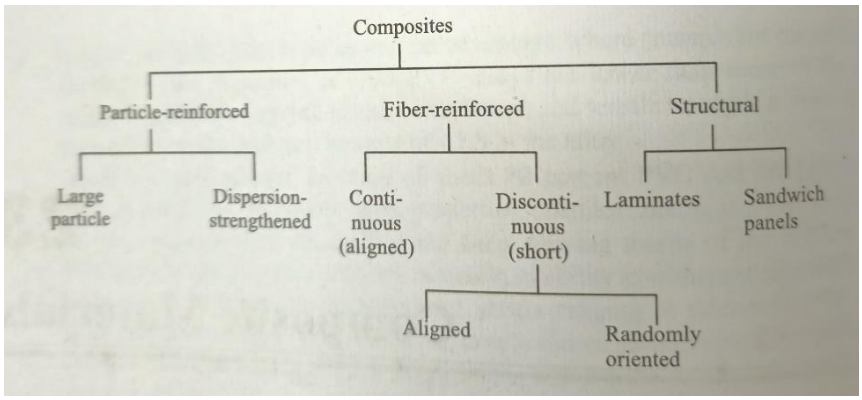
- It soft during their first heating and become permanently hard when cooled
- So it cannot be remolded
- If heated to excessive temperature, the polymer degradation takes place
- Properties:-
  - Harder
  - Brittle
  - Better dimensional stability
  - High temperature resistance
- Example:-
  - Bakelite
  - Vulcanized Rubber
  - Polyester

Elastomer:-

- An elastomer is a polymeric material that may experience large and reversible elastic deformation
- These are commonly known as rubber
- Characteristics:-
  - Non-crystalline
  - Non-conductor of electricity and heat
  - High resistance to chemical and corrosion
  - Low softening temperature
- Properties:-
  - Hardness
  - High Tensile strength
  - Low Tear resistance
  - High resilience
  - Resistance to abrasion
  - Resistance to friction
- Types of elastomer
  - Natural rubber
  - Styrene butadiene rubber
  - Chloroprene
  - Isobutylene-Isoprene
  - Isoprene
  - Polyacrylate
  - Nitrile butadiene
  - Polybutadiene

Composite:-

- Composite materials are produced by combining two dissimilar materials into a new material that may be better suited for a particular application than either of the original material alone
- Example:-fiberglass, reinforced plastic
- Classification:-



Particle reinforced composites:-

- The dispersed phase for particle reinforced composites is equiaxed

Large particle composites:-

- In this type of composite, particle interaction cannot be treated at atomic or molecular level
- Examples:-polymeric materials with fillers, concrete
- The particles should be approximately the same dimension in all directions and should be small and evenly distributed. So that the mechanical properties are enhanced with increasing particulate content
- Both elastomers and plastics are frequently reinforced with various particulate materials. Example :- Carbon black
- These type of composite contain enhanced tensile strength, toughness, tear and abrasion resistance

Dispersion strengthened composites:-

- In this type of composite, particle interaction treated at molecular level
- Examples:-thoria dispersed nickel and sintered aluminium powder
- These type of composites are very hard in nature

Fiber reinforced composites:-

- The most important composites are those in which the dispersed phase is in form of a fiber

- Basic characteristics of these composites are specific strength and specific modulus
- Some critical fiber length is necessary for effective strengthening and stiffening of the composite material

