MECHANICAL ENGINEERING SCIENCE (UE24ME141A)

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MECHANICAL ENGINEERING SCIENCE

Unit1

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Chapter 1 – Basic Principles of Thermodynamics and Fluid Energy

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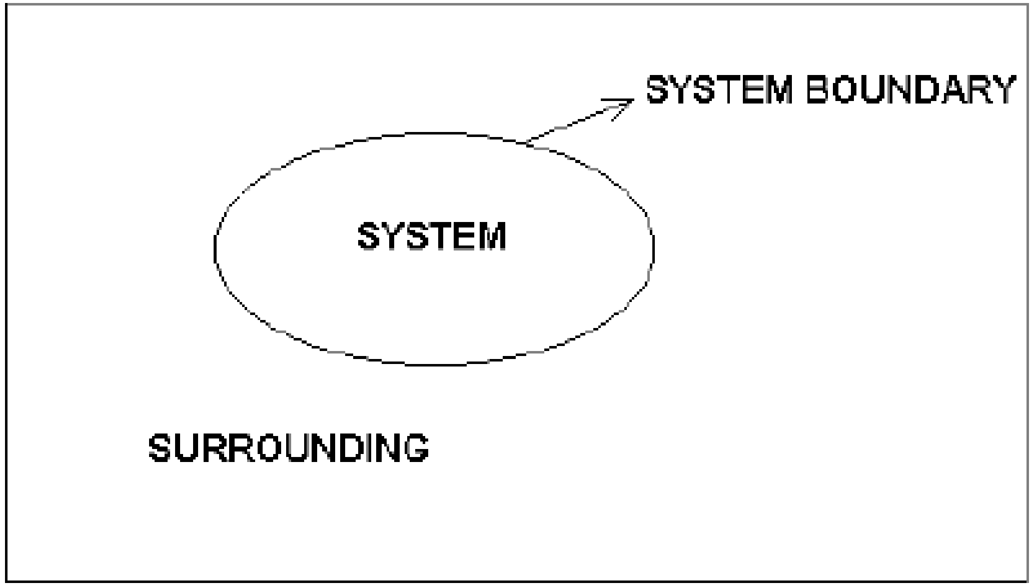
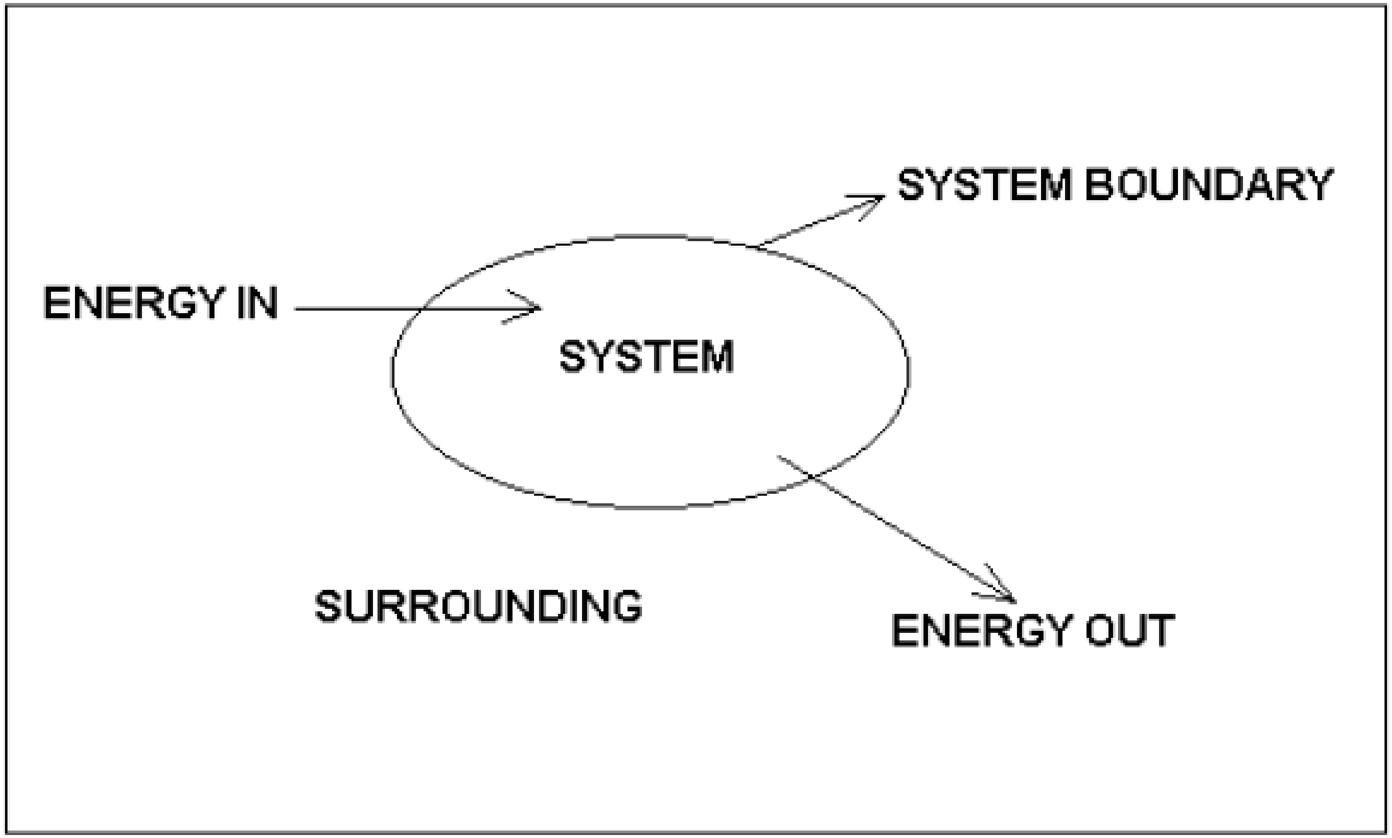
Courtesy: Dr. V Krishna, Department of Mechanical Engineering

System, Boundary and Surroundings

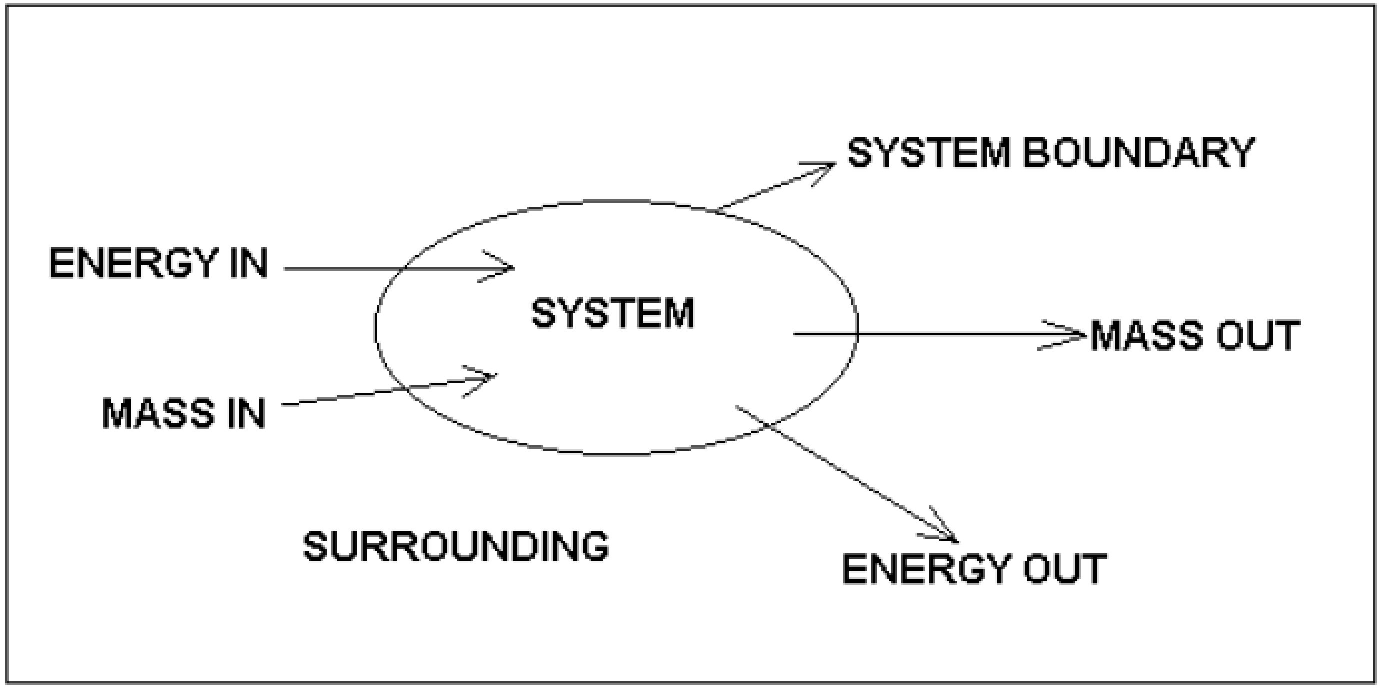
1. Thermodynamic System
2. Surroundings
3. Boundary
4. Universe



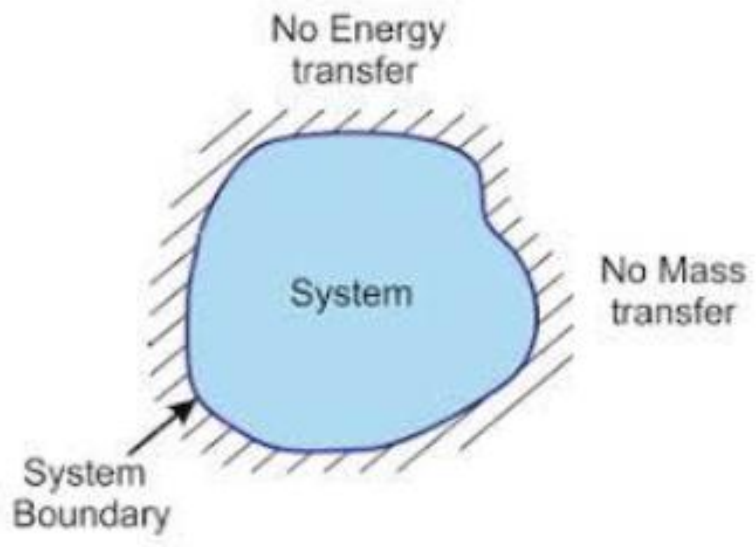
Closed System

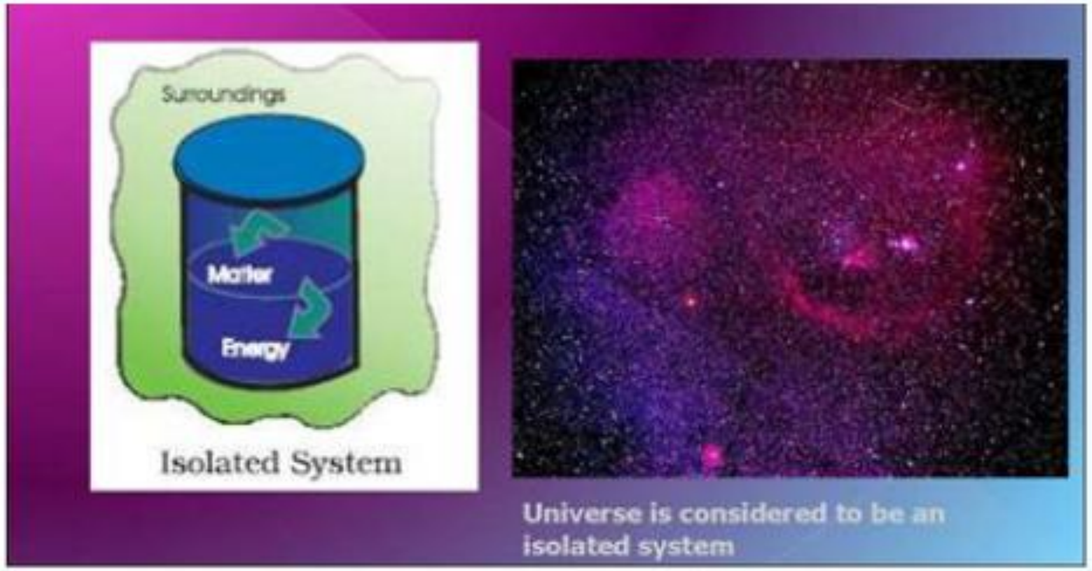


Open System


SYSTEM BOUNDARY
ENERGY IN
SYSTEM
MASS OUT
MASS IN
SURROUNDING
ENERGY OUT

Isolated System



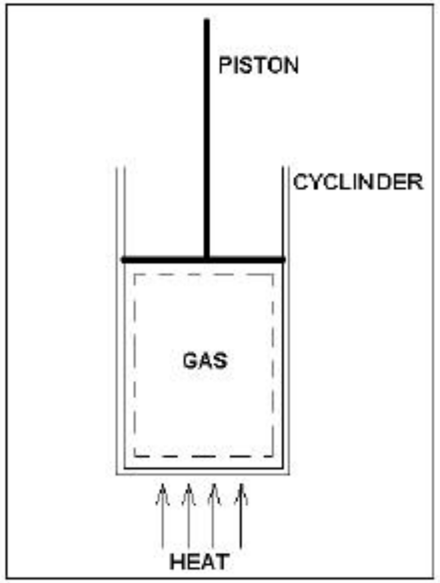


Can you recognize and classify the following as closed, open and isolated systems?

Electric Bulb

Centrifugal Pump

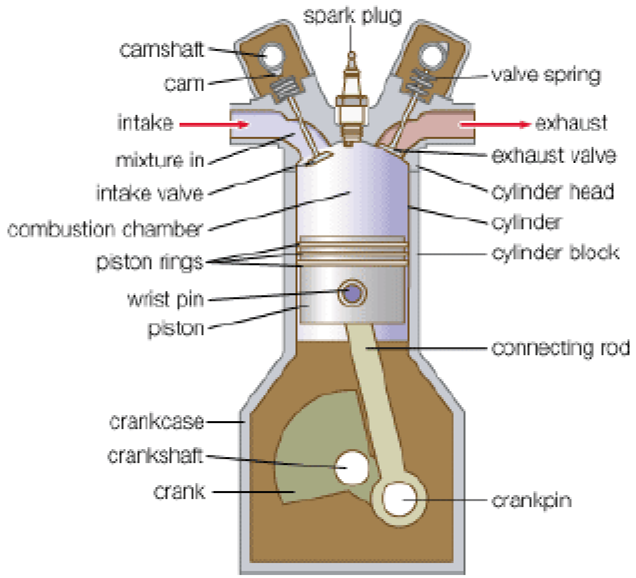
Can you recognize and classify the following as closed, open and isolated systems?



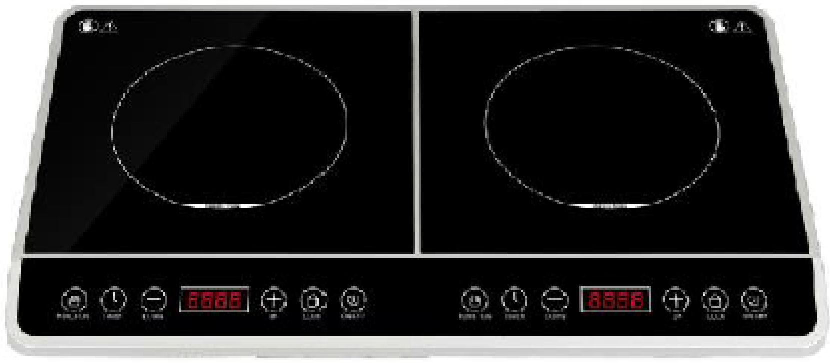
Gas in a piston-cylinder enclosure

Thermos Flask

Can you recognize and classify the following as closed, open and isolated systems?



IC Engine



Electric Stove

Can you recognize and classify the following as closed, open and isolated systems?

Air Compressor

Refrigerator

Macroscopic study

- This is the study and analysis of systems taking the entire mass of the system as a whole.
- The branch of thermodynamics that deals with such a study is called **classical thermodynamics**.

Microscopic study

- In this, the study and analysis of systems is made at a molecular level taking into consideration the effect of individual molecules on the behaviour of the system.
- The branch of thermodynamics that deals with such a study is called **statistical thermodynamics.**

State of a system

- It refers to the condition of the system at any given instant of time.

Properties of a system

- These are the observable characteristics of a system that can be used to define the state of the system.

Intensive and Extensive Properties

Intensive properties

- These are the properties that are independent of the mass of a system. E.g. temperature, pressure

Extensive properties

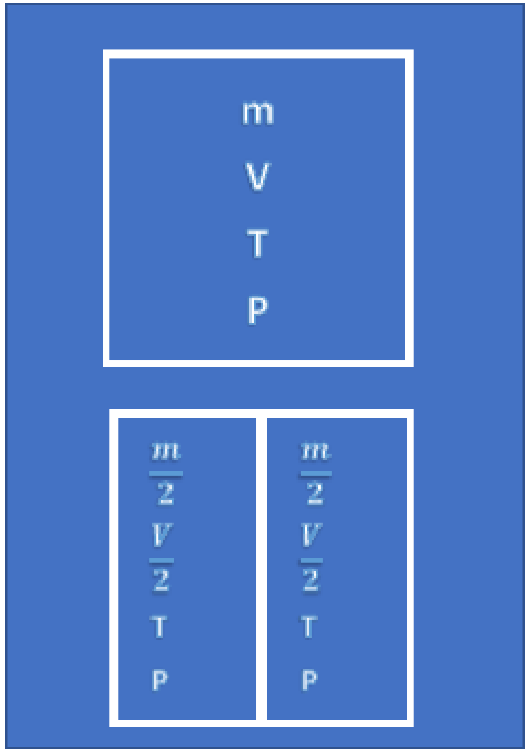
- These are the properties that are dependent on the mass of a system. E.g. volume, mass

Important Observations

- Value of intensive properties is the same at all points in a system.
- Value of an extensive property for a system is the sum of the values of the property at different points.

Intensive and Extensive Properties

When a system is divided into two equal parts its extensive properties in each part will be one half of the value for the undivided part, where as the value of intensive properties remain unchanged



Thermodynamic Equilibrium

Equilibrium refers to a state of balance within the system and between the system and its surroundings.

A system is said to be thermodynamic equilibrium when no change in macroscopic property is observed after it is isolated from its surroundings.

Such a system has to possess the following types of equilibria: -

1. Mechanical Equilibrium
2. Chemical Equilibrium
3. Thermal Equilibrium
4. Other Equilibria such as Electrical Equilibrium, Phase Equilibrium etc.

Process

When a system undergoes a change of state, it is said to have undergone a process. During a process, it is implicit that the system is not in a state of thermodynamic equilibrium.

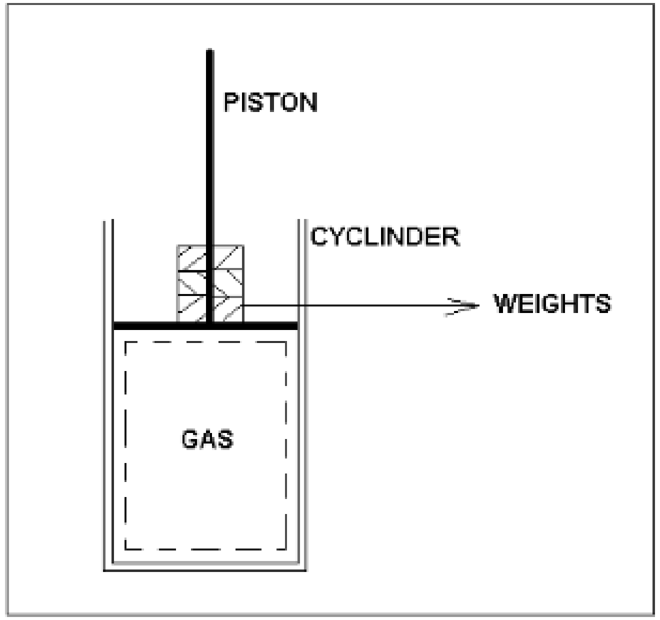
When a process takes place, the values of the properties change.

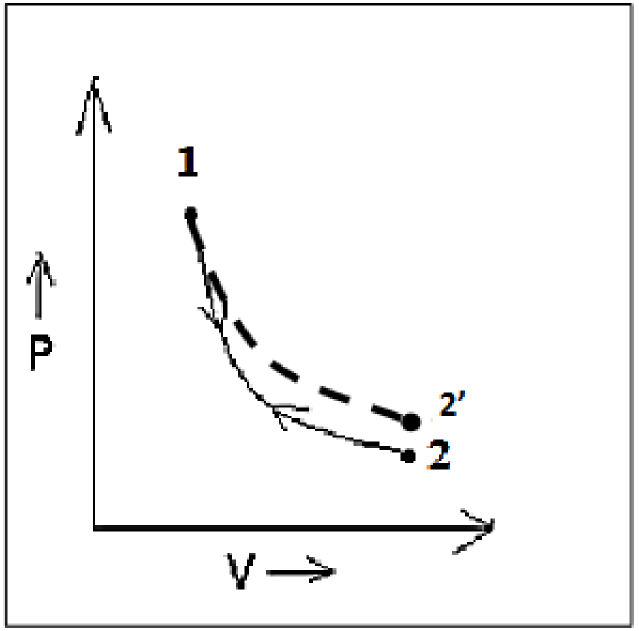
However, during a process, one or more properties of the system may remain constant. This makes the process distinct and gives it a name: -

- ✓ isothermal process – temperature remains constant
- ✓ Isobaric process– pressure remains constant
- ✓ Isochoric process – volume remains constant
- ✓ Isentropic process – entropy remains constant.

Quasi static or Quasi Equilibrium Process

Quasi – Static or Quasi – Equilibrium process is a process during the course of which deviation from thermodynamic equilibrium is negligibly small.





1-2: Quasi-static Process

1–2': Real Process

Temperature is a measure of the hotness or coldness of a system

Since hotness or coldness is a highly relative term, temperature cannot be measured in an absolute sense.

To overcome this, we define equality of temperature or thermal equilibrium.

Equality of Temperature

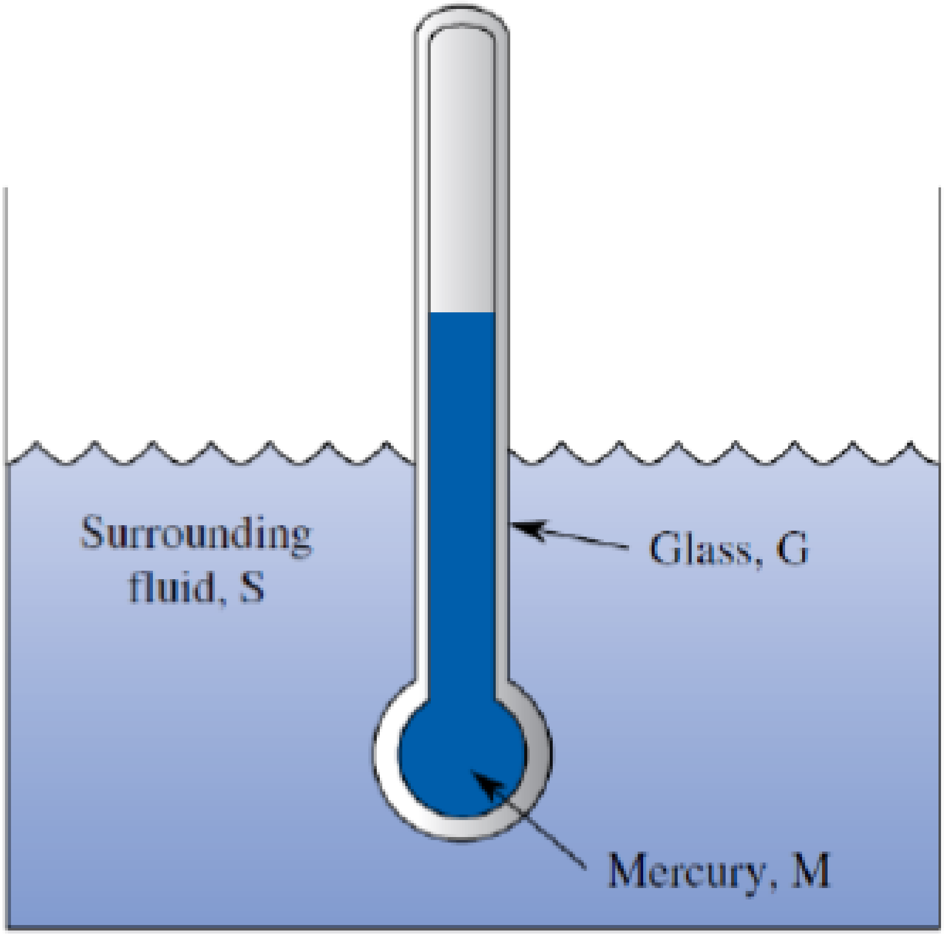
Two systems or a system and its surrounding are said to have equality of temperature if there is no change in any observable property when they are brought into thermal contact.

Zeroth Law of Thermodynamics

"When two systems, say A and B are independently in thermal equilibrium with a third system, say C, then they are in thermal equilibrium with each other. "

A=B
A=C
B=C
Hence, A=B=C

Illustration of Zeroth Law of Thermodynamics as basis for Temperature Measurement



Zeroth law;

$T_G = T_S$

and

$T_M = T_G$

therefore,

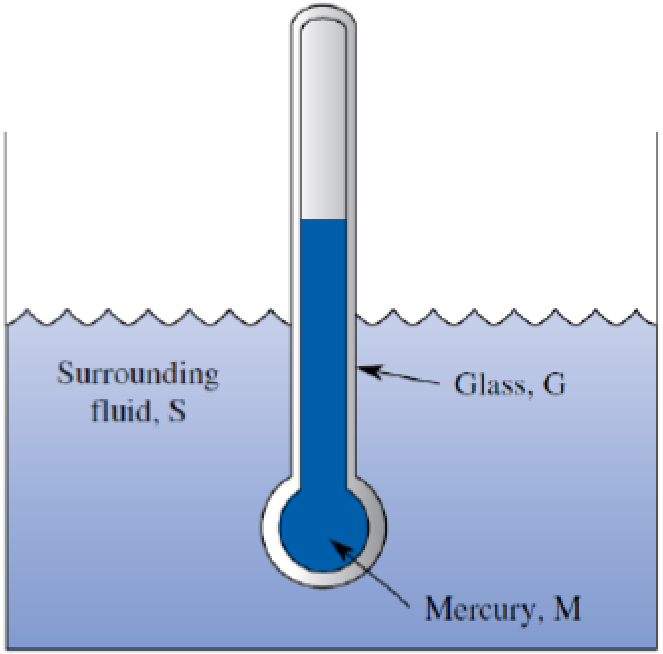
$T_M = T_S$

Illustration of Zeroth Law of Thermodynamics as basis for Temperature Measurement

Consider the mercury in glass thermometer shown.

The Zeroth Law tell us that if the glass is at the same temperature (thermal equilibrium) as the surrounding fluid, and if the mercury is at the same temperature as the glass, then the mercury is at the same temperature as the surrounding fluid.

Thus, the thermometer can be calibrated to show the temperature of mercury, and this temperature, by the Zeroth Law, is equal to the temperature of the surrounding fluid.



Zeroth law;

$T_G = T_S$

and

$T_M = T_G$

therefore,

$T_M = T_S$

The zeroth law of thermodynamics forms the basis for temperature measurement.

Temperature measurement is accomplished by the following:

1. Reference System & Reference Property
2. Reference Points
3. Formation of Temperature Scale

1. Reference System and Reference Property:

It is referred to as the thermometer and possesses a property that is measurable and changes with temperature.

The property that changes is referred to as a thermometric property.

The variation in the value of the thermometric property is taken as the measure of the variation of temperature.

Some of the common thermometers with their thermometric properties are listed below:

Sl. No.	Thermometer	Thermometric property
1.	Mercury column in glass capillary	Volume (Length)
2.	Constant volume of gas enclosed in the vessel	Pressure
3.	Thermocouple	e.m.f.
4.	Electric resistance thermometer	Electric resistance
5.	Radiation thermometer	Radiation

Temperature – Reference Points

2. Reference points:

They are distinct, reproducible states at any place on the earth.

E.g.: Ice Point: A mixture of ice and water in thermal equilibrium at a pressure of 101.325 kPa. In the Celsius scale of temperature measurement, the temperature of this mixture is assigned the value 0 and written as 0°C.

Steam Point: It is the temperature of a mixture of water and wet steam in thermal equilibrium at a pressure of 101.325 kPa. In the Celsius scale, this temperature is assigned the value 100°C.

Besides these points, the other notable reference points are Gold Point (1063°C), Silver Point (960.8°C), Sulphur Point (444.6°C), Oxygen Point (-182.97°C).

Temperature – Reference Points

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Method before 1954

Till 1954, two reference points were used for temperature measurement:-

1. Ice Point
2. Steam Point

However, the use of the two fixed points was abandoned later due to the following reasons:-

a. The difficulty of achieving equilibrium between pure ice and air-saturated water, as when ice melts, it surrounds itself only with pure water and prevents intimate contact with air-saturated water

b. Extreme sensitiveness of steam point to change in pressure

Method after 1954

After 1954, the triple point of water, the state at which ice, liquid water and water vapour co-exist in thermal equilibrium, is the standard fixed point of thermometry.

This is because triple point of water is an easily reproducible state.

The temperature corresponding to triple point of water is 0.01^0C or 273.16 K.

Temperature – Reference Points

Method after 1954

If T is temperature and X is the thermometric property we may write: -

$$T = AX$$

At triple point we may write $273.16 = AX_{\text{triple point}}$

$$A = \frac{273.16}{X_{\text{triple point}}}$$

Substituting for A we may write

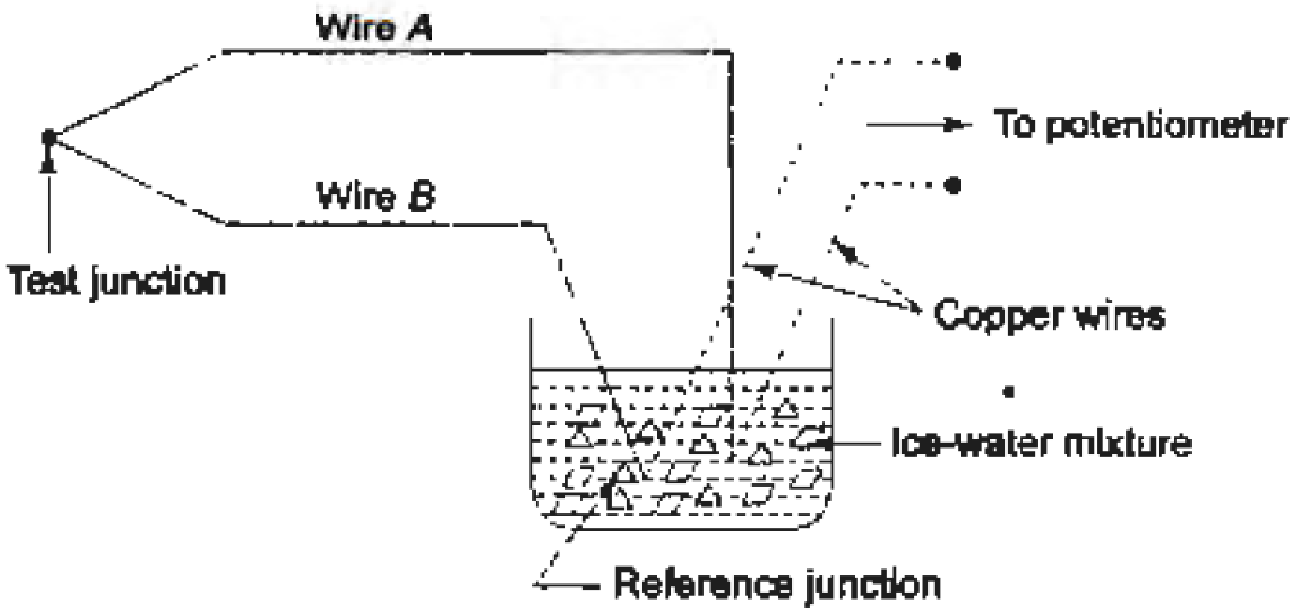
$$T = \left(\frac{273.16}{X_{\text{triple point}}}\right) X$$

$$T = 273.16 \left(\frac{X}{X_{\text{triple point}}}\right)$$

The e.m.f. in a thermocouple with the test junction at t^{0}C on a gas thermometer scale and reference junction at ice point is given by

$$e = 0.25t - 6 \times 10^{-4}t^2, mV$$

The millivoltmeter is calibrated at ice and steam points. What will this thermometer read in a place where the gas thermometer reads 60^{0}C?



Solution

$$e_{ice} = 0.25(0) - 6 \times 10^{-4}(0^2) = 0$$

$$e_{steam} = 0.25(100) - 6 \times 10^{-4}(100^2) = 19\ \mathrm{mV}$$

Since it is calibrated at ice and steam points, it is assumed that emf ‘e’ is a linear function of temperature between them.

$e = a + bt'$, where t' is the temperature on the linear scale.

At ice point

$0 = a + b(0) \rightarrow$ **a = 0**

At steam point

$19 = a + b(100) \rightarrow$ **b = 0.19**

$$\mathbf{e = 0.19t'}$$

Solution

When t = 50^{0}C, the emf generated is given by

$$e = 0.25(50) - 6 \times 10^{-4}(50^2) = 11 \text{ mV}$$

Substituting for e = 11mV, in the equation $e = 0.19t'$

$$11 = 0.19t'$$

$$t' = \frac{11}{0.19}$$

$$\mathbf{t' = 57.89\,^0C}$$

Thus we notice that the assumption of linear scale leads to an erroneous value of temperature.

% Error = $\left(\frac{57.89 - 50}{50}\right) \times 100 = 15.78\,\%$

The temperature t on a thermometric scale is defined in terms of a property K by the relation $t = a \ln K + b$, where a and b are constants.

The values of K are found to be 1.83 and 6.78 at the ice point and steam point, the temperatures of which are assigned the numbers 0 and 100 respectively.

Determine the temperature corresponding to a reading of K equal to 2.42 on the thermometer.

Solution

At ice point, $t = 0$ & $K = 1.83$

$t = a \ln K + b$ gives us → $0 = a \ln(1.83) + b$ → $0 = a(0.6043) + b$

$\mathbf{b = -0.6043a}$

At steam point, $t = 100$, $K = 6.78$

$100 = a \ln(6.78) + b$ → $100 = a(1.9139) - 0.6043a$

$\mathbf{a = 75.35}$

$b = -0.6043a$ → $b = -0.6043 \times 75.36$ → $\mathbf{b = -45.53}$

When $K = 2.42$, $t = 75.36(\ln 2.42) - 45.53$.

$\mathbf{t = 21.3°C}$

Temperature Measurement - Numericals

A new scale N of temperature is divided in such a way that the freezing point of ice is 100°N and boiling point is 400°N. What is the temperature reading on this new scale when the temperature is 45°C? At what temperature will the Celsius and this new scale produce the same reading?

Solution

Assuming a linear relationship for N and a thermometric property X we write

$$N = AX + B$$

For ice point $\rightarrow N = AX + B \rightarrow 100 = AX_{ice} + B \rightarrow \mathbf{B = 100 - AX_{ice}}$

For steam point $\rightarrow N = AX + B \rightarrow 400 = AX_{steam} + B$

$$\rightarrow 400 = AX_{steam} + (100 - AX_{ice})$$

$$\rightarrow A = \frac{300}{X_{steam} - X_{ice}}$$

$$\rightarrow B = 100 - \frac{300X_{ice}}{X_{steam} - X_{ice}}$$

Solution

Substituting for A and B and simplifying we get

$$N = 300\left[\frac{X - X_{ice}}{X_{steam} - X_{ice}}\right] + 100$$

On similar lines for the Celsius Scale we get

$$C = 100\left[\frac{X - X_{ice}}{X_{steam} - X_{ice}}\right]$$

Substituting for C in the expression for N we may write

$$\mathbf{N = 3C + 100}$$

Solution

$$\mathbf{N = 3C + 100}$$

For $C = 45°C$

$$N = 3 \times 45 + 100$$

$$\mathbf{N = 235°N}$$

Both will read the same value when N = C

$$\text{i.e.,}\, N = 3C + 100 \rightarrow N = 3N + 100 \rightarrow 2N = -100$$

$$\mathbf{N = C = -50}$$

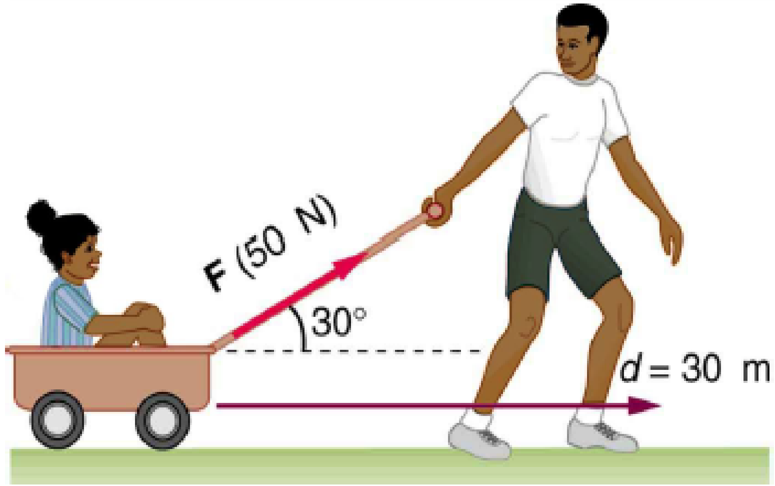
A platinum wire is used as a resistance thermometer. The wire resistance was found to be 10 ohm and 16 ohm at ice point and steam point respectively, and 30 ohm at Sulphur point of 444.6°C.

Find the resistance of the wire at 300°C, if the resistance varies with temperature by the relation $R = R_o(1 + \alpha t + \beta t^2)$

Work

From engineering mechanics point of view, work is said to be done when the point of application of a force moves through a certain distance.

The amount of work done is evaluated as the product of the force applied and the distance moved.

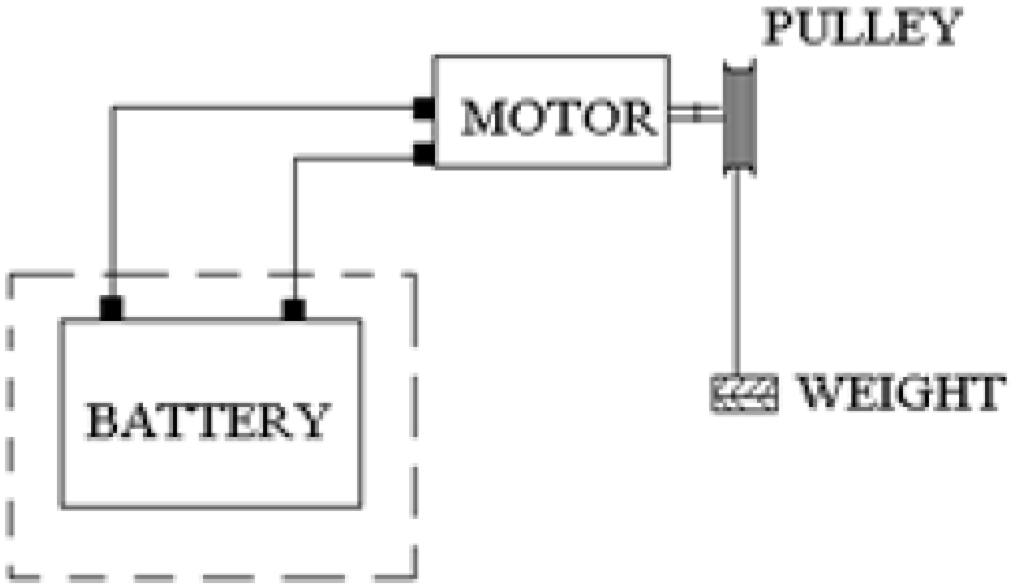


$$W = \text{Force} \times \text{distance}$$
$$= 50 \cos 30^0 \times 30$$
$$= 1299.04 \text{ N}$$

Work

Work in thermodynamics is the energy transferred from one thermodynamic system into another thermodynamic system, often a transfer from heat energy to another form of energy.

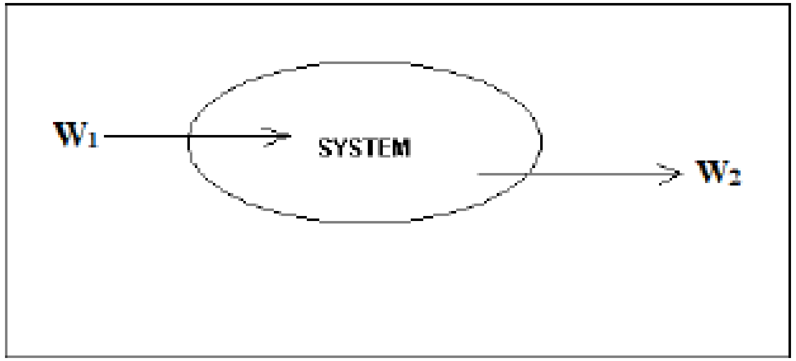
Illustration of Work



Sign Conventions of Work

Work done by the system is treated positive

Work done on the system is treated negative.

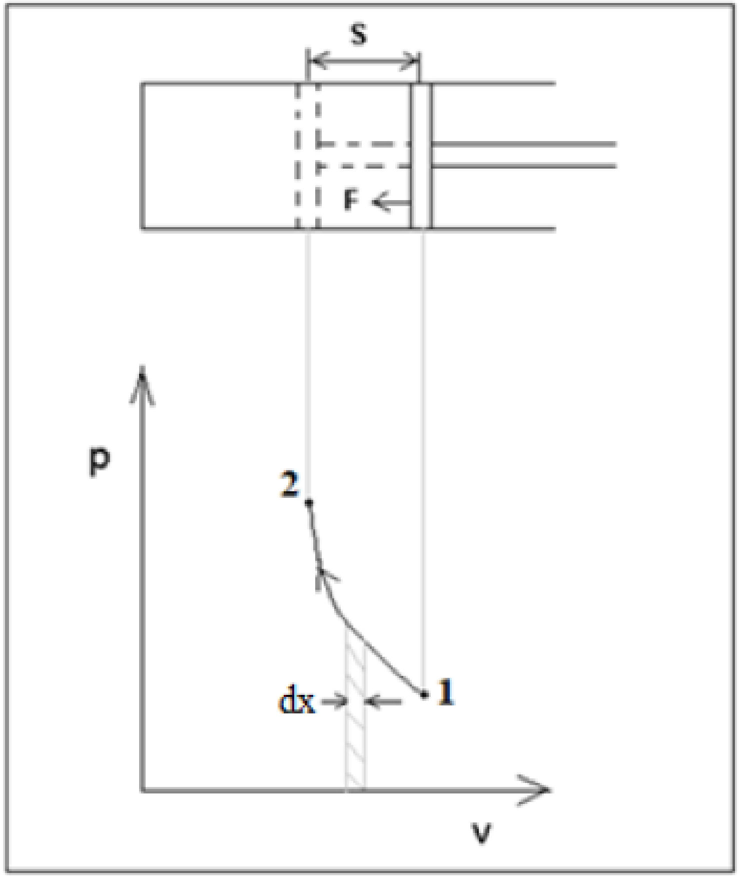


W_1 is -ve and W_2 is +ve

Units of work → joules(J), kilo joules(kJ)

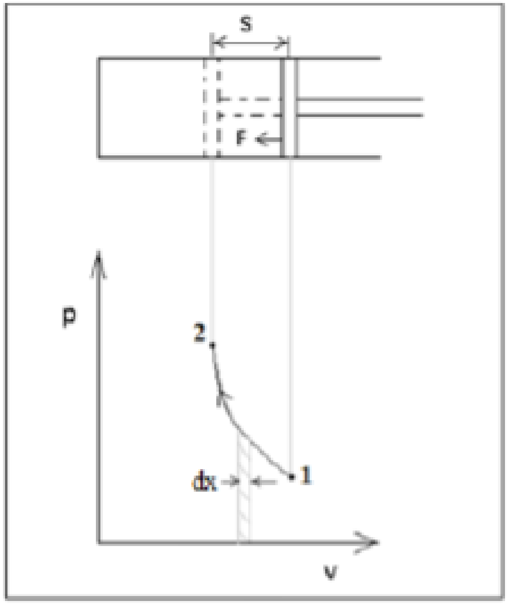
Sometimes work transferred/unit time is mentioned and the unit would be J/s or Watts (W).

Moving boundary or pdV work



Consider a fixed quantity of gas enclosed in a cylinder provided with a piston, as shown. Let the gas enclosed be treated as the system. Let it be compressed from initial state 1 to final state 2 by means of a quasi-static process.

Moving boundary or pdV work



Let F be the force applied and A be the cross sectional area of the piston. Let p be the pressure exerted on the gas.
Between the end states 1 and 2, consider a small displacement dx as indicated.
Let ∂W be the work done to achieve this small displacement.

Moving boundary or pdV work

We may write

$$\partial W = F \times dx$$

$$\partial W = (p \times A) \times dx$$

$$\partial W = p \times (A \times dx)$$

$$\partial W = p \times dV$$

To get the total work done between 1 and 2, we need to integrate: -

$$\int_1^2 \partial W = \int_1^2 p \, dV$$

$$W_{1-2} = \int_1^2 p \, dV$$

Moving boundary or pdV work

The expression $\int \mathrm{pdV}$ can be integrated only if we know the relation between p and V.

When the relation between p and V is defined, the path followed gets defined. The path depends on the type of process.

Or, we can say that for different processes there are different paths.