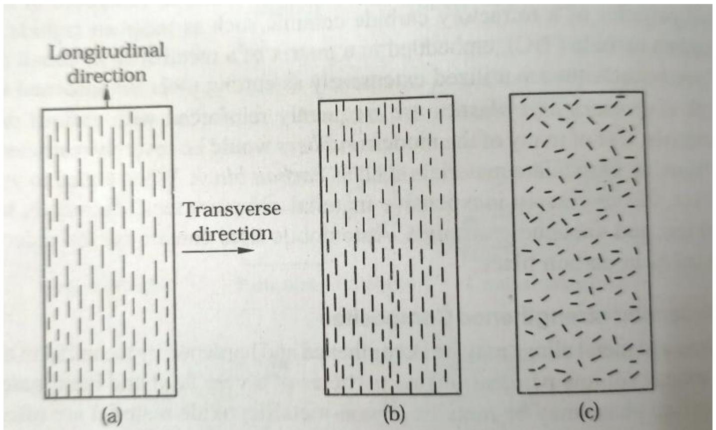
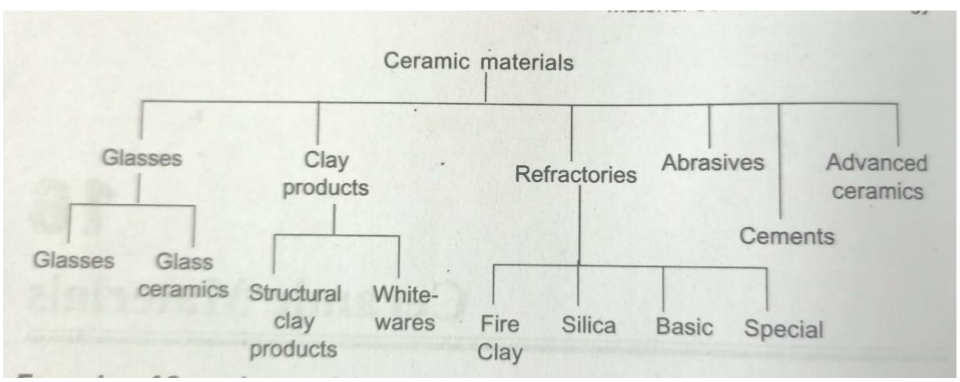


Fig. 23.2 Schematic representations of (*a*) continuous and aligned, (*b*) discontinuous and aligned; and (*c*) discontinuous and randomly oriented fiber-reinforced composites

Ceramics:-

- Ceramics are inorganic, non-metallic materials that are processed and used at high temperatures
- They are brittle materials that withstand compression but do not hold up well under tension
- They are abrasive resistant, heat resistant
- Ceramics are chemically inert
- Types of ceramics



- Uses:-
    - Brick and concrete saws
    - Used for sand paper
    - Used for cleaning aircraft engine parts
    - Used as a refractory material
    - Floor sanding machines

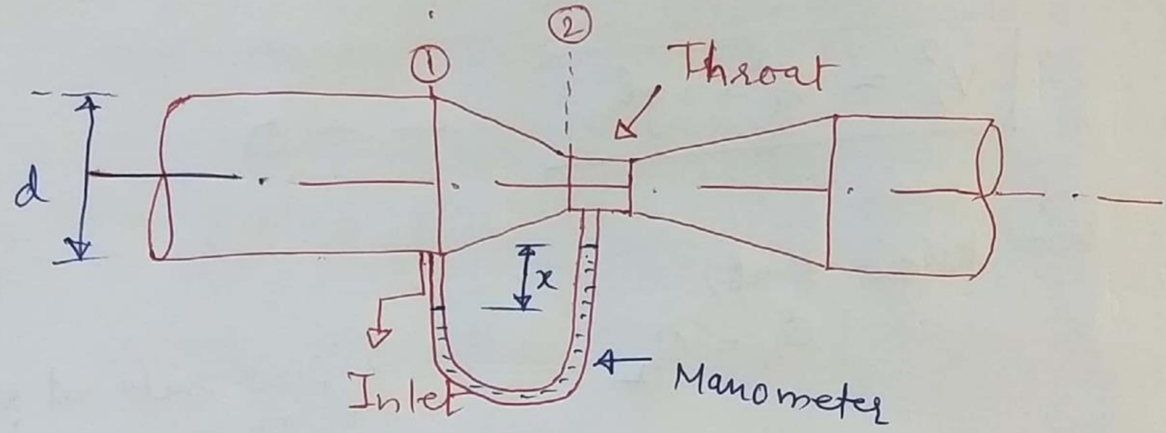
* Venturi meter :-

> It is a device used to measure the flow rate of the fluid flowing through a pipe.

> It can not be used in open channel.

> It consists of three parts as shown in figure.

ⓐ Converging part
ⓑ Throat
ⓒ Diverging part



> Manometer is used to measure pressure difference between section ① & ②.

> Divergent angle must be very small to avoid energy loss. (5° to 9°). and ~~throat~~ throat diameter shoube be between $d/3$ to $d/2$.

> Consider two sections ① & ②

> Let, P_1, V_1, a_1 are the pressure, velocity and area at section ①.

And P_2, V_2, a_2 are the corresponding values at section ②

On applying Bernoulli's ~~eq^n~~ equation,

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + \cancel{Z_1} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + \cancel{Z_2}$$

If pipe is horizontal
$Z_1 = Z_2$

$$\therefore \frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g}$$

$$\therefore h = \frac{V_2^2 - V_1^2}{2g}$$

$\left\{ \because \frac{P_1 - P_2}{\rho g} = h \right.$

$$\therefore \boxed{V_2^2 = V_1^2 + 2gh} \quad \text{---} (1)$$

We know that,

$$Q_1 = Q_2$$

{ flow rate at section (1) is equal to flow rate at section (2)

$$a_1 V_1 = a_2 V_2$$

$$V_1 = \frac{a_2 V_2}{a_1}$$

-- put it in eq^n (1)

$$\therefore V_2^2 = \frac{a_2^2 V_2^2}{a_1^2} + 2gh$$

$$\therefore V_2^2 \left(1 - \frac{a_2^2}{a_1^2}\right) = 2gh$$

$$\therefore V_2^2 = \frac{a_1^2 \times 2gh}{a_1^2 - a_2^2}$$

$$\therefore V_2 = a_1 \sqrt{\frac{2gh}{a_1^2 - a_2^2}} \quad \text{--- (11)}$$

$\therefore$ Flow rate $Q = a_2 V_2$ or $a_1 V_1$

$$\therefore Q_{th} = \frac{a_2 \times a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

Above eqn gives the theoretical value of flow rate.

Actual flow rate $Q_a = C_d \times Q_{th}$

Where C_d = Coefficient of discharge.

—x—

* Strain measurement :-

Strain gauge :-

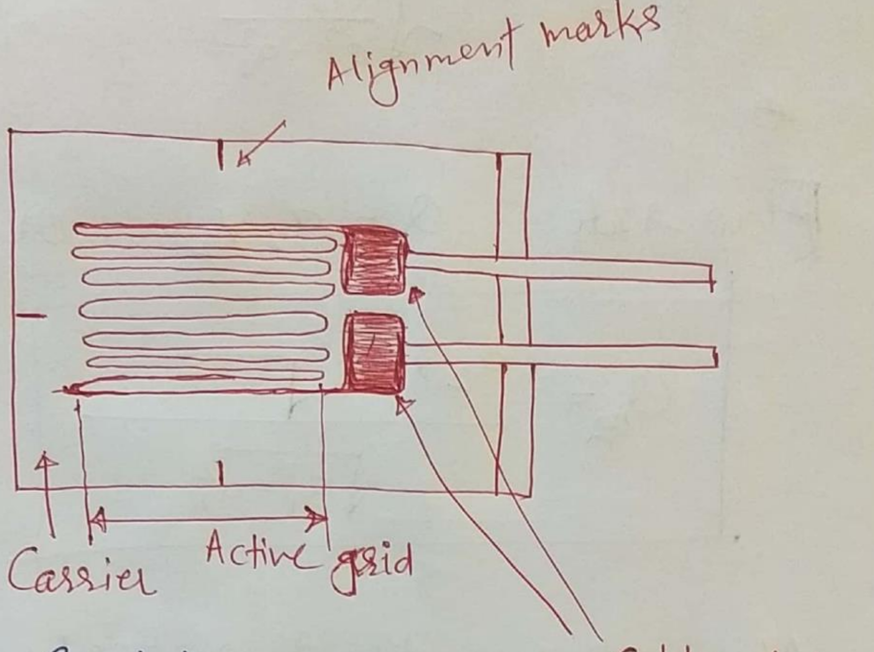


Fig. Bonded metallic strain gauge

> Most common device for strain measurement is strain gauge.

> Its electrical resistance varies in proportion to the amount of strain produced in the device.

> It consists of a very fine wire arranged in a grid pattern. It maximizes the amount of wire.

> The grid is bonded to a thin backing called as carrier which is attached directly to the ~~carrier~~. specimen whose strain is to be measured.

> Strain experienced by the specimen is directly transferred to the strain gauge.

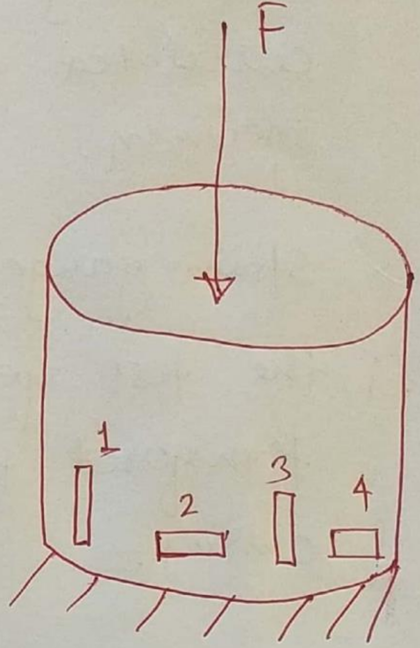
> Its electrical ~~r~~ resistance changes ~~p~~ ~~in~~ proportionally to the strain produced.
This change in electrical resistance is ~~corelated~~ correlated with the strain produced in the specimen.