Moving boundary or pdV work for Isothermal Process

For an Isothermal Process

We have $P_1V_1 = P_2V_2 = PV = \text{Constant}$

Hence $P = \text{Constant}/V$

$$\text{Moving Boundary Work, } W = \int_1^2 PdV$$

$$= \int_1^2 \left(\frac{\text{Constant}}{V}\right) dV$$

$$= \text{Constant} \int_1^2 \left(\frac{dV}{V}\right)$$

$$= \text{Constant}\ \ln(V)_1^2$$

$$= P_1V_1\ \ln\left(\frac{V_2}{V_1}\right)$$

IMPORTANT

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Moving boundary or pdV work for Various processes

Sl. No	Process	Relation between P and V	Expression for pdV work
1	Isothermal process	PV = const. $P_1V_1 = P_2V_2$	$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$
2	Adiabatic process	PV^γ = constant $P_1V_1^\gamma = P_2V_2^\gamma$	$W = \frac{p_1V_1 - p_2V_2}{\gamma - 1}$
3	Polytropic process	PV^n = const $P_1V_1^n = P_2V_2^n$	$W = \frac{p_1V_1 - p_2V_2}{n - 1}$
4	Isochoric process	V =constant. dV = O $P_1/P_2 = T_1/T_2$ (Kelvin)	W = O
5	Isobaric process	P = constant. dP = O $V_1/T_1 = V_2/T_2$	$W = P(V_2 - V_1)$

Other forms of Work

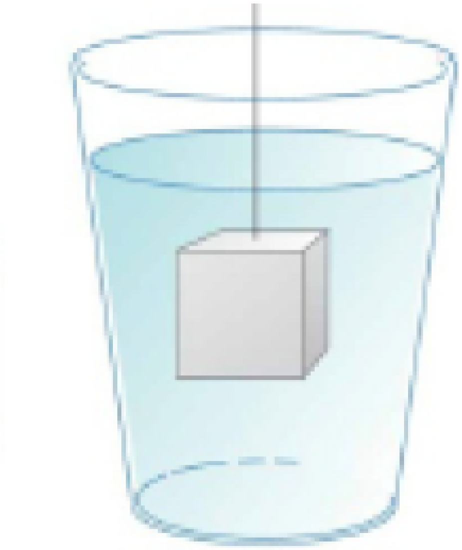
Sl. No	Type of Work Transfer	Expression for work
1	Shaft Work	• $W = \text{Torque} \times \text{Angular Displacement}$ $W = T \times 2\pi, \text{Joules per rotation}$ • $W = T \times 2\pi \times n, \text{Joules for n rotations}$ • $\text{Work done per second} =$ $\dot{W} = \frac{T \times 2\pi N}{60}, \text{Joules per second,}$ where N = number of rotations per minute (rpm)

Other forms of Work

Sl. No	Type of Work Transfer	Expression for work
2	Electric Work	W = Voltage * Current
3	Surface Tension Work	W = Surface Tension * Area = σ*A
4	Work done in stretching a wire	$W = -\frac{AEL}{2}(\varepsilon_2^2 - \epsilon_1^2)$ where A = cross sectional area E = Young's Modulus L = Length of the specimen ε = Linear Strain
5	Flow Work	W= pressure*volume

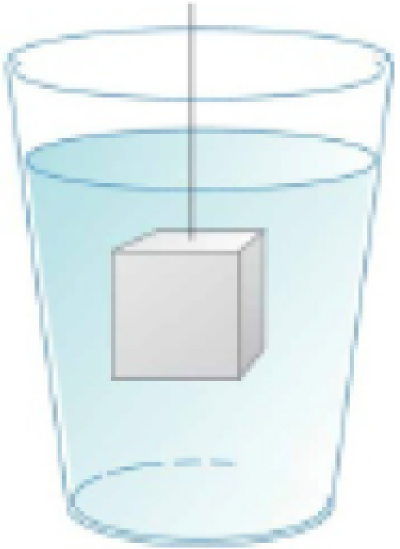
Heat

HEAT is defined as a form of energy in transition taking place due to a difference in temperature.



Consider a hot copper block and a beaker of cold water.
Let the hot block be immersed in cold-water.
On immersion, we note that there is a transfer of energy from the block to the cold water.
The transfer of energy is happening due to a difference in temperature between the block and the water.
This form of energy transfer is referred to as heat or heat transfer.

Heat



Heat is transferred only till there is a temperature difference.

Once equality of temperature has been attained, there is no heat or heat transfer.

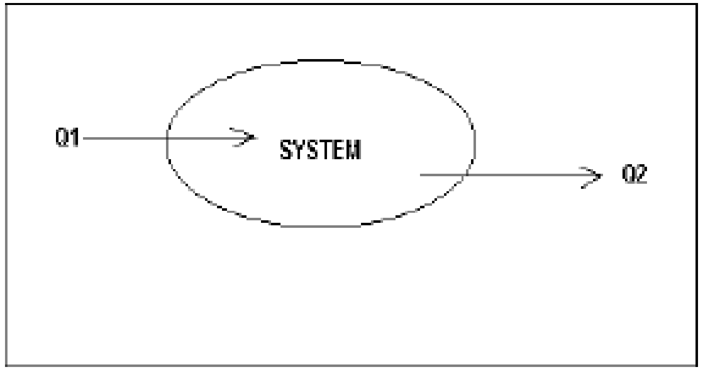
From this we conclude that systems do not possess heat, they only possess energy.

Heat is a transient phenomena, which can be observed at the system boundary.

Sign Convention for Heat

Heat added to a system is treated +ve

Heat removed from a system is treated as –ve.



Q1 is +ve

Q2 is –ve

Units of heat → joules(J), kilo joules(kJ)

Sometimes heat transferred/unit time is mentioned and the unit would be J/s or Watts(W).

Comparison between Work and Heat

Systems do not possess heat or work, they only possess energy.

Transient phenomena: Heat and Work are observed only there is transfer of energy and hence are transient in nature.

Boundary phenomena: Both heat and work are observed at the system boundary. On change of the system boundary the form of energy transfer may change from heat to work or vice versa.

Path functions: Both heat and work are path functions and hence inexact differentials.

Comparison between Work and Heat – Sign Convention

Heat:

Heat added to the system is +ve

Heat removed from the system is –ve.

Work:

Work done by the system is +ve

Work done on the system is –ve

A mass of 1.5 kg of air is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa during which PV=constant. If the initial density of air is 1.16 kg/ m³, determine the work done by the system.

Important Observations

Process is isothermal since PV=constant

$$p_1 V_1 = p_2 V_2 \text{ OR } \frac{p_1}{p_2} = \frac{V_2}{V_1}$$

$$v = \frac{V}{m}$$

Data provided

$$m = 1.5 \text{ kg}; \; p_1 = 0.1 \text{ MPa};$$

$$p_2 = 0.7 \text{ MPa}; \; \rho_1 = 1.16 \frac{kg}{m^3}$$

Solution

$$W_{1-2} = p_1 V_1 \ln \frac{V_2}{V_1} = p_1 V_1 \ln \frac{\mathbf{p_1}}{\mathbf{p_2}}$$

$$= p_1 (\mathbf{m v_1}) \ln \frac{p_1}{p_2} = m \times p_1 \, v_1 \times \ln \frac{p_1}{p_2}$$

$$W_{1-2} = 1.5 \times 0.1 \times \left(\frac{1}{1.16}\right) \ln \frac{0.1}{0.7}$$

$$\mathbf{W_{1-2} = -0.2516 \text{ MJ}}$$

A mass of gas is compressed in a quasi static process from 80 kPa, 0.1m³ to 0.4MPa , 0.03m³. Assuming the P & V are related by up PVⁿ = constant, determine the work done by the system.

Important Observations

Process is polytropic → PV^n = constant

Data provided

$p_1 = 80\ \text{kPa};\ V_1 = 0.1\ m^3$

$p_2 = 0.4\ \text{MPa};\ V_2 = 0.03\ m^3$

Solution

1. **Determination of polytropic index n**

$$p_1 V_1^n = p_2 V_2^n$$

$$\left(\frac{p_1}{p_2}\right) = \left(\frac{V_2}{V_1}\right)^n$$

Taking log on both sides

$$\text{Log}\left(\frac{p_1}{p_2}\right) = n \times \text{Log}\left(\frac{V_2}{V_1}\right)$$

$$\text{Log}\left(\frac{80}{400}\right) = n \times \text{Log}\left(\frac{0.03}{0.1}\right)$$

Solving we get **n = 1.337**

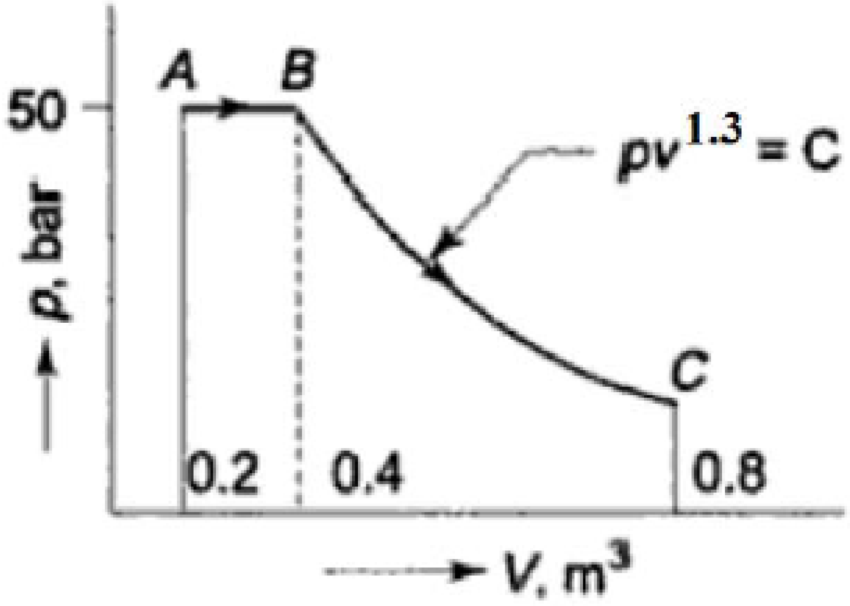
2. Determination of work done

$$W_{1-2} = \frac{p_1 V_1 - p_2 V_2}{n-1} \text{ for a polytropic process}$$

$$W_{1-2} = \frac{(80 \times 0.1) - (400 \times 0.03)}{1.337 - 1}$$

$$\mathbf{W_{1-2} = -11.87\ kJ}$$

Determine the total work done by a gas system following an expansion process shown in the figure.



Important Observations

A-B: Constant Pressure Process

B-C: Polytropic Process

Data Provided

$$p_A = p_B = 50 \text{ bar}$$

1 bar = 100 kPa

$$V_A = 0.2 \text{ m}^3; V_B = 0.4 \text{ m}^3; V_C = 0.8\text{m}^3$$

$$p_B V_B^{1.3} = p_C V_C^{1.3}$$

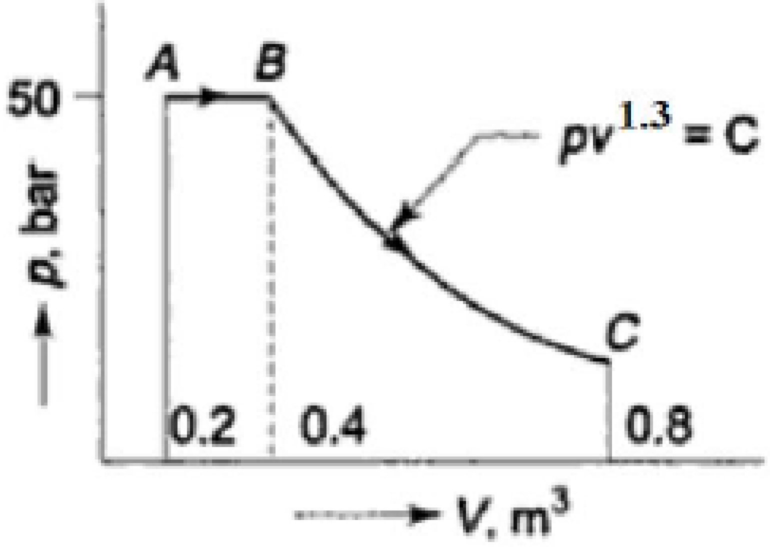
Solution

1. Determination of p_C

$$p_B V_B^{1.3} = p_C V_C^{1.3}$$

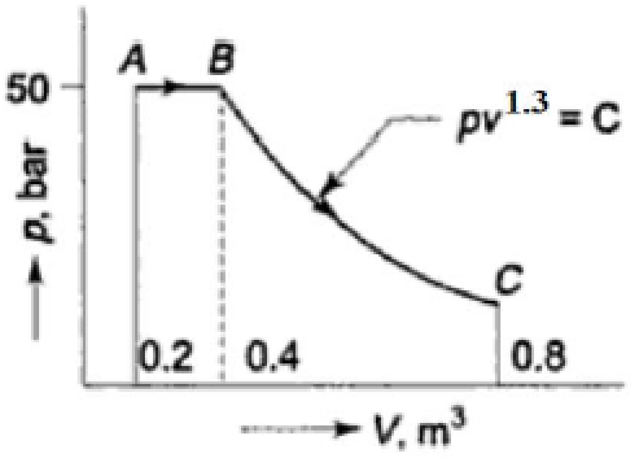
$$p_C = p_B \left(\frac{V_B}{V_C}\right)^{1.3} = 50 \times 100 \times \left(\frac{0.4}{0.8}\right)^{1.3}$$

$$\mathbf{p_C = 2030.63\ kPa}$$



Solution (Cont'd)

2. Determination of total work done



$$W_{A-B} = p_A(V_B - V_A) = 50 \times 100 \times (0.4 - 0.2)$$

$$\mathbf{W_{A-B} = 1000\ kJ}$$

$$W_{B-C} = \frac{p_B V_B - p_C V_C}{n-1} = \frac{50 \times 100 \times 0.4 - 2030.63 \times 0.8}{1.3 - 1}$$

$$\mathbf{W_{B-C} = 1251.65\ kJ}$$

$$W_{Total} = W_{A-B} + W_{B-C} = \mathbf{1000 + 1251.65}$$

$$\mathbf{W_{Total} = 2251.65\ kJ}$$

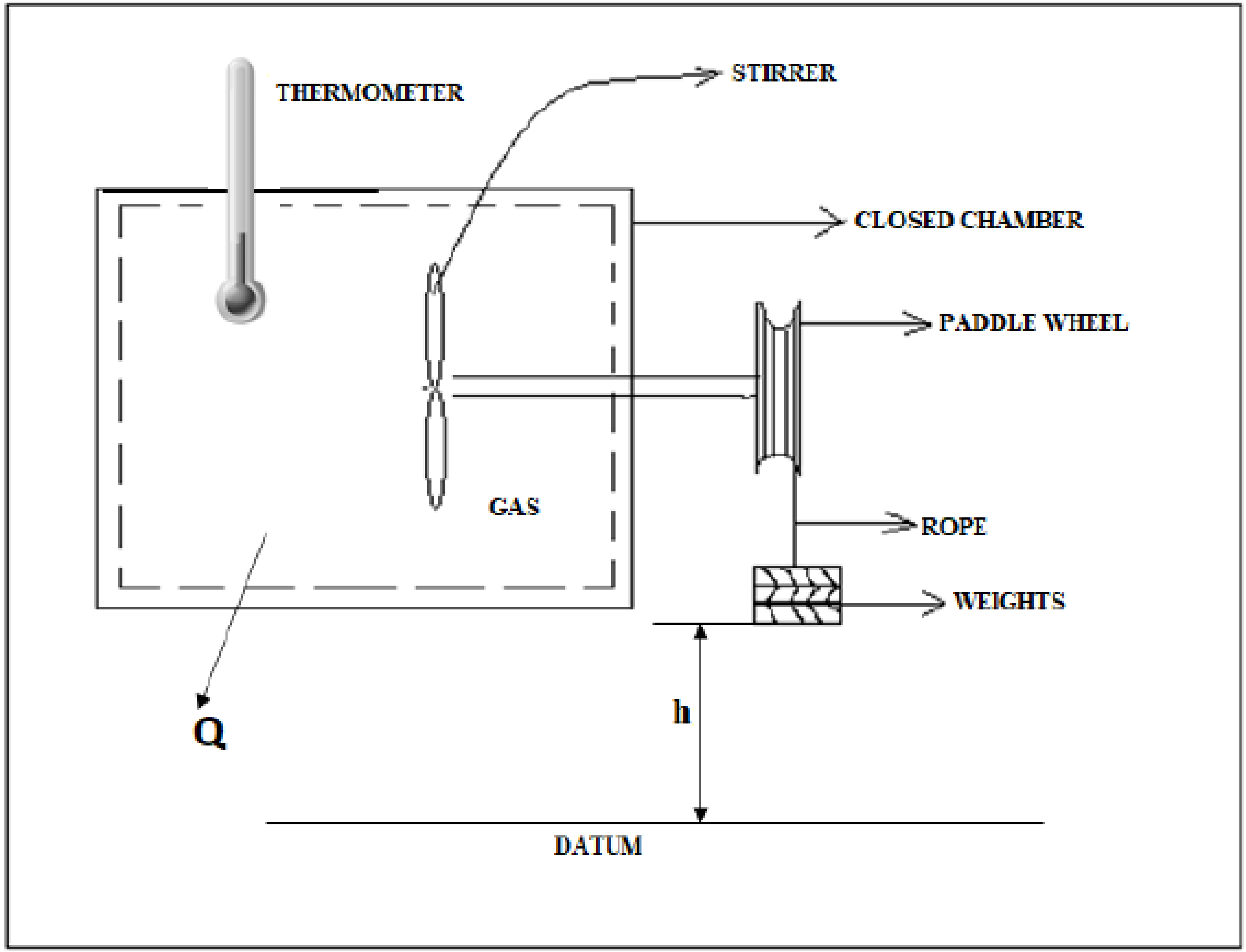
First Law of Thermodynamics – Joule's Experiment

In 1845, Joule published a paper entitled "**The Mechanical Equivalent of Heat**", in which he specified a numerical value for the amount of mechanical work required to produce a unit of heat.

In particular Joule had experimented on the amount of mechanical work generated by friction needed to raise the temperature of a pound of water by one degree Fahrenheit and found a consistent value of 778.24 foot pound force (4.1550 $J.cal^{-1}$ later corrected to 4.1868 $J.cal^{-1}$)

Joule contended that motion and heat were mutually interchangeable and that, in every case, a given amount of work would generate the same amount of heat.

First Law of Thermodynamics – Joule's Experiment



First Law of Thermodynamics – Joule's Experiment

Energy imparted to paddle wheel and converted to work done on gas by stirrer = W = $m_w gh$

where m_w is the mass of the weights and h is the height of fall.

The temperature of the gas rises due to the conversion of work to heat by friction. Let this be ΔT.

We have Q = $mc\Delta T$, where m is the mass of the gas and c the specific heat.

It is observed that W α Q for every different height of fall.

On removing this amount of heat the system is restored to its initial state, thus completing a cycle.

This was the Joule's experiment.

Statement of First Law of Thermodynamics for Cyclic Process

'When a system undergoes a cyclic process, the algebraic sum (or cyclic integral), of heat transfers is proportional to, the algebraic sum (or cyclic integral), of work transfers.'

Or we say

$$\sum_{\text{cycle}} W \;\alpha\; \sum_{\text{cycle}} Q$$

$$\Sigma_{\text{cycle}} W = J\,\Sigma_{\text{cycle}} Q,$$

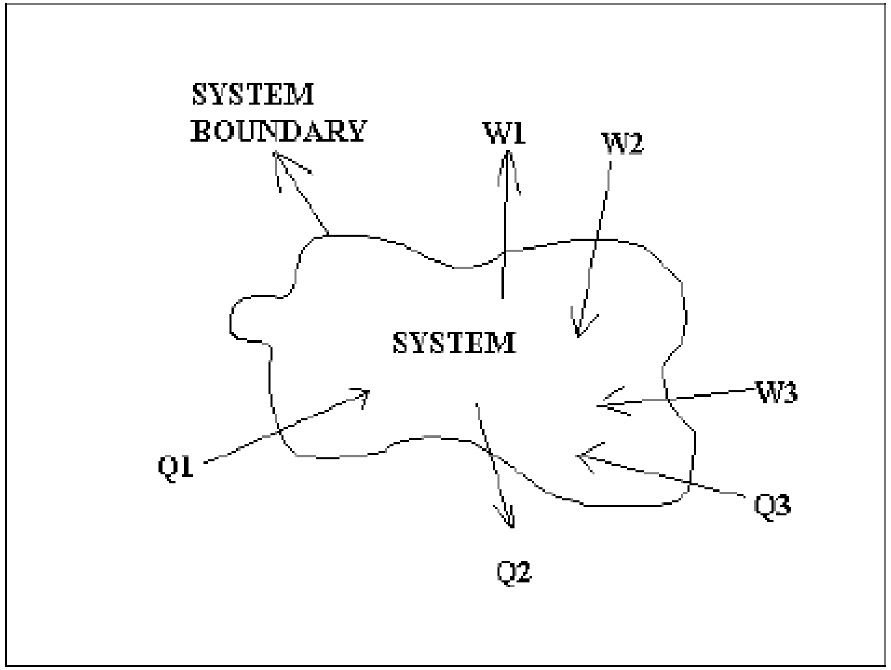
where J is the proportionality constant called the Joule's constant.

In the language of calculus

$$\oint \partial W = J \oint \partial Q$$

J = 418.68 kJ/kCal OR
J = 427 kgf-m/ kCal

Statement of First Law of Thermodynamics for Cyclic Process



Consider the system shown.

Let it experience the heat and work transfers indicated while undergoing a cyclic process.

By law of conservation of energy

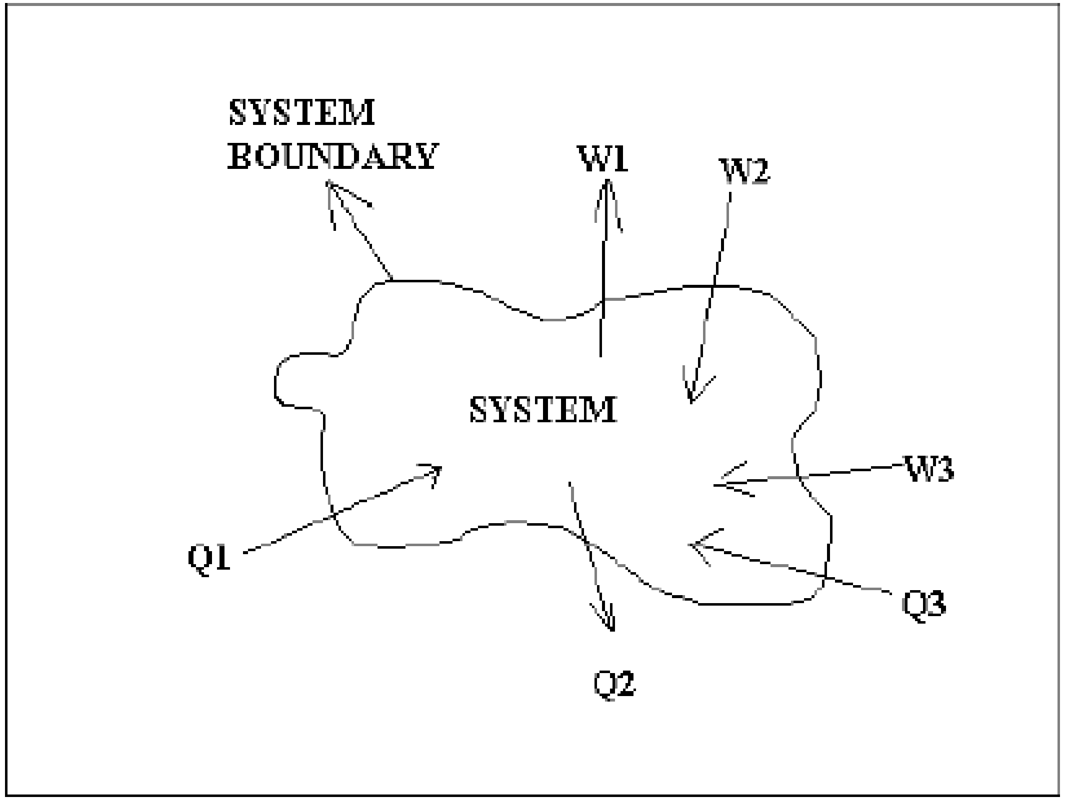
Total energy entering the system = Total energy leaving the system

$$Q_1+Q_3+W_2+W_3=Q_2+W_1$$

Putting the Qs on side and Ws on the other side we have

$$W_1-W_2-W_3 = Q_1-Q_2+Q_3$$

Statement of First Law of Thermodynamics for Cyclic Process



Or we say

$$\sum_{\text{cycle}} W = \sum_{\text{cycle}} Q$$

This is itself the statement of the First Law of Thermodynamics for a closed system undergoing a cyclic process

First Law of Thermodynamics for a closed system undergoing process

It can be shown that the quantity $(\partial Q - \partial W)$
is a property of the system and we call this property ENERGY with symbol E

OR $(\boldsymbol{\partial Q - \partial W}) = \mathbf{dE}$

$$\left.\begin{aligned} \partial Q - \partial W &= dE \\ \partial Q &= dE + \partial W \end{aligned}\right\} \quad \textbf{(4)}$$

Equations (4) are the differential forms of the first law for a closed system undergoing an infinitesimal change of state.

Between end states 1 and 2 we can integrate and write

$$\int_1^2 \partial Q = \int_1^2 dE + \int_1^2 \partial W$$

First Law of Thermodynamics for a closed system undergoing process

$$\left.\begin{aligned} &\mathbf{Q_{1-2} = (E_2 - E_1) + W_{1-2}} \\ &\text{OR in general } \mathbf{Q = \Delta E + W} \\ &\text{OR } \mathbf{Q - W = \Delta E} \end{aligned}\right\} \quad (5)$$

Equations (5) represent the first law of thermodynamics for a closed system undergoing a finite change of state.

Energy or Stored Energy of a System

Potential Energy = mgz

z is height (m)

Internal Energy, U

Energy of a System

Kinetic Energy = $\frac{mV^2}{2}$

Other Forms: Magnetic Energy, Electrical Energy, Distortion Energy, Surface Energy, etc

Internal Energy of a System

Internal energy is attributed to the energy inherent in the system inclusive of

a. Vibrational kinetic energy of the molecules.
b. Translatory and rotatory energy of the molecules
c. Energy needed to pack the molecules (molecular potential energy)
d. Binding energy present in the nucleus etc.

Internal energy is an extensive property while specific internal energy (energy per unit mass) is an intensive property.

Symbol for Internal Energy is 'U', with units J, kJ.. etc.

Symbol for specific internal energy is 'u' , with units J/kg, kJ/kg.. etc

1. During one cycle, the working fluid of an engine engages in two work interactions : 15 kJ to the fluid and 44 kJ from the fluid, and three heat interactions, two of which are known : 75 kJ to the fluid and 40 kJ from the fluid. Evaluate the magnitude and direction of the third heat transfer.

1. During one cycle, the working fluid of an engine engages in two work interactions : 15 kJ to the fluid and 44 kJ from the fluid, and three heat interactions, two of which are known : 75 kJ to the fluid and 40 kJ from the fluid. Evaluate the magnitude and direction of the third heat transfer.

Brother see this properly when revising. You made a mistake in sign convention :)

Important Observations

Heat transferred to the fluid is taken with *a positive sign*, while that transferred *from* the fluid is with *a negative sign*.

Work transferred to the fluid is taken with a *negative sign*, while that transferred *from* the fluid is with *a positive sign*.

Solution

$$\sum_{\text{cycle}} Q = \sum_{\text{cycle}} W$$

$$+75 - 40 + Q = 44 - 15$$

Q = -6 kJ.

2. A closed system passes through a complete cycle of 4 processes. The sum of all heat transfers is –170 kJ/cycle. The system completes 100 cycles/min. Complete the following table showing the method for each item and compute the net rate of work output in kW.

PROCESS	Q (kJ/min)	W (kJ/min)	ΔE (kJ/min)
a –b	0	2,170	
b–c	–21,000	0	
c–d	–2,100		–36,600
d–a			

Important Observations

The values of heat, work and energy change are given in kJ/min.

The sum of all heat transfers is mentioned in kJ/cycle.

Data Provided

$$\sum_{\text{cycle}} Q = -170 \frac{\text{kJ}}{\text{cycle}}$$

Number of cycles per minute = 100

Solution

Process a–b

$Q_{a-b} = W_{a-b} + \Delta E_{a-b}$

$0 = 2{,}170 + \Delta E_{a-b}$

$\Delta E_{a-b} = -2{,}170$ kJ/min

Process b–c

$Q_{b-c} = W_{b-c} + \Delta E_{b-c}$

$-21{,}000 = 0 + \Delta E_{b-c}$

$\Delta E_{b-c} = -21{,}000$ kJ/min

Process c–d

$Q_{c-d} = W_{c-d} + \Delta E_{c-d}$

$-2100 = W_{c-d} - 36{,}600$

$W_{c-d} = 34{,}500$ kJ/min

$\Sigma \Delta E = 0$

$\Delta E_{a-b} + \Delta E_{b-c} + \Delta E_{c-d} + \Delta E_{d-a} = 0$

$-2{,}170 - 21{,}000 - 36{,}600 + \Delta E_{d-a} = 0$

$\Delta E_{d-a} = 59{,}770$ kJ/min

PROCESS	Q (kJ/min)	W (kJ/min)	ΔE (kJ/min)
a –b	0	2,170	-2,170
b–c	–21,000	0	-21,000
c–d	–2,100	34,500	-36,600
d–a			59,770

$\Sigma Q = -170$ kJ / cycle

= -170 x 100 cycles / min = -17,000 kJ / min

$Q_{a\text{-}b} + Q_{b\text{-}c} + Q_{c\text{-}d} + Q_{d\text{-}a} = -17{,}000$

$0 - 21{,}000 - 2{,}100 + Q_{d\text{-}a} = -17{,}000$

$Q_{d\text{-}a} = 6{,}100$ **kJ / min**

PROCESS	Q (kJ/min)	W (kJ/min)	ΔE (kJ/min)
a –b	0	2,170	-2,170
b–c	–21,000	0	-21,000
c–d	–2,100	34,500	-36,600
d–a	6,100	-53,670	59,770

Process d–a

$Q_{d\text{-}a} = W_{d\text{-}a} + \Delta E_{d\text{-}a}$

$6{,}100 = W_{d\text{-}a} + 59{,}770$

$W_{d\text{-}a} = -53{,}670$ kJ/min

By First Law of thermodynamics $\Sigma Q = \Sigma W = -17{,}000$ kJ/min

Therefore the **net work output** = –17,000 kJ/min = $\frac{-17{,}000}{60} = -283.33$ kW

3. 1.5 kg of liquid having constant specific heat of 2.5 kJ/kg K is stirred in a well insulated chamber, causing the temperature to rise by 15°C. Find ΔE and W for the process.

3. 1.5 kg of liquid having constant specific heat of 2.5 kJ/kg K is stirred in a well insulated chamber, causing the temperature to rise by 15°C. Find ΔE and W for the process.

Important Observations

The temperature of the liquid rises in spite of no transfer of heat.

This is because of conversion of the stirring work to heat by friction.

Data Provided

Mass of the liquid = m = 1.5 kg

Specific Heat of the liquid = C = 2.5 kJ/kg-K

Temperature Rise = ΔT = 15 ^{0}C

Solution

$$\Delta E = mC\Delta T = 1.5 \times 2.5 \times 15$$

$$\mathbf{\Delta E = 56.25\ kJ}$$

$$Q = \Delta E + W$$

$$0 = \Delta E + W$$

$$W = -\Delta E$$

$$\mathbf{W = -56.25\ kJ}$$

First Law of Thermodynamics - Limitations

The First Law of Thermodynamics is another form of the Law of Conservation of Energy. It merely states that when a process takes place, energy can neither be created nor destroyed.

However, from many observations of common experiences, it is observed that

1. Processes follow a definite direction.

2. Heat and work are qualitatively different.

These are not addressed by the I Law of Thermodynamics and thus are referred to as 'Limitations of the I Law of Thermodynamics'.

Important Definitions

Heat Reservoir: is a body of infinite heat capacity, whose temperature is not affected by any heat transfer.
It can also be defined as a body of infinite heat capacity, which can absorb or supply heat without any change in its temperature.

Heat Source : is a heat reservoir which can supply heat without any change in its temperature.

Heat Sink : is a heat reservoir which can absorb heat without any change in temperature.

Important Definitions - Source

The Sun

Important Definitions - Source

Furnace

Important Definitions - Sink

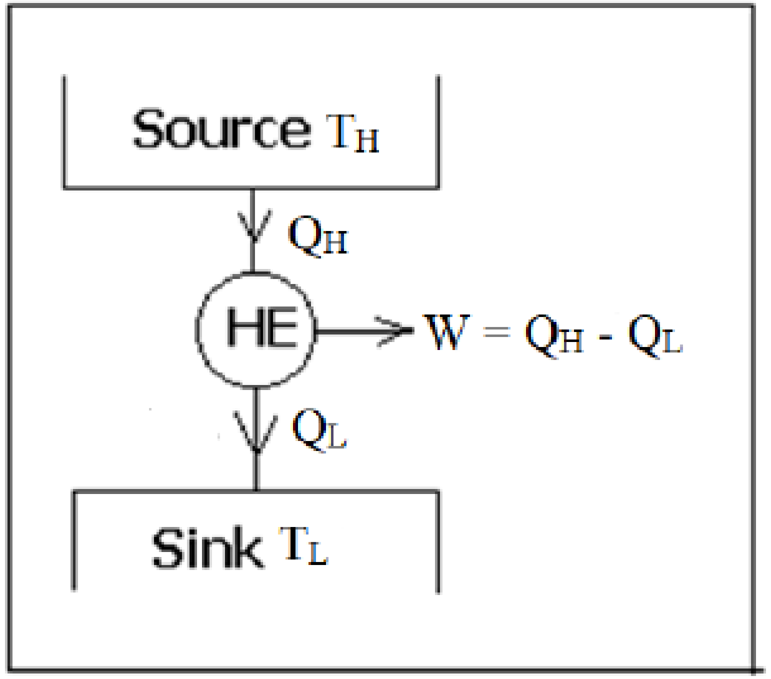
The Atmosphere

Important Definitions - Sink

The Ocean

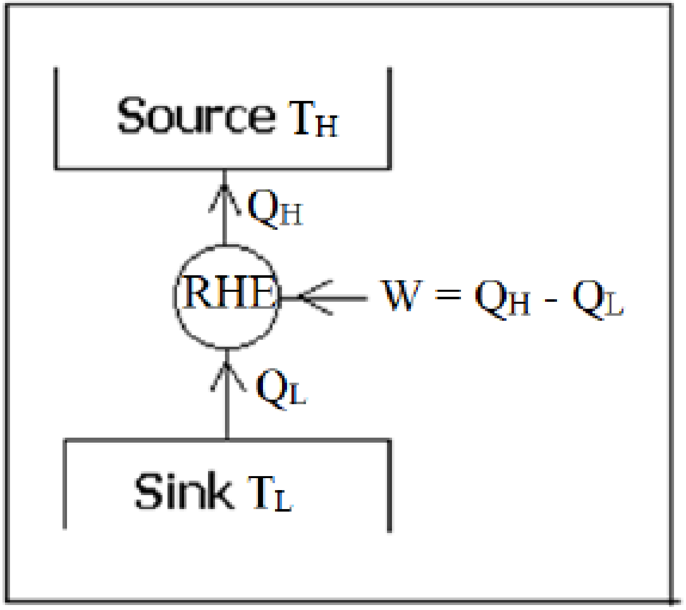
Important Definitions – Heat Engine

Heat Engine : is a device that works in a thermodynamic cycle and produces net positive work while absorbing heat from a source and dissipating heat to a sink.



Important Definitions – Reversed Heat Engine

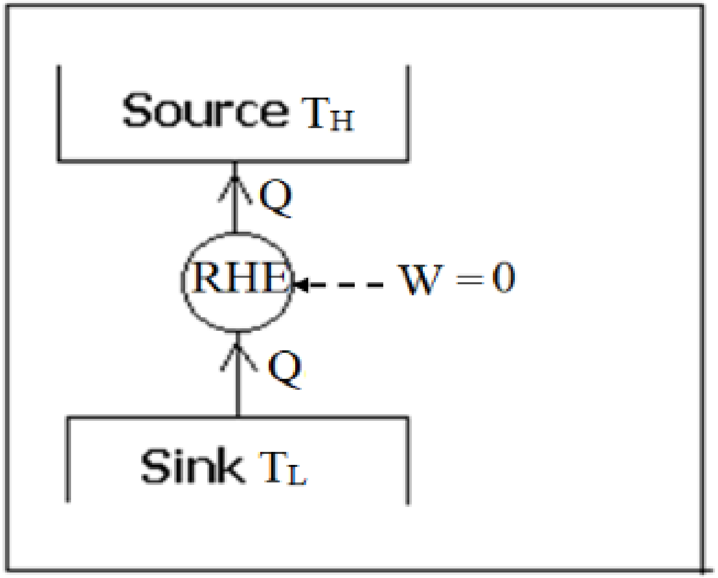
Reversed Heat Engine: is a device that operates in a thermodynamic cycle and transfers heat from a low temperature body (sink) to a high temperature body (source) with the aid of external work.



Statement of Second Law of Thermodynamics

Clausius Statement

It is impossible to construct a device that operates in a thermodynamic cycle and transfers heat from a cold body to a hot body without the input of external energy.



PRINCIPLE OF REFRIGERATION

This is a reverse heat engine example. [READ THIS PROPERLY]

- ***The process of cooling or reducing the temperature of a substance below that of the surrounding atmosphere and maintaining this lower temperature within the boundary of a given space is called refrigeration.***

- The machine or device employed to produce refrigeration effect is called **refrigerator.**

- In order to keep the substance cold, heat must be continuously removed from the given substance.

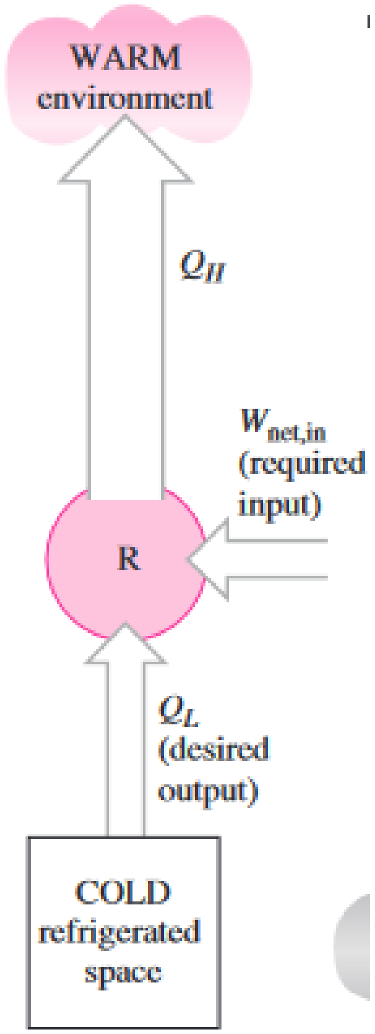
- According to the law of thermodynamics, heat naturally flows from a hot substance to a cold substance. But if heat has to flow from a cold substance to a hot substance, some form of work has to be performed.

PRINCIPLE OF REFRIGERATION

- Refrigeration works on the principle that heat is continuously extracted from the low temperature substance ***by performing mechanical work***. This heat is then rejected to the surrounding atmosphere (high temperature level).

- A carrier substance is used to extract the heat and this substance is known as ***refrigerant***.

- The refrigerant is a chemical substance like ammonia, carbon di oxide, methyl chloride, Freon etc.



MECHANICAL ENERGY AND EFFICIENCY

- Many fluid systems are designed to transport a fluid from one location to another at a specified flow rate, velocity, and elevation difference, and the system may generate mechanical work in a turbine or it may consume mechanical work in a pump or fan during this process.

- These systems do not involve the conversion of nuclear, chemical, or thermal energy to mechanical energy. Also, they do not involve heat transfer in any significant amount, and they operate essentially at constant temperature.

- Such systems can be analyzed conveniently by considering only the mechanical forms of energy and the frictional effects that cause the mechanical energy to be lost (i.e., to be converted to thermal energy that usually cannot be used for any useful purpose)

- The **mechanical energy** is defined as the form of energy that can be converted to mechanical work completely and directly by an ideal mechanical device such as an ideal turbine.

MECHANICAL ENERGY AND EFFICIENCY

- Kinetic and potential energies are the familiar forms of mechanical energy. Thermal energy is not mechanical energy, however, since it cannot be converted to work directly and completely (the second law of thermodynamics).

- The mechanical energy of a flowing fluid can be expressed on a unit-mass basis as

$$e_{\text{mech}} = \frac{P}{\rho} + \frac{V^2}{2} + gz$$

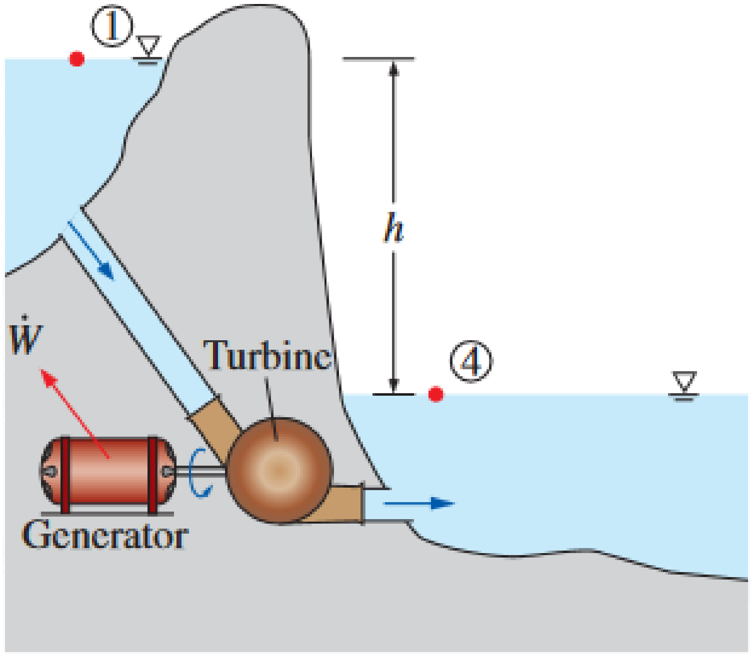
P - pressure
p - rho - density
V - volume
g - gravitational speed
z - height

where P/ρ is the flow energy, $V^2/2$ is the kinetic energy, and gz is the potential energy of the fluid, all per unit mass. Then the mechanical energy change of a fluid during incompressible flow becomes

$$\Delta e_{\text{mech}} = \frac{P_2 - P_1}{\rho} + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \quad \text{(kJ/kg)}$$

- Therefore, the mechanical energy of a fluid does not change during flow if its pressure, density, velocity, and elevation remain constant.

- In the absence of any irreversible losses, the mechanical energy change represents the mechanical work supplied to the fluid (if $\Delta e_{mech} > 0$) or extracted from the fluid (if $\Delta e_{mech} < 0$). The maximum (ideal) power generated by a turbine, for example, is Wmax = $\dot{m}\Delta e_{mech}$



$$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}g(z_1 - z_4) = \dot{m}gh$$
since $P_1 \approx P_4 = P_{atm}$ and $V_1 = V_4 \approx 0$

MECHANICAL ENERGY AND EFFICIENCY

- The transfer of mechanical energy is usually accomplished by a rotating shaft, and thus mechanical work is often referred to as shaft work.

- A pump or a fan receives shaft work (usually from an electric motor) and transfers it to the fluid as mechanical energy (less frictional losses). A turbine, on the other hand, converts the mechanical energy of a fluid to shaft work.

- Because of irreversibilities such as friction, mechanical energy cannot be converted entirely from one mechanical form to another, and the mechanical efficiency of a device or process is defined as

$$\eta_{\text{mech}} = \frac{\text{Mechanical energy output}}{\text{Mechanical energy input}} = \frac{E_{\text{mech, out}}}{E_{\text{mech, in}}} = 1 - \frac{E_{\text{mech, loss}}}{E_{\text{mech, in}}}$$

MECHANICAL ENERGY AND EFFICIENCY

- The degree of perfection of the conversion process between the mechanical work supplied or extracted and the mechanical energy of the fluid is expressed by the pump efficiency and turbine efficiency. In rate form, these are defined as

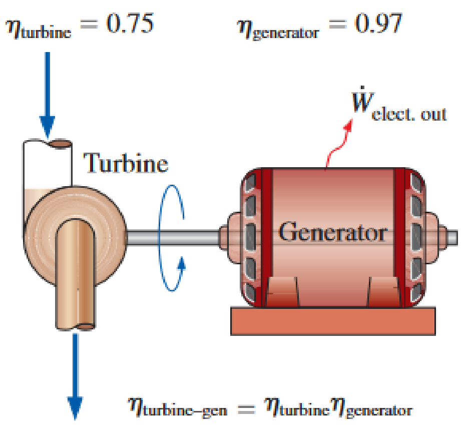
$$\eta_{\text{pump}} = \frac{\text{Mechanical power increase of the fluid}}{\text{Mechanical power input}} = \frac{\Delta \dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{shaft, in}}} = \frac{\dot{W}_{\text{pump}, u}}{\dot{W}_{\text{pump}}}$$

$$\Delta \dot{E}_{\text{mech, fluid}} = \dot{E}_{\text{mech, out}} - \dot{E}_{\text{mech, in}}$$

$$\eta_{\text{turbine}} = \frac{\text{Mechanical power output}}{\text{Mechanical power decrease of the fluid}} = \frac{\dot{W}_{\text{shaft, out}}}{|\Delta \dot{E}_{\text{mech, fluid}}|} = \frac{\dot{W}_{\text{turbine}}}{\dot{W}_{\text{turbine}, e}}$$

$$|\Delta \dot{E}_{\text{mech, fluid}}| = \dot{E}_{\text{mech, in}} - \dot{E}_{\text{mech, out}}$$

- The mechanical efficiency should not be confused with the motor efficiency and the generator efficiency, which are defined as



Motor:

$$\eta_{motor} = \frac{\text{Mechanical power output}}{\text{Electric power input}} = \frac{\dot{W}_{shaft,\ out}}{\dot{W}_{elect,\ in}}$$

and

Generator:

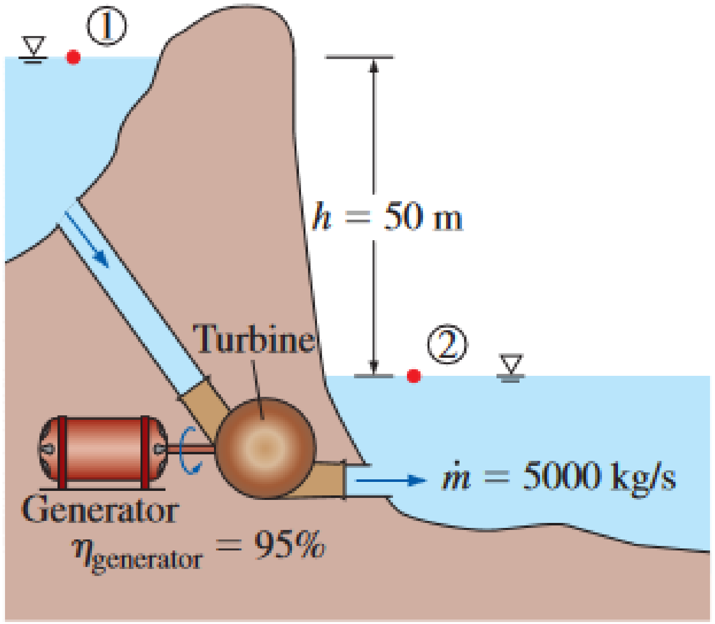
$$\eta_{generator} = \frac{\text{Electric power output}}{\text{Mechanical power input}} = \frac{\dot{W}_{elect,\ out}}{\dot{W}_{shaft,\ in}}$$

- A pump is usually packaged together with its motor, and a turbine with its generator. Therefore, we are usually interested in the combined or overall efficiency of pump–motor and turbine–generator combinations, which are defined as

$$\eta_{pump\text{-}motor} = \eta_{pump}\,\eta_{motor} = \frac{\dot{W}_{pump,\ u}}{\dot{W}_{elect,\ in}} = \frac{\Delta \dot{E}_{mech,\ fluid}}{\dot{W}_{elect,\ in}}$$

$$\eta_{turbine\text{-}gen} = \eta_{turbine}\,\eta_{generator} = \frac{\dot{W}_{elect,\ out}}{\dot{W}_{turbine,\ e}} = \frac{\dot{W}_{elect,\ out}}{|\Delta \dot{E}_{mech,\ fluid}|}$$

- **The water in a large lake is to be used to generate electricity by the installation of a hydraulic turbine–generator. The elevation difference between the free surfaces upstream and downstream of the dam is 50 m. Water is to be supplied at a rate of 5000 kg/s. If the electric power generated is measured to be 1862 kW and the generator efficiency is 95 percent, determine (a) the overall efficiency of the turbine–generator, (b) the mechanical efficiency of the turbine, and (c) the shaft power supplied by the turbine to the generator.**



Analysis (*a*) We perform our analysis from inlet (1) at the free surface of the lake to outlet (2) at the free surface of the downstream discharge site. At both free surfaces the pressure is atmospheric and the velocity is negligibly small. The change in the water's mechanical energy per unit mass is then

$$e_{\text{mech, in}} - e_{\text{mech, out}} = \underbrace{\cancel{\frac{P_{\text{in}} - P_{\text{out}}}{\rho}}}_{0} + \underbrace{\cancel{\frac{V_{\text{in}}^2 - V_{\text{out}}^2}{2}}}_{0} + g(z_{\text{in}} - z_{\text{out}})$$

$$= gh$$

$$= (9.81 \text{ m/s}^2)(50 \text{ m})\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = 0.491 \frac{\text{kJ}}{\text{kg}}$$

Then the rate at which mechanical energy is supplied to the turbine by the fluid and the overall efficiency become

$$|\Delta \dot{E}_{\text{mech, fluid}}| = \dot{m}(e_{\text{mech, in}} - e_{\text{mech, out}}) = (5000 \text{ kg/s})(0.491 \text{ kJ/kg}) = 2455 \text{ kW}$$

$$\eta_{\text{overall}} = \eta_{\text{turbine-gen}} = \frac{\dot{W}_{\text{elect, out}}}{|\Delta \dot{E}_{\text{mech, fluid}}|} = \frac{1862 \text{ kW}}{2455 \text{ kW}} = \mathbf{0.760}$$

Basically put the higher one in denominator instead of dying for which is what in formula:)

(*b*) Knowing the overall and generator efficiencies, the mechanical efficiency of the turbine is determined from

remember

$$\eta_{\text{turbine-gen}} = \eta_{\text{turbine}}\,\eta_{\text{generator}} \rightarrow \eta_{\text{turbine}} = \frac{\eta_{\text{turbine-gen}}}{\eta_{\text{generator}}} = \frac{0.76}{0.95} = \mathbf{0.800}$$

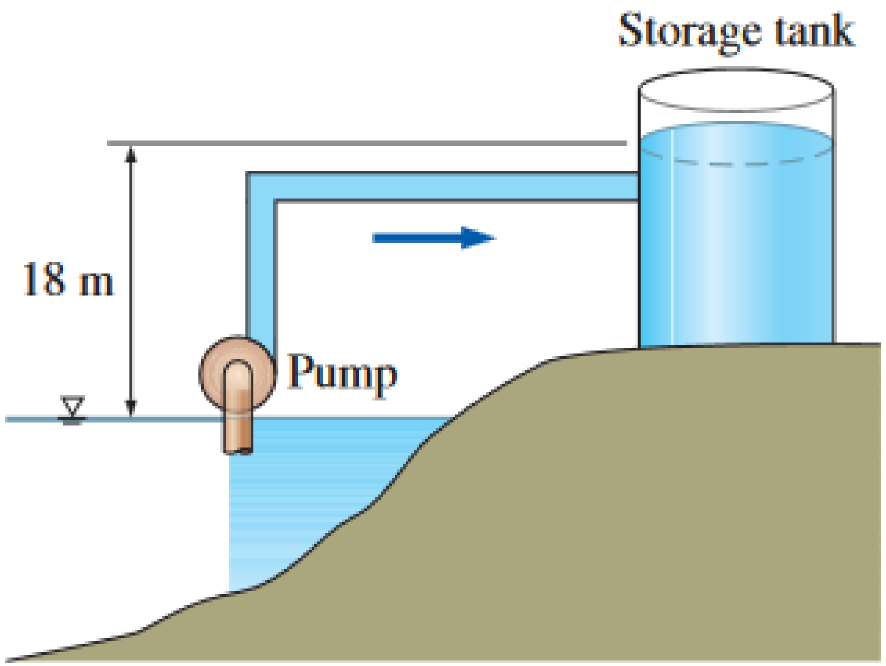
(*c*) The shaft power output is determined from the definition of mechanical efficiency,

$$\dot{W}_{\text{shaft, out}} = \eta_{\text{turbine}}|\Delta\dot{E}_{\text{mech, fluid}}| = (0.800)(2455\text{ kW}) = 1964\text{ kW} \approx \mathbf{1960\ kW}$$

Discussion Note that the lake supplies 2455 kW of mechanical power to the turbine, which converts 1964 kW of it to shaft power that drives the generator, which generates 1862 kW of electric power. There are irreversible losses through each component. Irreversible losses in the pipes are ignored

1kg = 1L

- **Water is pumped from a lake to a storage tank 18 m above at a rate of 70 L/s while consuming 20.4 kW of electric power. Disregarding any frictional losses in the pipes and any changes in kinetic energy, determine (a) the overall efficiency of the pump–motor unit and (b) the pressure difference between the inlet and the exit of the pump.**



Pressure is same both inside storage and below outside the pump. So change in pressure = Rho * g * h i.e
density for water = rho = 1000
g = 9.81
h = z = 18

MECHANICAL ENGINEERING SCIENCE

Chapter 2 – IC Engines

Dr. Mantesh B Khot
Department of Mechanical Engineering

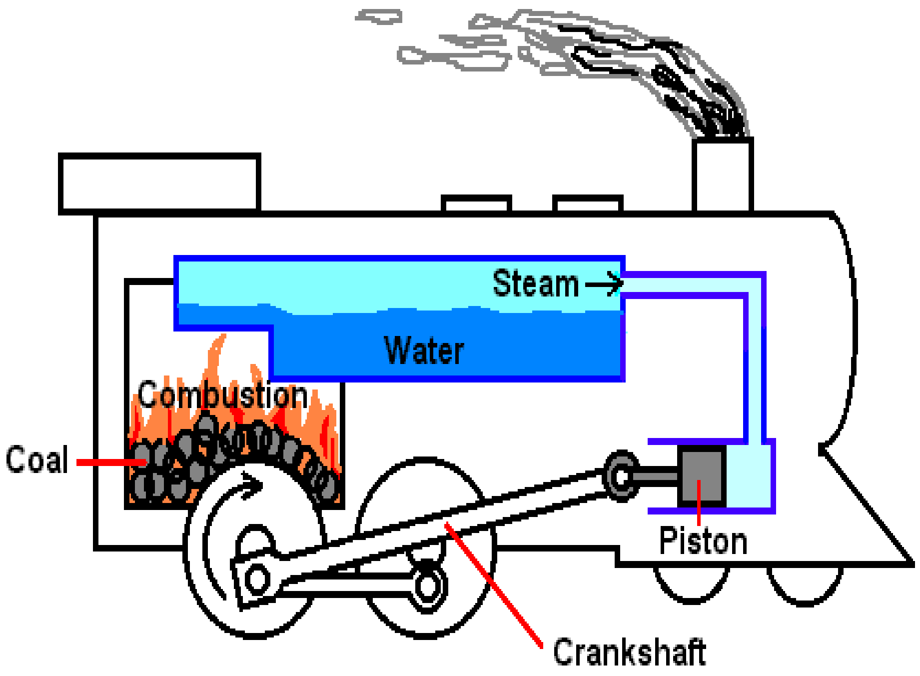
- **ENGINE –** An engine is a device which transforms one form of energy into another form.

- **HEAT ENGINE -** Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine.

- Heat engines can be broadly classified into two categories:
  (i) Internal Combustion Engines (IC Engines)
  (ii) External Combustion Engines (EC Engines)

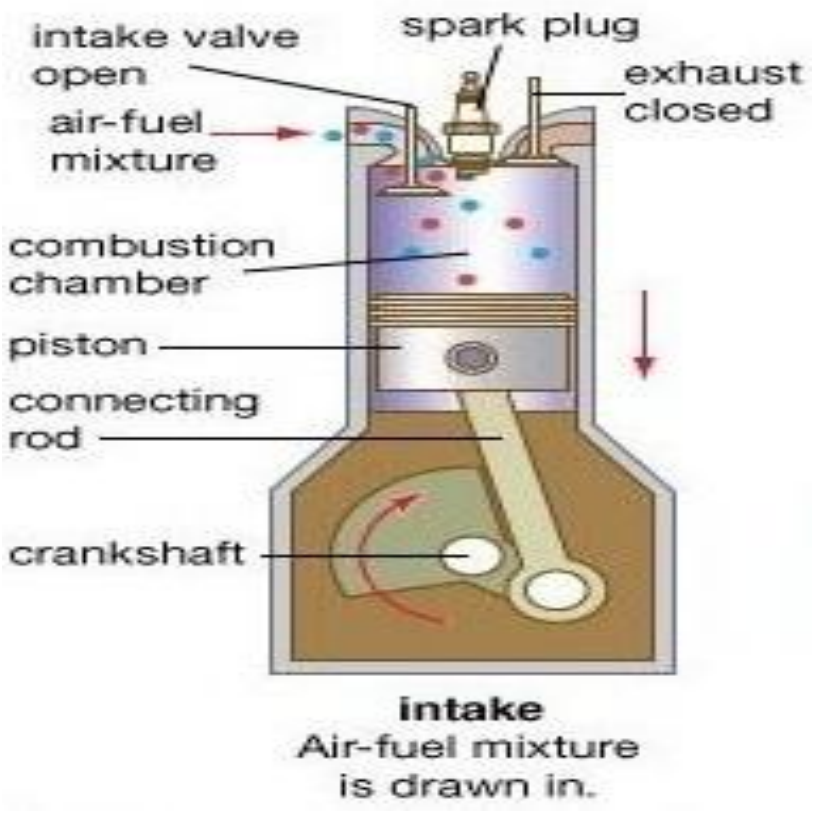
- External combustion engines are those in which combustion takes place outside the engine.

- For example, in a steam engine or a steam turbine, the heat generated due to the combustion of fuel is employed to generate high pressure steam which is used as the working fluid in a reciprocating engine or a turbine.



- Internal combustion engines are those in which combustion takes place within the engine.

- For example, in case of petrol or diesel engines, the products of combustion generated by the combustion of fuel and air within the cylinder form the working fluid.



- **CLASSIFICATION OF IC ENGINES** - There are several criteria for classification of I.C. engines. Some of the important criteria can be explained as:
  - Number of strokes per cycle
  - Nature of thermodynamic cycle
  - Ignition systems
  - Fuel used
  - Arrangement of cylinders
  - Cooling systems
  - Fuel supply systems

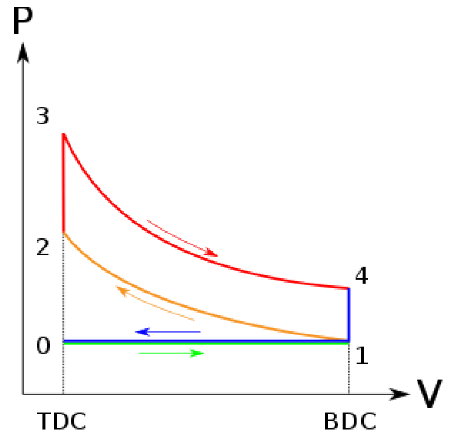
Number of Strokes Per Cycle:

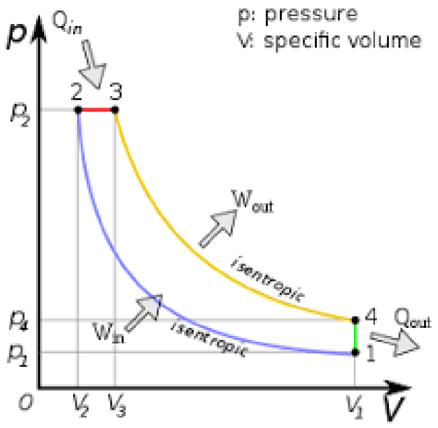
- I.C. engines can be classified as **four-stroke engines (4S)** and **two-stroke engines (2S).**

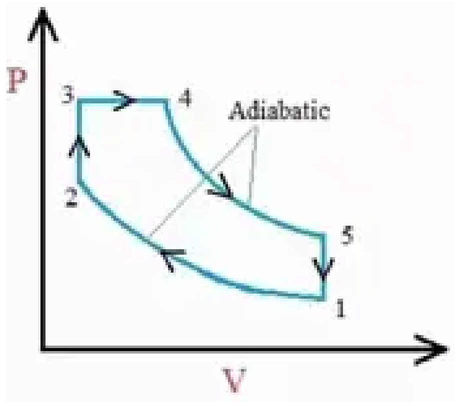
- In four-stroke engines, the thermodynamic cycle is completed in four strokes of the piston or two revolutions of the crankshaft whereas, in two-stroke engines, the thermodynamic cycle is completed in two strokes of the piston or one revolution of the crankshaft.

Nature of Thermodynamic Cycle:

- I.C. engines can be classified as **Otto cycle, Diesel cycle, and Dual cycle engines**.







Ignition Systems:

- There are two modes of ignition of fuel inside the cylinder — **spark ignition** and **compression ignition**.

- In spark ignition, sparking starts at the end of compression stroke from spark plug while in compression ignition the temperature of the fuel is increased to the self-ignition point by compressing the air alone and at the end of compression, fuel is injected into the cylinder.

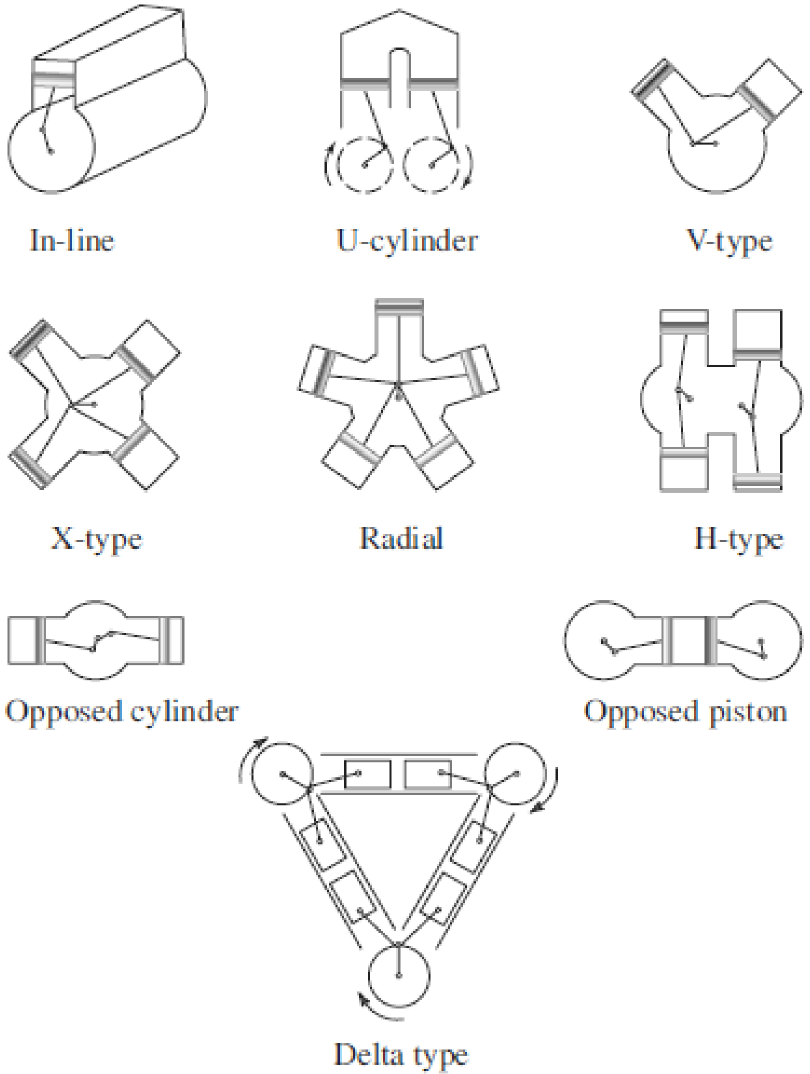
Fuel Used:

- On the basis of fuel used, I.C. Engines can be classified as (a) **Gas engines** like CNG, LPG, etc. (b) **Petrol engine**, (c) **Diesel engine**, and (d) **Bi-fuel engine**. In a bi-fuel engine, two types of fuels are used like gaseous fuel and liquid fuel.

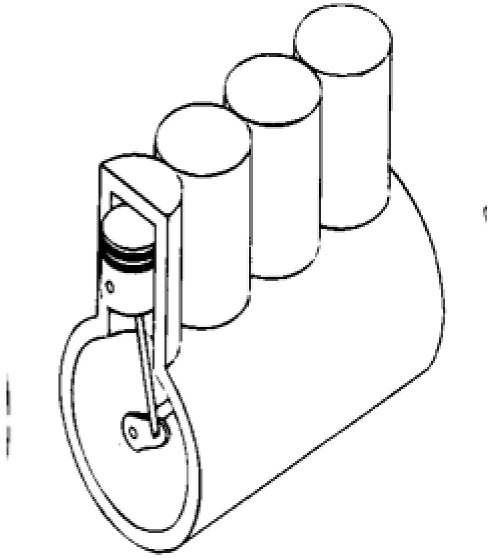
Arrangement of Cylinders:

- Another common method of classifying IC engines is by the cylinder arrangement. The cylinder arrangement is only applicable to multi cylinder engines.

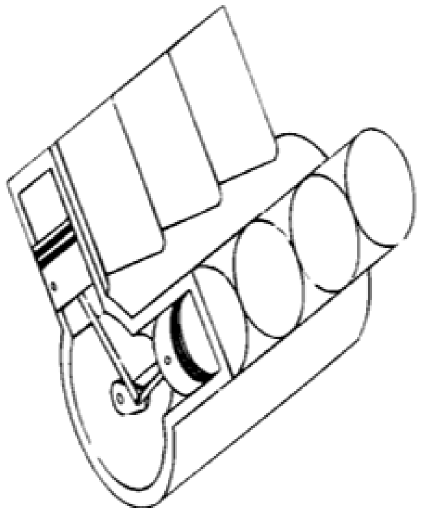
- A number of cylinder arrangements are popular with designers. The details of various cylinder arrangements are shown.



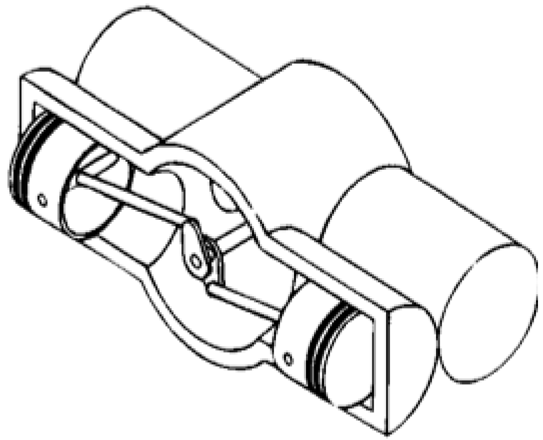
In-line Engine : The in-line engine is an engine with one cylinder bank, i.e. all cylinders are arranged linearly, and transmit power to a single crankshaft. This type is quite common with automobile engines. Four and six cylinder in-line engines are popular in automotive applications.



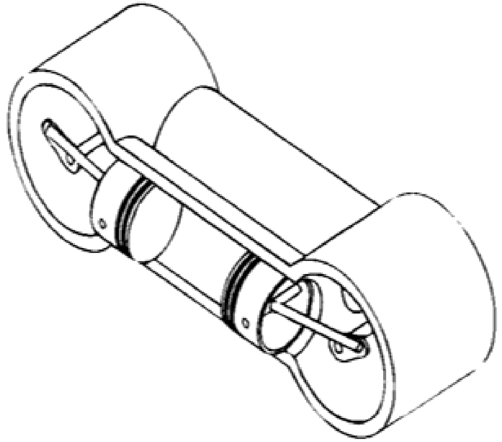
'V' Engine : In this engine there are two banks of cylinders (i.e., two in line engines) inclined at an angle to each other and with one crankshaft. Most of the high powered automobiles use the 8 cylinder 'V' engine, four in-line on each side of the 'V'. Engines with more than six cylinders generally employ this configuration.



Opposed Cylinder Engine : This engine has two cylinder banks located in the same plane on opposite sides of the crankshaft. It can be visualized as two 'in-line' arrangements 180 degrees apart. It is inherently a well balanced engine and has the advantages of a single crankshaft. This design is used in small aircrafts.



Opposed Piston Engine : When a single cylinder houses two pistons, each of which driving a separate crankshaft, it is called an opposed piston engine. The movement of the pistons is synchronized by coupling the two crankshafts. Opposed piston arrangement, like opposed cylinder arrangement is inherently well balanced.



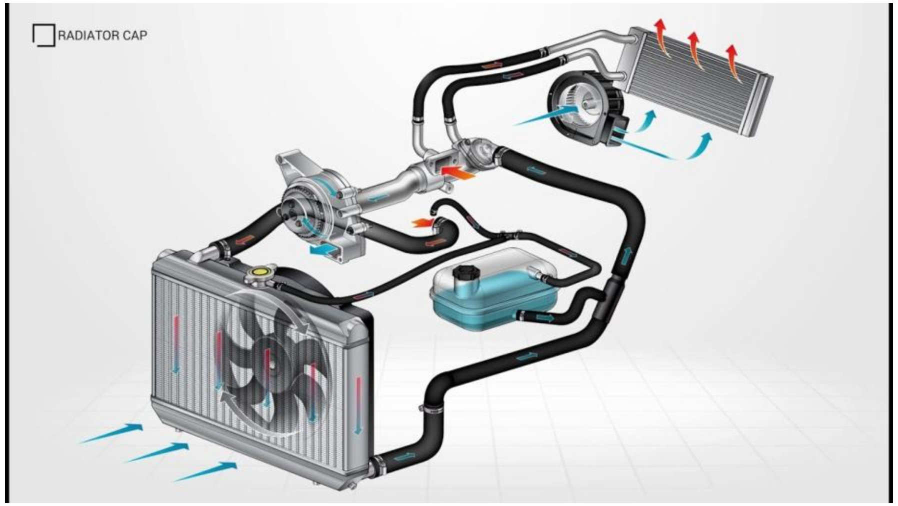
Radial Engine :

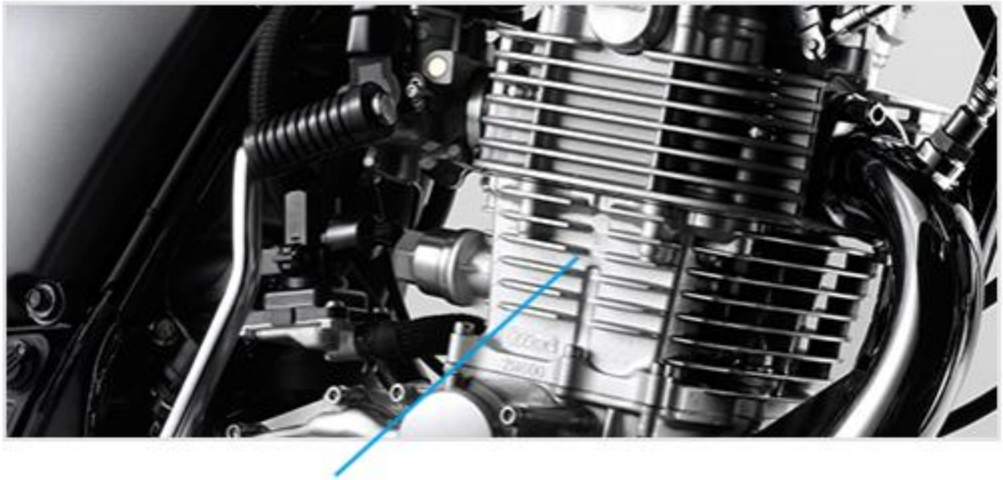
Radial engine is one where more than two cylinders in each row are equally spaced around the crankshaft. The radial arrangement of cylinders is most commonly used in conventional air-cooled aircraft engines. Pistons of all the cylinders are coupled to the same crankshaft.

Cooling Systems:

- There are two types of cooling systems in I.C. Engines—**water cooling** and **air cooling**.

- In water cooling, coolant and radiators are provided to cool the cylinder. In air cooling, fins are provided on the surface of the cylinder to radiate the heat into the atmosphere. Low power engines like motorbikes are equipped with air cooling systems, whereas large power producing engines like a car, bus, truck, etc. are equipped with water cooling systems.





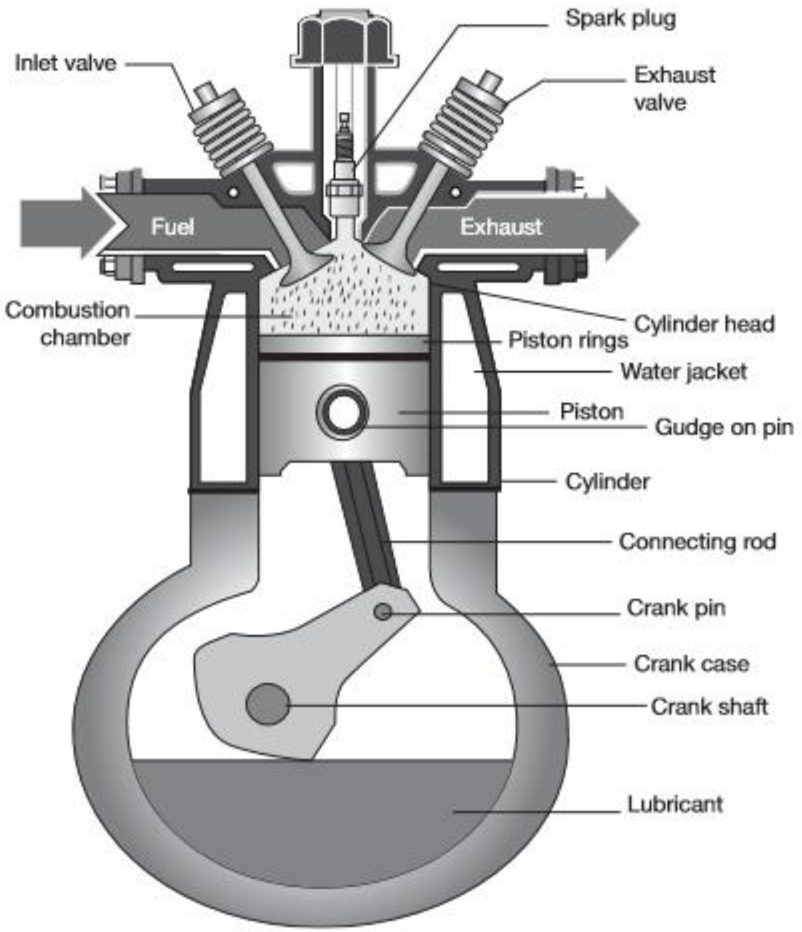
Fins on an air-cooled engine

Fuel Supply Systems:

- On the basis of fuel supply systems, I.C. Engines can be classified as:
  (a) Carburetor engine,
  (b) Air injection engine, and
  (c) Airless or solid or Mechanical injection engines.

- In a carburetor engine, air and fuel are properly mixed into the carburetor and then fed into the cylinder. In air injection engines, fuel is supplied to the cylinder with the help of compressed air. In mechanical injection engines, the fuel is injected into the cylinder with the help of mechanical pump and nozzle.

BASIC STRUCTURE OF AN IC ENGINE:

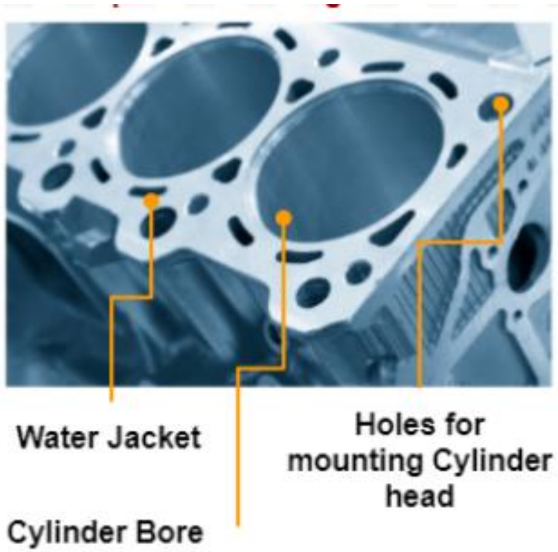


Cylinder:

- It is a hollow cylindrical structure closed at one end with the cylinder head.

- The combustion of the fuel takes place inside the cylinder. This is known as the heart of the engine. It is made of hard and high thermal conductivity materials by casting. A piston reciprocates inside the cylinder and produces power.

Cylinder Head: It covers one end of the cylinder and consists of valves/ports and spark plug/injector.



Piston:

- It is a cylindrical component which is fitted perfectly inside the cylinder providing a gas-tight space with the piston rings and the lubricant.

- The piston is connected to connecting rod by gudgeon pin. The main function of the piston is to transfer the power produced by combustion of the fuel to the crankshaft.

Piston Rings:

- The outer periphery of the piston is provided with several grooves into which piston rings are fitted. The piston is fitted with these rings. The upper ring is known as **compression ring** and the lower rings are known as **oil rings**.

Oil ring reduces friction between the piston and the walls which cover it

- The function of the compression ring is to compress the air or air-fuel mixture and the function of the oil rings is to collect the surplus lubricating oil on the liner surface.

Connecting Rod:

- It connects the piston and the crankshaft. One end, called the small end, is connected to the gudgeon pin located in the piston and the other end, called big end, is connected to crank pin.

- The function of the connecting rod is to transfer the reciprocating motion of the piston into rotary motion of the crankshaft.

Crankshaft:

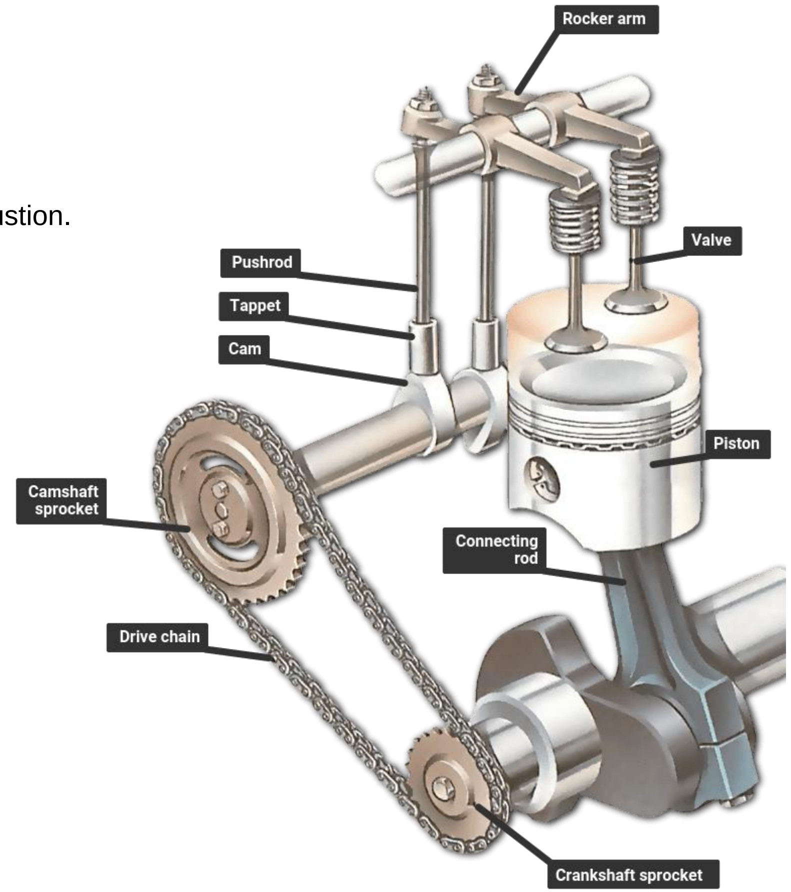
- It is principal rotating part of the engine which controls the sequence of reciprocating motion of the pistons. It consists of several bearings and crank pins.

Valves:

Inlet and outlet valve. inlet to take in air-fuel mixture, outlet to remove the residue after combustion.

- Normally, the two valves are used for each cylinder, which may be of mushroom shaped poppet type.

- They are provided on the cylinder head for regulating the charge coming into the cylinder and for discharging the products of combustion from the cylinder. The valve mechanism consists of cams, cam follower, push rod, rocker arms, and spring.

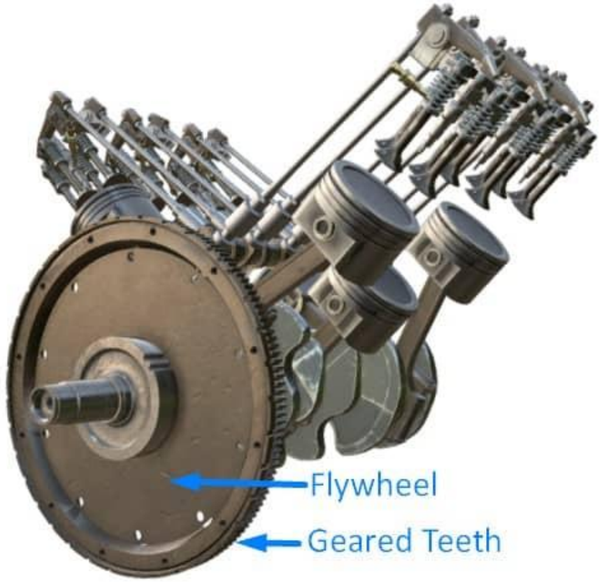


Crankcase:

- The bottom portion of the cylinder block is called crankcase. A cover called crankcase which becomes a sump for lubricating oil is fastened to the bottom of the cylinder block.

Flywheel:

- It is a heavy wheel mounted on the crankshaft to minimize the cyclic variations in speed. It absorbs the energy during the power stroke and releases it during the non-power stroke.



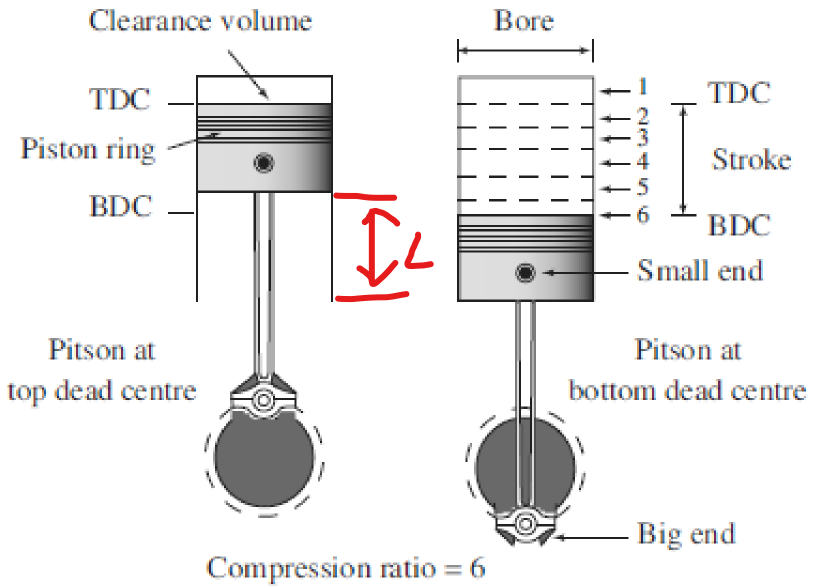
NOMENCLATURE:

Cylinder Bore (d) : The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d.

Piston Area (A) : The area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A.

Stroke (L) : The nominal distance through which a working piston moves between two successive reversals of its direction of motion is called the stroke and is designated by the letter L.

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 of the stroke is called the dead centre.



NOMENCLATURE:

There are two dead centres in the engine as indicated in Fig. They are:

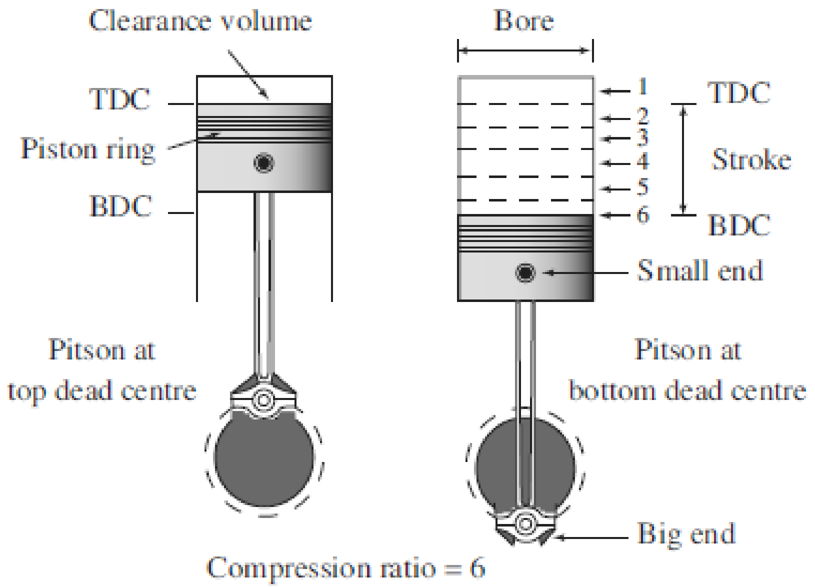
(i) Top Dead Centre (ii) Bottom Dead Centre

(i) Top Dead Centre (TDC) : It is the dead centre when the piston is farthest from the crankshaft.

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

Displacement or Swept Volume (Vs) : The nominal volume swept by the working piston when travelling from one dead centre to the other is called the displacement volume. It is usually expressed in terms of cubic centimeter (cc).

$$V_s = A \times L = \frac{\pi}{4} d^2 L$$

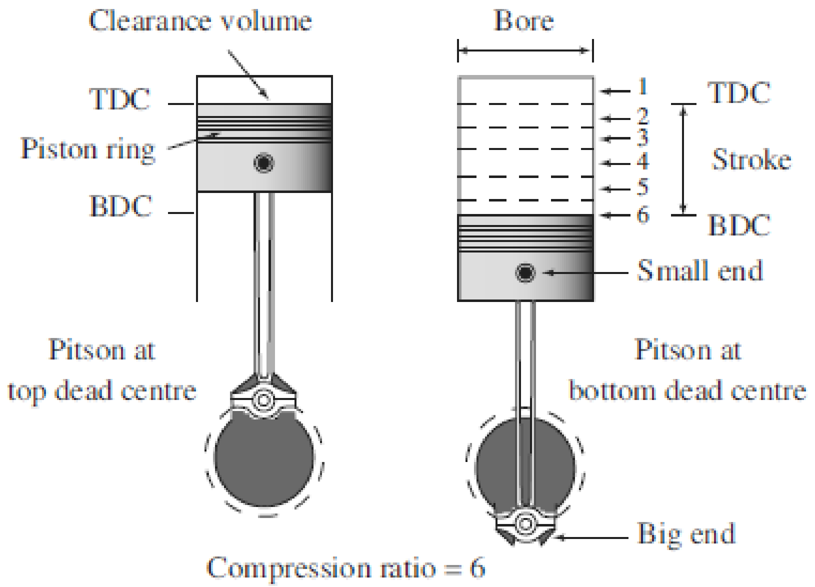


NOMENCLATURE:

Clearance Volume (Vc): The nominal volume of the combustion chamber above the piston when it is at the top dead centre is the clearance volume.

Compression Ratio (r) : It is the ratio of the total cylinder volume when the piston is at the bottom dead centre, Vt , to the clearance volume, Vc.

$$r = \frac{V_T}{V_C} = \frac{V_C + V_s}{V_C} = 1 + \frac{V_s}{V_C}$$



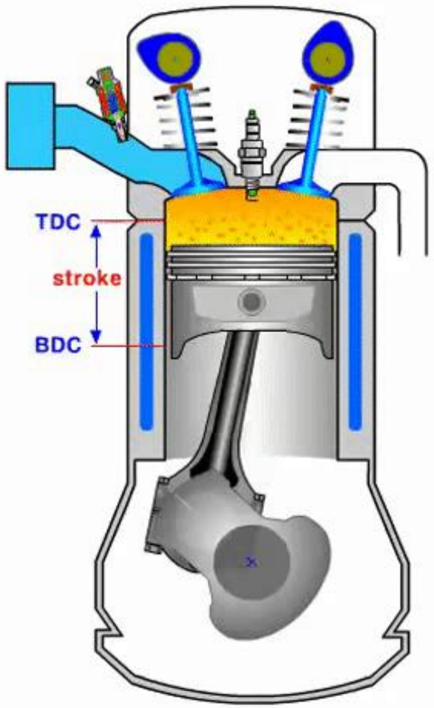
WORKING PRINCIPLE OF 4S PETROL ENGINE (SPARK IGNITION ENGINE)

- In a four-stroke engine, the cycle of operations is completed in **four strokes** of the piston or **two revolutions** of the crankshaft.

- During the four strokes, there are five events to be completed, viz., suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crankshaft rotation and hence a four-stroke cycle is completed through 720° of crank rotation.

- The cycle of operation for an ideal four-stroke SI engine consists of the following four strokes :

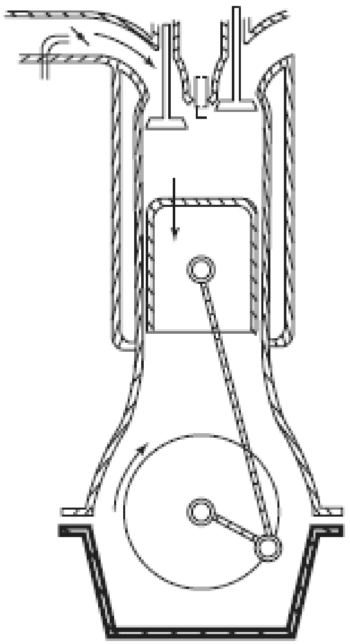
  (i) suction or intake stroke;
  (ii) compression stroke;
  (iii) expansion or power stroke and
  (iv) exhaust stroke.

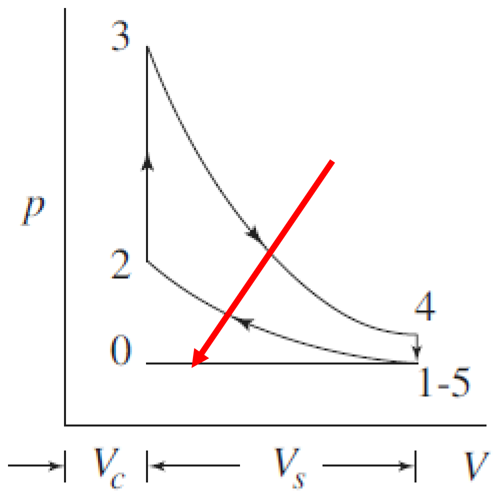


WORKING PRINCIPLE OF 4S PETROL ENGINE

Suction Stroke:

- Suction stroke 0→1 starts when the piston is at the top dead centre and about to move downwards.
- The inlet valve is assumed to open instantaneously and at this time the exhaust valve is in the closed position.
- Due to the suction created by the motion of the piston towards the bottom dead centre, the charge consisting of fuel-air mixture is drawn into the cylinder.
- When the piston reaches the bottom dead centre the suction stroke ends and the inlet valve closes instantaneously.





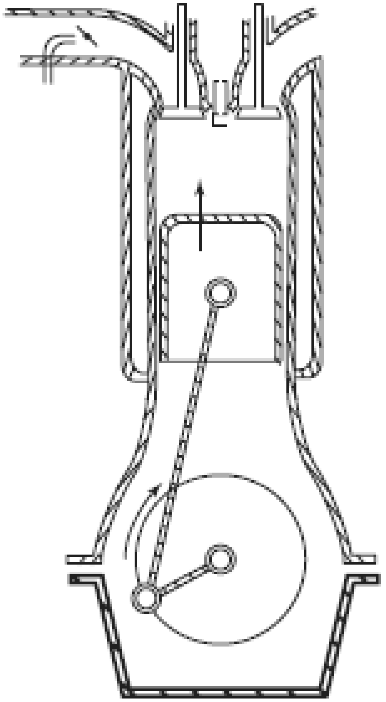
WORKING PRINCIPLE OF 4S PETROL ENGINE

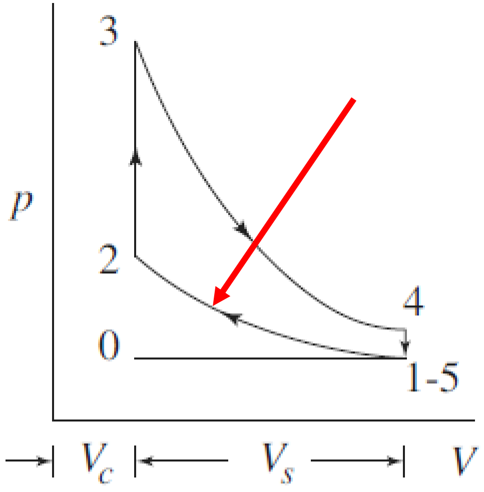
Compression Stroke:

- The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston 1→2.

- During this stroke both inlet and exhaust valves are in closed position.

- The mixture which fills the entire cylinder volume is now compressed into the clearance volume.

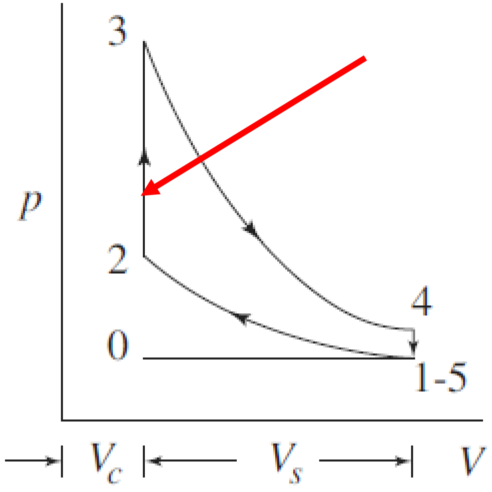




WORKING PRINCIPLE OF 4S PETROL ENGINE

Compression Stroke:

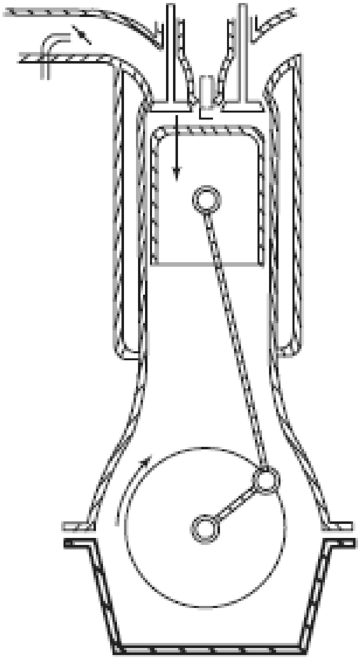
- At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head.
- In ideal engines it is assumed that burning takes place instantaneously when the piston is at the top dead centre and hence the burning process can be approximated as **heat addition at constant volume**.
- During the burning process the chemical energy of the fuel is converted into heat energy producing a temperature rise of about 2000°C (process 2→3).
- The pressure at the end of the combustion process is considerably increased due to the heat release from the fuel.

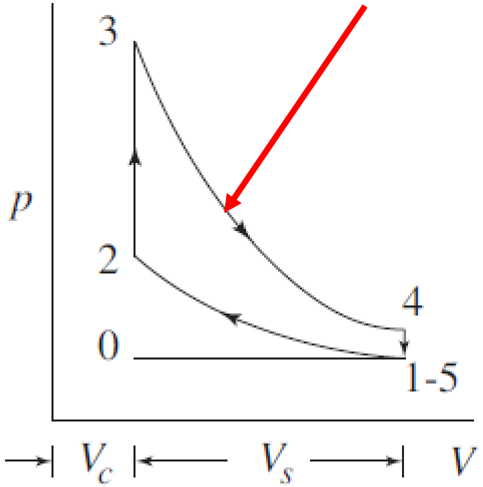


WORKING PRINCIPLE OF 4S PETROL ENGINE

Expansion or Power Stroke :

- The high pressure of the burnt gases forces the piston towards the BDC, (stroke 3→4).
- Both the valves are in closed position.
- Of the four-strokes only during this stroke power is produced. Both pressure and temperature decrease during expansion.