> Strain gauge should be properly mounted on the test specimen so that strain is accurately transferred from specimen to grid through carrier.

———— x ————

* Force measurement :-

* Load Cell :-



Load cell with four strain gauges.

- Force can be measured easily from a load cell.
- In this device, an elastic member such as ~~ste stra~~ stainless steel is used in cylindrical ~~form~~. shape.
- Four strain gauges are mounted on it.
- Two strain gauges measure the longitudinal strain while two other measure transverse strain as shown in figure.
- The strain gauges measuring the similar strain are placed in opposite arms.
- Adjacent arms measure opposite strains (One tensile & other compressive).
- When force is applied on elastic member, longitudinal strain developed in the load cell would be compression in nature and is given by,

$$\varepsilon_1 = -\frac{F}{AE}$$

Where,
F ⇒ applied force
A ⇒ Cross section area
E = Young's modulus

This strain develops in strain gauge ① & ③.

while tensile strain produced in strain gauges ② & ④ would be,

$$\varepsilon_2 = -\frac{\nu F}{AE}$$

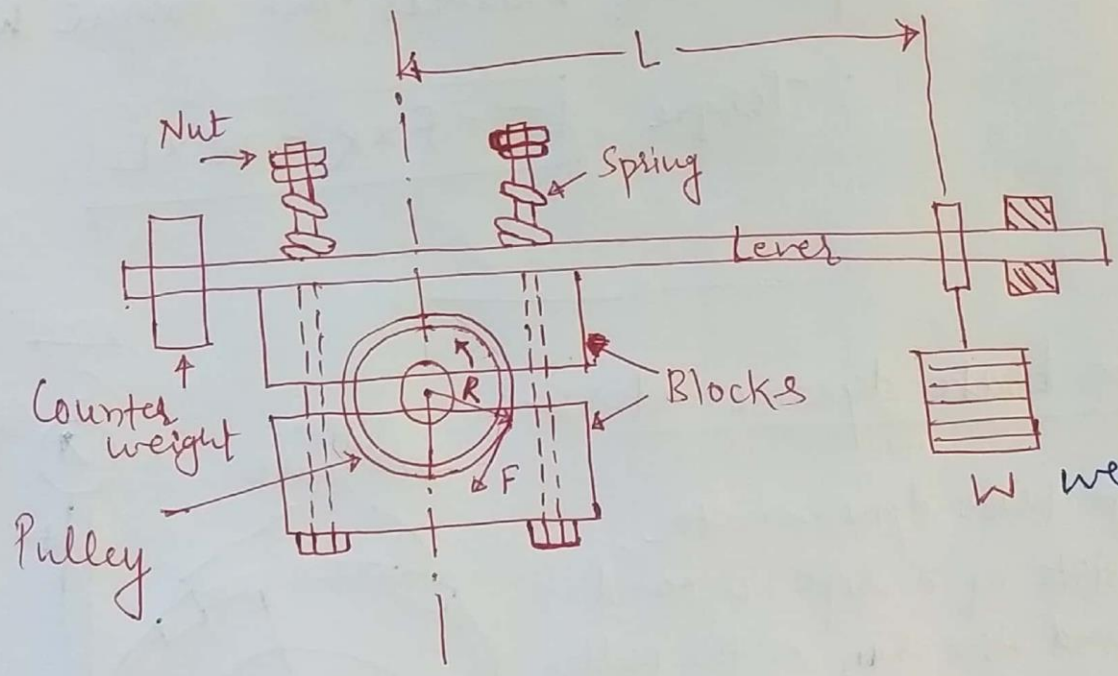
$\nu \Rightarrow$ Poisson's ratio.

—— x ——

* Torque measurement :—

> A torque is a vector product of force & radial distance that measures the ~~tendency~~ tendency of a force to rotate an object about ~~its~~ an axis.

① Prony Brake Dynamometer :—



> It consists of two wooden blocks placed around a pulley fixed to the shaft whose power or torque is to be measured.

> A helical spring is provided between nut and upper block to adjust the pressure on the pulley to control its speed.