WORKING PRINCIPLE OF 4S PETROL ENGINE

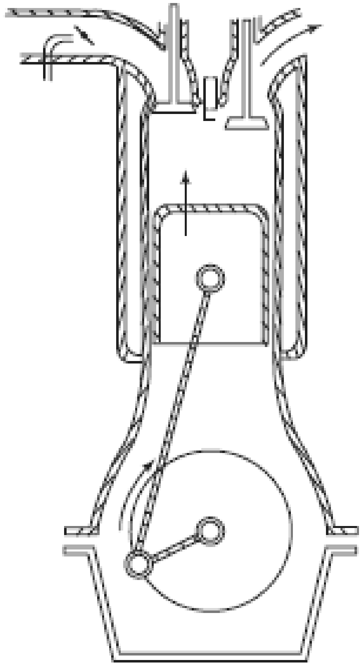
Exhaust Stroke:

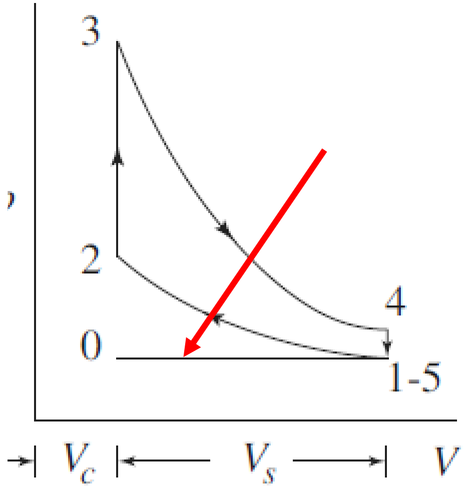
- At the end of the expansion stroke the exhaust valve opens instantaneously and the inlet valve remains closed.

- The pressure falls to atmospheric level a part of the burnt gases escape.

- The piston starts moving from the bottom dead centre to top dead centre (stroke 5→0) and sweeps the burnt gases out from the cylinder almost at atmospheric pressure.

- The exhaust valve closes when the piston reaches TDC.





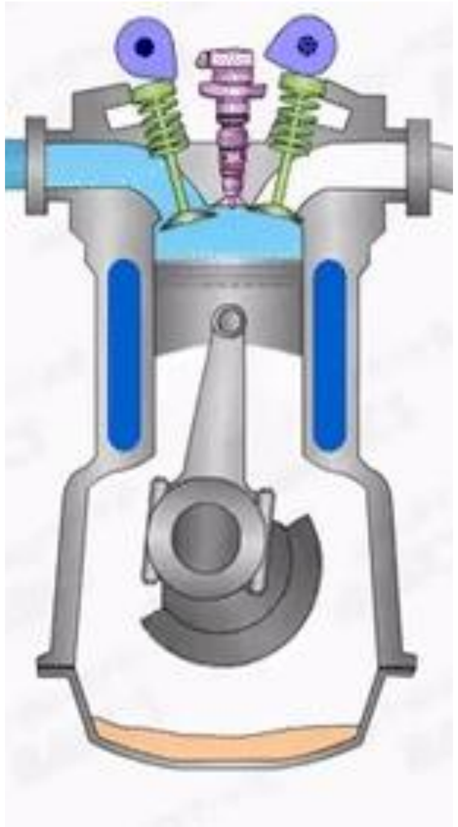
WORKING PRINCIPLE OF 4S DIESEL ENGINE (COMPRESSION IGNITION ENGINE)

- The four-stroke CI engine is similar to the four-stroke SI engine but it operates at a much higher compression ratio. The compression ratio of an SI engine is between 6 and 10 while for a CI engine it is from 16 to 20.

- In the CI engine during suction stroke, air, instead of a fuel-air mixture, is inducted.

- Due to higher compression ratios employed, the temperature at the end of the compression stroke is sufficiently high to self ignite the fuel which is injected into the combustion chamber.

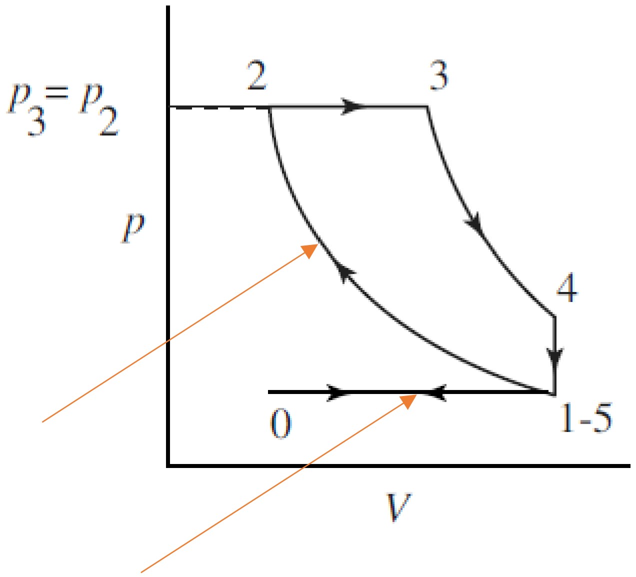
- In CI engines, a high pressure fuel pump and an injector are provided to inject the fuel into the combustion chamber. The carburettor and ignition system necessary in the SI engine are not required in the CI engine.

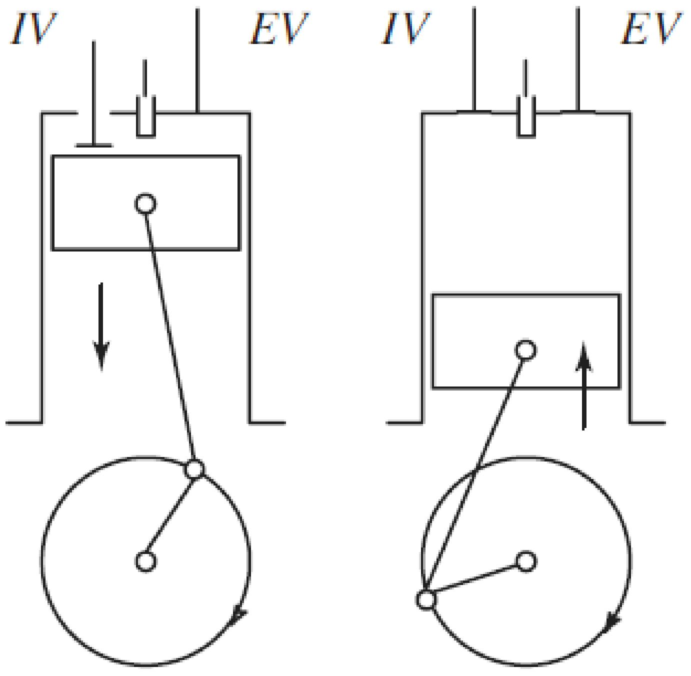


WORKING PRINCIPLE OF 4S DIESEL ENGINE

Suction Stroke: Air alone is inducted during the suction stroke. During this stroke inlet valve is open and exhaust valve is closed.

Compression Stroke: Air inducted during the suction stroke is compressed into the clearance volume. Both valves remain closed during this stroke.





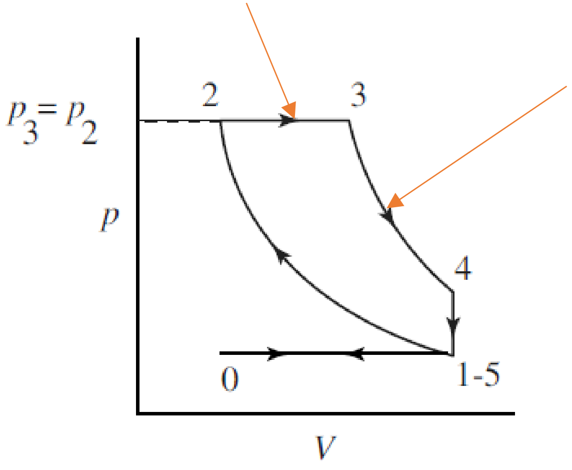
(a) Suction (b) Compression

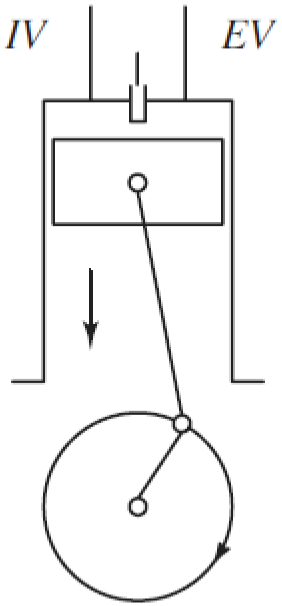
WORKING PRINCIPLE OF 4S DIESEL ENGINE

Expansion Stroke : Fuel injection starts nearly at the end of the compression stroke.

The rate of injection is such that combustion maintains the pressure constant in spite of the piston movement on its expansion stroke increasing the volume. Heat is assumed to have been added at **constant pressure**.

After the injection of fuel is completed (i.e. after cut-off) the products of combustion expand. Both the valves remain closed during the expansion stroke.





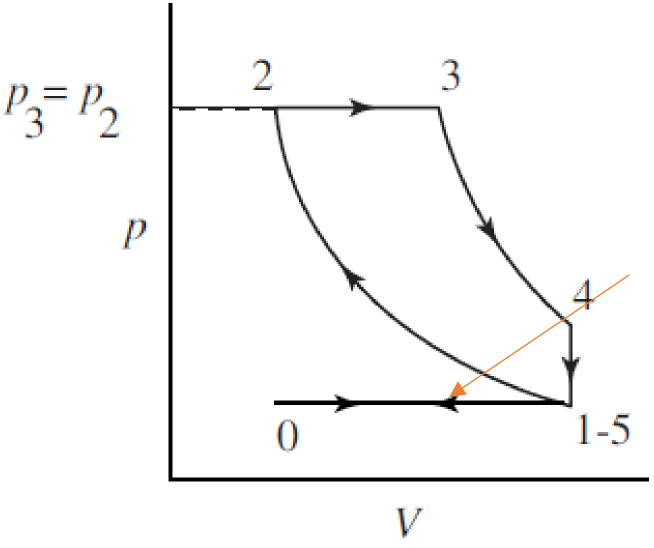
(c) Expansion

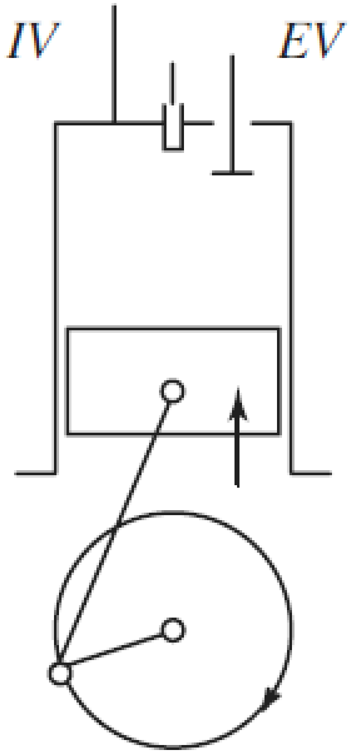
WORKING PRINCIPLE OF 4S DIESEL ENGINE

Exhaust Stroke :

The piston travelling from BDC to TDC pushes out the products of combustion.

The exhaust valve is open and the intake valve is closed during this stroke.





(d) Exhaust

COMPARISON OF PETROL AND DIESEL ENGINES

Description	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
Basic cycle	Works on **Otto cycle** or constant volume heat addition cycle.	Works on **Diesel cycle** or constant pressure heat addition cycle.
Fuel	Petrol, a highly volatile fuel. Self-ignition temperature is high.	Diesel oil, a non-volatile fuel. Self-ignition temperature is comparatively low.
Introduction of fuel	A gaseous mixture of fuel-air is introduced during the suction stroke. A carburettor and an ignition system are necessary. Modern engines have petrol injection	Fuel is injected directly into the combustion chamber at high pressure at the end of the compression stroke. A fuel pump and injector are necessary.

COMPARISON OF PETROL AND DIESEL ENGINES

Description	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
Ignition	Requires an ignition system with spark plug in the combustion chamber.	Self-ignition occurs due to high temperature of air because of the high compression.
Compression ratio	6 to 10. Upper limit is fixed by antiknock quality of the fuel.	16 to 20. Upper limit is limited by weight increase of the engine.
Speed	Due to light weight they are high speed engines.	Due to heavy weight they are low speed engines.
Thermal efficiency	Because of the lower CR, the maximum value of thermal efficiency that can be obtained is lower.	Because of higher CR, the maximum value of thermal efficiency that can be obtained is higher.

COMPARISON OF PETROL AND DIESEL ENGINES

Description	Petrol Engine (SI Engine)	Diesel Engine (CI Engine)
Weight	Lighter due to comparatively lower peak pressures.	Heavier due to comparatively higher peak pressures.

APPLICATIONS OF IC ENGINES

- The most important application of IC engines is in transport on land, sea and air. Other applications include industrial power plants and as prime movers for electric generators.

4S Petrol Engines:

- The most important application of small four-stroke petrol engines is in automobiles. A typical automobile is powered by a four-stroke four cylinder engine developing an output in the range of 30-60 kW at a speed of about 4500 rpm.

- Another application of four-stroke petrol engine is in small pumping sets and mobile electric generating sets.

- Smaller aircrafts normally employ four-stroke gasoline (SI) radial engines.

APPLICATIONS OF IC ENGINES

4S Diesel Engines:

- The four-stroke diesel engine is one of the most efficient and versatile prime movers. It is manufactured in sizes from 50 mm to more than 1000 mm of cylinder diameter and with engine speeds ranging from 100 to 4500 rpm while delivering outputs from 1 to 35000 kW.

- Small diesel engines are used in pump sets, construction machinery, air compressors, drilling rigs and many miscellaneous applications.

- Tractors for agricultural application use about 30 kW diesel engines whereas jeeps, buses and trucks use 40 to 100 kW diesel engines.

- Diesel engines are used both for mobile and stationary electric generating plants of varying capacities.

PERFORMANCE PARAMETERS OF IC ENGINES

- The following factors are to be considered in evaluating the performance of an engine:

  (i) **Maximum power or torque**

  (ii) **Specific fuel consumption**

  (iii) **Reliability and durability**

- Engine performance characteristics can be determined by the following two methods.

  (i) By using **experimental results** obtained from engine tests.

  (ii) By **analytical calculation** based on theoretical data.

PERFORMANCE PARAMETERS OF IC ENGINES

Engine Power

- The energy flow through the engine is expressed in three distinct terms. They are indicated power, IP, friction power FP and brake power, BP.

- Indicated power can be computed from the measurement of forces in the cylinder and brake power may be computed from the measurement of forces at the crankshaft of the engine. Friction power can be calculated with the above two values.

PERFORMANCE PARAMETERS OF IC ENGINES

ii) Indicated Power - The power developed inside the cylinder of the engine is called the indicated power (IP).

PERFORMANCE PARAMETERS OF IC ENGINES

iii) Brake Power – It is the net power available at the crank shaft of the engine for performing useful work (BP).

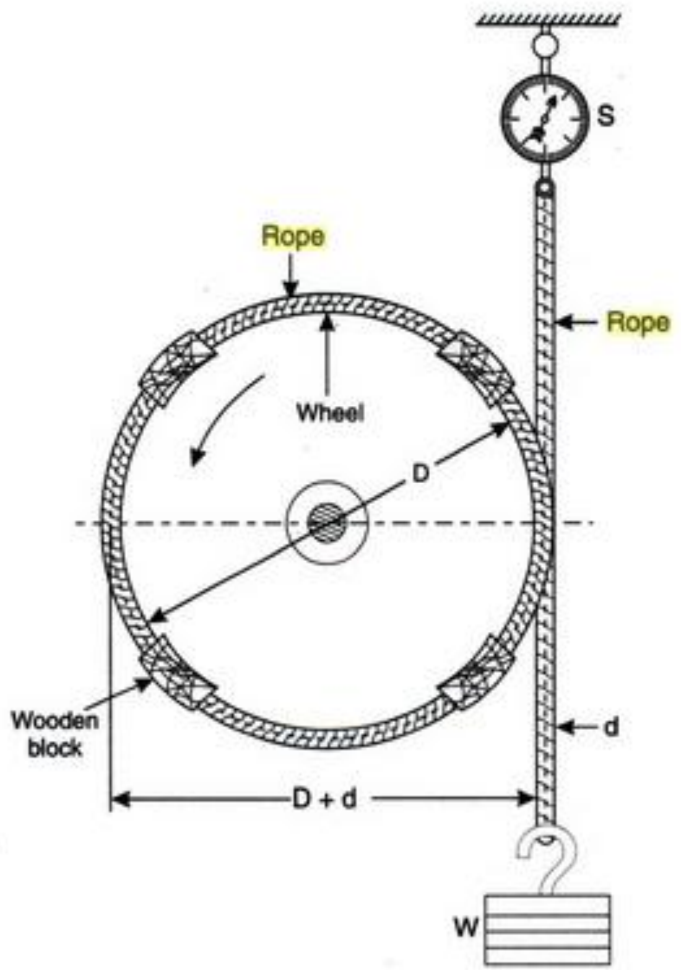
- It is always less than indicated power since a part of the power developed in the engine cylinder is used to overcome the frictional losses at different moving parts of the engine.
- Brake power of an engine can be determined by a brake of some kind applied to the brake pulley of the engine. The arrangement used for determination of BP of the engine is known as dynamometer. Usually, **rope brake dynamometer** is used for this purpose.
- BP is given by,

$$BP = \frac{2\pi NT}{60 \times 1000} \quad (expressed\ in\ kW)$$

where
N = Crank speed in rpm; T = Torque in N-m

PERFORMANCE PARAMETERS OF IC ENGINES

- The rope brake dynamometer consists of rope wrapped round the brake drum or flywheel keyed to crankshaft of an engine whose BP is to be determined.
- One end of the rope is connected to the spring balance (with reading ‘S’) while at the other end is hung a weight W.
- Wooden blocks are incorporated to check the rope slipping off the brake drum/flywheel.
- It is evident from the figure that the net brake load which opposes the rotation is (W-S) and the effective radius at which the net load acts = (D+d)/2, where D is the diameter of the brake drum and d is the diameter of the rope.



PERFORMANCE PARAMETERS OF IC ENGINES

- Therefore,

$\therefore$ Braking torque,

$$T = \text{Frictional force} \times \text{radius} = (W - S)\left(\frac{D+d}{2}\right) \text{ Nm.}$$

$$\therefore \quad \text{Brake power, B.P.} = \frac{(W-S)\pi(D+d)N}{60 \times 10^3} \text{ kW}$$

PERFORMANCE PARAMETERS OF IC ENGINES

iv) Friction Power – It is the difference between the indicated power and brake power.

$$FP = IP - BP$$

- Apart from expressing engine performance in terms of power, it is also essential to express in terms of efficiencies.

v) Mechanical efficiency - Mechanical efficiency takes into account the mechanical losses in an engine like friction losses in case of pistons, bearings, gears, valve mechanisms, losses due to absorption of power by fuel pump, oil pump, radiator etc. In general, mechanical efficiency of engines varies from 65 to 85%.

It is defined as the ratio of brake power to indicated power.

$$\eta_{mech} = \frac{Brake\ power\ (BP)}{Indicated\ power\ (IP)}$$

PERFORMANCE PARAMETERS OF IC ENGINES

vi) Thermal efficiency – It gives an idea of the output generated by the engine with respect to heat supplied in the form of fuel.

- Thermal efficiency is expressed in two ways, viz., **indicated thermal efficiency** and **brake thermal efficiency.**

- **Indicated thermal efficiency =** $\eta_{ith} = \dfrac{IP}{CV \times m_f}$

- **Brake thermal efficiency** = $\eta_{bth} = \dfrac{BP}{CV \times m_f} \times 100$

CV is the calorific value of the fuel in KJ/kg and m_f is mass flow rate of the fuel in kg/s. IP and BP are in kW.

PERFORMANCE PARAMETERS OF IC ENGINES

vii) Specific fuel consumption – It is the mass of fuel consumed per kW of power developed per hour and is a criterion of economical power production.

- Specific fuel consumption is expressed in two ways, viz., **indicated specific fuel consumption (ISFC)** and **brake specific fuel consumption (BSFC).**
- **ISFC =** $\dfrac{\boldsymbol{Mass\ of\ fuel\ consumed\ in\ kg/hr}}{\boldsymbol{Indicated\ Power\ in\ kW}}$
- **BSFC =** $\dfrac{\boldsymbol{Mass\ of\ fuel\ consumed\ in\ kg/hr}}{\boldsymbol{Brake\ Power\ in\ kW}}$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

1) The following data refers to a test on a single cylinder engine working on four stroke cycle:

   Diameter of brake drum = 60 cm
   Rope diameter = 3 cm
   Load on brake drum = 25 kg
   Spring balance reading = 5 kg
   Speed of engine = 400 rpm
   Bore = 10 cm
   Stroke = 15 cm
   Indicated Power = 3.141 kW

   Calculate (i) Brake Power (ii) Mechanical Efficiency

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

1) Brake Power (BP)

Torque $= T = (W - S) \times \left(\frac{D_b + d_r}{2}\right) = (25 - 5) \times 9.81 \times \left(\frac{0.6+0.03}{2}\right) = 61.803\ Nm$

Brake Power = $BP = \frac{2\pi NT}{60\times1000} = \frac{2\times\pi\times400\times61.803}{60\times1000} = 2.589\ kW$

2) Mechanical Efficiency

$$\eta_{mech} = \frac{BP}{IP} = \frac{2.589}{3.141} = 0.8241\ or\ 82.41\%$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

2) The following observations are taken during a trial on four stroke diesel engine.

Cylinder diameter = 25 cm
Stroke = 40 cm
Speed = 250 rpm
Brake load = 70 kg
Brake drum diameter = 2m
Diesel oil consumption = 0.1 litres/min
Specific gravity of fuel = 0.78
Calorific value of fuel = 43900 kJ/kg
Indicated Power = 24.54 kW

Determine (i) Brake Power (ii) Mechanical efficiency (iii) Brake thermal efficiency (iv) Indicated thermal efficiency.

[redacted]

PERFORMANCE PA[redacted]

Solution:

1) Brake Power

rope diameter = 0

(D+d)/2 = 0+2/2 = 1

We know that brake power is given by

$$BP = \frac{2\pi NT}{60000} = \frac{2\times\pi\times250\times70\times9.81\times1}{60000} = 17.98\ kW$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

2) Mechanical efficiency

We know that mechanical efficiency is given by,

$$\eta_{mech} = \frac{BP}{IP} = 73.3\%$$

3) Brake Thermal Efficiency

We know that brake thermal efficiency is given by,

$$\eta_{Bth} = \frac{BP}{m_f \times CV} = \frac{17.98}{\frac{0.1\times0.78\times1000}{1000\times60}\times43900} = 31.5\%$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

4) Indicated Thermal Efficiency

We know that indicated thermal efficiency is given by,

$$\eta_{Ith} = \frac{IP}{m_f \times CV} = \frac{24.54}{\frac{0.1\times0.78\times1000}{1000\times60}\times43900} = 43\%$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

3) A four cylinder four stroke petrol engine develops 30 kW at 2500 rpm. The mean effective pressure on each piston is 8 bar and mechanical efficiency is 80%. Calculate the diameter and stroke of each cylinder.

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

We know that,

$$\eta_{mech} = \frac{BP}{IP}$$

Therefore,

$$IP = \frac{BP}{\eta_{mech}} = \frac{30}{0.8} = 37.5\ kW$$

Also, $IP = \frac{np_m LANK}{60 \times 1000}$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

$$37.5 = \frac{4 \times 8 \times 10^5 \times L \times (\frac{\pi}{4} d^2) \times 2500 \times (\frac{1}{2})}{60 \times 1000}$$

$$7.16 \times 10^{-4} = Ld^2$$

From data, L/d = 1.5 or L = 1.5d

Therefore,

$$7.16 \times 10^{-4} = (1.5d)d^2$$

This gives, d = 0.078 m = 78 mm; L = 1.5d = 117 mm

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

4) A diesel engine develops 5 kW. Its indicated thermal efficiency is 30% and mechanical efficiency is 75%. Estimate the fuel consumption of the engine in a) kg/hr and b) litres/hr. Also find ISFC and BSFC. Take CV of fuel = 42000 kJ/kg and specific gravity of fuel = 0.87.

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

We have,

$$\eta_{mech} = \frac{BP}{IP}$$

$$Therefore, IP = \frac{BP}{\eta_{mech}} = \frac{5}{0.75} = 6.67 kW$$

We know that,

$$\eta_{ITH} = \frac{IP}{m_f \times CV}$$

$$Therefore, m_f = \frac{IP}{\eta_{ITH} \times CV}$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

We have,

$$\eta_{mech} = \frac{BP}{IP}$$

$$Therefore, IP = \frac{BP}{\eta_{mech}} = \frac{5}{0.75} = 6.67\,kW$$

We know that,

$$\eta_{ITH} = \frac{IP}{m_f \times CV}$$

$$Therefore, m_f = \frac{IP}{\eta_{ITH} \times CV}$$

PERFORMANCE PARAMETERS OF IC ENGINES - NUMERICALS

Solution:

So,

$$m_f = \frac{6.67}{0.3 \times 42000} = 5.293 \times 10^{-4} kg/s = 1.9057 kg/hr$$

To get fuel consumption in litres/hr,

$$m_f = \frac{1.9057}{0.87 \times 1000} = 2.1905 \times 10^{-3} m^3/hr$$

$$= 2.1905 \times 10^{-3} \times 1000 = 2.1905 \ litres/hr$$

$$ISFC = \frac{m_f}{IP} = \frac{1.9057}{6.67} = 0.2857 kg/kWhr$$

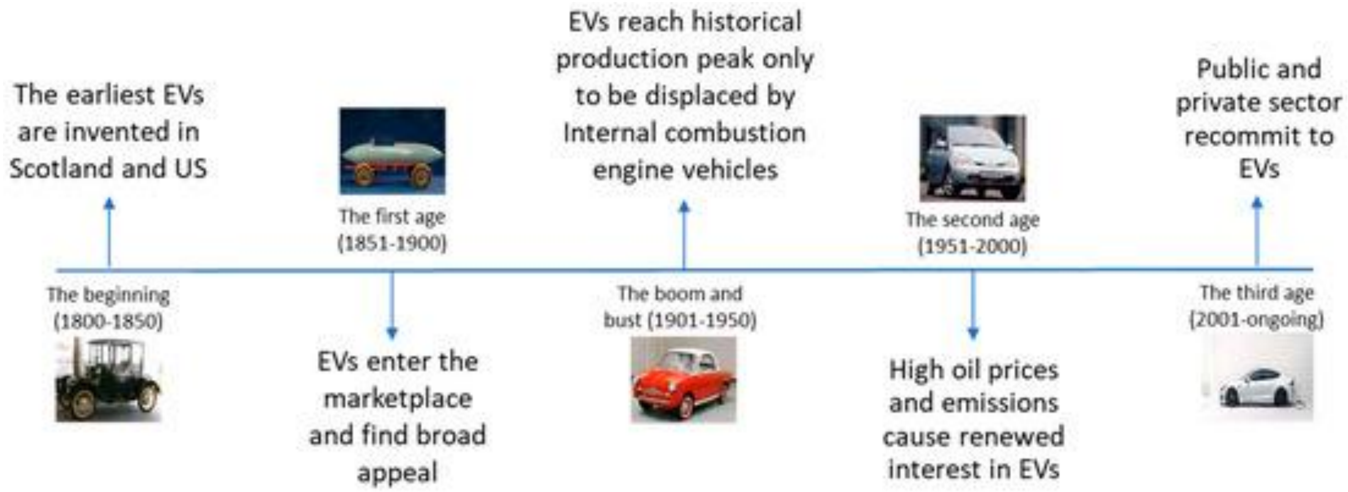
$$BSFC = \frac{m_f}{BP} = \frac{1.9057}{5} = 0.3811 kg/kWhr$$

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

- The issues like global warming, depleting fossil fuel reserves, and greenhouse gas (GHG) emissions need dire attention for ensuring a sustainable future.

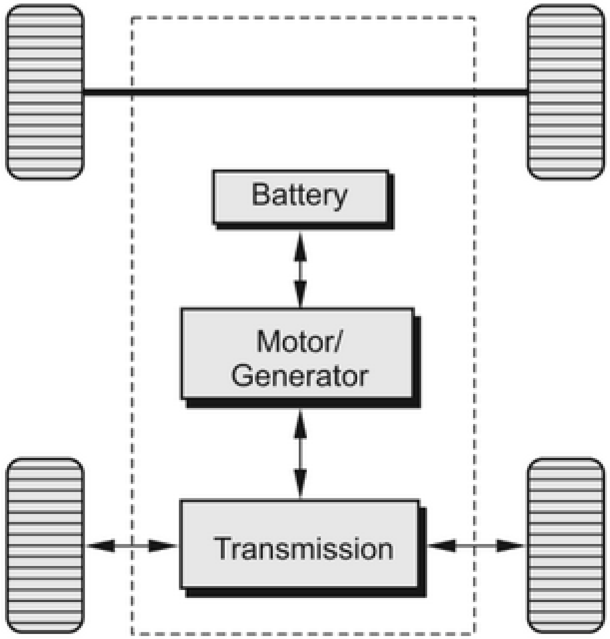
- Because the transportation sector is one of the largest contributors to the rising harmful emissions, the electrification of transportation is seen as a promising solution for this problem.

History of Electric Vehicles –



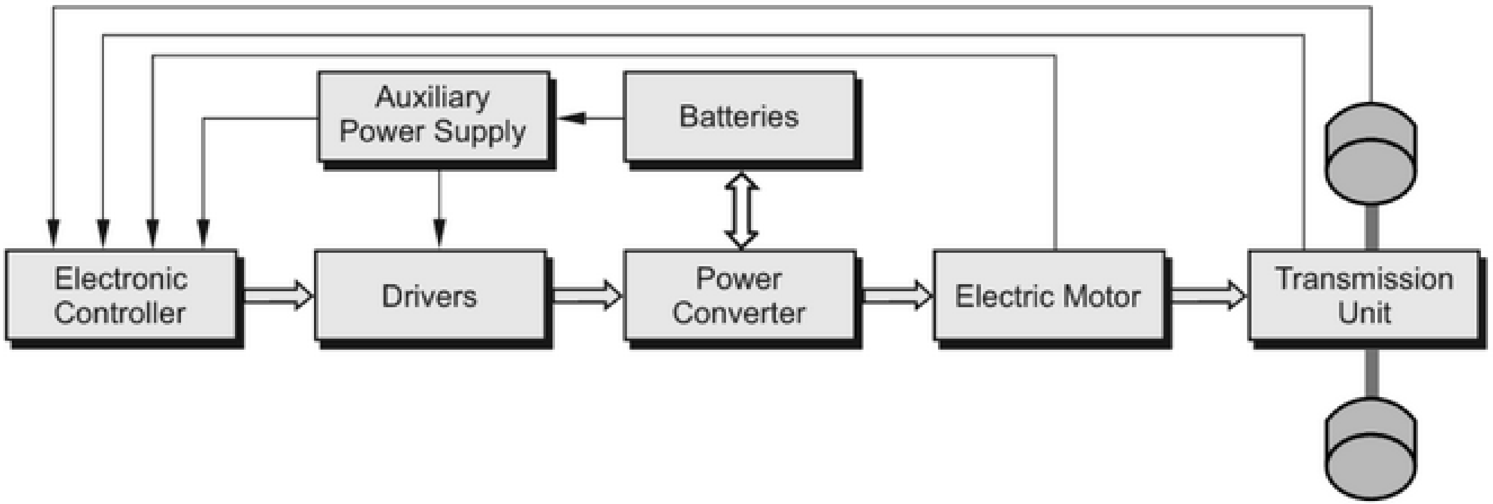
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

- Electric vehicles are defined as vehicles which use an electric motor for propulsion.
- They are propelled by one or more electric motors, receiving power from an onboard source of electricity such as batteries, fuel cells, ultra capacitor, flywheel etc.
- EVs include a large range of vehicles from electric two wheelers, three wheelers (rickshaws), cars and electric buses and trucks.



INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:



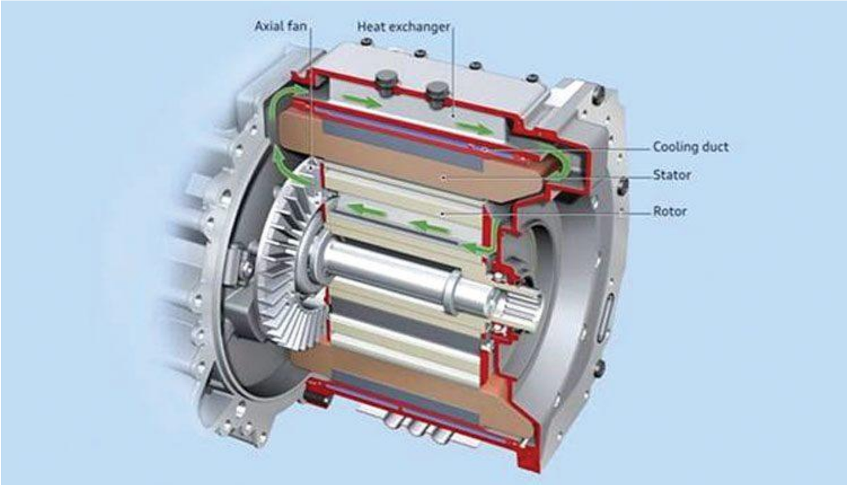
- An electric vehicle consists of a battery that provides energy, an electric motor that drives the wheels and a controller that regulates the energy flow to the motor. There are no gear box and clutch in these vehicles.

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:

Motor –

- The prime mover in electric vehicle is the high torque electric motor.
- It converts the energy stored in the power pack into mechanical motion. The power is directly delivered to the wheels or through the transaxle that propels the vehicle.
- While braking, it acts like a generator (regenerative braking) and recharges the batteries.



INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:

Power pack (Battery) –

- Automobile manufacturers use three types of rechargeable batteries. Those are lead acid batteries, nickel metal hydride (NiMH) batteries and lithium ion (Li – ion) batteries.

Charger –

- EVs have an on – board charger, which converts AC into DC power to charge the power pack.

Controller -

- EVs also have a computerized motor controller. This regulates the flow of energy from the power pack to the motor in direct relation to the pressure applied on the accelerator.

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Major Components of EV:

DC/DC converter –

- A 12V auxiliary battery is normally used in an electric car to power all 12V accessories such as lights, horn etc. EVs use a DC/DC converter which taps the full battery pack voltage and cuts it down to a regulated 13.5 V output similar to an alternator.

Energy Management System –

- The brain of EVs is the energy management system that monitors and controls all required functions.

- It is a computer based system that optimizes charging and energy output of batteries to maximize operating range and improve performance.

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Classification of EVs –

- There are 3 types of electric vehicle:

i) Battery Electric Vehicle (BEV)

ii) Hybrid Electric Vehicle (HEV)

iii) Plug in Hybrid Electric Vehicle (PHEV)

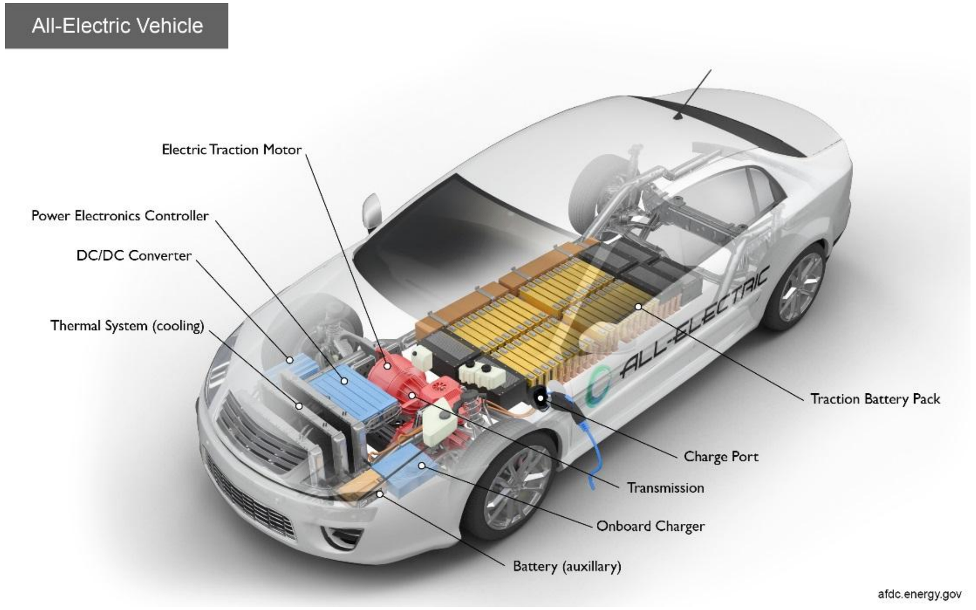
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Battery Electric Vehicle (BEV) –

- A battery electric vehicle (BEV) runs entirely using an electric motor and battery, without the support of a traditional internal combustion engine and must be plugged into an external source of electricity to recharge its battery.

- BEVs can also recharge their batteries through a process known as regenerative braking, which uses the vehicle's electric motor to assist in slowing the vehicle and to recover some of the energy normally converted to heat by the brakes.

- Examples – Tesla Model S Nissan Leaf, BMW i3, Mitsubishi iMi etc.



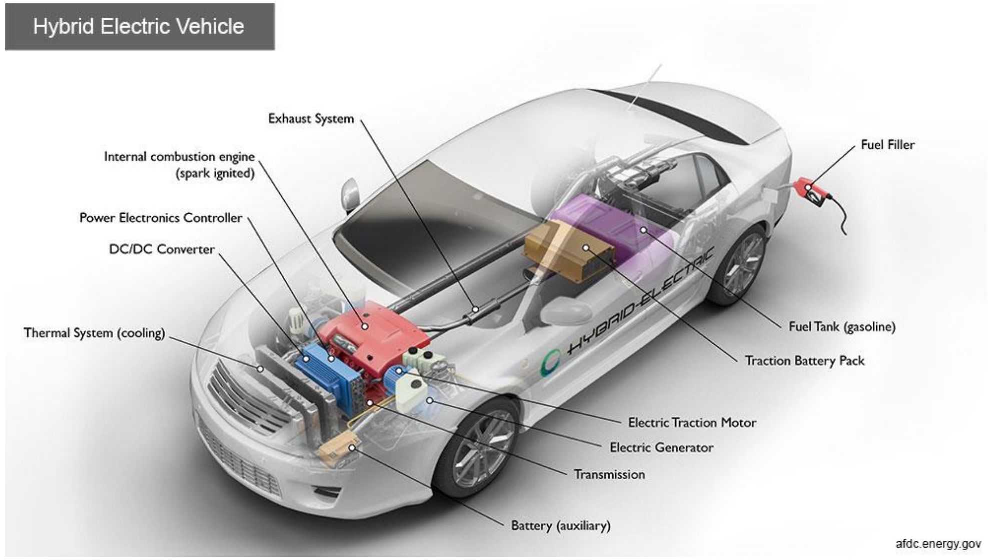
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Hybrid Electric Vehicle (HEV) –

- Hybrid electric vehicles have a supplemental fuel source to produce electricity on – board. They have two complementary drive systems: an IC engine with a fuel tank and an electric motor with a battery.

- Both the drive systems can be used to turn the transmission and the transmission then turns the wheels.

- HEVs cannot be recharged from the electricity grid – all their energy comes from fuel and from regenerative braking.

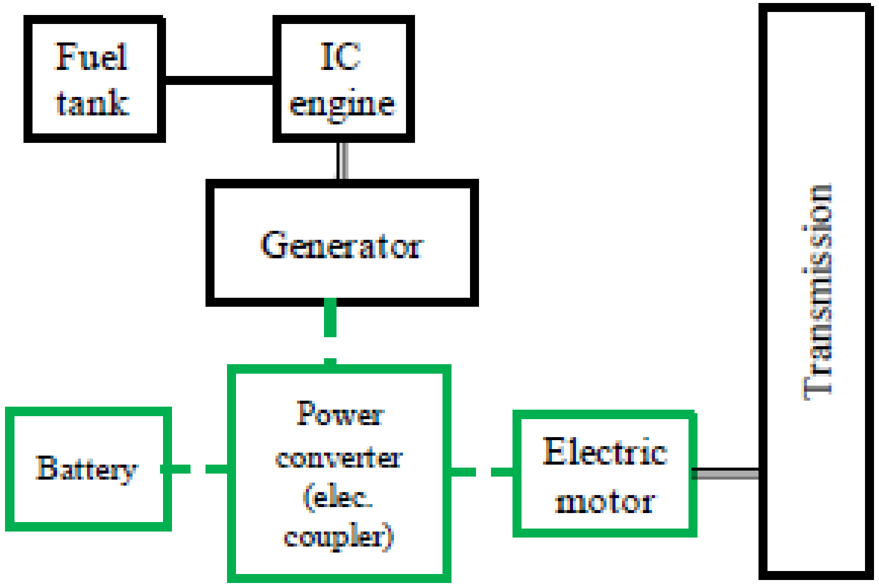


INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

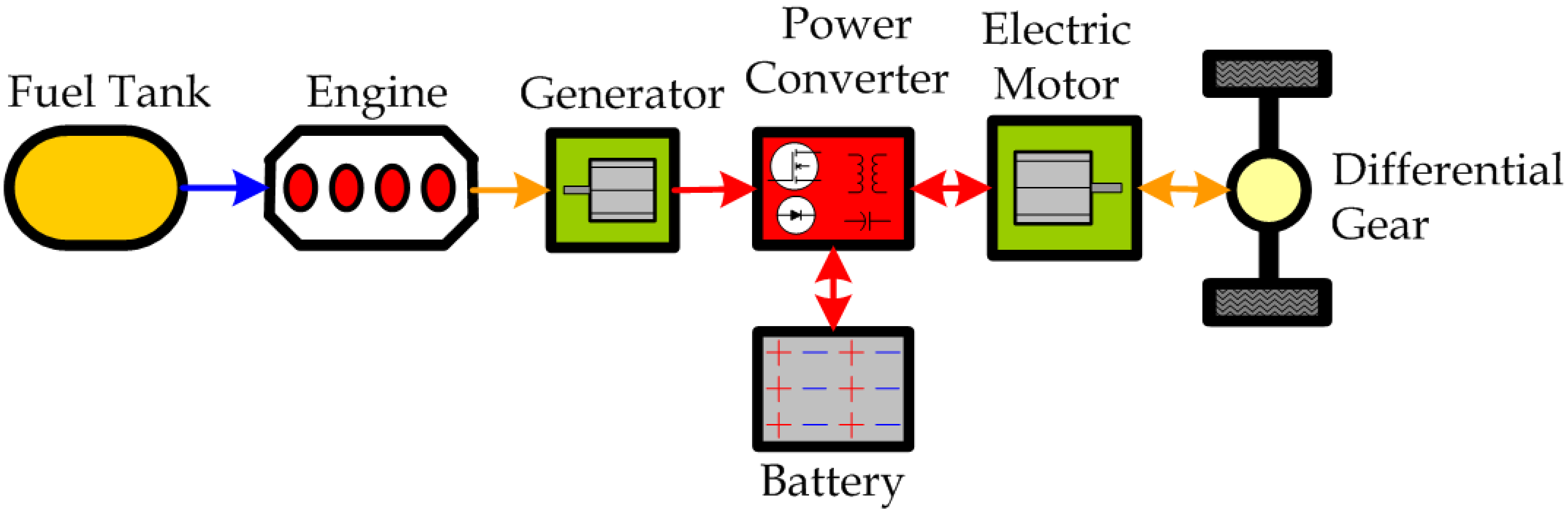
Hybrid Electric Vehicle (HEV) – Architectures

i) Series Architecture

- In case of series hybrid system, the mechanical output is first converted into electricity using a generator.
- The converted electricity either charges the battery or can bypass the battery to propel the wheels via the motor and mechanical transmission.
- Conceptually, it is an ICE assisted Electric Vehicle (EV).



Series HEV Architecture



Example: BMW i3

INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

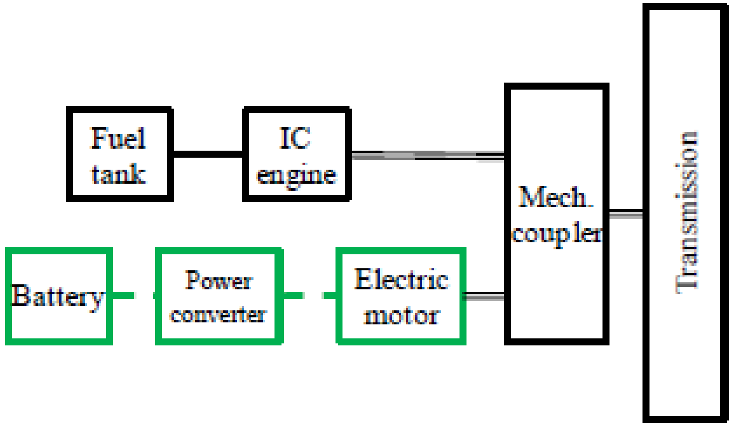
Hybrid Electric Vehicle (HEV) – Architectures

ii) Parallel Architecture

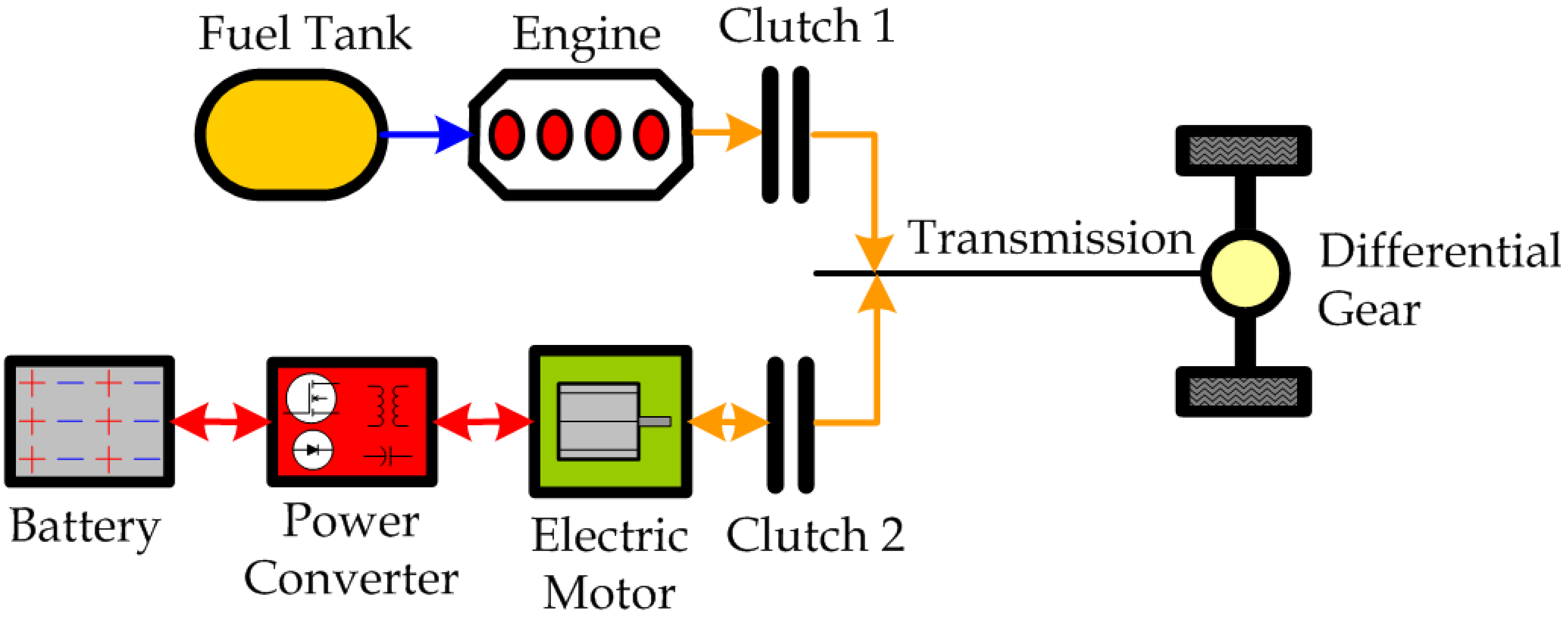
- The parallel HEV allows both ICE and electric motor (EM) to deliver power to drive the wheels.

- Since both the ICE and EM are coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by ICE alone, by EM only or by both ICE and EM.

- The EM can be used as a generator to charge the battery by regenerative braking or absorbing power from the ICE when its output is greater than that required to drive the wheels.



Parallel HEV Architecture



Example: Toyota Prius, Chevy Malibu

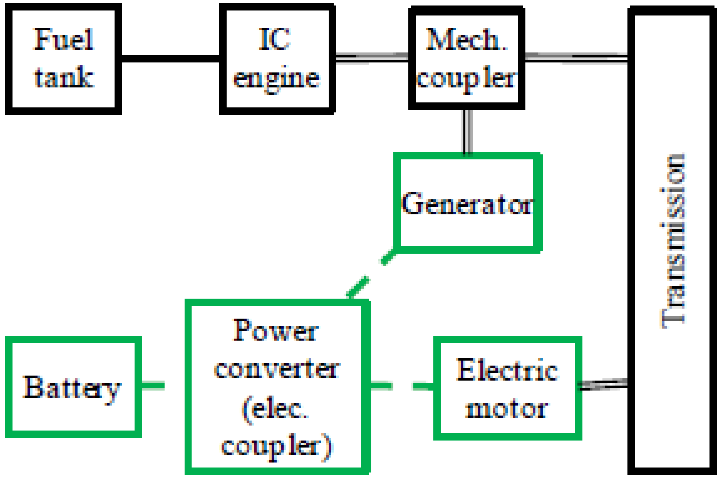
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Hybrid Electric Vehicle (HEV) – Architectures

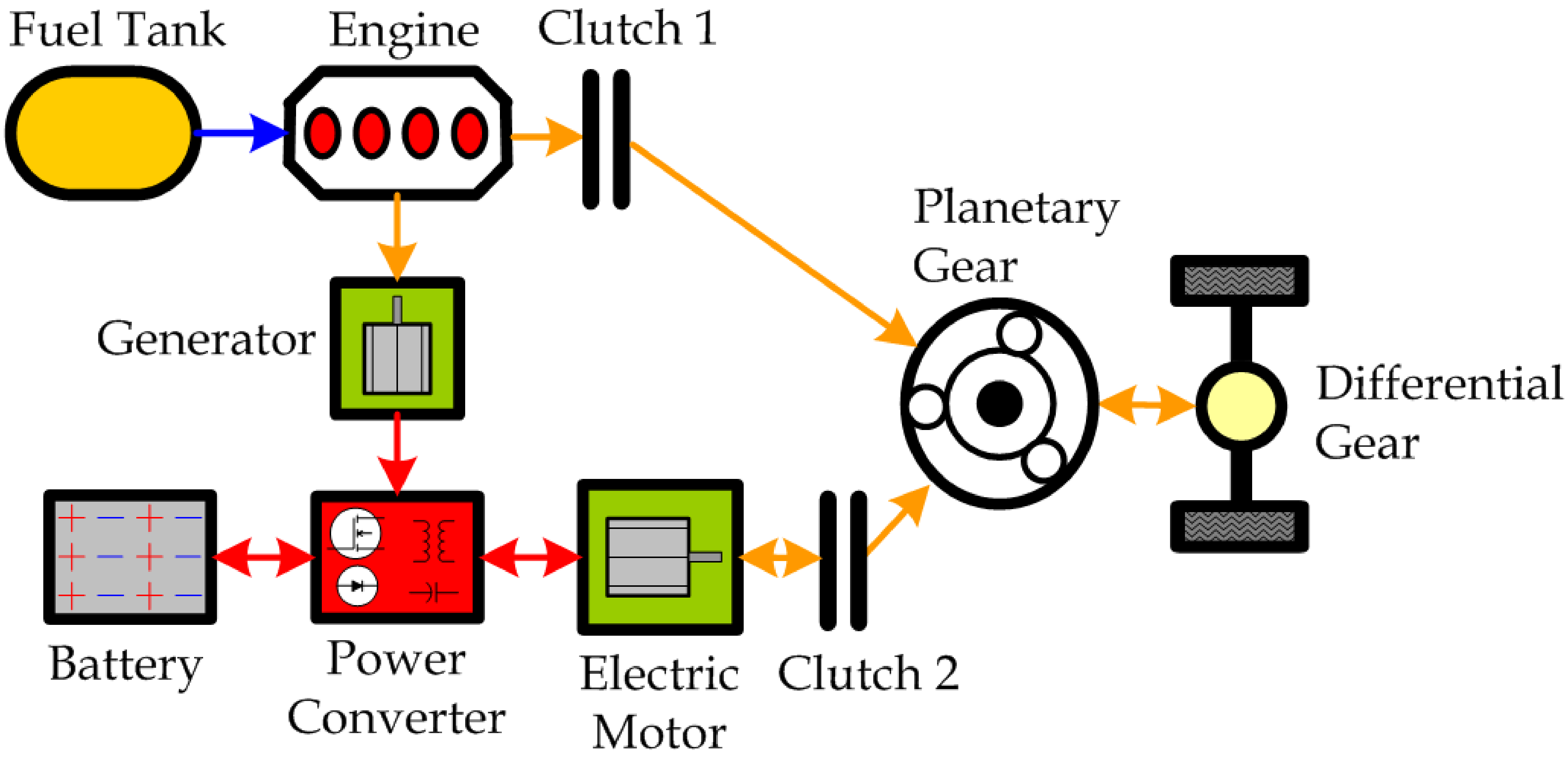
iii) Series - Parallel Architecture

- In the series-parallel hybrid, the configuration incorporates the features of both the series and parallel HEVs.

- However, this configuration needs an additional electric machine and a planetary gear unit making the control complex.



Series & Parallel HEV Architecture



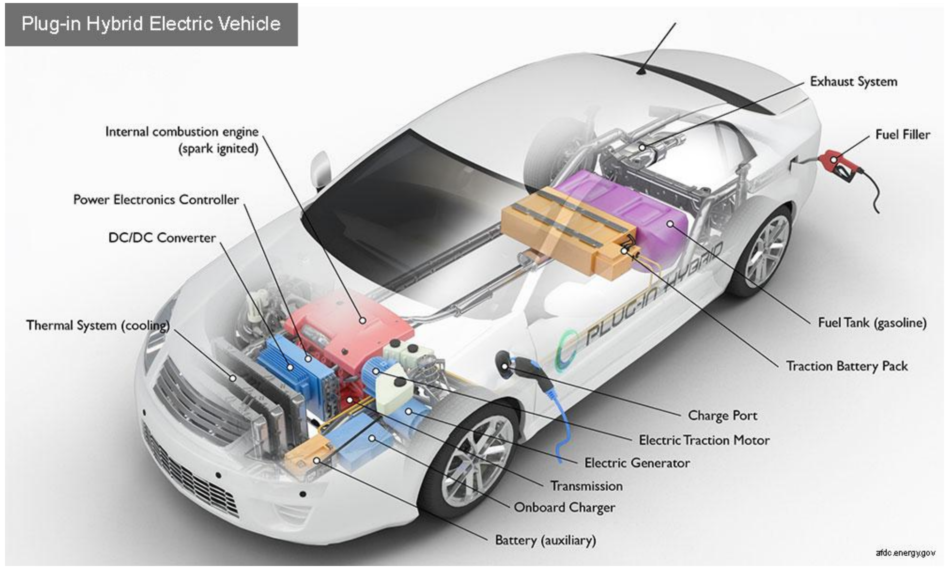
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES

Plug in Hybrid Electric Vehicle (PHEV) –

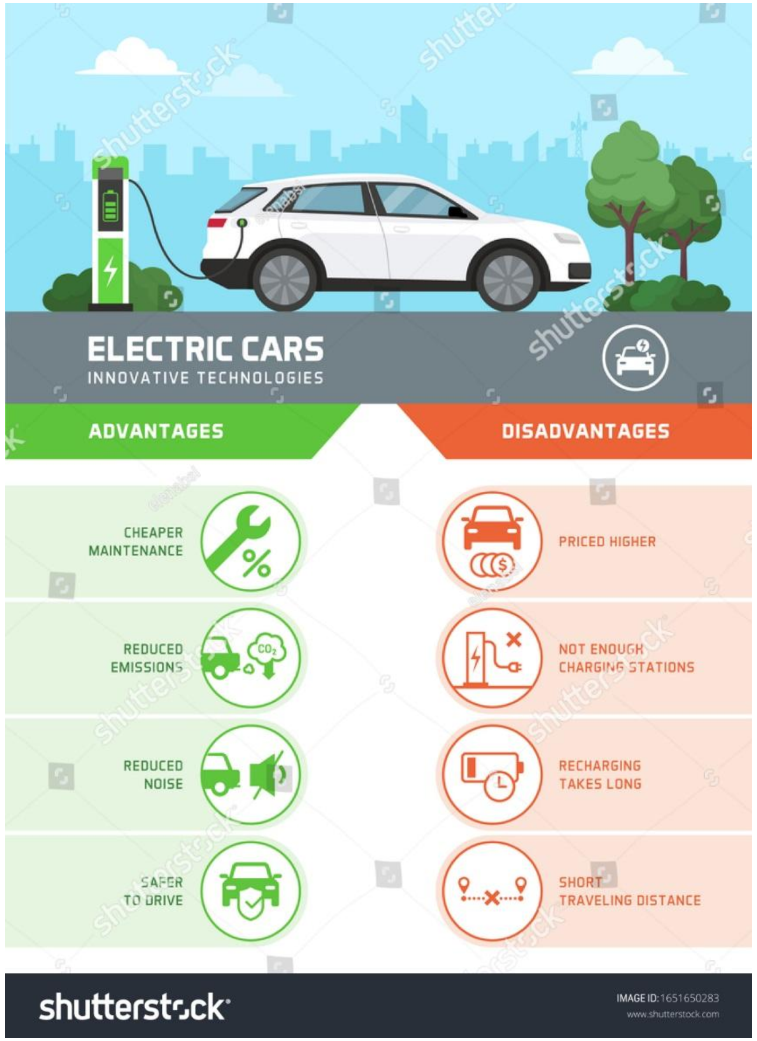
- Plug in hybrids use an electric motor and battery that can be plugged into the power grid to charge the battery, but also have the support of an internal combustion engine that may be used to recharge the vehicle's battery and/or to replace the electric motor when the battery is low.

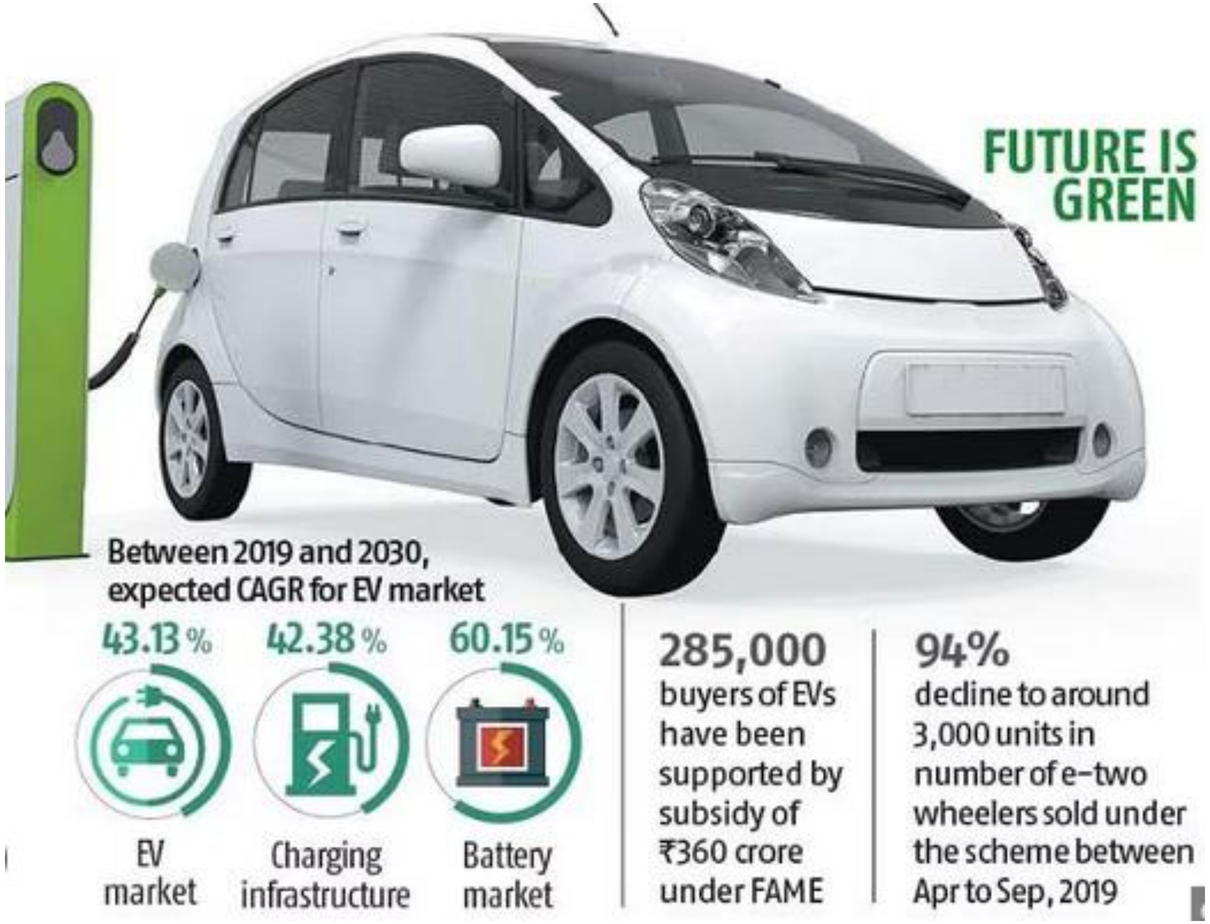
- Because Plug in hybrids use electricity from the power grid, they often realize more savings in fuel costs than tradition hybrid electric vehicles (HEV).

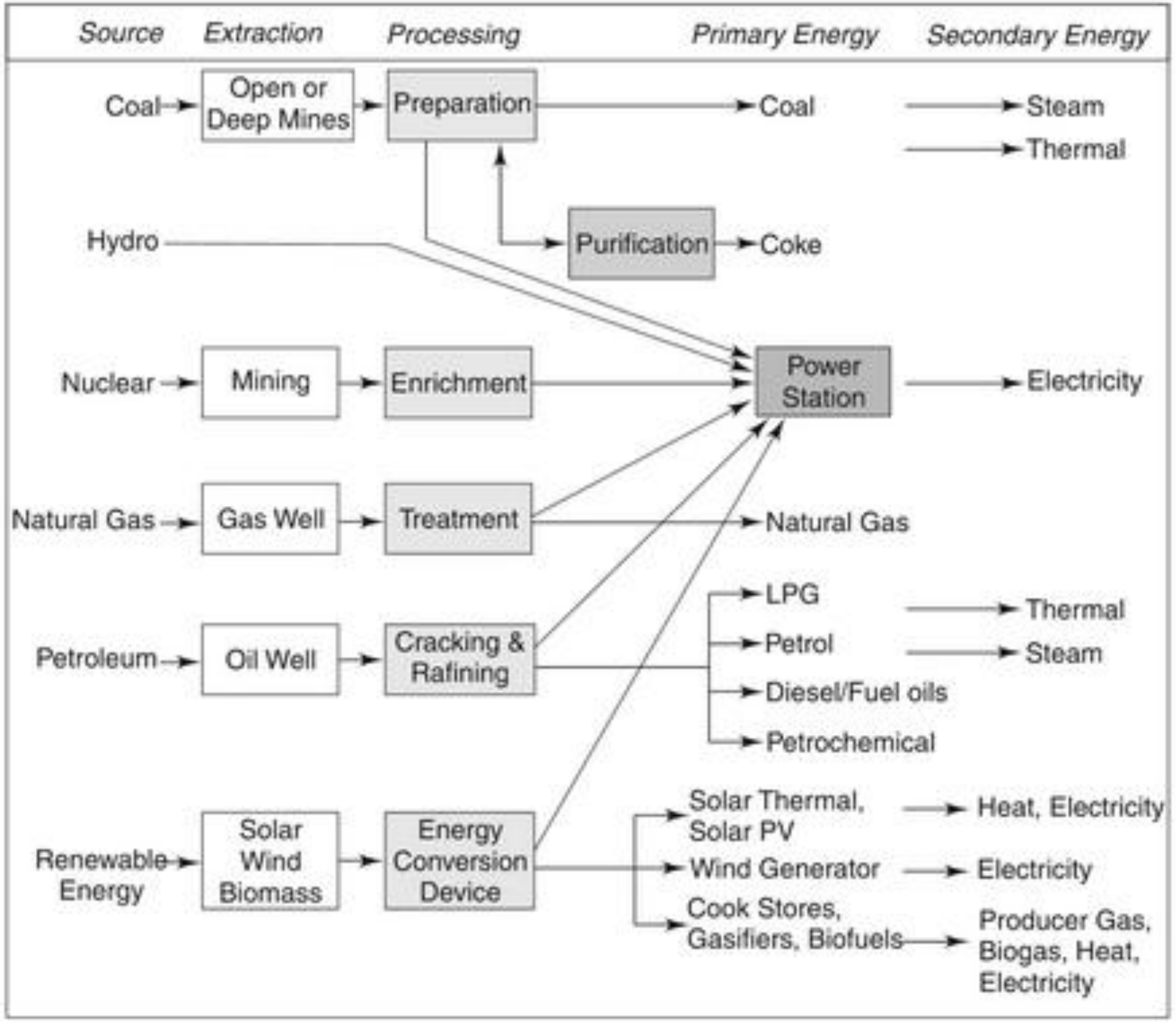
- Examples – Cadillac ELR, GM Chevy Volt, Toyota Prius Plugin etc.



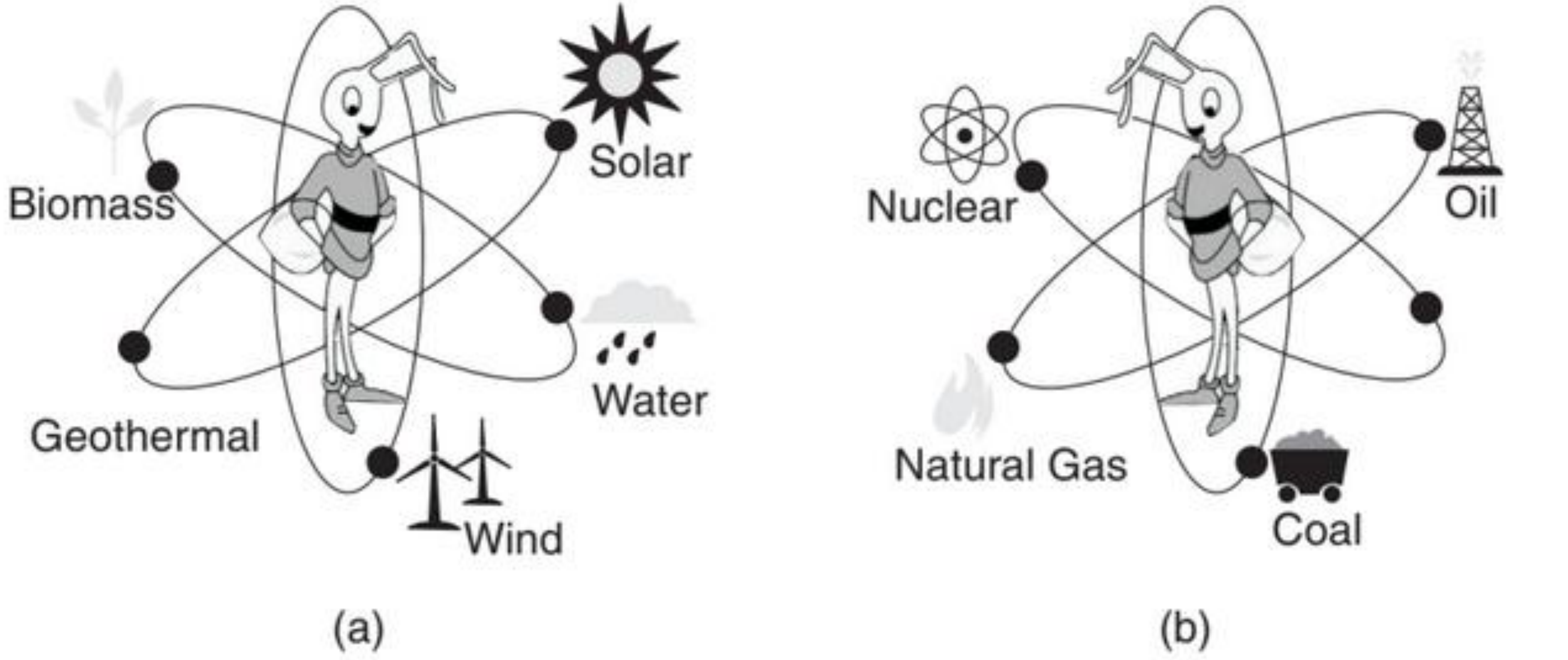
INTRODUCTION TO ELECTRIC AND HYBRID VEHICLES







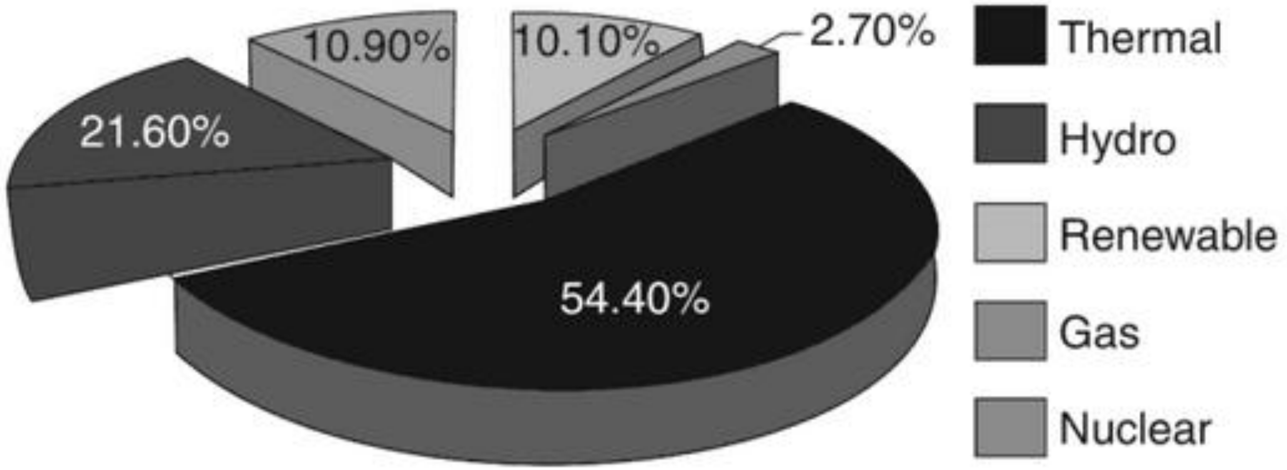
Major primary and secondary energy sources



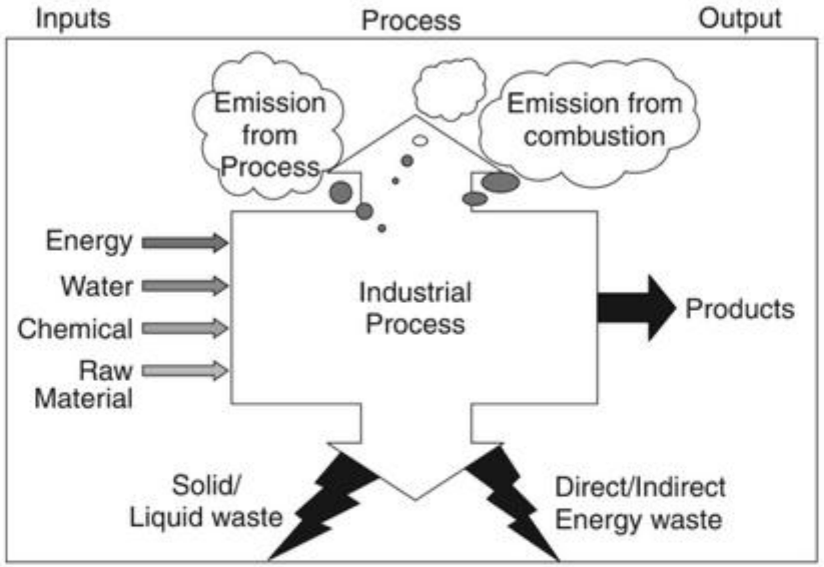
(a) Renewable and (b) Non-renewable energy sources

Given the limited amount of domestic resources of conventional energy, renewable energy resources have been an important component of India's energy planning process.

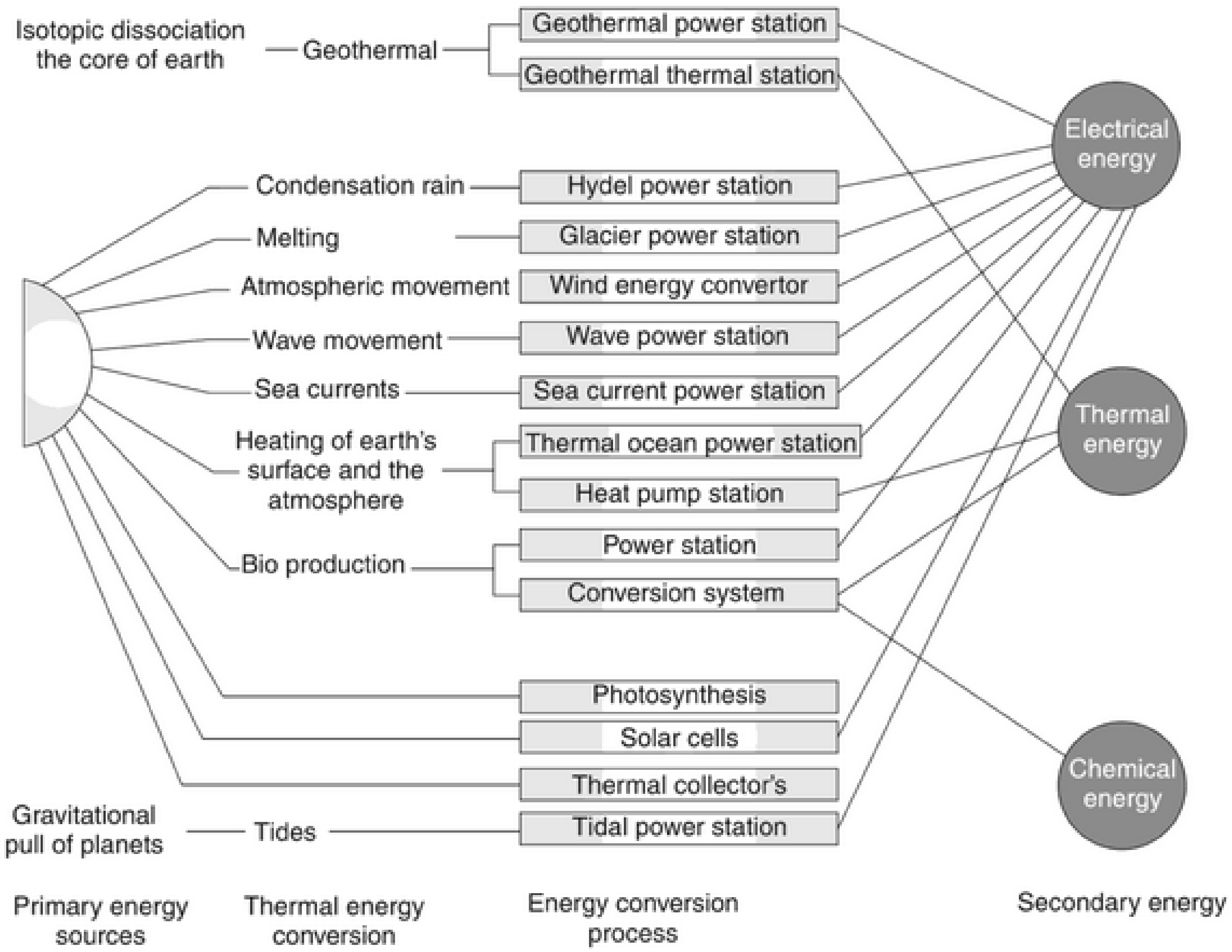
Technology	Capacity installed (MW)
Coal	11,202
Hydro	38,990
Renewable	27,300
Gas	18,381
Nuclear	4,780
Total	201,473



The use of fossil fuels by the industry (coal, oil and gas) leads to environment pollution by emitting oxides of sulphur (SO_x), nitrogen (NO_x), particulates and carbon mono-oxide. In addition, refrigerant systems use chlorofluorocarbons which on discharge or leakage deplete the ozone layer of the atmosphere. Very often, the industry discharges waste materials into water bodies or on earth resulting in water and groundwater contamination. Chemical and fertilizer industries release toxic gases, while cement and power plants spew particulates into the atmosphere. Typical inputs, outputs, and emissions for a typical industrial process are shown



NON CONVENTIONAL ENERGY SOURCES



Thank You

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MECHANICAL ENGINEERING SCIENCE (UE23ME131A)

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MECHANICAL ENGINEERING SCIENCE

Unit2

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MECHANICAL ENGINEERING SCIENCE

Chapter 1 – Engineering Materials

Dr. Mantesh B Khot

Department of Mechanical Engineering

INTRODUCTION TO ENGINEERING MATERIALS

- ***Engineering materials*** are defined as substances which are manufactured and used for various engineering applications.

- ***Why do we study materials?***

- An applied scientist or engineer, whether mechanical, civil, chemical, or electrical, will at one time or another be exposed to a design problem involving materials. Examples might include a transmission gear, the superstructure for a building, an oil refinery component, or an integrated circuit chip.

- Often a materials problem is really one of selecting the material that has the right combination of characteristics for a specific application. The selection will be usually based on ***in – service conditions, any deterioration of material properties that may occur during service operation, consideration of cost etc.***

- The more familiar an engineer or scientist is with the various characteristics and structure–property relationships, as well as processing techniques of materials, the more proficient and confident he or she will be to make judicious materials choices based on these criteria.

CLASSIFICATION OF MATERIALS

- Solid materials have been conveniently grouped into three basic classifications: ***metals, ceramics, and polymers.***

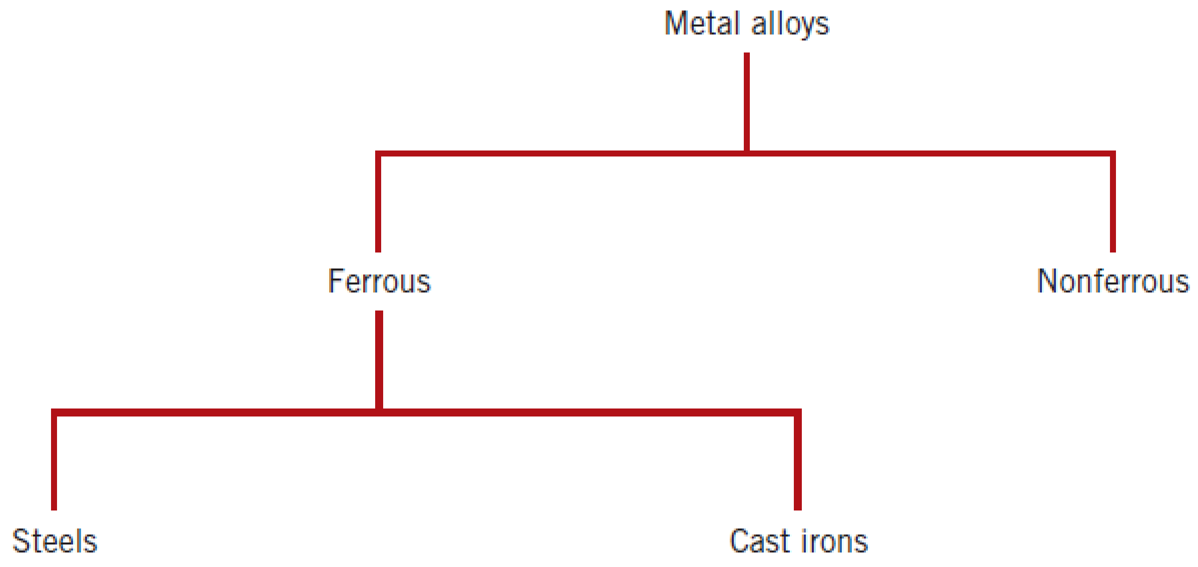
- This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another, although there are some intermediates.

- In addition, there are the ***composites***, combinations of two or more of the above three basic material classes.

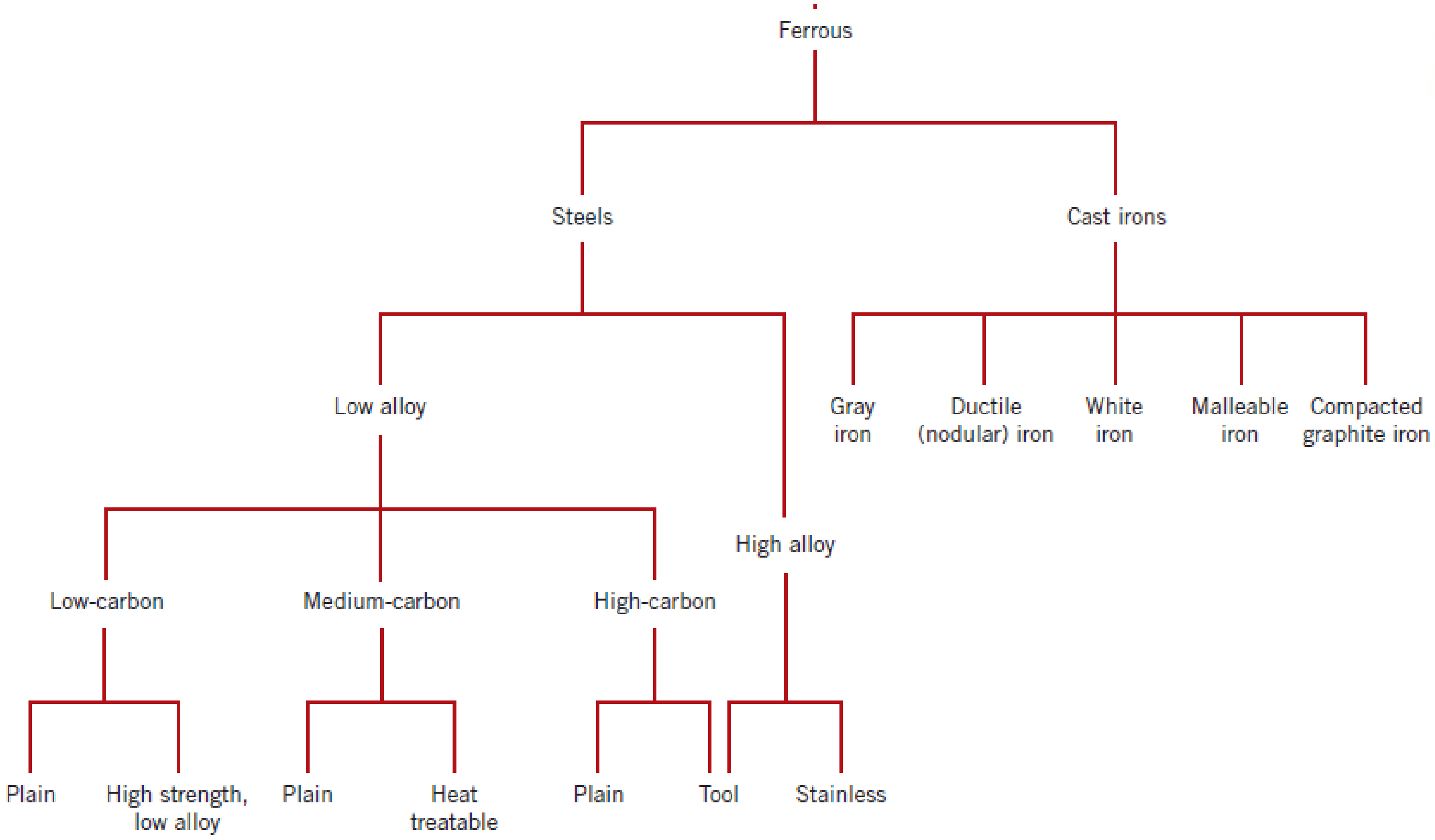
- Another classification is advanced materials—those used in high-technology applications—viz. ***semiconductors, biomaterials, smart materials, and nano engineered materials***.

METAL ALLOYS

- Metal alloys, by virtue of composition, are often grouped into two classes—***ferrous and nonferrous***.
- Ferrous alloys, those in which iron is the principal constituent, include ***steels and cast irons***.
- The nonferrous ones—all alloys that are not iron based.



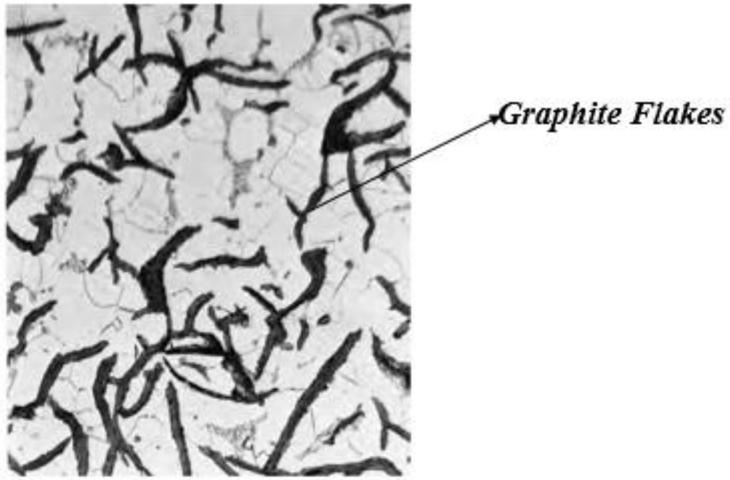
FERROUS ALLOYS



GRAY CAST IRON

- **Composition** – 2.5% to 4% Carbon by weight ; 1% to 3% Silicon by weight ; Rest Iron

- **Microstructure** – Graphite exists in the form of flakes normally surrounded by a matrix. Because of these graphite flakes, a fractured surface of cast iron structure takes on a gray appearance. Hence the name



Microstructure

GRAY CAST IRON

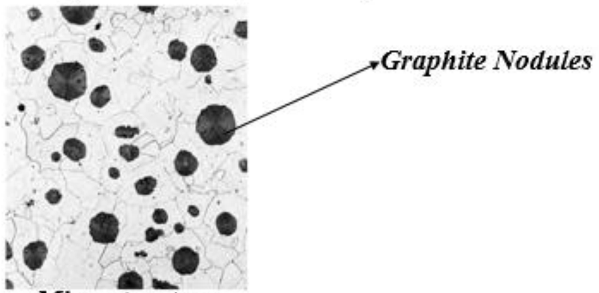
- **Properties** – Weak and brittle in tension
  Higher Compressive strength
  Very effective in damping vibrations (Remember Lathe bed which is made of CI in order to reduce transmission of vibrations to the ground)
  High resistance to wear
  High fluidity at molten state (This permits casting pieces to have intricate shapes)
  Low Cost

Cast Iron Engine Block

- **Applications** – Automotive Engine Blocks
  Brake discs and drums
  Base structure of machines and heavy equipments that are exposed to vibrations etc.

DUCTILE OR NODULAR CAST IRON

- **Composition** – 3% to 4% Carbon by weight ; 1.6% to 2.8% Silicon by weight; Rest Iron. Very low percentage of Sulphur and Phosphorous



Microstructure

- **Microstructure** – **Dark graphite nodules** surrounded by matrix

- **Properties** – Highly ductile
  Very good machinability
  High Corrosion Resistance

Nodular Cast Iron Crankshaft

- **Applications** – Valves
  Pump bodies
  Crankshafts
  Gears and other automotive and machine components etc.

WHITE CAST IRON

- **Composition** – 1.8% to 3.2% Carbon by weight ; 0.3% to 1.8% Silicon by weight; Rest Iron
- **Microstructure** –

Iron Carbide (Light phase); Pearlite (Dark phase)
No Graphite. A fractured surface of this alloy has a white appearance. Hence the name.

- **Properties** – Very hard and brittle
  Highly wear resistant
  No Ductility and Malleability
  Not Machinable

- **Applications** – Liners for Cement Mixers
  Ball Mill
  Certain types of Drawing Dies
  Extrusion Nozzles etc.

Microstructure

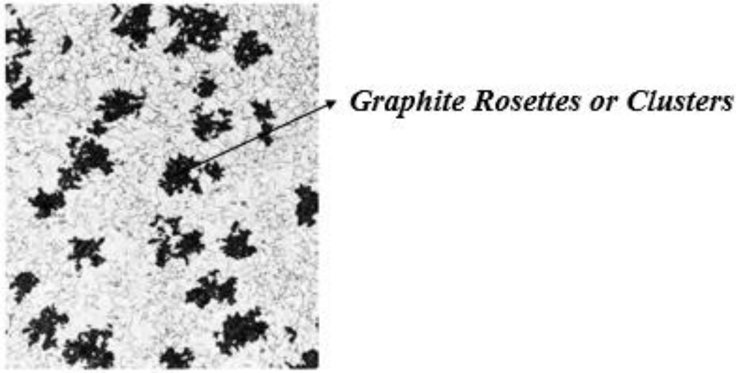
White Cast Iron Rolls

MALLEABLE CAST IRON

- **Composition** – 1.8% to 3.2% Carbon by weight ; 0.3% to 1.8% Silicon by weight, Rest Iron

- **Microstructure** – Dark Graphite Rosettes in a matrix.
- **Properties** – Highly Malleable
  Very good Machinability
  Good Magnetic properties
  Wear Resistance

- **Applications** – Connecting Rods
  Transmission Gears
  Flanges
  Pipe Fittings
  Differential Cases for Automobiles etc.



Microstructure

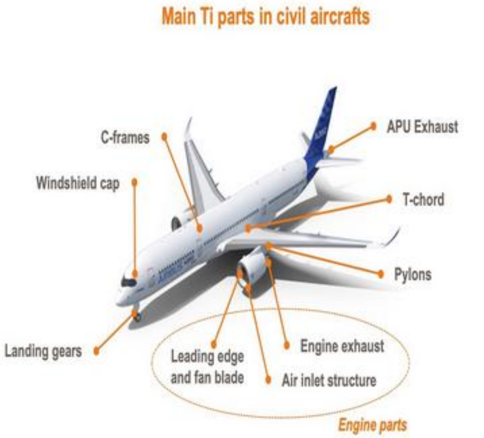

Cast Iron Connecting Rod

NON FERROUS ALLOYS

- Steel and other ferrous alloys are consumed in exceedingly large quantities because they have such a wide range of mechanical properties, may be fabricated with relative ease, and are economical to produce.

- However, they have some distinct limitations, chiefly:
  (1) a relatively high density,
  (2) a comparatively low electrical conductivity, and
  (3) an inherent susceptibility to corrosion in some common environments.

- Thus, for many applications it is advantageous or even necessary to utilize other alloys having more suitable property combinations.

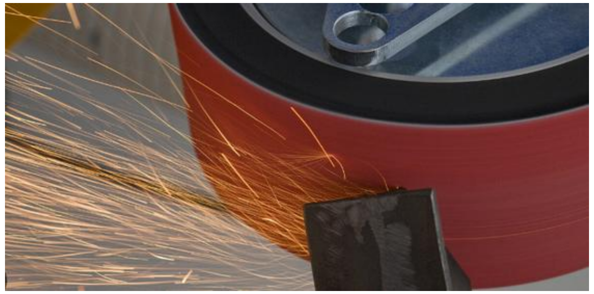


CERAMICS AND PLASTICS

- Ceramics can be defined as a compound of metallic and non – metallic elements with predominantly ‘ionic’ interatomic bonding.

- Some of their examples are **Magnesia (MgO), Alumina (Al_2O_3), Zirconia (ZrO_2), Beryllia (BeO), Silicon Carbide (SiC) and Tungsten Carbide (TiC).**

- Typical applications **- ceramic substrates for electronic devices, turbocharger rotors, aerospace turbine blades, nuclear fuel rods, lightweight armour, cutting tools, abrasives, thermal barriers and furnace/kiln furniture.**



CERAMICS AND PLASTICS

- ***A plastic can be defined as a solid material consisting of an organic polymer of a long molecular chain and high molecular weight.***

- Plastics are divided into two basic groups depending on their behaviour at elevated temperatures, viz., ***thermoplastics and thermosetting plastics***.

- Typical applications –
  Polyamide (Nylon etc.) – gears, bearing, conveyor rollers, cooling fans
  Polyethylene (Polythene) – gaskets, washers, pipes
  Polytetrafluoroethylene (Teflon) – self lubricating bearing
  Phenolic – clutch and brake linings

COMPOSITES

- **A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other.**

- One constituent is called the **reinforcing phase** and the one in which it is embedded is called the **matrix**. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous.

- Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc.

- Some examples of naturally found composites - **wood**, where the lignin matrix is reinforced with cellulose fibers and **bones** in which the bone-salt plates made of calcium and phosphate ions reinforce soft collagen.

COMPOSITES

The advantages of using composites over metals -

- Monolithic metals and their alloys cannot always meet the demands of today's advanced technologies. Only by combining several materials can one meet the performance requirements.

- For example, trusses and benches used in satellites need to be dimensionally stable in space during temperature changes between –256°F (–160°C) and 200°F (93.3°C). Limitations on coefficient of thermal expansion thus are low and may be of the order of $\pm 1.8\times10^{-7}$ m/m/°C. Monolithic materials cannot meet these requirements; this leaves composites, such as graphite/epoxy, as the only materials to satisfy them.

- In many cases, using composites is more efficient. For example, in the highly competitive airline market, one is continuously looking for ways to lower the overall mass of the aircraft without decreasing the stiffness and strength of its components. This is possible by replacing conventional metal alloys with composite materials.