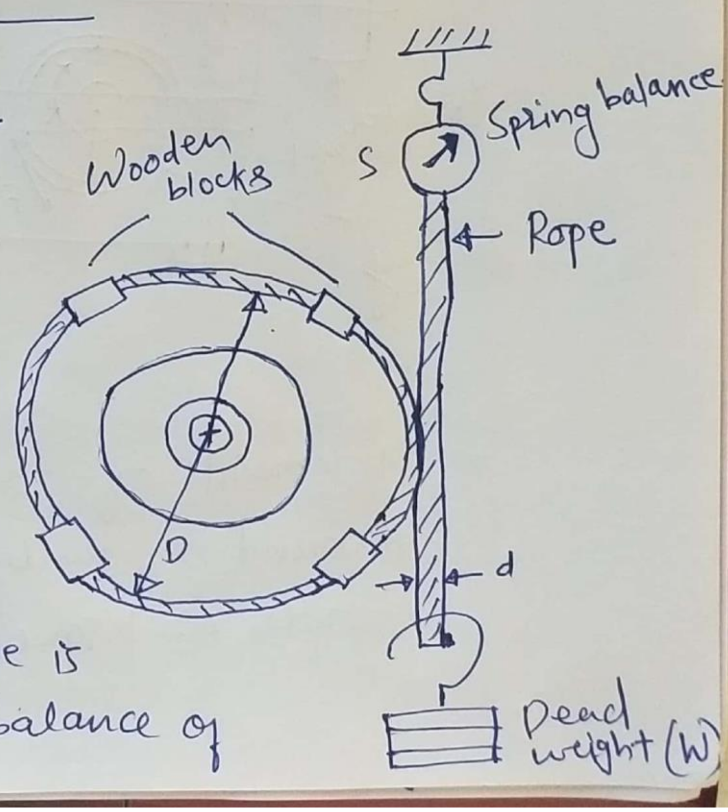
> The upper block has long lever attached to it and carries a weight W at its outer end.

> Prony brake develops mechanical friction on the periphery of a rotating pulley by means of ~~brake~~ blocks that are squeezed against the wheel by tightening the bolts until the friction torque F·R balances the torque W·L

∴ Torque , $T = F \times R = W \times L$

———x———

② **Rope brake dynamometer:-**



> Rope brake dynamometer consists of a rope wound round the rim of the pulley fixed to the shaft of the engine whose torque is to be measured.

> The upper end of the rope is attached with a spring balance of

stiffness S. ~~and for~~

> Lower end of the rope is attached with a load W as shown in figure.

> If the diameter of pulley is D and rope diameter is d then the torque can be measured as -

$$T = (W - S) \times \frac{D + d}{2}$$

—— x ——

Introduction to robotics :-

> Robot is any automatically operated machine that replaces human effort.

Robotics is the engineering discipline which deals with the design, construction and operation of robots.

* Anotomy of Robots :-

There are several classes of robots.
~~to assembly, painting, welding etc.~~
Application of robot is in industry for assembly, painting, welding etc.

Industrial robots consist of manipulators which are controlled by a microprocessor.

Subsystem of robots —

1. Actuators
2. Transmission system.
3. Power supplies and power storage system.
4. Sensors
5. Microprocessors and controllers.
6. Algorithms and softwares.

① Actuators:-

- Actuators are prime movers for providing force and motion.
- Advanced actuators are based on smart materials.

② Transmission system:-

- The transmission system used in robots to transmit power and motion consists of chains, belts, cables, pulleys, gears etc.

③ Power supplies:-

- Hydraulic and pneumatic power packs consists of ~~two~~ pumps or compressors to generate high pressure fluid flow.
- Electric motors, electronic devices consisting of transistors used as switches to rapidly switch on and off the supply in controlled manner.

④ Sensors and other electronics:-

- The sensors for feedback in robots consists of tachometers and ~~encoders~~ ~~on~~ potentiometer to sense motor motions.

It also consists of force sensor, acceleration sensors, ~~spee~~ optical systems, special cameras etc.

⑤ Electronics :-

> It consists of electronic circuits, motor controllers, analog to digital converters and digital to analog converters and so on to handle sensors and vision systems.

⑥ Softwares :-

> Softwares used consists of several levels. Motor control software consists of algorithms which help the servo to move smoothly.

> At next level there is a software to plan the trajectory of the end effector.
The output of sensor is also to be interpreted and decisions made.

> At the highest level there is software which accepts commands from the user of the robot and translate it into appropriate actions. ~~at~~

———x———.