COMPOSITES

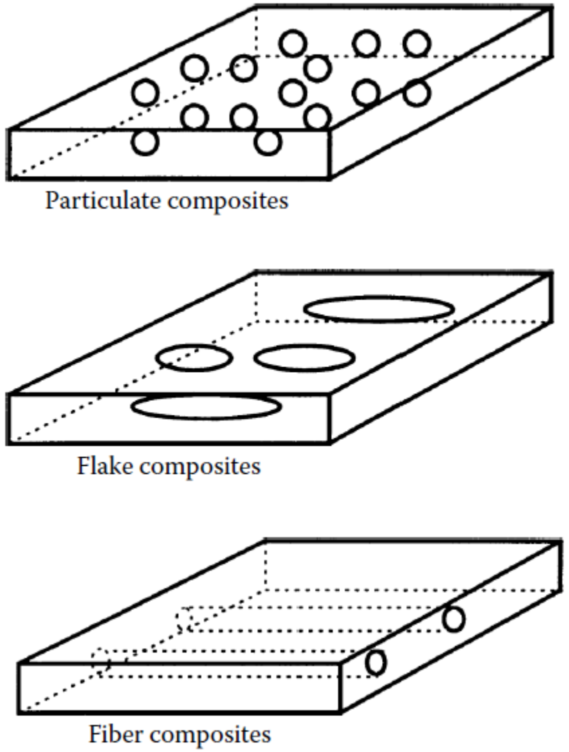
- Even if the composite material costs may be higher, the reduction in the number of parts in an assembly and the savings in fuel costs make them more profitable. Reducing one lbm (0.453 kg) of mass in a commercial aircraft can save up to 360 gal (1360 l) of fuel per year; fuel expenses are 25% of the total operating costs of a commercial airline.

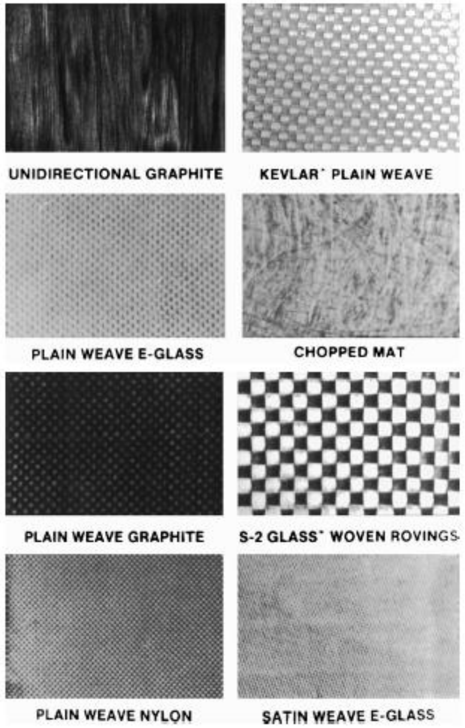
- Composites offer several other advantages over conventional materials. These may include
  improved strength,
  improved stiffness,
  improved fatigue and impact resistance,
  improved thermal conductivity,
  improved corrosion resistance etc.

COMPOSITES

Classification of composites

- Composites are classified by the geometry of the reinforcement — **particulate, flake, and fibers** — or by the type of matrix — **polymer, metal, ceramic, and carbon**.





COMPOSITES

Examples –

Particulate composites - aluminum particles in rubber; silicon carbide particles in aluminum; and gravel, sand, and cement to make concrete

Fiber reinforced composites - Fibers are generally anisotropic and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum, and ceramics such as calcium–alumino silicate.

Polymer matrix composites – It consists of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron). For example, graphite/ epoxy composites are approximately five times stronger than steel on a weight for weight basis.

Metal matrix composites - Examples of matrices in such composites include aluminum, magnesium, and titanium. Typical fibers include carbon and silicon carbide.

Ceramic matrix composites - Ceramic matrix composites (CMCs) have a ceramic matrix such as alumina calcium alumino silicate reinforced by fibers such as carbon or silicon carbide.

COMPOSITES

Applications –

Aircraft - Use of composites is limited to secondary structures such as rudders and elevators made of graphite/epoxy for the Boeing 767 and landing gear doors made of Kevlar–graphite/epoxy. Composites are also used in panels and floorings of airplanes.

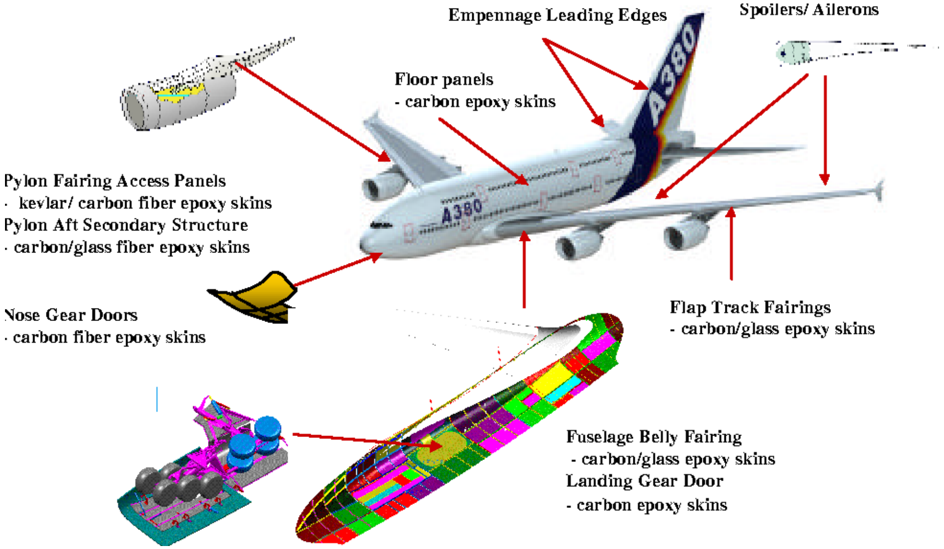
Sporting goods - Graphite/epoxy is replacing metals in golf club shafts mainly to decrease the weight and use the saved weight in the head. Tennis and racquetball rackets with graphite/epoxy frames are now commonplace.

Medical devices - Applications here include the use of glass–Kevlar/epoxy lightweight face masks for epileptic patients. Artificial portable lungs are made of graphite–glass/epoxy so that a patient can be mobile.

Automobile - The fiberglass body of the Corvette comes to mind when considering automotive applications of composites. In addition, the Corvette has glass/epoxy composite leaf springs with a fatigue life of more than five times that of steel.

COMPOSITES

Cynergy C7 Z06 Corvette Fiberglass body



Composite materials in Airbus A - 380

Graphite/Epoxy tennis racket

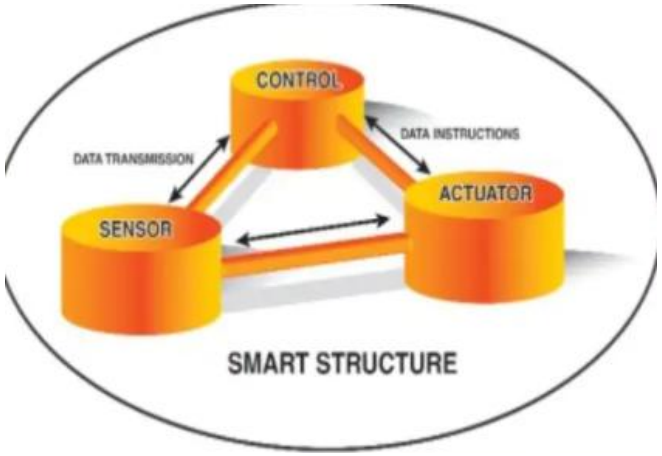
SMART MATERIALS

- Smart materials are materials that have to respond to stimuli and environmental changes and to activate their functions according to these changes.

- The stimuli like temperature, pressure, electric flow, magnetic flow, light, mechanical etc. can originate internally or externally.

- A smart system/ structure involves actuators and sensors, one or microprocessors that analyse the responses from the sensors and use integrated control theory to command the actuators to apply localized action to alter system response.

- Key elements of smart system/structure-
  Sensor
  Actuator
  Control System
  Power and Signal Conditioning Electronics
  Computer

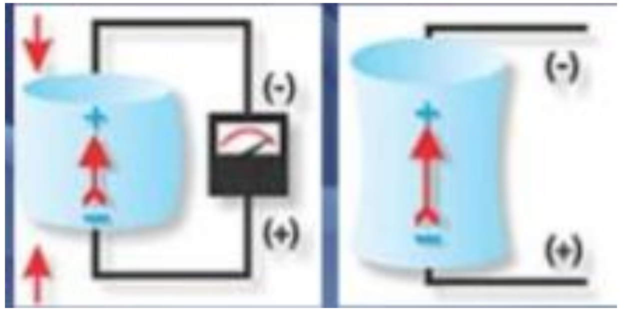


SMART MATERIALS

Types -

Piezoelectric Materials
Shape Memory Alloys
Electrostrictive Materials
Magnetostrictive Materials
Rheological Fluids
Thermoresponsive Materials
Electrochromic Materials etc.

PIEZOELECTRIC MATERIALS



- Piezoelectricity is a phenomenon that occurs in certain class of anisotropic crystals subjected to change in mechanical deformation.
- By applying mechanical deformations to these crystals, electric dipoles are generated and potential difference develops that is contingent upon the changing deformations – **Direct effect**
- By applying potential difference across the crystal, mechanical deformations are also generated – **converse effect**.
- Commercially available industrial piezoelectric materials are piezoceramics such as **Lead Zirconate Titanate (PZT)** ad piezopolymers such as **polyvinylidene fluoride**
- Applications – Voltage and power sources, sensors, actuators, piezoelectric motors, active vibration control, surgery etc.

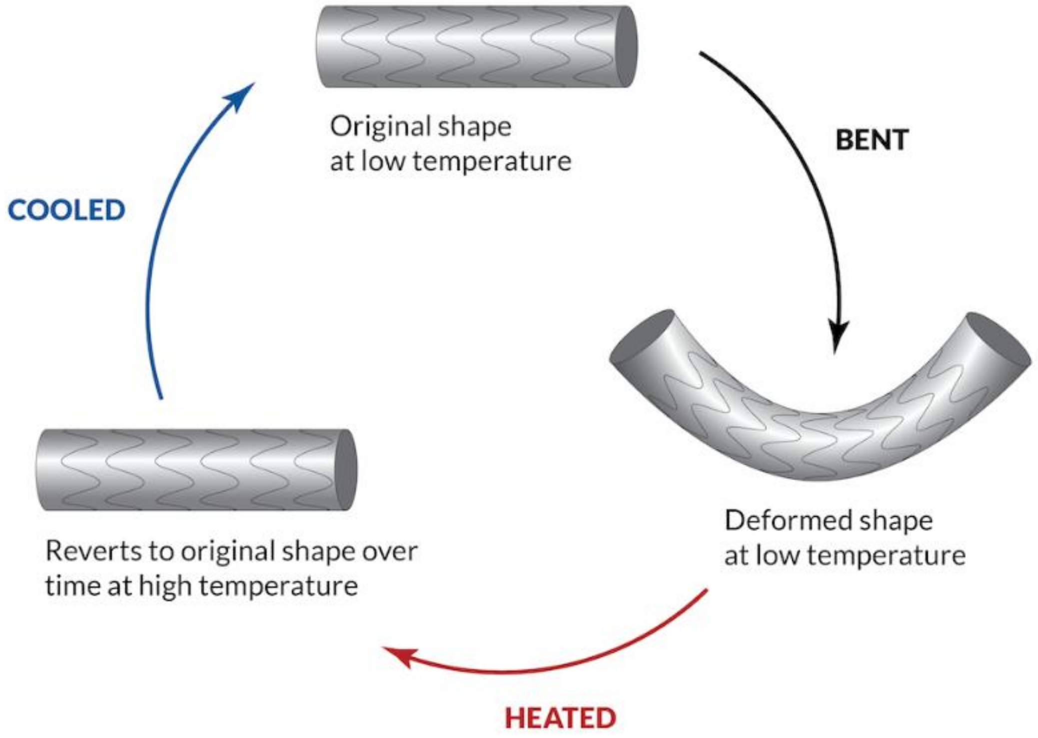
SHAPE MEMORY ALLOYS

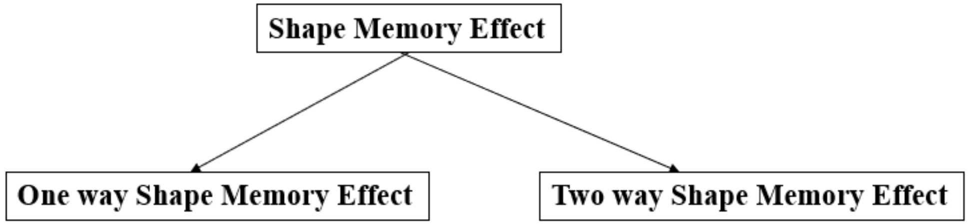
- A shape memory alloy is a material that undergoes a phase transformation when it experiences a mechanical stress or temperature change. When the conditions return to normal, the SMA “remembers” its original shape and reverts to it.

- Certain classes of metallic alloys have a special ability to ‘memorize’ their shape at a low temperature, and recover large deformations imparted at a low temperature on thermal activation. These alloys are called Shape Memory Alloys (SMA).

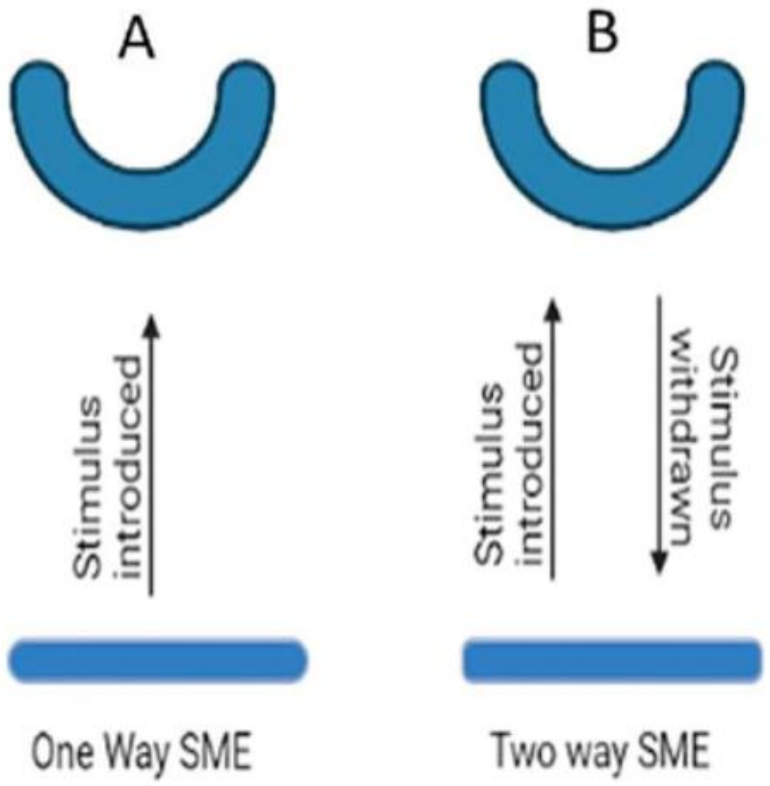
- The recovery of strains imparted to the material at a lower temperature, as a result of heating, is called the **Shape Memory Effect (SME).**

SHAPE MEMORY ALLOYS





SHAPE MEMORY ALLOYS



SHAPE MEMORY ALLOYS

One way Shape Memory Effect –

A deformation imparted to the material in the low temperature martensite phase is fully recovered upon heating as the material completely transforms to the high temperature austenite phase. On subsequent cooling, the material returns completely to the martensite phase, but there is no further change in the shape of the material. Because the shape change occurs only during heating, this transformation is called the ***one-way shape memory effect.***

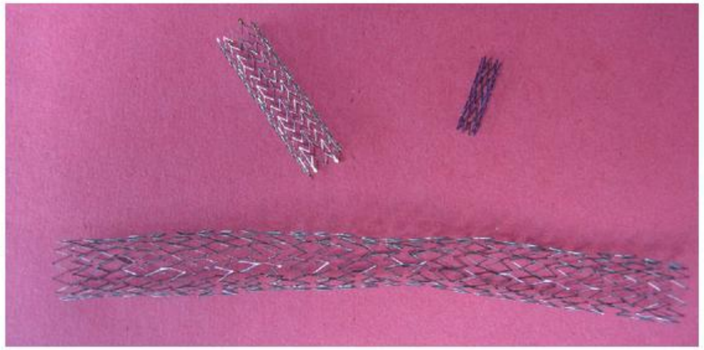
Two way Shape Memory Effect –

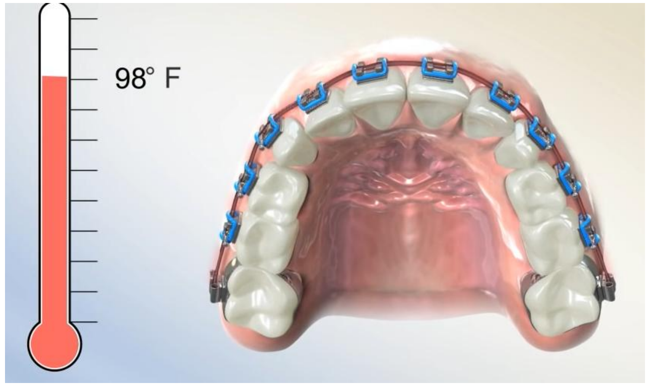
In the two-way effect, the material 'remembers' both a high and a low temperature shape. Consequently, the material can continuously cycle between the two shapes as the temperature is raised and lowered, without the need for an external stress.

SHAPE MEMORY ALLOYS

Materials exhibiting shape memory effect –
NiTiNOL (**Ni**ckel **Ti**tanium alloy developed at the **N**aval **O**rdinance **L**ab)
Cu-Al-Ni, Cu-Zn-Al, Au-Cd, Mn-Cu and Ni-Mn-Ga

Applications –
Medical field – braces, stents etc.
Actuation systems – Aerospace (Actuation systems in jet engines, variable geometry chevron)
Automotive (Chevrolette Corvett SMA actuator)





RHEOLOGICAL FLUIDS

- Rheology is a science dealing with the deformation and flow of matter. Rheological fluids are materials whose flow behavior and deformation depend on the applied stress or strain
- A special class of fluids exists that change their rheological properties on the application of an electric or a magnetic field.
- These controllable fluids can in general be grouped under one of two categories: **electrorheological (ER) fluids and magnetorheological (MR) fluids.**
- An electric field causes a change in the viscosity of ER fluids, and a magnetic field causes a similar change in MR fluids. The change in viscosity can be used in a variety of applications.
- **Composition** - Both ER and MR fluids consist of a colloidal suspension of particles in a carrier fluid. In the case of ER fluids, the particles are micron-sized dielectric particles, and could be corn starch or some alumino-silicate compound. The carrier fluid is electrically non-conducting, and could be mineral oil, silicone oil or paraffin oil. In the case of MR fluids, the properties of the carrier fluid are similar to those of ER fluids. However, the particles must be some ferromagnetic material.

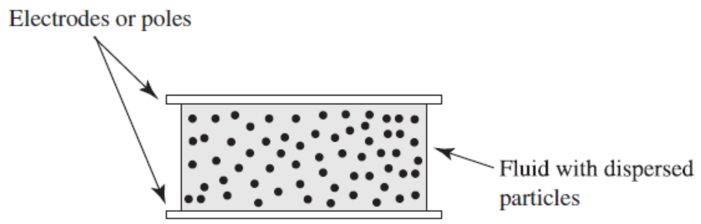
RHEOLOGICAL FLUIDS

- In the case of an ER/MR fluid, when an electric/magnetic field is applied, the particles become polarized and attract each other. As a result, chains of particles form in the fluid between the electrodes.

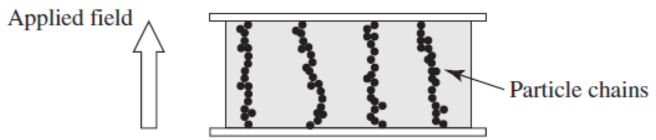
- In the absence of a field, the fluid can freely flow across the electrodes in response to an applied pressure gradient, or can be sheared by a relative motion of the electrodes.

- On the application of the field, the fluid flow across the electrodes is impeded by the particle chains. A larger pressure gradient is required to break the chains and maintain the flow of the fluid. As a result, a larger force is required on the electrodes to produce a relative motion between them.

- The forming and breaking of the chains results in a significant change in the **viscosity** of the fluid.



(a) No field



(b) With applied field

RHEOLOGICAL FLUIDS

Applications –

Applications: Rheological fluids are found in various industries, including:

- Food and Beverage: Understanding flow behavior for processing and packaging.
- Cosmetics: Formulating products with desired textures.
- Pharmaceuticals: Ensuring proper drug delivery through different formulations.
- Materials Science: Designing polymers and other materials with specific flow properties.

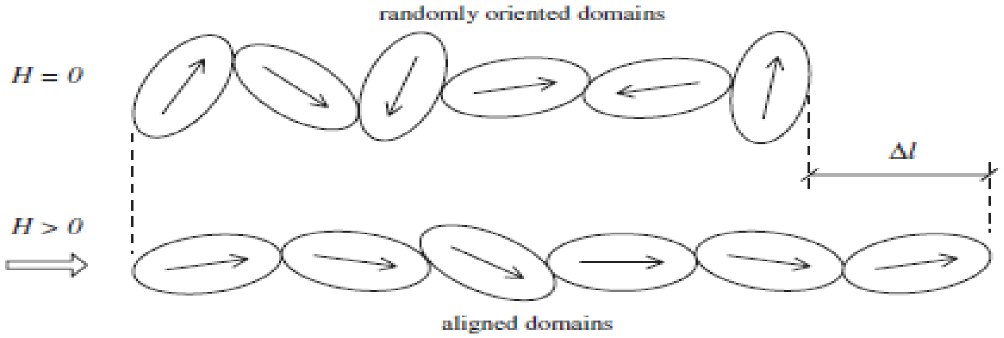
Other examples are
controllable dampers,
clutches,
suspension shock absorbers,
valves,
brakes,

MAGNETOSTRICTIVE MATERIAL

- Magnetostrictive materials are materials that change their shape or dimensions in response to an applied magnetic field. This phenomenon, known as magnetostriction, occurs due to the alignment of magnetic domains within the material. Magnetostrictives are active materials that exhibit magneto mechanical coupling.

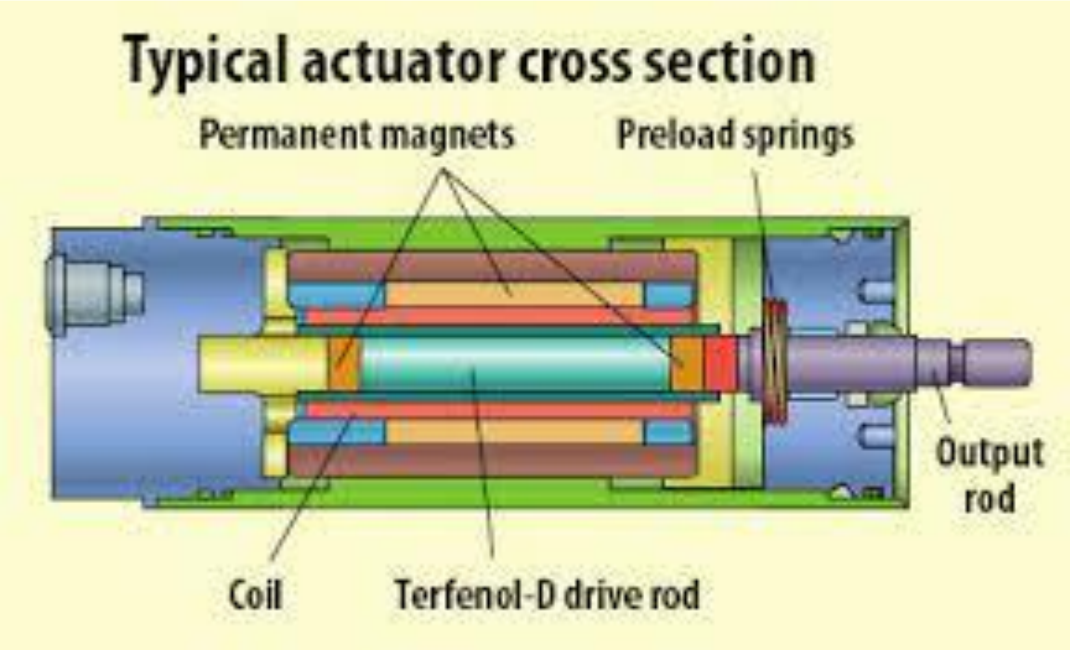
- **Mechanism:** When a magnetic field is applied, results in change in material dimensions in response to an applied magnetic field. This can lead to elongation or contraction, depending on the direction of the magnetic field.

- Example for magnetostricitve material – **Terfenol – D** (Ter for Terbium, Fe for Ferrous, NOL for Naval Ordnance Laboratory, and D for Dysprosium)



MAGNETOSTRICTIVE MATERIAL

Applications –
Sensors
Actuators - Low frequency, high power sonar applications
Motion generation against external loads
Ultrasonic applications



MECHANICAL ENGINEERING SCIENCE

Chapter 2 – Stress and Strain

Dr. Mantesh B Khot
Department of Mechanical Engineering

INTRODUCTION TO MECHANICS OF MATERIALS

- **Mechanics of materials** is a branch of applied mechanics that deals with the behavior of solid bodies subjected to various types of loading. Other names for this field of study are **strength of materials** and **mechanics of deformable bodies**.

- The principal objective of mechanics of materials is to determine the **stresses, strains, and displacements** in structures and their components due to the loads acting on them. If we can find these quantities for all values of the loads up to the loads that cause failure, we will have a complete picture of the mechanical behavior of these structures.

- An understanding of mechanical behavior is essential for the safe design of all types of structures, whether airplanes and antennas, buildings and bridges, machines and motors, or ships and spacecraft. That is why mechanics of materials is a basic subject in so many engineering fields.

NORMAL STRESS AND STRAIN

- The most fundamental concepts in mechanics of materials are stress and strain. These concepts can be illustrated in their most elementary form by considering a prismatic bar subjected to axial forces.

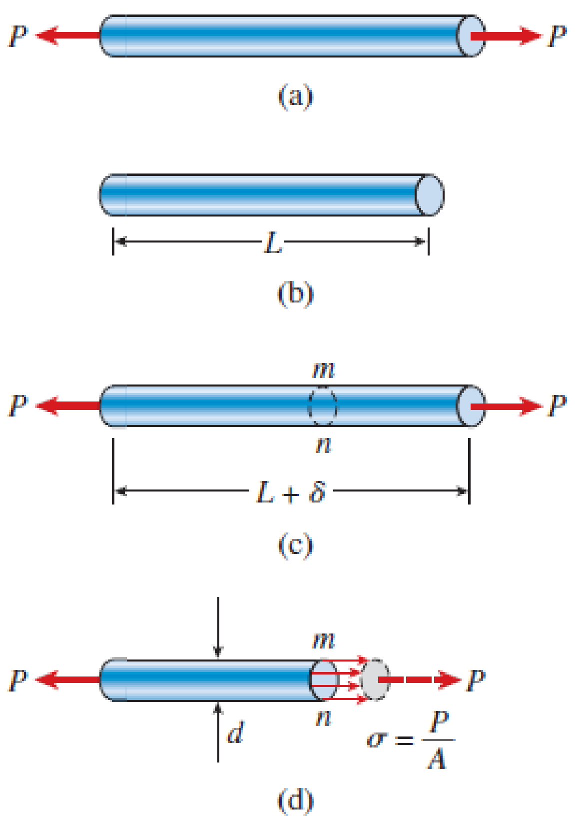
- A ***prismatic bar*** is a straight structural member having the same cross section throughout its length, and an axial force is a load directed along the axis of the member, resulting in either tension or compression in the bar.

- Examples are the tow bar, a prismatic member in tension; the landing gear strut, a member in compression; the members of a bridge truss, wing struts in small airplanes etc.

NORMAL STRESS AND STRAIN

- Consider a bar subjected to equal and opposite tensile forces of magnitude P.
- The internal actions in the bar are exposed if we make an imaginary cut through the bar at section mn.
- If we consider the equilibrium of either the left part or the right part at section mn, taken as a free body, we observe that the resultant of the ***internal resisting forces*** acting on the section must be equal to P and they may be assumed to be uniformly distributed over the whole area of the cross – section.
- ***The average intensity of these distributed forces is equal to the force per unit area and is called stress denoted by the Greek letter σ.***

$$\sigma = \frac{P}{A}$$



NORMAL STRESS AND STRAIN

- When the bar is stretched by the forces P, the stresses are ***tensile stresses***; if the forces are reversed in direction, causing the bar to be compressed, we obtain ***compressive stresses***. Inasmuch as the stresses act in a direction perpendicular to the cut surface, they are called ***normal stresses***. Thus, normal stresses may be either tensile or compressive.

- When a sign convention for normal stresses is required, it is customary to define ***tensile stresses as positive and compressive stresses as negative***.

- Because the normal stress σ is obtained by dividing the axial force by the cross-sectional area, it has units of force per unit of area (N/m^2).

NORMAL STRESS AND STRAIN

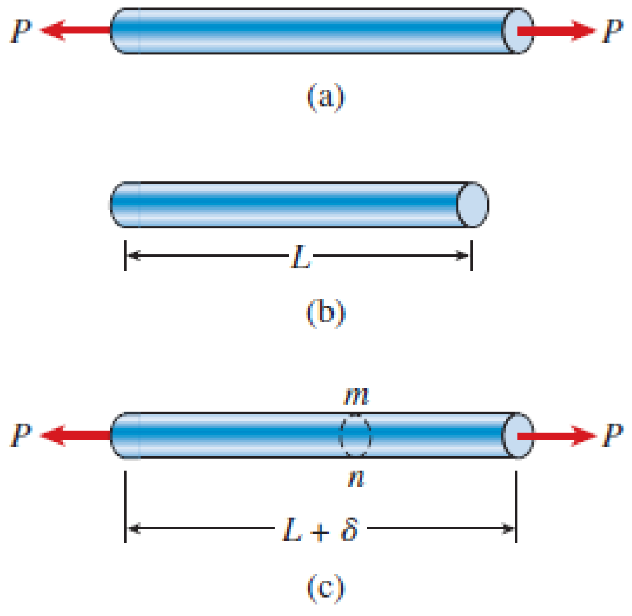
- As already observed, a straight bar will change in length when loaded axially, becoming longer when in tension and shorter when in compression.

- For instance, consider again the prismatic bar. The elongation δ of this bar is the cumulative result of the stretching of all elements of the material throughout the volume of the bar.

- In general, the elongation of a segment is equal to its length divided by the total length L and multiplied by the total elongation δ. Therefore, a unit length of the bar will have an elongation equal to 1/L times δ.

- ***This quantity is called the elongation per unit length, or strain, and is denoted by the Greek letter ε.*** We see that strain is given by the equation

$$\epsilon = \frac{\delta}{L}$$



(a)
(b)
(c)

NORMAL STRESS AND STRAIN

- If the bar is in tension, the strain is called a **tensile strain**, representing an elongation or stretching of the material.

- If the bar is in compression, the strain is a **compressive strain** and the bar shortens.

- **Tensile strain is usually taken as positive and compressive strain as negative**.

- The strain ε is called a normal strain because it is associated with normal stresses.

- Because normal strain is the ratio of two lengths, it is a **dimensionless quantity**, that is, it has no units.

STRESS – STRAIN DIAGRAM

- The design of machines and structures so that they will function properly requires that we understand the **mechanical behavior** of the materials being used.

- Ordinarily, the only way to determine how materials behave when they are subjected to loads is to perform experiments in the laboratory.

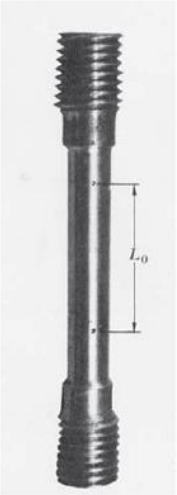
- The usual procedure is to place small specimens of the material in testing machines, apply the loads, and then measure the resulting deformations (such as changes in length and changes in diameter).

- Most materials-testing laboratories are equipped with machines capable of loading specimens in a variety of ways, including both **static and dynamic loading in tension and compression.**

STRESS – STRAIN DIAGRAM

- A typical tensile-test machine is shown in Figure. The test specimen is installed between the two large grips of the testing machine and then loaded in tension.

- Measuring devices record the deformations, and the automatic control and data-processing systems (at the left in the photo) tabulate and graph the results.



- A more detailed view of a tensile-test specimen is shown in Figure. The ends of the circular specimen are enlarged where they fit in the grips so that failure will not occur near the grips themselves.

STRESS – STRAIN DIAGRAM

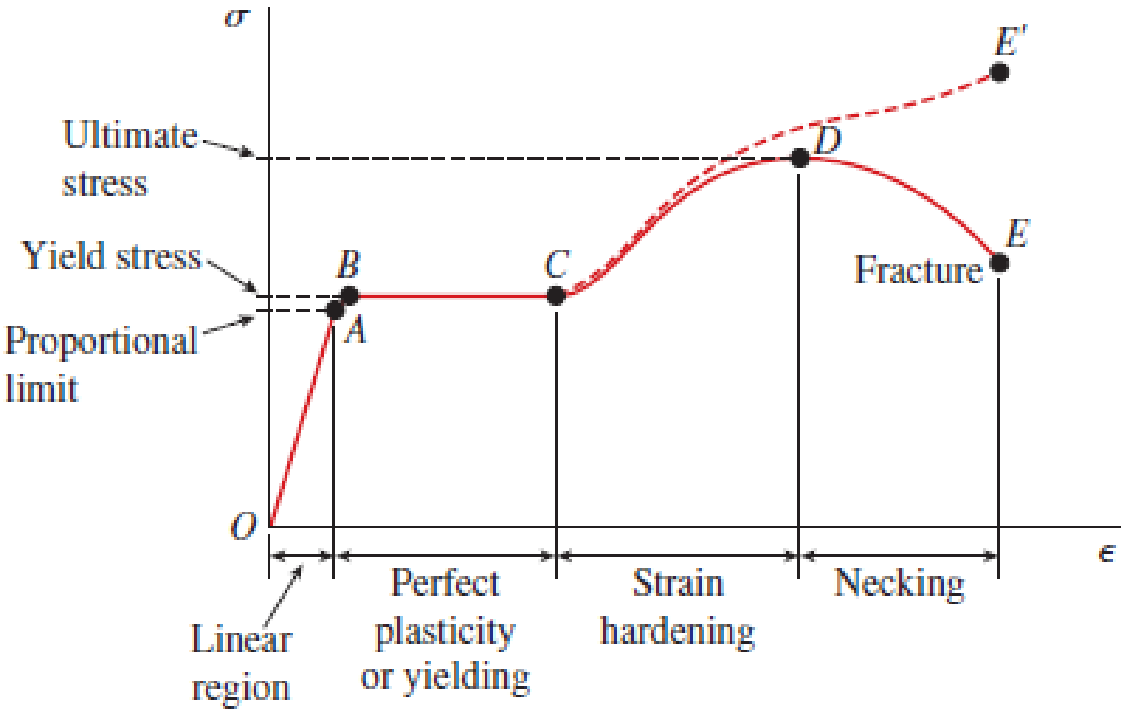
- The device at the left, which is attached by two arms to the specimen, is an extensometer that measures the elongation during loading.
- In order that test results will be comparable, the dimensions of test specimens and the methods of applying loads must be standardized.
- One of the major standards organizations in the United States is the **American Society for Testing and Materials (ASTM)**, a technical society that publishes specifications and standards for materials and testing.
- The ASTM standard tension specimen has a diameter of 0.505 in. and a gage length of 2.0 in. between the gage marks, which are the points where the extensometer arms are attached to the specimen.

STRESS – STRAIN DIAGRAM

- As the specimen is pulled, the axial load is measured and recorded, either automatically or by reading from a dial.
- The elongation over the gage length is measured simultaneously.
- In a **static test**, the load is applied slowly and the precise *rate* of loading is not of interest because it does not affect the behavior of the specimen.
- After performing a tension or compression test and determining the stress and strain at various magnitudes of the load, we can plot a diagram of stress versus strain.
- Such a **stress-strain diagram** is a characteristic of the particular material being tested and conveys important information about the mechanical properties and type of behavior.

STRESS – STRAIN DIAGRAM OF MILD STEEL

- The first material we will discuss is structural steel, also known as **mild steel** or low-carbon steel.
- A stress-strain diagram for a typical structural steel in tension is shown in Figure.



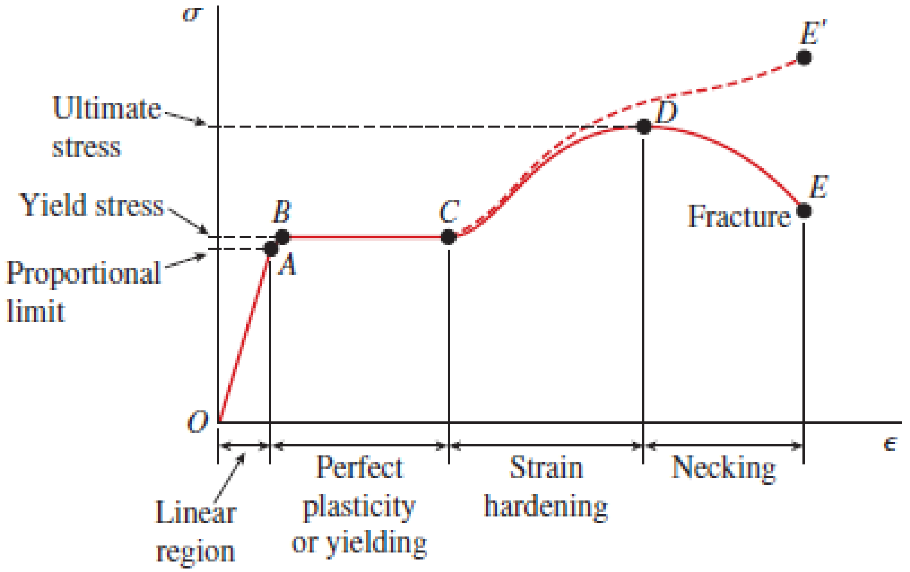
STRESS – STRAIN DIAGRAM OF MILD STEEL

- The diagram begins with a straight line from the origin O to point A, which means that the relationship between stress and strain in this initial region is not only linear but also proportional.

- Beyond point A, the proportionality between stress and strain no longer exists; hence the stress at A is called the **proportional limit**.

- For low-carbon steels, this limit is in the range (210 to 350 MPa), but high-strength steels (with higher carbon content plus other alloys) can have proportional limits of more than 550 MPa.

- The slope of the straight line from O to A is called ***the modulus of elasticity.***



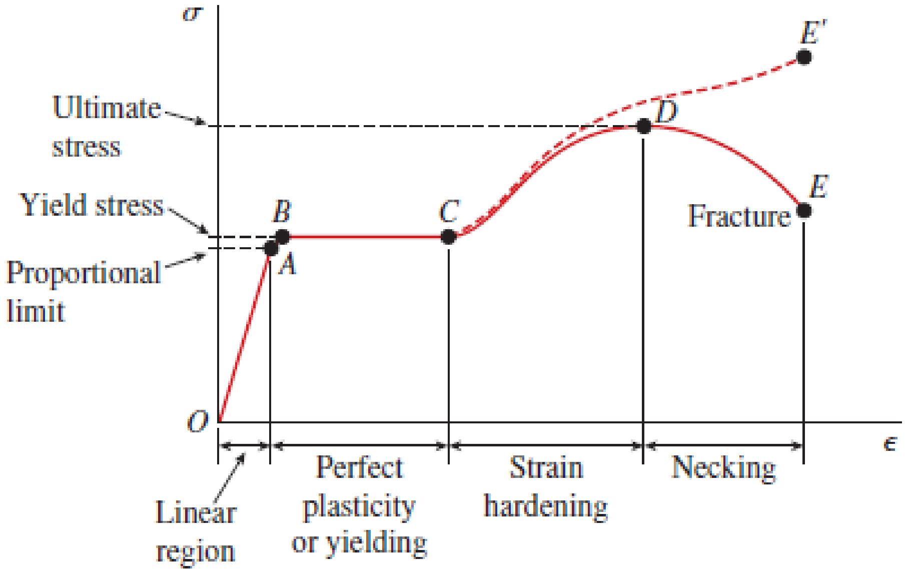
STRESS – STRAIN DIAGRAM OF MILD STEEL

- With an increase in stress beyond the proportional limit, the strain begins to increase more rapidly for each increment in stress.

- Consequently, the stress-strain curve has a smaller and smaller slope, until, at point B, the curve becomes horizontal.

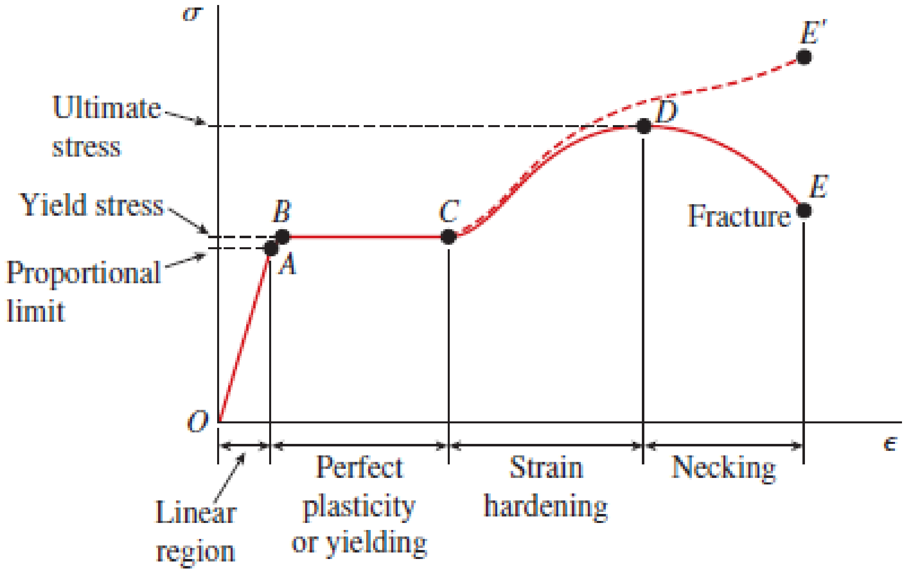
- Beginning at this point, considerable elongation of the test specimen occurs with no noticeable increase in the tensile force (from B to C). This phenomenon is known as **yielding** of the material, and point B is called the **yield point**. The corresponding stress is known as the **yield stress** of the steel.

- In the region from *B* to *C* , the material becomes **perfectly plastic**, which means that it deforms without an increase in the applied load.



STRESS – STRAIN DIAGRAM OF MILD STEEL

- After undergoing the large strains that occur during yielding in the region BC, the steel begins to strain harden.
- During **strain hardening**, the material undergoes changes in its crystalline structure, resulting in increased resistance of the material to further deformation.
- Elongation of the test specimen in this region requires an increase in the tensile load, and therefore the stress-strain diagram has a positive slope from C to D.
- The load eventually reaches its maximum value, and the corresponding stress (at point D) is called the **ultimate stress**.
- Further stretching of the bar is actually accompanied by a reduction in the load, and fracture finally occurs at a point such as E.



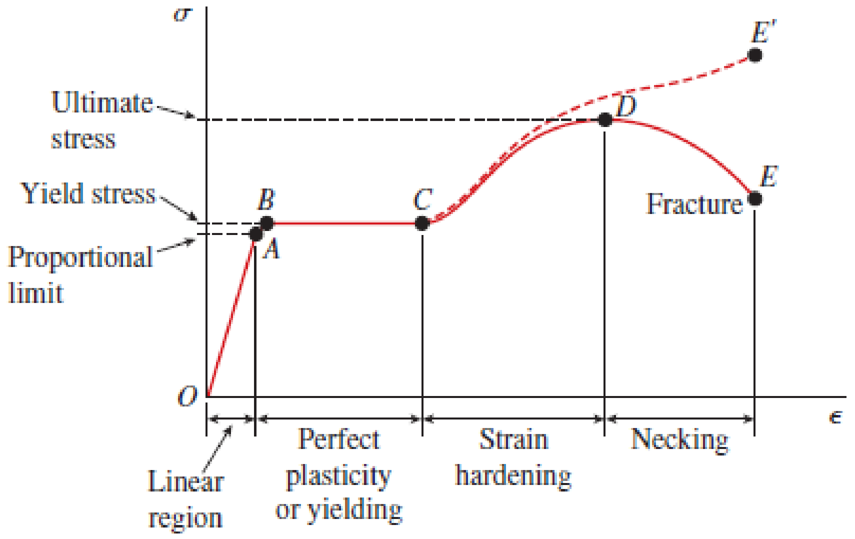
STRESS – STRAIN DIAGRAM OF MILD STEEL

- When a test specimen is stretched, lateral contraction occurs, as previously mentioned.

- The resulting decrease in cross-sectional area is too small to have a noticeable effect on the calculated values of the stresses up to about point C.

- In the vicinity of the ultimate stress, the reduction in area of the bar becomes clearly visible and a pronounced **necking** of the bar occurs.

- Fracture finally occurs at a point such as E.



STRESS – STRAIN DIAGRAM OF MILD STEEL

- The axial stress σ in a test specimen is calculated by dividing the axial load P by the cross-sectional area A.

- When the initial area of the specimen is used in the calculation, the stress is called the **nominal stress** (other names are conventional stress and engineering stress).

- A more exact value of the axial stress, called the **true stress**, can be calculated by using the actual area of the bar at the cross section where failure occurs. Since the actual area in a tension test is always less than the initial area, the true stress is larger than the nominal stress.

- The average axial strain ε in the test specimen is found by dividing the measured elongation δ between the gage marks by the gage length L.

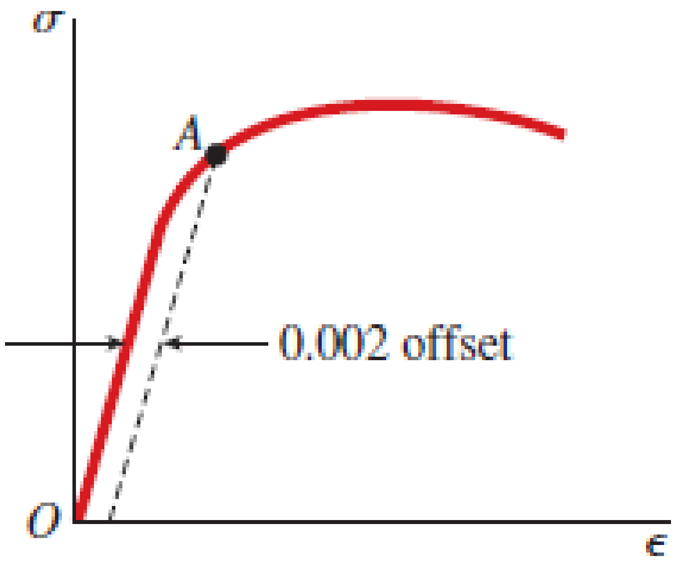
- If the initial gage length is used in the calculation then the **nominal strain** is obtained. Since the distance between the gage marks increases as the tensile load is applied, we can calculate the **true strain** (or natural strain) at any value of the load by using the actual distance between the gage marks. In tension, true strain is always smaller than nominal strain.

STRESS – STRAIN DIAGRAM OF OTHER MATERIALS

- The presence of a clearly defined yield point followed by large plastic strains is an important characteristic of structural steel that is sometimes utilized in practical design.

- Metals such as structural steel that undergo large permanent strains before failure are classified as **ductile**. Other materials that behave in a ductile manner (under certain conditions) include aluminum, copper, magnesium, lead, molybdenum, nickel, brass, bronze, monel metal, nylon, and teflon.

- Although they may have considerable ductility, **aluminum alloys** typically do not have a clearly definable yield point, as shown by the stress-strain diagram of Figure.

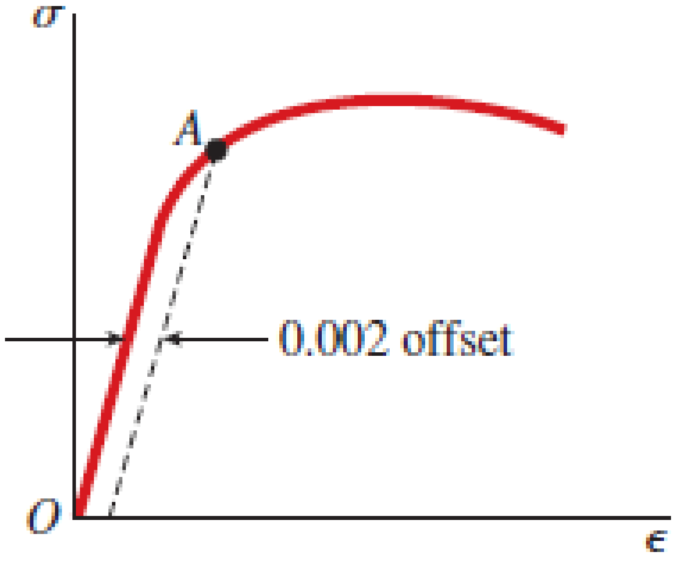


STRESS – STRAIN DIAGRAM OF OTHER MATERIALS

- When a material such as aluminum does not have an obvious yield point and yet undergoes large strains after the proportional limit is exceeded, an arbitrary yield stress may be determined by the offset method.

- A straight line is drawn on the stress-strain diagram parallel to the initial linear part of the curve but offset by some standard strain, such as 0.002 (or 0.2%). The intersection of the offset line and the stress-strain curve (point A in the figure) defines the yield stress.

- Because this stress is determined by an arbitrary rule and is not an inherent physical property of the material, it should be distinguished from a true yield stress by referring to it as the **offset yield stress**.



MEASURES OF DUCTILITY

- The ductility of a material in tension can be characterized by its elongation and by the reduction in area at the cross section where fracture occurs.

- The **percent elongation** is defined as follows:

$$\text{Percent elongation} = \frac{L_1 - L_0}{L_0}(100)$$

in which L_0 is the original gage length and L_1 is the distance between the gage marks at fracture.

- Because the elongation is not uniform over the length of the specimen but is concentrated in the region of necking, the percent elongation depends upon the gage length. Therefore, when stating the percent elongation, the gage length should always be given. For a 2 in. gage length, steel may have an elongation in the range from 3% to 40%, depending upon composition.

MEASURES OF DUCTILITY

- The **percent reduction in area** measures the amount of necking that occurs and is defined as follows

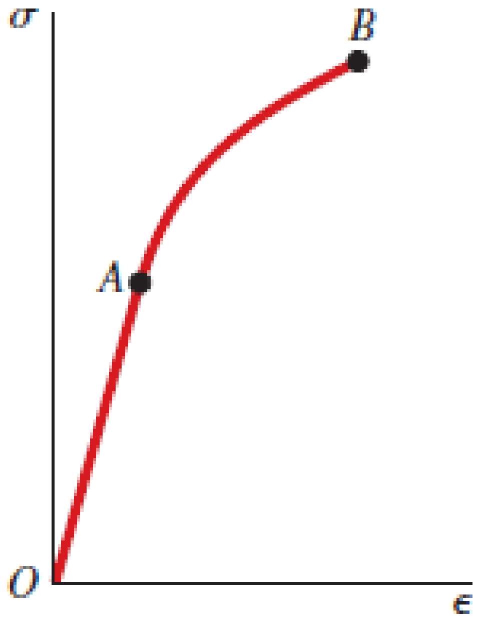
$$\text{Percent reduction in area} = \frac{A_0 - A_1}{A_0}(100)$$

- in which A_0 is the original cross-sectional area and A_1 is the final area at the fracture section. For ductile steels, the reduction is about 50%.

STRESS- STRAIN DIAGRAM OF A BRITTLE MATERIAL

- Materials that fail in tension at relatively low values of strain are classified as **brittle**. Examples are concrete, stone, cast iron, glass, ceramics, and a variety of metallic alloys.

- Brittle materials fail with only little elongation after the proportional limit is exceeded. Furthermore, the reduction in area is insignificant, and so the nominal fracture stress (point B) is the same as the true ultimate stress.



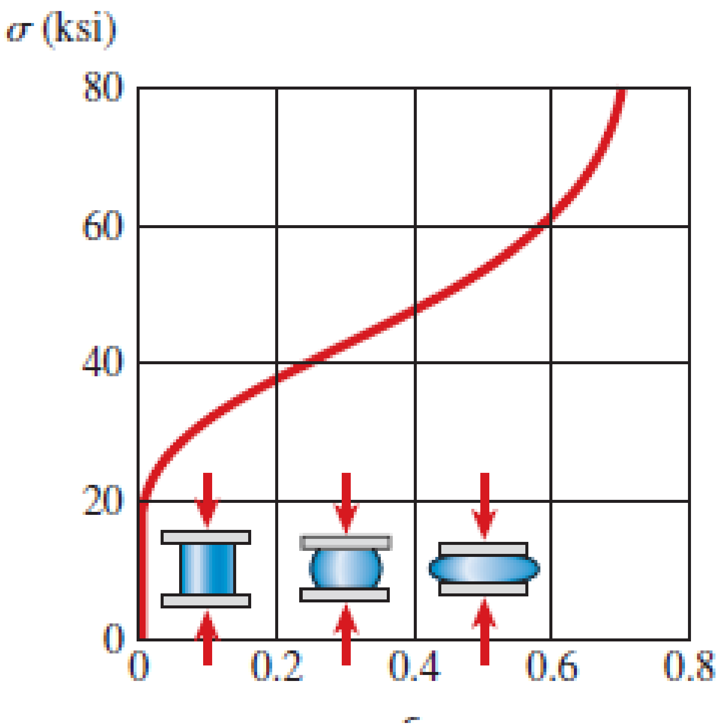
STRESS- STRAIN DIAGRAM IN COMPRESSION

- Stress-strain curves for materials in compression differ from those in tension.

- Ductile metals such as steel, aluminum, and copper have proportional limits in compression very close to those in tension, and the initial regions of their compressive and tensile stress-strain diagrams are about the same.

- However, after yielding begins, the behavior is quite different.

- In a tension test, the specimen is stretched, necking may occur, and fracture ultimately takes place. When the material is compressed, it bulges outward on the sides and becomes barrel shaped, because friction between the specimen and the end plates prevents lateral expansion.



STRESS- STRAIN DIAGRAM IN COMPRESSION

- With increasing load, the specimen is flattened out and offers greatly increased resistance to further shortening (which means that the stress-strain curve becomes very steep.

- Brittle materials loaded in compression typically have an initial linear region followed by a region in which the shortening increases at a slightly higher rate than does the load.

- The stress-strain curves for compression and tension often have similar shapes, but the ultimate stresses in compression are much higher than those in tension.

- Also, unlike ductile materials, which flatten out when compressed, brittle materials actually break at the maximum load.

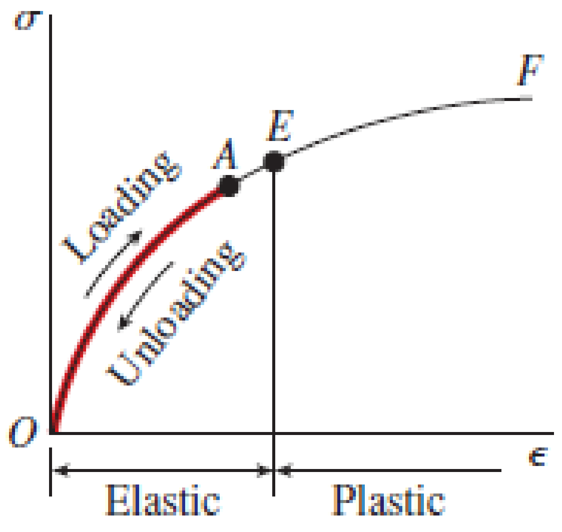
ELASTICITY AND PLASTICITY

- Stress-strain diagrams portray the behavior of engineering materials when the materials are loaded in tension or compression, as described in the preceding section. To go one step further, let us now consider what happens when the load is removed and the material is ***unloaded***.

- Assume, for instance, that we apply a load to a tensile specimen so that the stress and strain go from the origin O to point A on the stress strain curve.

- Suppose further that when the load is removed, the material follows exactly the same curve back to the origin O. This property of a material, by which it returns to its original dimensions during unloading, is called **elasticity**, and the material itself is said to be **elastic**.

- Note that the stress-strain curve from O to A need not be linear in order for the material to be elastic.



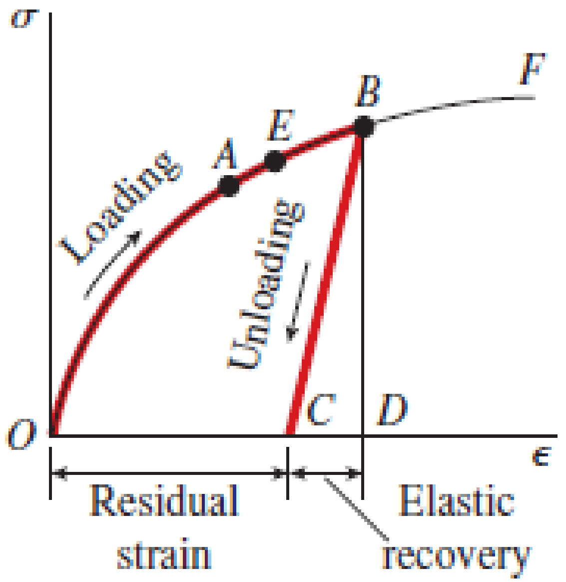
ELASTICITY AND PLASTICITY

- Now suppose that we load this same material to a higher level, so that point B is reached on the stress-strain curve.

- When unloading occurs from point B, the material follows line BC on the diagram. This unloading line is parallel to the initial portion of the loading curve; that is, line BC is parallel to a tangent to the stress-strain curve at the origin.

- When point C is reached, the load has been entirely removed, but a **residual strain, or permanent strain,** represented by line OC, remains in the material. As a consequence, the bar being tested is longer than it was before loading. This residual elongation of the bar is called the permanent set.

- Of the total strain OD developed during loading from O to B, the strain CD has been recovered elastically and the strain OC remains as a permanent strain. Thus, during unloading the bar returns partially to its original shape, and so the material is said to be **partially elastic**.



ELASTICITY AND PLASTICITY

- Between points A and B on the stress-strain curve, there must be a point before which the material is elastic and beyond which the material is partially elastic.

- To find this point, we load the material to some selected value of stress and then remove the load. If there is no permanent set (that is, if the elongation of the bar returns to zero), then the material is fully elastic up to the selected value of the stress.

- The process of loading and unloading can be repeated for successively higher values of stress. Eventually, a stress will be reached such that not all the strain is recovered during unloading.

- By this procedure, it is possible to determine the stress at the upper limit of the elastic region, for instance, the stress at point E. The stress at this point is known as the ***elastic limit*** of the material.

- The characteristic of a material by which it undergoes inelastic strains beyond the strain at the elastic limit is known as ***plasticity***.

LINEAR ELASTICITY AND HOOKE'S LAW

- Many structural materials, including most metals, wood, plastics, and ceramics, behave both elastically and linearly when first loaded. Consequently, their stress-strain curves begin with a straight line passing through the origin.

- When a material behaves elastically and also exhibits a linear relationship between stress and strain, it is said to be ***linearly elastic***.

- The linear relationship between stress and strain for a bar in simple tension or compression is expressed by the equation

$$\sigma = E\epsilon$$

in which σ is the axial stress, ε is the axial strain, and E is a constant of proportionality known as the **modulus of elasticity** for the material.

LINEAR ELASTICITY AND HOOKE'S LAW

- The equation $\sigma = E\varepsilon$ is commonly known as **Hooke's law**, named for the famous English scientist Robert Hooke (1635–1703).

- The modulus of elasticity has relatively large values for materials that are very stiff, such as structural metals.

- Steel has a modulus of approximately 210 GPa; for aluminum, values around 73 GPa) are typical.

- More flexible materials have a lower modulus—values for plastics range from 0.7 to 14 GPa.

- For most materials, the value of E in compression is nearly the same as in tension.

DEFORMATIONS OF MEMBERS UNDER AXIAL LOADING

- Consider a homogeneous rod BC of length L and uniform cross section of area A subjected to a centric axial load P.

- If the resulting axial stress $\sigma = P/A$ does not exceed the proportional limit of the material, Hooke's law applies and

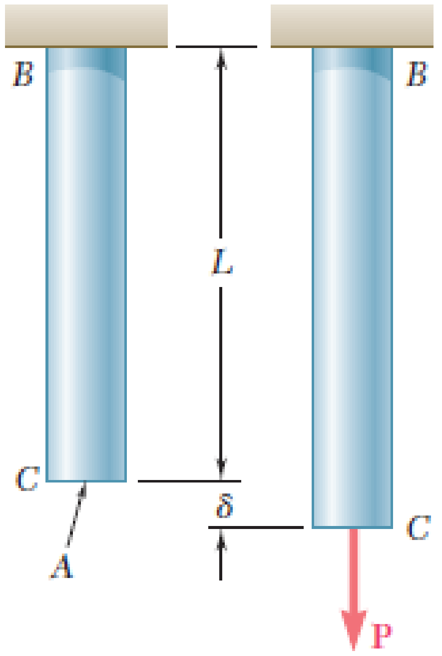
$$\sigma = E\epsilon$$

from which

$$\epsilon = \frac{\sigma}{E} = \frac{P}{AE}$$

- Recalling that the strain $\varepsilon = \delta/L$ and substituting for ε

$$\boxed{\delta = \frac{PL}{AE}}$$



DEFORMATIONS OF MEMBERS UNDER AXIAL LOADING

- Equation above can be used only if the rod is homogeneous (constant E), has a uniform cross section of area A, and is loaded at its ends.

- If the rod is loaded at other points, or consists of several portions of various cross sections and possibly of different materials, it must be divided into component parts that satisfy the required conditions for the application of above Eq.

- Using the internal force Pi , length Li , cross sectional area Ai, and modulus of elasticity Ei , corresponding to part i, the deformation of the entire rod is

$$\delta = \sum_i \frac{P_i L_i}{A_i E_i}$$

NUMERICALS

1) A circular rod of 12 mm diameter was tested for tension. The total elongation on a 300 mm length was 0.22 mm under a tensile load of 17 kN. Determine the value of E.

NUMERICALS

Solution:

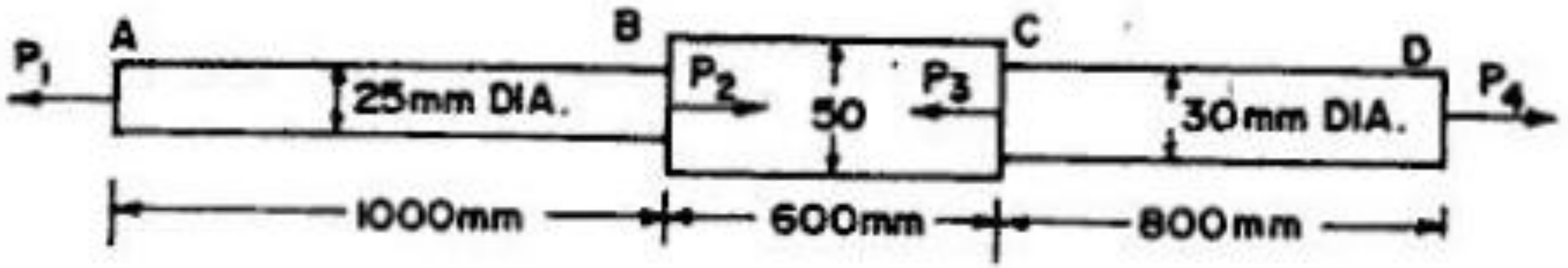
Stress $$p = \frac{P}{A} = \frac{17 \times 10^3}{\frac{\pi}{4}(12)^2} = 150.31 \text{ N/mm}^2$$

Strain $$\varepsilon = \frac{\Delta L}{L} = \frac{0.22}{300} = 7.333 \times 10^{-4}$$

$\therefore$ $$E = \frac{\text{Stress}}{\text{Strain}} = \frac{150.31}{7.333 \times 10^{-4}} = 2.05 \times 10^5 \text{ N/mm}^2 = 210 \text{ kN/mm}^2$$

NUMERICALS

2) A member ABCD is subjected to point loads P_1, P_2, P_3 and P_4 as shown in figure below. Calculate the force P_2 necessary for equilibrium if P_1 = 10 kN, P_3 = 40 kN and P_4 = 16 kN. Taking modulus of elasticity as 2.05×10^5 N/mm^2, determine the total elongation of the member.



NUMERICALS

Solution:

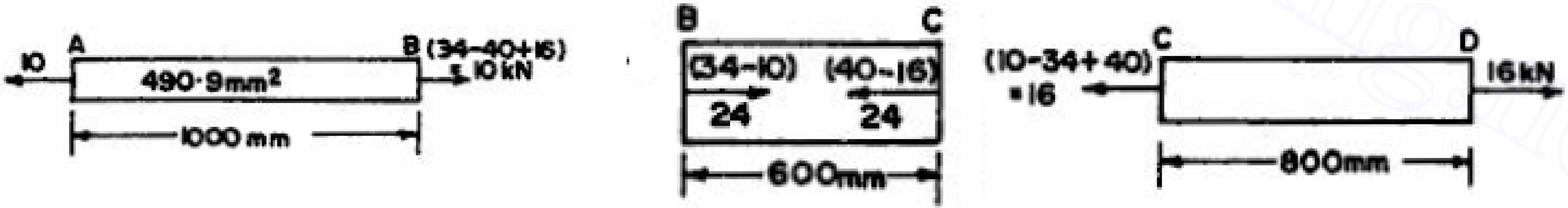
For the equilibrium of the bar,

$$P_1 + P_3 = P_2 + P_4$$

or $$10 + 40 = P_2 + 16 \text{ , From which } P_2 = 34 \text{ kN } (\rightarrow)$$

Now from Eq. 2.14, $\Delta = \frac{1}{E} \Sigma \frac{PL}{A}$

The free body diagrams for the three portions of the bar are shown



NUMERICALS

Solution:

$$A_1 = \frac{\pi}{4}(25)^2 = 490.9\ \text{mm}^2\ ;\ A_2 = \frac{\pi}{4}(50)^2 = 1963.5\ \text{mm}^2\ ;\ A_3 = \frac{\pi}{4}(30)^2 = 706.9\ \text{mm}^2$$

$$\Delta_1 = \frac{10 \times 1000 \times 1000}{490.9 \times 2.05 \times 10^5} = 0.099\ \text{(elongation)}$$

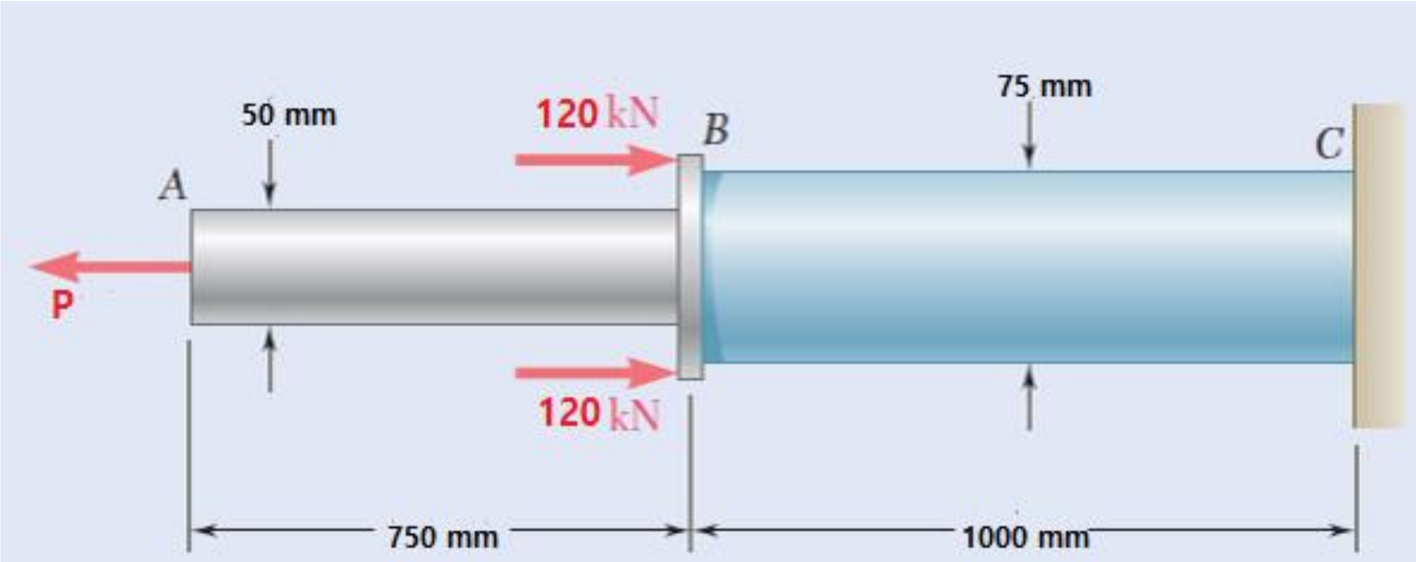
$$\Delta_2 = \frac{24 \times 1000 \times 600}{1963.5 \times 2.05 \times 10^5} = 0.036\ \text{(contraction)}$$

$$\Delta_3 = \frac{16 \times 1000 \times 800}{706.9 \times 2.05 \times 10^5} = 0.088\ \text{(elongation)}$$

Total $\Delta = \Delta_1 - \Delta_2 + \Delta_3 = 0.099 - 0.036 + 0.088 = \mathbf{0.151\ mm.}$

NUMERICALS

3) Two solid cylindrical rods AB and BC are welded together at B and loaded as shown. Determine the magnitude of the force P for which the tensile stress in rod AB has the same magnitude as the compressive stress in rod BC.



NUMERICALS

Solution:

$$\sigma_{AB} = \frac{P}{A_{AB}} = \frac{P}{\frac{\pi}{4}(50\times 10^{-3})^2} = 509.3P$$

$$\sigma_{BC} = \frac{2(120)-P}{A_{BC}} = \frac{240-P}{\frac{\pi}{4}(75\times 10^{-3})^2} = 54324 - 226.35P$$

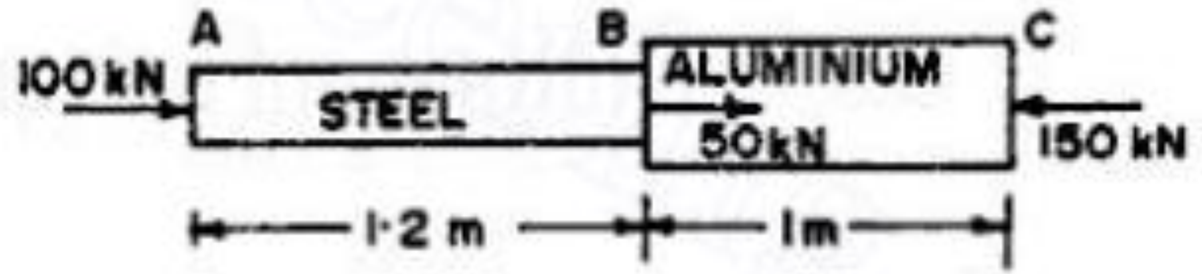
Equating both the stresses,

$$509.39P = 54324 - 226.35P$$

$$=> P = 73.84kN$$

NUMERICALS

4) A member ABC is formed by connecting a steel bar of 20 mm diameter to an aluminium bar of 30 mm diameter and is subjected to forces as shown in figure below. Determine the total deformation of the bar, taking E for aluminium as 0.7×10^5 N/mm^2 and that for steel as 2×10^5 N/mm^2



NUMERICALS

Solution:

$$\Delta = \Sigma \frac{PL}{AE} = \frac{P_1 L_1}{A_1 E_1} + \frac{P_2 L_2}{A_2 E_2}$$

Portion AB

Force $P_1 = 100$ kN (or $150 - 50 = 100$ kN), compressive;

$L_1 = 1200$ mm

$A_1 = \frac{\pi}{4}(20)^2 = 314.16\ \text{mm}^2$

$E_1 = 2 \times 10^5\ \text{N/mm}^2$

$\therefore \quad \Delta_1 = \frac{100 \times 10^3 \times 1200}{314.16 \times 2 \times 10^5} \approx 1.91$ mm (contraction)

Portion BC

Force $P_2 = 100 + 50 = 150$ kN; $L_2 = 1000$ mm

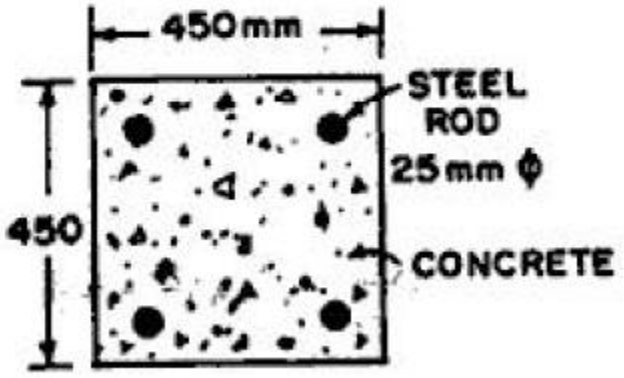
$A_2 = \frac{\pi}{4}(30)^2 = 706.86$; $E_2 = 0.7 \times 10^5\ \text{N/mm}^2$

$\Delta_2 = \frac{150 \times 10^3 \times 1000}{706.86 \times 0.7 \times 10^5} = 0.303$ mm (contraction)

$\therefore$ Total $\Delta = \Delta_1 + \Delta_2 = 1.91 + 0.303 = \mathbf{2.213\ mm}$ (contraction)

NUMERICALS

5) A reinforced concrete column 450 mm×450 mm has four steel rods of 25 mm diameter embedded in it. Determine the stresses in steel and concrete when total load on the column is 1000 kN. Take moduli of elasticity for steel and concrete as 205 MPa and 13.6 KN/mm^2 respectively.



NUMERICALS

Solution

$$\text{Total area of column} = 450 \times 450$$
$$= 202500 \text{ mm}^2$$

$$\text{Area of steel rods} = 4\left(\frac{\pi}{4}25^2\right)$$
$$= 1963.5 \text{ mm}^2$$

$$\therefore \quad \text{Area of concrete, } A_c = 202500 - 1963.5$$
$$= 200536.5 \text{ mm}^2$$

$$\text{From equilibrium, } p_s A_s + p_c A_c = 1000 \times 10^3 \quad \ldots(i)$$

NUMERICALS

From compatibility, $\frac{p_s}{E_s} = \frac{p_c}{E_c}$

or $$p_s = p_c \cdot \frac{E_s}{E_c} = p_c \frac{205}{13.6} = 15.074\, p_c \quad ...(2)$$

Substituting this value of p_s in (1) we get

$\therefore$ $15.074\, p_c\,(1963.5) + p_c\,(200536.5) = 1000 \times 10^3$

From which, $p_c = \mathbf{4.345\ N/mm^2}$

Hence $p_s = 15.074 \times 4.345 = \mathbf{65.501\ N/mm^2}$

Now, average compressive stress $= \frac{1000 \times 10^3}{202500} = 4.938\ \text{N/mm}^2$

$\therefore$ Average load carried by concrete $= 4.938 \times 200536.5 \times 10^{-3} = 990.3$ kN

Actual load carried by concrete $= 4.345 \times 200536.5 \times 10^{-3} = 871.3$ kN

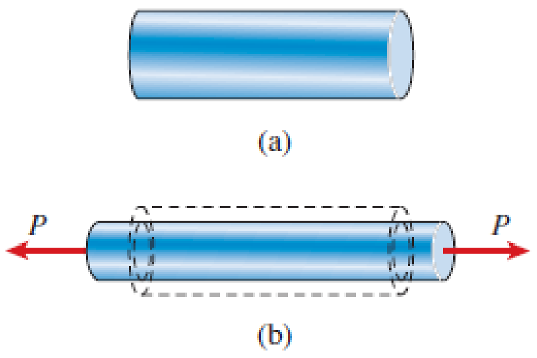
POISSON'S RATIO

- When a prismatic bar is loaded in tension, the axial elongation is accompanied by lateral contraction (that is, contraction normal to the direction of the applied load).

- The lateral strain ε' at any point in a bar is proportional to the axial strain ε at that same point if the material is linearly elastic.

- ***The ratio of these strains is a property of the material known as Poisson's ratio***.

- This dimensionless ratio, usually denoted by the Greek letter ν (nu), can be expressed by the equation



$$\nu = -\frac{\text{lateral strain}}{\text{axial strain}} = -\frac{\epsilon'}{\epsilon}$$

POISSON'S RATIO

- The minus sign is inserted in the equation to compensate for the fact that the lateral and axial strains normally have opposite signs.

- Poisson's ratio lies in the range 0.25 to 0.35 for most metals and many other materials.

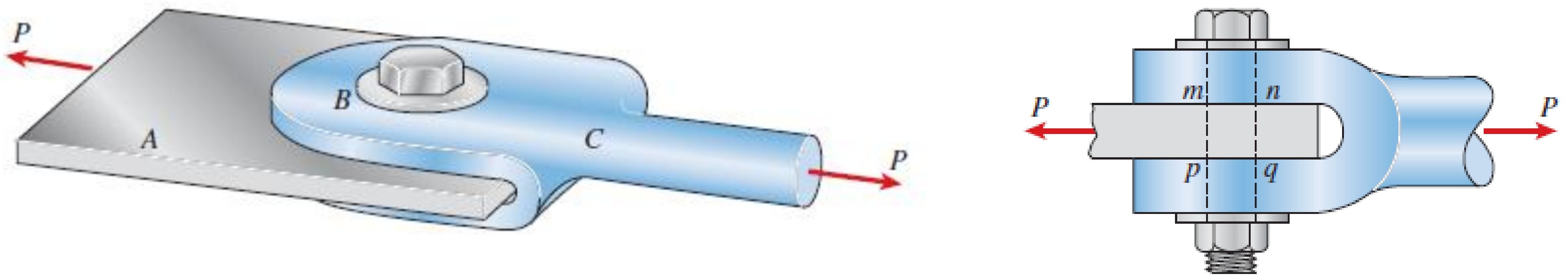
- Materials with an extremely low value of Poisson's ratio include cork, for which ν is practically zero, and concrete, for which ν is about 0.1 or 0.2.

- A theoretical upper limit for Poisson's ratio is 0.5. Rubber comes close to this limiting value.

SHEAR STRESS AND SHEAR STRAIN

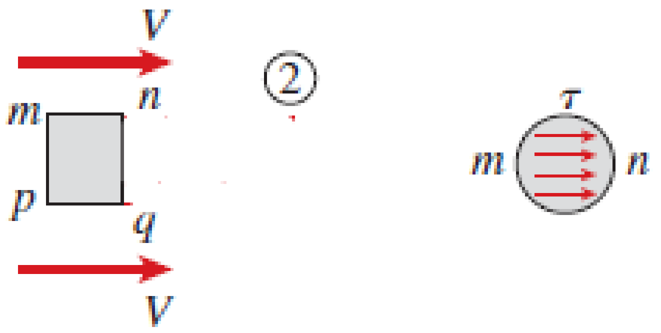
- Consider the bolted connection shown in Figure. This connection consists of a flat bar A, a clevis C, and a bolt B that passes through holes in the bar and clevis.

- Under the action of the tensile loads P, the bar and clevis tend to shear the bolt, that is, cut through it.



SHEAR STRESS AND SHEAR STRAIN

- The free-body diagram of Figure shows that there is a tendency to shear the bolt along cross sections mn and pq. From a free-body diagram of the portion mnpq of the bolt, we see that shear forces V act over the cut surfaces of the bolt.



- The shear forces V are the resultants of the shear stresses distributed over the cross-sectional area of the bolt. ***These stresses act parallel to the cut surface.***

- The average shear stress on the cross section of a bolt is obtained by dividing the total shear force V by the area A of the cross section on which it acts, as follows:

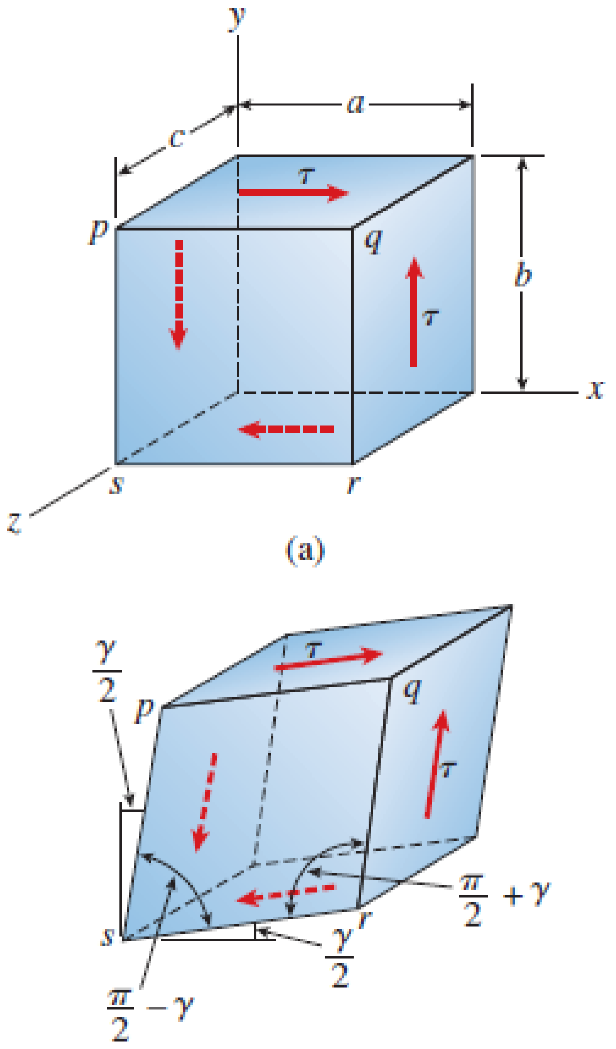
$$\tau_{aver} = \frac{V}{A}$$

SHEAR STRESS AND SHEAR STRAIN

- Shear stresses acting on an element of material are accompanied by shear strains.

- As an aid in visualizing these strains, we note that the shear stresses have no tendency to elongate or shorten the element in the x, y, and z directions—in other words, the lengths of the sides of the element do not change.

- Instead, the shear stresses produce a change in the shape of the element. The original element, which is a rectangular parallelepiped, is deformed into an oblique parallelepiped, and the front and rear faces become rhomboids.



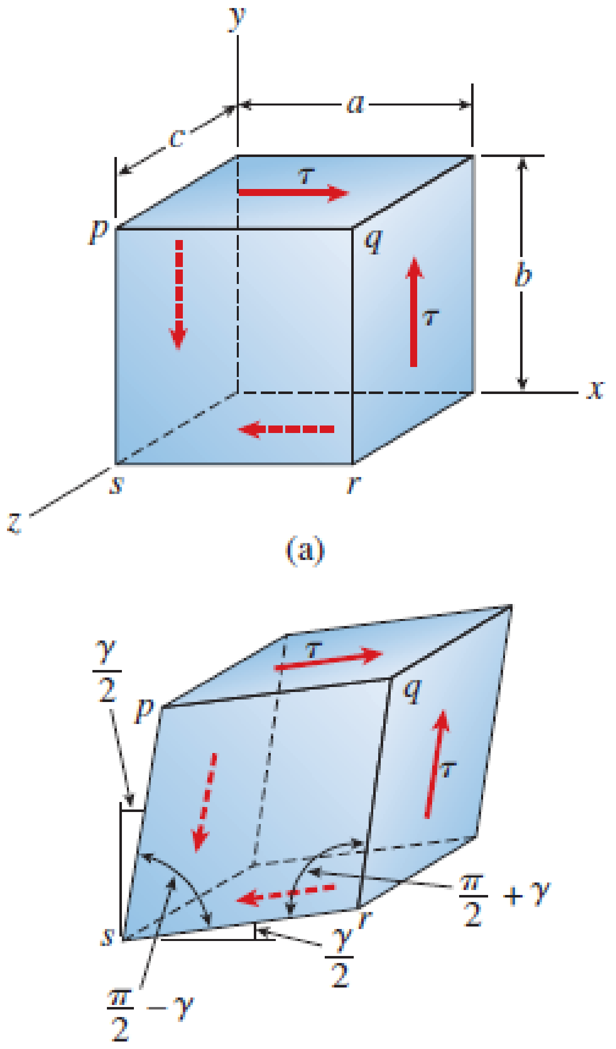
SHEAR STRESS AND SHEAR STRAIN

- Because of this deformation, the angles between the side faces change.

- For instance, the angles at points q and s, which were $\pi/2$ before deformation, are reduced by a small angle γ to $\pi/2$ - γ.

- At the same time, the angles at points p and r are increased to $\pi/2+\gamma$. The angle γ is a measure of the distortion, or change in shape, of the element and is called the **shear strain**.

- Because shear strain is an angle, it is usually measured in degrees or radians.



HOOKE'S LAW IN SHEAR

- The properties of a material in shear can be determined experimentally from direct-shear tests or from torsion tests.

- From the results of these tests, we can plot shear stress-strain diagrams (that is, diagrams of shear stress τ versus shear strain γ). These diagrams are similar in shape to tension-test diagrams (σ versus ε) for the same materials, although they differ in magnitudes.

- For many materials, the initial part of the shear stress-strain diagram is a straight line through the origin, just as it is in tension. For this linearly elastic region, the shear stress and shear strain are proportional, and therefore we have the following equation for Hooke's law in shear:

$$\tau = G\gamma$$

in which G is the shear modulus of elasticity (also called the modulus of rigidity).

HOOKE’S LAW IN SHEAR

- The moduli of elasticity in tension and shear are related by the following equation:

$$G = \frac{E}{2(1 + \nu)}$$

FACTOR OF SAFETY

- The maximum load that a structural member or a machine component will be allowed to carry under normal conditions is considerably smaller than the ultimate load.

- This smaller load is called the allowable load or working or design load. Thus, only a fraction of the ultimate load capacity of the member is used when the allowable load is applied.

- The remaining portion of the load-carrying capacity of the member is kept in reserve to assure its safe performance. ***The ratio of the ultimate load to the allowable load is used to define the factor of safety*****:**

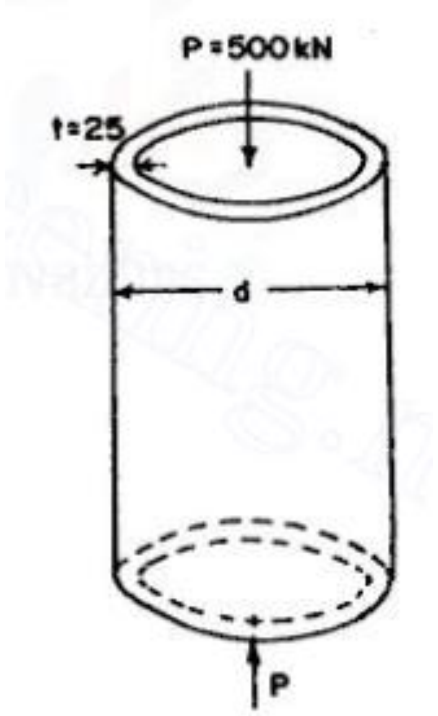
$$\text{Factor of safety} = F.S. = \frac{\text{ultimate load}}{\text{allowable load}}$$

- An alternative definition of the factor of safety is based on the use of stresses:

$$\text{Factor of safety} = F.S. = \frac{\text{ultimate stress}}{\text{allowable stress}}$$

NUMERICALS

5) A short hollow circular cast iron cylinder shown in Figure below is to support an axial compressive load of P = 500 kN. The ultimate stress in compression for the material is 240 N/mm^2. Determine the minimum required outside diameter d of the cylinder of 25 mm wall thickness, if the factor of safety is to be 3.0 with respect to ultimate strength.



NUMERICALS

Solution:

Allowable stress $p_{allow.} = \frac{p_u}{F} = \frac{240}{3} = 80 \text{ N/mm}^2$

$\therefore$ Required area of cross-section,

$$A = \frac{P}{p_{allow}} = \frac{500 \times 10^3}{80} = 6250 \text{ mm}^2$$

Now, for a hollow cylinder of outside diameter d and thickness t

$$A = \frac{\pi}{4} d^2 - \frac{\pi}{4}(d - 2t)^2 = \pi t (d - t)$$

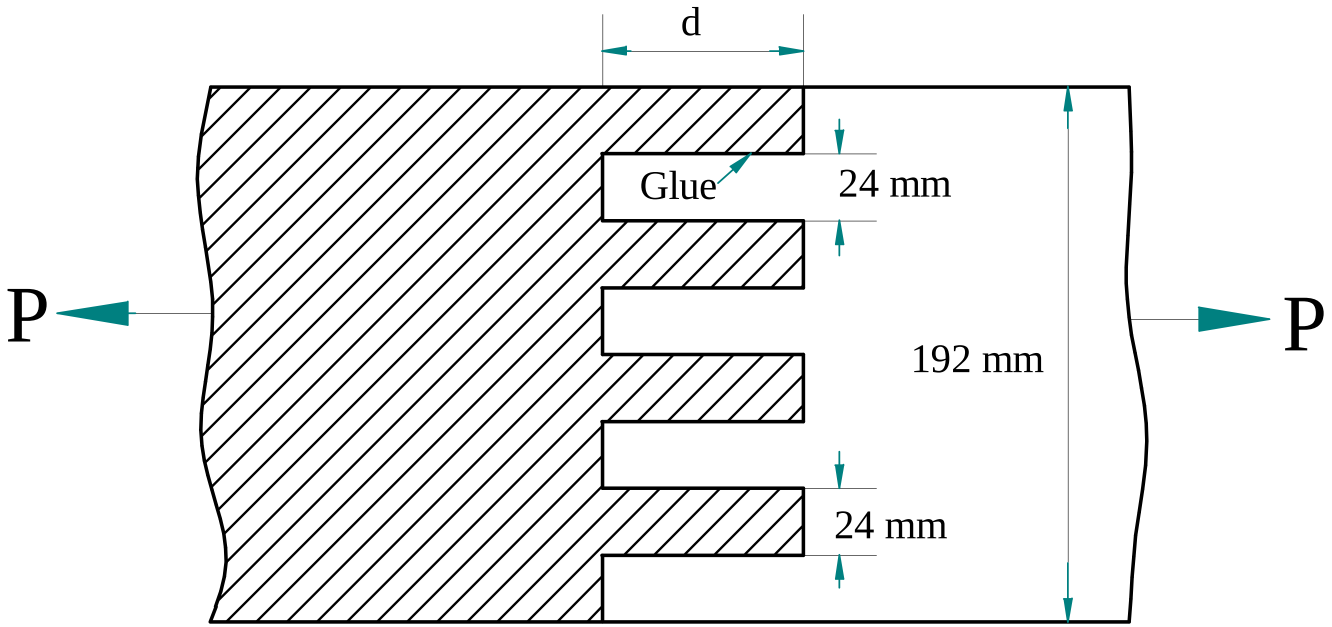
or

$$d = t + \frac{A}{\pi t} = 25 + \frac{6250}{\pi (25)}$$

$$= 104.58 \text{ mm} \approx \mathbf{105 \text{ mm}}$$

NUMERICALS

6) Two wooden planks, each 20 mm thick and 192 mm wide, are joined by the glued mortise joint shown. Knowing that the joint will fail when the average shearing stress in the glue reaches 800 KPa, determine the smallest allowable length d of the cut if the joint is to withstand an axial load of magnitude P = 6 KN



NUMERICALS

Solution: Given t = 20 mm, P = 6 KN
From Fig., seven surfaces carry the applied axial load P = 6 KN = 6×10^3 N

Area of each glue is A = dt

Shear stress $\tau = \frac{P}{7A}$

$$A = \frac{P}{7\tau} = \frac{6 \times 10^3}{7 \times 800 \times 10^3} = 1.0714 \times 10^{-3}\ m^2$$

$$\boldsymbol{A = 1.0714 \times 10^3\ mm^2}$$

w.k.t

$$d = \frac{A}{t} = \frac{1.0714 \times 10^3}{20}$$

$$\boldsymbol{d = 53.57\ mm}$$

NUMERICALS

7) A bar of steel has rectangular cross – section 30 mm×20 mm. Determine the dimensions of the sides and percentage decrease of area of cross – section, when it is subjected to a tensile force of 120 kN in the direction of its length. Take E = 2×10^5 N/mm^2 and ν = 0.3

NUMERICALS

Solution:

Strain in the direction of pull $e_1 = \frac{P}{AE} = \frac{120 \times 10^3}{30 \times 20 \times 2 \times 10^5} = 10 \times 10^{-4}$

Lateral strain $= -\frac{e_1}{m} = -\frac{3}{10} \times 10 \times 10^{-4} = 3 \times 10^{-4}$

Hence 30 mm side is decreased by $30 \times 3 \times 10^{-4} = 0.009$ mm

and 20 mm side is decreased by $20 \times 3 \times 10^{-4} = 0.006$ mm

Hence dimension of 30 mm side $= 30 - 0.009 \approx 29.991$ mm

and dimension of 20 mm side $= 20 - 0.006 = 19.994$ mm.

New area of cross-section $= (30 - 0.009)(20 - 0.006) \approx 600 - 0.36$

% decrease of area of cross-section $= \frac{0.36}{600} \times 100 =$ **0.06%**

MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

1) **Strength**: ***Strength is defined as the ability of the material to resist, without rupture, external forces causing various types of stresses.***
Depending upon the type of stresses induced by external loads, strength is expressed as tensile strength, compressive strength or shear strength. The terms yield strength and ultimate strength have been explained previously.

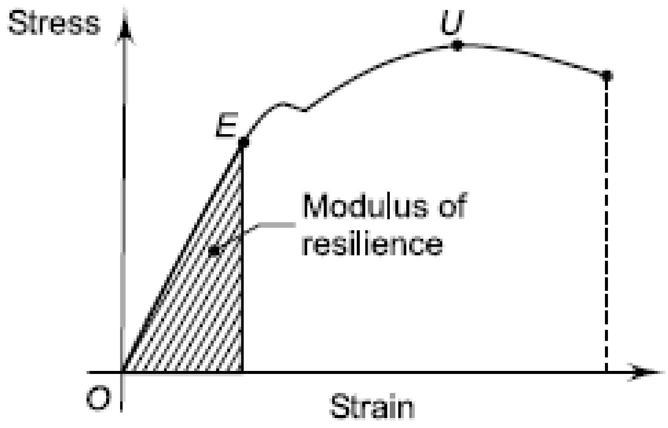
2) **Elasticity**: ***Elasticity is defined as the ability of the material to regain its original shape and size after the deformation, when the external forces are removed.***

3) **Plasticity**: ***Plasticity is defined as the ability of the material to retain the deformation produced under the load on a permanent basis.***

4) **Stiffness**: ***Stiffness or rigidity is defined as the ability of the material to resist deformation under the action of an external load.***

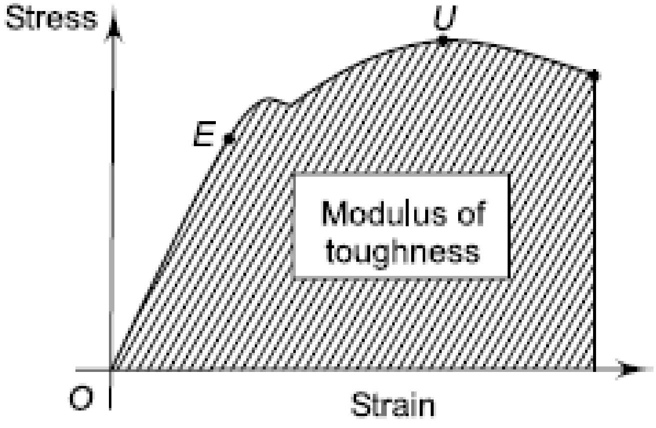
MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

5) **Resilience**: ***Resilience is defined as the ability of the material to absorb energy when deformed and to release this energy when loaded.***
This property is essential for spring materials. It is measured by a quantity called **modulus of resilience** which is represented by the area under stress strain curve from the origin to the elastic limit**.**



(a)

6) **Toughness**: ***Toughness is defined as the ability of the material to absorb energy before fracture takes place.***
This property is essential for machine components which are required to withstand impact loads. It is measured by a quantity called **modulus of toughness**. Modulus of toughness is the total area under stress – strain curve in a tension test.



(b)

MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

7) **Malleability:** *Malleability is defined as the ability of a material to deform to a greater extent before the sign of crack, when it is subjected to compressive force.*

8) **Ductility:** *Ductility is defined as the ability of a material to deform to a greater extent before the sign of crack, when it is subjected to tensile force.*

9) **Brittleness:** *Brittleness is the property of a material which shows negligible plastic deformation before fracture takes place.*

MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

10) Hardness: *Hardness is defined as the resistance of the material to penetration.*

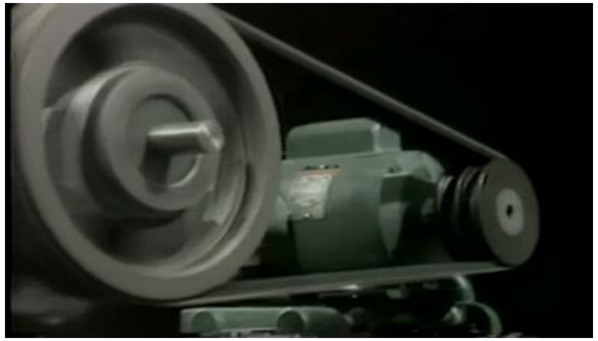
It usually indicates resistance to abrasion, scratching, cutting or shaping. It is an important property in the selection of material for parts which rub on one another such as pinion and gear, cam and follower, rail and wheel and parts of a ball bearing. Wear resistance of these parts is improved by increasing surface hardness by case hardening.

MECHANICAL ENGINEERING SCIENCE

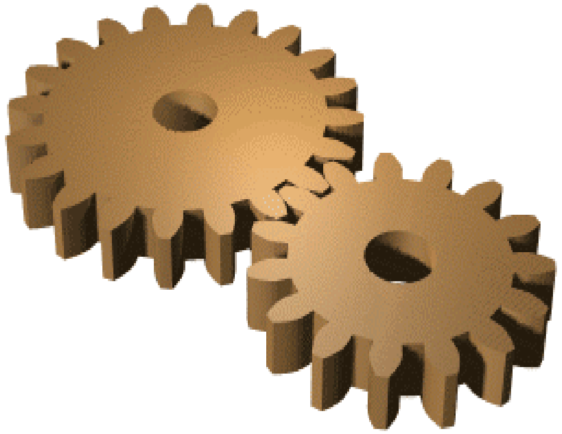
Chapter 3 – Power Transmission

Dr. Mantesh B Khot
Department of Mechanical Engineering

INTRODUCTION TO POWER TRANMISSION DRIVES



- Power transmission drives are mainly used to transmit power from one shaft to another which rotate at the same speed or at different speeds.
- There are two types of drives – **rigid and flexible**.
- In flexible drives, there is an intermediate link such as **belt, rope or chain** between the driving and the driven shafts. Since the link is flexible, the drives are called '**flexible**' drives.
- The rotary motion of the driving shaft is first converted into translatory motion of the belt or chain and then again converted into rotary motion of the driven shaft.

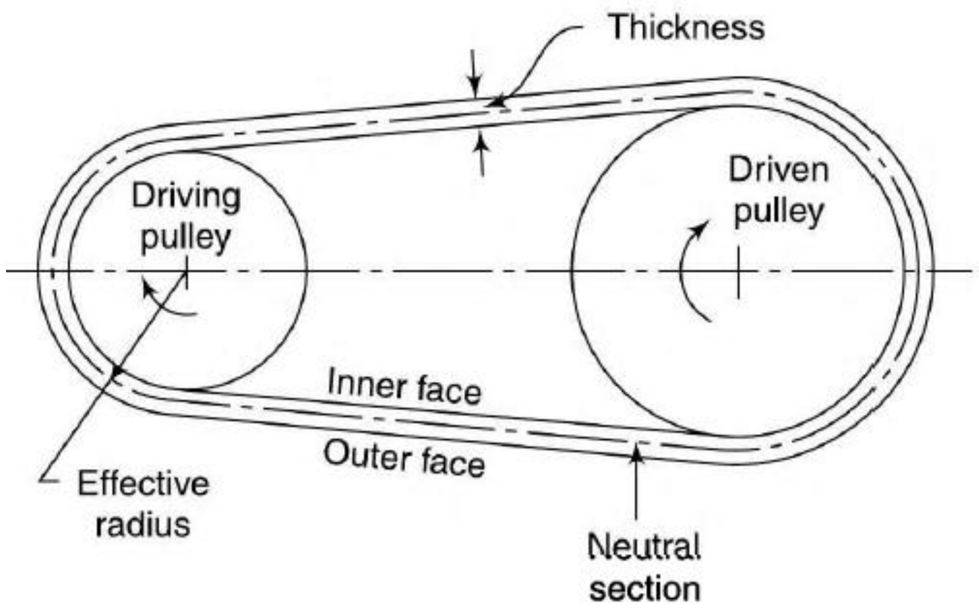


- In rigid drives like **gear** drives, there is direct contact between the driving and the driven shafts through the drive.
- The rotary motion of the driving shaft is directly converted into rotary motion of the driven shaft.

BELT DRIVES

- Belts are used to transmit power between two shafts by means of **friction**.

- A belt drive consists of three elements – driving and driven pulleys and an endless belt, which envelopes them. The belt is kept in tension so that motion of one pulley is transferred to the other without slip. It is used when the distance between the shafts is large.



BELT DRIVES

- Depending upon the shape of the cross – section, belts are classified as –

1) Flat belts

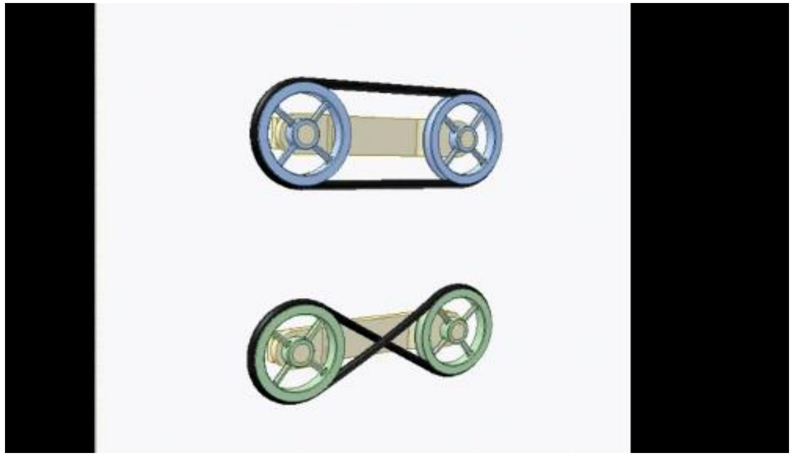
2) V belts

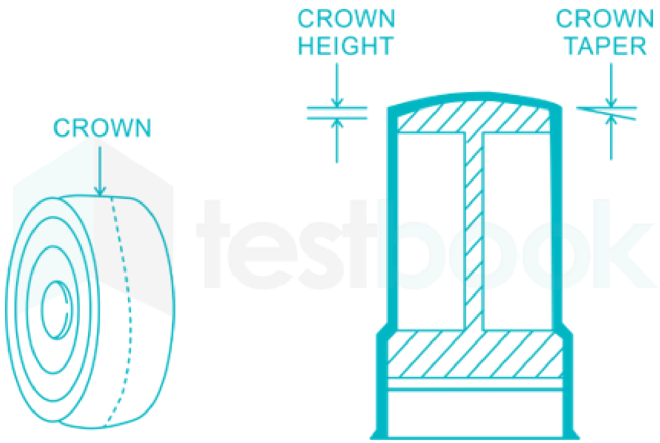
3) Round belts

BELT DRIVES

Flat belts

- These belts have rectangular cross section and the rim of the pulley is slightly crowned which helps to keep the belt running centrally on the pulley rim.





BELT DRIVES

V - belts

- V – belts have **trapezoidal cross – section**. A groove is made on the rim of the pulley of a V –belt drive to take the advantage of the **wedge action.**

- Some advantages of V – belt are:
  1) Positive drive as slip between belt and pulley is negligible
  2) Higher power transmitting capacity

- Some disadvantages of V – belt are:
  1) Cannot be used for large centre distances
  2) Costlier as compared to flat belts.

BELT DRIVES

Round belts

- There are certain applications where ‘**round**’ belts are used.
- Round belts can operate satisfactorily over pulleys in several different planes. They are suitable for 90 degree twist, reverse bends or serpentine drives.
- They can be stretched over the pulley and snapped into the groove very easily. This makes the assembly and replacement simple.
- Round belts are limited to light duties. They are used in dishwasher drives, sewing machines, vacuum cleaners and light textile machinery.

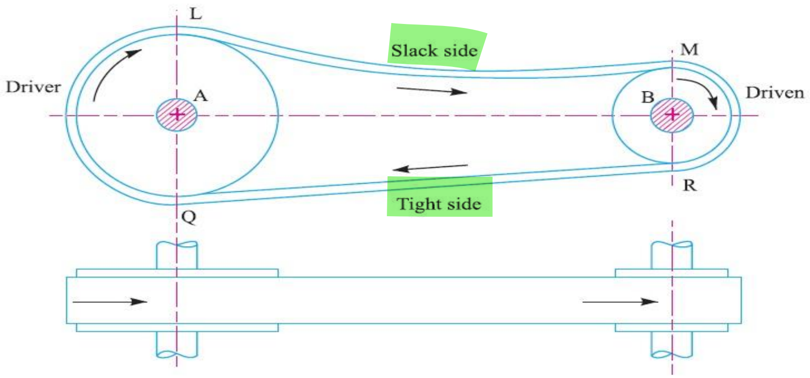
BELT DRIVES

Open belt drive

- An open belt drive is used when the driven pulley is desired to be rotated in the same direction as the driving pulley.

- While transmitting power, one side of the belt is more tightened known as '**tight side'** as compared to the other known as '**slack side'**.

- In case of horizontal drives, it is always desired that the tight side is at the lower side of the two pulleys. This is because the sag of the belt will be more on the upper side than the lower side. This slightly increases the angles of wrap of the belt on the two pulleys.

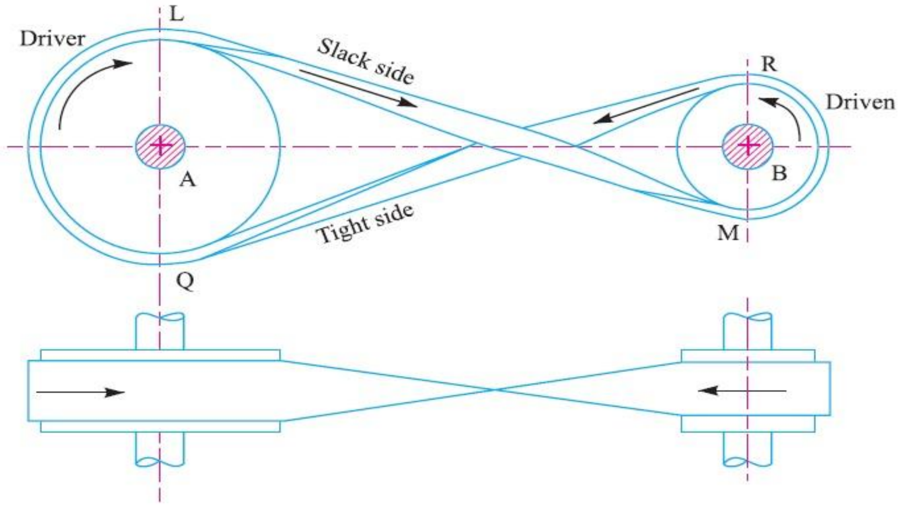


BELT DRIVES

Crossed belt drive

- A crossed belt drive is adopted when the drive pulley is to be rotated in the **opposite direction** to that of the driving pulley.

- A crossed belt drive can transmit more power than the open belt drive as the angle of wrap is more. However, the belt has to bend in two different planes and it wears out more.



TERMINOLOGIES OF BELT DRIVES

Velocity Ratio of belt drives

It is the ratio of the speed of the driven pulley to that of the driving pulley.

- Let d_1 = Diameter of the driving pulley, d_2= Diameter of the driven pulley,
  N_1= Speed of the driving pulley in rpm, and
  N_2 = Speed of the driven pulley in rpm

- Speed of the belt on driving pulley = $\pi d_1 N_1$

- Speed of the belt on driven pulley = $\pi d_2 N_2$

- Equating both of them, we get, **Velocity Ratio = VR =** $\mathbf{\frac{N_2}{N_1} = \frac{d_1}{d_2}}$

TERMINOLOGIES OF BELT DRIVES

Velocity Ratio of belt drives

When the thickness of the belt (t) is considered, then velocity ratio,

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}$$

TERMINOLOGIES OF BELT DRIVES

Slip of belt

- When the frictional grip between the belt and the pulley becomes insufficient, it may cause some forward motion of the driving pulley without carrying the belt with it. This may also cause some forward motion of the belt without carrying the driven pulley with it. This is called **slip of the belt** and is generally expressed as a percentage.
- The result of the belt slipping is to reduce the velocity ratio of the system.
- Let s_1 = % Slip between the driving pulley and the belt, and s_2 = % Slip between the belt and the driven pulley.
- Velocity ratio is then given by,

$$\frac{N_2}{N_1} = \frac{d_1 + t}{d_2 + t}\left(1 - \frac{s}{100}\right)$$ where $s = s_1 + s_2$, *i.e.* total percentage of slip

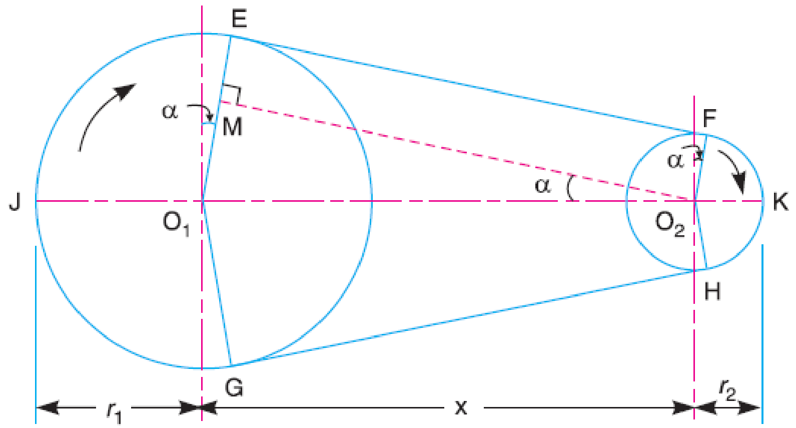
TERMINOLOGIES OF BELT DRIVES

Length of an Open belt drive

- Let r_1 and r_2 = Radii of the larger and smaller pulleys,
  x = Distance between the centres of two pulleys (*i.e.* O_1O_2), and
  L = Total length of the belt.

- Length of the belt is given by,

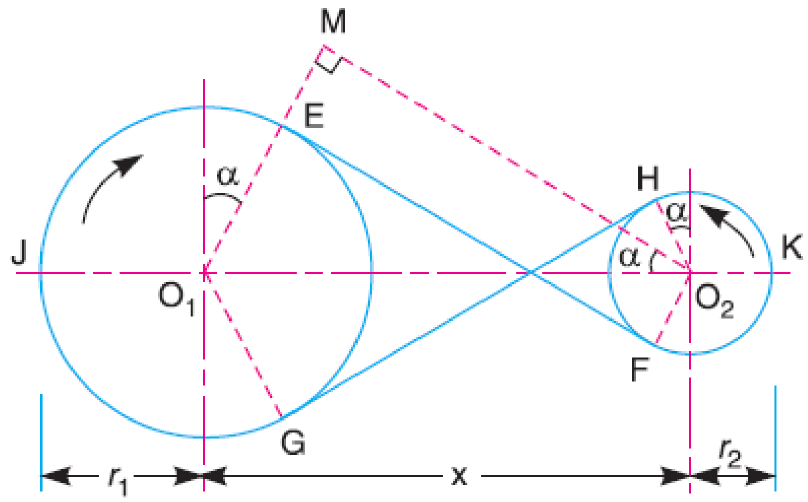
$$L_0 = \pi\,(r_1 + r_2) + 2\,x + \frac{(r_1 - r_2)^2}{x}$$



TERMINOLOGIES OF BELT DRIVES

Length of a Crossed belt drive

- Let r_1 and r_2 = Radii of the larger and smaller pulleys,
  x = Distance between the centres of two pulleys (*i.e.* O_1O_2), and
  L = Total length of the belt.



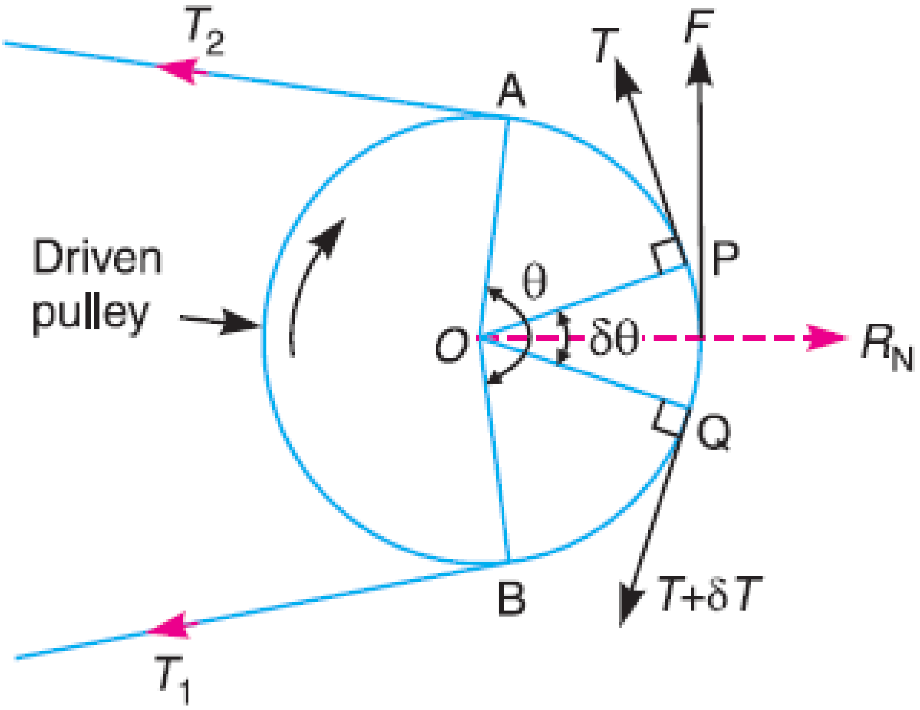
- Length of the belt is given by,

$$L_c = \pi\,(r_1 + r_2) + 2\,x + \frac{(r_1 + r_2)^2}{x}$$

TERMINOLOGIES OF BELT DRIVES

Ratio of Belt Tensions for a Flat Belt Drive

- Let T_1 = Tension in the belt on the tight side,
  T_2 = Tension in the belt on the slack side, and
  θ = Angle of contact in radians
  μ = coefficient of friction between the belt and the pulley



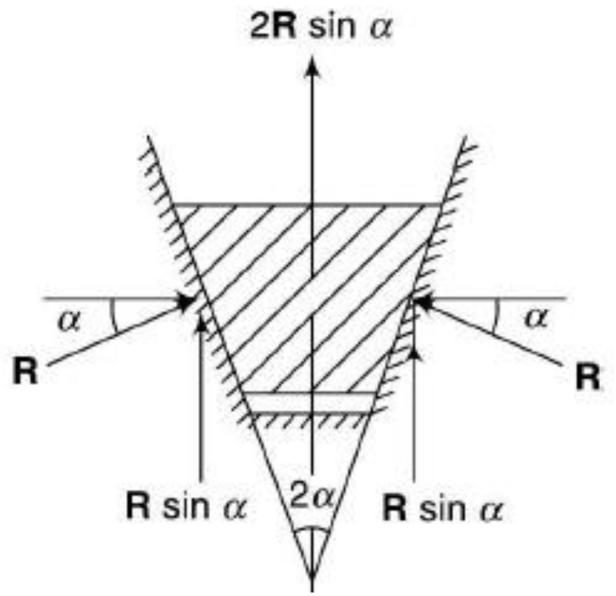
- The ratio belt tensions is given by,

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

TERMINOLOGIES OF BELT DRIVES

Ratio of Belt Tensions for a V - Belt Drive

- Let T_1 = Tension in the belt on the tight side,
  T_2 = Tension in the belt on the slack side, and
  θ = Angle of contact in radians
  μ = coefficient of friction between the belt and the pulley
  α = semi grove angle



- The ratio belt tensions is given by,

$$\frac{T_1}{T_2} = e^{\mu\theta / \sin\alpha}$$

TERMINOLOGIES OF BELT DRIVES

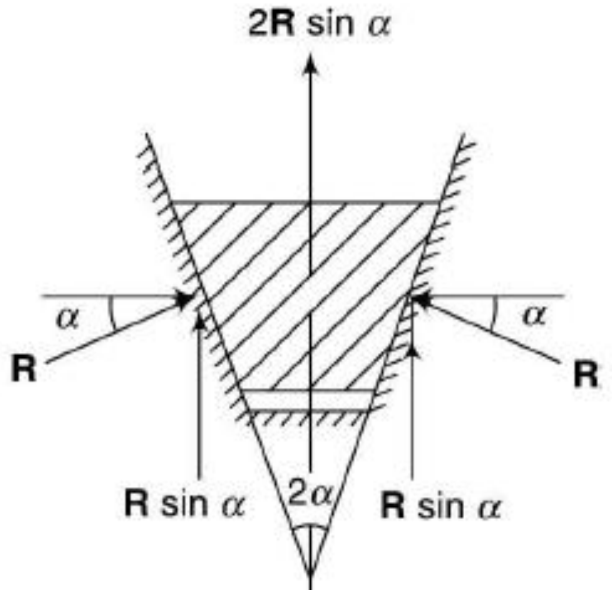
Ratio of Belt Tensions for a V - Belt Drive

- The expression for ratio of belt tensions is similar to that for a flat belt drive except that μ is replaced by μ/sin α, i.e., the coefficient of friction is increased by 1/sin α.

- Therefore, for identical materials of belt and pulleys, the coefficient of friction of V – belt is far greater than that of flat belt.

- Consequently, the power transmitting capacity of V – belt is much more than that of flat belt. Therefore, V – belts are more powerful.

- Due to increased frictional force, the slip is less in V – belt compared with flat belt.



TERMINOLOGIES OF BELT DRIVES

Power Transmitted

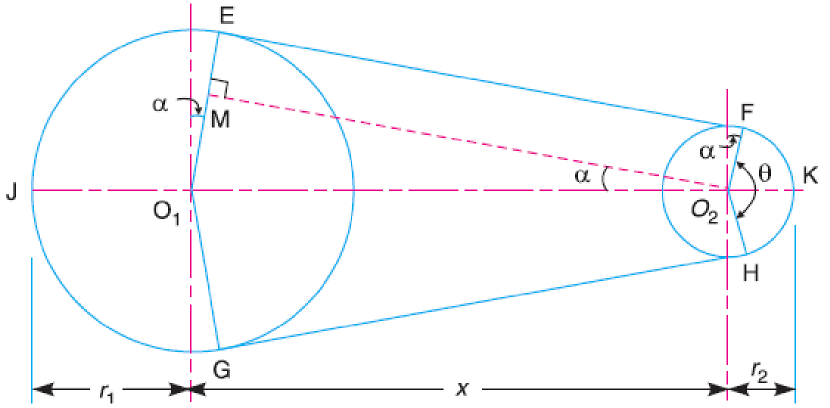
- Let T_1 = Tension in the belt on the tight side,
  T_2 = Tension in the belt on the slack side
  v = linear velocity of the belt = $(\pi \times d \times N)/60$ in m/s
  P = Power transmitted

- Then, P = Net force × Distance moved/second

$$P = (T_1 - T_2) \times V \quad \text{watts}$$

TERMINOLOGIES OF BELT DRIVES

Determination of Angle of Contact



- When the two pulleys of different diameters are connected by means of an open belt as shown in Fig., then the angle of contact or lap (θ) at the smaller pulley must be taken into consideration.

- Let r_1 and r_2 = Radii of the larger and smaller pulleys,
  x = Distance between the centres of two pulleys (*i.e.* O_1O_2)

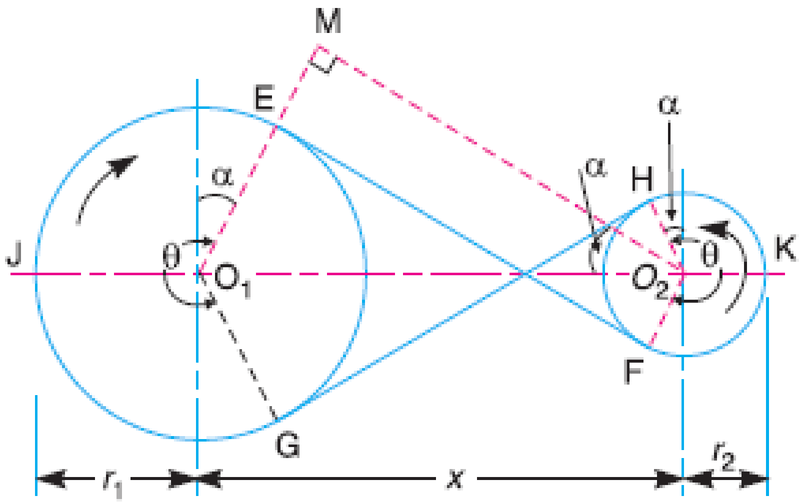
- From Figure,

$$\sin\alpha = \frac{O_1 M}{O_1 O_2} = \frac{O_1 E - ME}{O_1 O_2} = \frac{r_1 - r_2}{x} \qquad ...(\because ME = O_2 F = r_2)$$

- Angle of contact or lap, $\theta = (180° - 2\alpha)\dfrac{\pi}{180}$ rad

TERMINOLOGIES OF BELT DRIVES

Determination of Angle of Contact



- A little consideration will show that when the two pulleys are connected by means of a crossed belt as shown in Fig., then the angle of contact or lap (θ) on both the pulleys is same.
- Let r_1 and r_2 = Radii of the larger and smaller pulleys,
  x = Distance between the centres of two pulleys (*i.e.* O_1O_2)
- From figure,

$$\sin\alpha = \frac{O_1 M}{O_1 O_2} = \frac{O_1 E + ME}{O_1 O_2} = \frac{r_1 + r_2}{x}$$

- Angle of contact or lap $\theta = (180^\circ + 2\alpha)\dfrac{\pi}{180}$ rad

NUMERICALS

1) A shaft runs at 80 rpm and drives another shaft at 150 rpm through belt drive. The diameter of the driving pulley is 600 mm. Determine the diameter of the driven pulley in the following cases:
   (i) Neglecting belt thickness
   (ii) Taking belt thickness as 5 mm
   (iii) Assuming for case (ii) a total slip of 4%

NUMERICALS

Solution:

$$N_1 = 80 \text{ rpm} \qquad D_1 = 600 \text{ mm}$$
$$N_2 = 150 \text{ rpm}$$

(i) $$\frac{N_2}{N_1} = \frac{D_1}{D_2} \quad \text{or} \quad \frac{150}{80} = \frac{600}{D_2}$$

or $D_2 = \underline{320 \text{ mm}}$

(ii) $$\frac{N_2}{N_1} = \frac{D_1 + t}{D_2 + t} \quad \text{or} \quad \frac{150}{80} = \frac{600 + 5}{D_2 + 5}$$

$$D_2 = 317.7 \text{ mm}$$

NUMERICALS

Solution:

(iii) $$\frac{N_2}{N_1} = \frac{D_1 + t}{D_2 + t}\left(\frac{100 - S}{100}\right)$$

or $$\frac{150}{80} = \left(\frac{600 + 5}{D_2 + 5}\right)\left(\frac{100 - 4}{100}\right)$$

$$D_2 = 304.8 \text{ mm}$$

NUMERICALS

2) Two parallel shafts, connected by a crossed belt, are provided with pulleys 480 mm and 640 mm in diameters. The distance between the centre lines of the shafts is 3 m. Determine by how much the length of the belt should be changed if it is desired to alter the direction of rotation of the driven shaft.

NUMERICALS

Solution:

Given: $d_1 = 2\, r_1 = 640\ mm$, $d_2 = 2\, r_2 = 480\ mm$, $x = 3000\ mm$

$\therefore\ r_1 = 320\ mm$, $r_2 = 240\ mm$

Find: $(L_c - L_o) = ?$

For crossed belt

$$L_c = \pi\,(r_1 + r_2) + 2\,x + \frac{(r_1 + r_2)^2}{x}$$

$$L_c = \pi\,(320 + 240) + 2\,(3000) + \frac{(320+240)^2}{3000}$$

$$\boldsymbol{L_c = 7863.83\ mm}$$

NUMERICALS

Solution:

For open belt

$$L_0 = \pi\,(r_1 + r_2) + 2\,x + \frac{(r_1 - r_2)^2}{x}$$

$$L_0 = \pi\,(320 + 240) + 2\,(3000) + \frac{(320 - 240)^2}{3000}$$

$$\boldsymbol{L_0 = 7761.43\ mm}$$

$\therefore$ Change in length of the belt = $(L_c - L_o) = (7863.83 - 7761.43) = \mathbf{102.4\ mm}$

$\therefore$ For open belt **shorten the belt by 102.4 *mm***

NUMERICALS

3) A casting weighs 6 kN and is freely suspended from a rope which makes 2.5 turns round a drum of 200 mm diameter. If the drum rotates at 40 rpm, determine the force required by a man to pull the rope from the other end of the rope. Also, determine the power to raise the casting. The coefficient of friction is 0.25.

NUMERICALS

Solution $T_1 = 6000$ N $\quad d = 0.2$ m

$N = 40$ rpm $\quad \mu = 0.25$

$\theta = 2.5 \times 2\pi = 15.7$ rad

$$v = \frac{\pi d N}{60} = \frac{\pi \times 0.2 \times 40}{60} = 0.419 \text{ m/s}$$

$$\frac{T_1}{T_2} = e^{\mu\theta} = e^{0.25 \times 15.7} = 50.8 \text{ or } T_1 = 50.8 T_2$$

or $\quad 6000 = 50.8\, T_2$ or $T_2 = 118$ N

and $\quad P = (T_1 - T_2)\, v = (6000 - 118) \times 0.419$

$= 2464$ W or $\underline{2.464 \text{ kW}}$

NUMERICALS

4) Two pulleys mounted on two parallel shafts that are 2 m apart are connected by a crossed belt drive. The diameters of the two pulleys are 500 mm and 240 mm. Determine the power transmitted if the larger pulley rotates at 180 rpm and the maximum permissible tension in the belt is 900 N. The coefficient of friction between the belt and pulley is 0.28

NUMERICALS

Solution:

Angle of contact

$$\theta = 180 + 2\alpha$$

Where $$\alpha = \sin^{-1}\left[\frac{(r_1 + r_2)}{x}\right] = \sin^{-1}\left[\frac{(250+120)}{2000}\right] = 10.7^{\circ}$$

$\therefore$ $$\theta = 180 + 2 \times 10.7 = \mathbf{201.4^{\circ}}$$

$$\theta = 201.4 \times \frac{\pi}{180} = 3.51\, rad$$

NUMERICALS

Solution:

w.k.t $\frac{T_1}{T_2} = e^{\mu\theta}$ or $T_1 = T_2 e^{\mu\theta}$

$900 = T_2 e^{0.28 \times 3.51}$

$900 = 2.67\ T_2$

Therefore $\boldsymbol{T_2 = 337\ \mathrm{N}}$

Power transmitted

$$V = \frac{\pi d_1 N_1}{60} = \frac{\pi \times 0.5 \times 180}{60} = 4.71\ \frac{m}{s}$$

$P = (T_1 - T_2)\ \mathrm{V} = (900 - 337) \times 4.71$

$= 2651.73\ \mathrm{W}$

or $\boldsymbol{P = 2.65\ kW}$

NUMERICALS

5) A belt drive transmits 5 kW of power between two parallel shafts. The distance between the shaft centers is 1.5 m and the diameter of the smaller pulley (driven pulley) is 440 mm. The driving and the driven shafts rotate at 60 rpm and 150 rpm respectively. The coefficient of friction is 0.22. Determine the tension in tight side of the belt if the two pulleys are connected by (i) open belt drive (ii) crossed belt drive.

NUMERICALS

Solution:

We have, velocity of the belt given by,

$$v = \frac{\pi d_2 N_2}{60} = \frac{\pi \times 440 \times 10^{-3} \times 150}{60} = 3.46\ m/s$$

We know that, power transmitted is given by,

$$P = (T_1 - T_2)v$$

Substituting P =5000 W, v = 3.46 m/s, we get,

$$5000 = (T_1 - T_2)3.46$$

$$(T_1 - T_2) = 1445.09 \text{---------} (1)$$

a) Open belt drive

We have, angle of contact on the smaller pulley of the open belt drive given by,

$$\theta = 180 - 2sin^{-1}\left(\frac{r_1 - r_2}{x}\right) = 180 - 2sin^{-1}\left(\frac{550 - 220}{1500}\right) = 154.58\ degrees\ or\ 2.7\ radians$$

NUMERICALS

Solution:

We have,

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

$\frac{T_1}{T_2} = e^{0.22\times2.7} = 1.81$---------(2)

Using (1) and (2), we get T_1 = 3229.15 N

a) Crossed belt drive

We have, angle of contact in case of crossed belt drive given by,

$$\theta = 180 + 2sin^{-1}\left(\frac{r_1 + r_2}{x}\right) = 180 + 2sin^{-1}\left(\frac{550 + 220}{1500}\right) = 241.77\ degrees\ or\ 4.22\ radians$$

NUMERICALS

Solution:

We have,

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

$\frac{T_1}{T_2} = e^{0.22\times4.22} = 2.53$---------(2)

Using (1) and (2), we get T_1 = 2389.6 N

ADVANTAGES OF BELT DRIVES

Belt drives offer the following advantages compared with other types of drives:

(i) Belt drives can transmit power over considerable distance between the axes of driving and driven shafts.
(ii) The operation of belt drive is smooth and silent.
(iii) They can transmit only a definite load, which if exceeded, will cause the belt to slip over the pulley, thus protecting the parts of the drive against overload.
(iv) They have the ability to absorb the shocks and damp vibration.
(v) They are simple to design.
(vi) They have low initial cost.

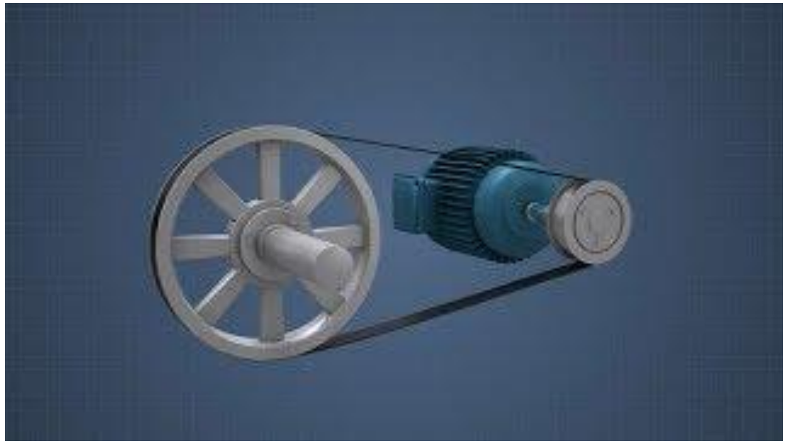
DISADVANTAGES OF BELT DRIVES

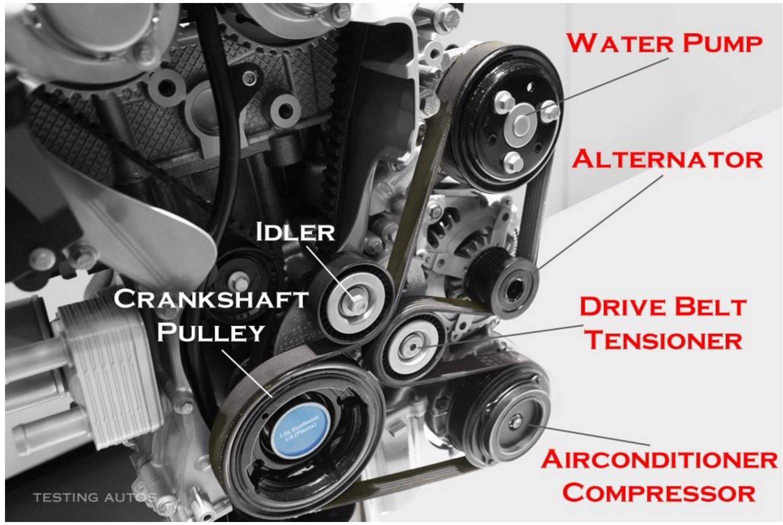
The disadvantages of belt drives compared to other types of drives are as follows:

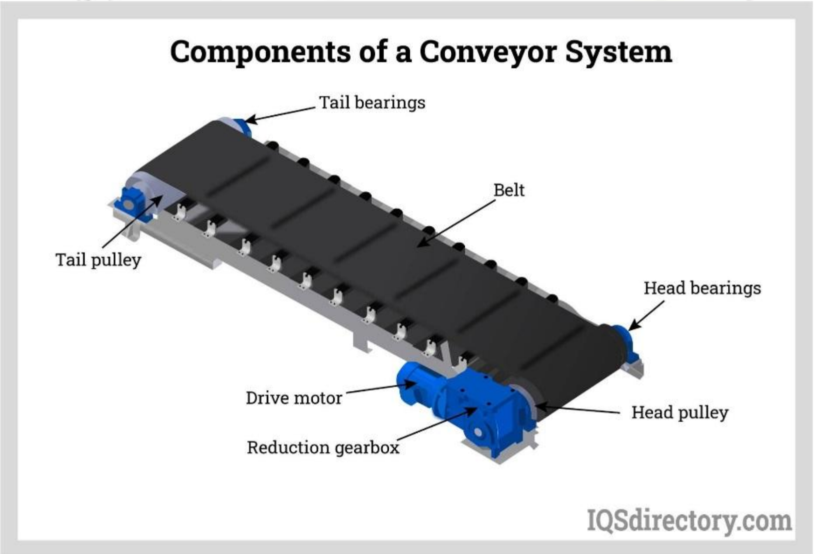
(i) Belt drives have large dimensions and occupy more space.
(ii) The velocity ratio is not constant due to belt slip.
(iii) They impose heavy loads on shafts and bearings.
(iv) There is considerable loss of power resulting in low efficiency.
(v) Belt drives have comparatively short service life.

APPLICATIONS OF BELT DRIVES

- Electric motors
- Automobiles
- Machine tools
- Conveyors







GEAR DRIVES

- Gears are defined as toothed wheels which transmit power and motion from one shaft to another by means of successive engagement of teeth.

- Gear drives offer the following advantages compared with chain or belt drives:
  (i) It is a **positive drive** and the velocity ratio remains constant.
  (ii) The centre distance between the shafts is relatively small, which results in compact construction.
  (iii) It can transmit very large power, which is beyond the range of belt or chain drives.
  (iv) It can transmit motion at very low velocity, which is not possible with the belt drives.
  (v) A provision can be made in the gearbox for gear shifting, thus changing the velocity ratio over a wide range.

GEAR DRIVES

- Gears can be classified according to the relative positions of their shaft axes as follows:

1) Parallel Shafts

a) Spur Gears

b) Helical Gears

c) Double helical or Herringbone Gears

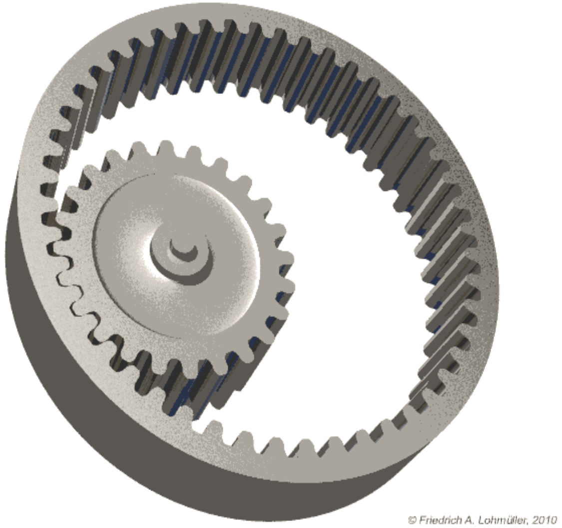
GEAR DRIVES

Spur Gears

- They have **straight teeth** parallel to the axes.

- At the time of engagement of the two gears, the contact extends across the entire width on a line parallel to the axes of rotation. This results in **sudden application of the load, high impact stresses and excessive noise at high speeds.**

- If the gears have external teeth on the outer surface of the cylinders, the shafts rotate in the **opposite** direction.

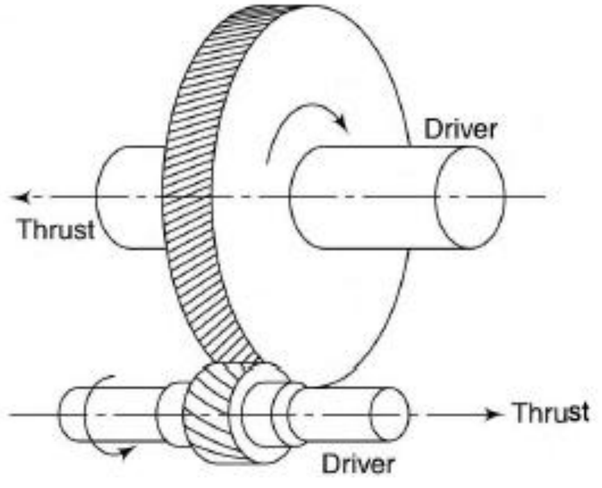


- In an internal spur gear, the teeth are formed on the inner surface of an annulus ring. An internal gear can mesh with an external pinion (smaller gear) only and the two shafts rotate in the **same** direction.

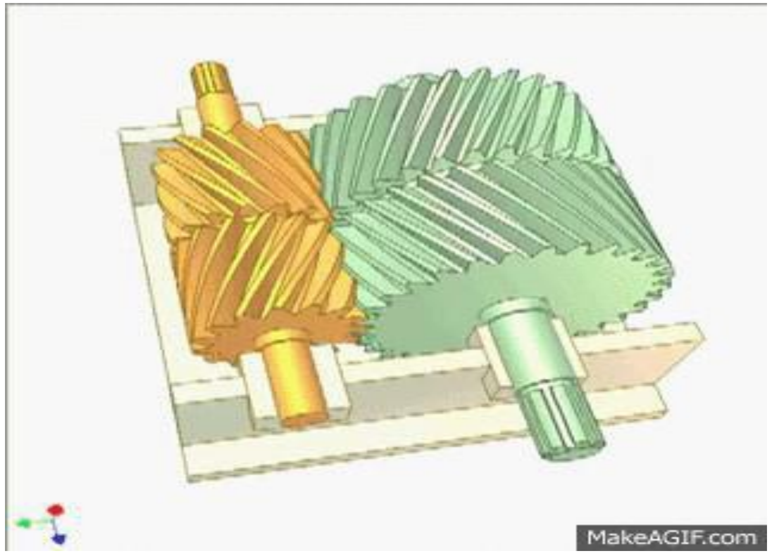
GEAR DRIVES

Helical Gears

- In helical gears, the teeth are curved, each being **helical** in shape.
- Two mating gears have the same helix angle, but have teeth of opposite hands.
- At the begining of engagement, contact occurs only at the point of leading edge of the curved teeth. As the gears rotate, the contact extends along a diagonal line across the teeth.
- Thus, the load application is gradual which results in low impact stresses and reduction in noise. Therefore, helical gears can be used at **higher velocities** than the spur gears and have greater load carrying capacity.
- Helical gears have the disadvantage of having **end thrust** as there is a force component along the gear axis.



GEAR DRIVES



Double - helical and Herringbone Gears

- A double helical gear is equivalent to a pair of helical gears secured together, one having a right hand helix and the other a left – hand helix.

- The teeth of the two rows are separated by a groove. Axial thrust which occurs in case of a single helical gears is eliminated in double helical gears. This is because the axial thrust of the two rows of teeth cancel each other out. These can be run at high speeds with less noise and vibrations.

- If the left and the right inclinations of a double helical gear meet at a common apex and there is no groove in between, the gear is known as **herringbone gear**.

GEAR DRIVES

2) **Intersecting Shafts**

   a) **Straight Bevel Gears**

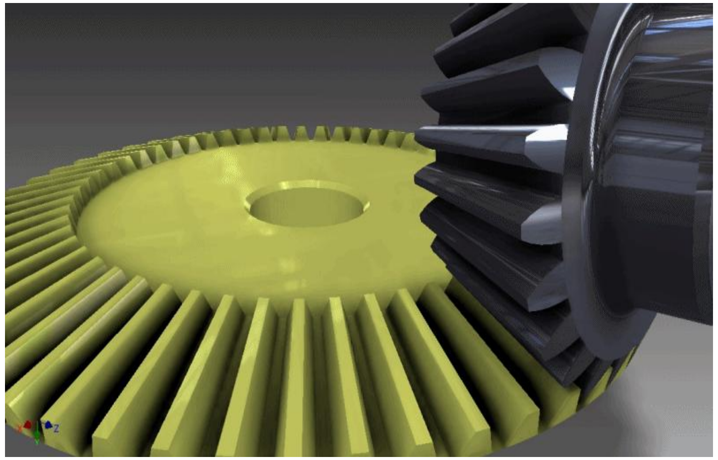
   b) **Spiral Bevel Gears**

GEAR DRIVES

Straight Bevel Gears

- The teeth are straight, radial to the point of intersection of the shaft axes and vary in cross section throughout their length.

- Usually they are used to connect shafts at right angles which run at lower speeds. Gears of same size and connecting two shafts at right angles to each other are known as **mitre gears**.



GEAR DRIVES

Spiral Bevel Gears

- When the teeth of a bevel gear are inclined at an angle to the face of the bevel, they are known as **spiral bevels or helical bevels.**

- They are smoother in action than straight tooth bevels as there is gradual load application and low impact stresses. Of course, there exists an axial thrust calling for stronger bearings and supporting assemblies.

- These are used for the drive to the differential of an automobile.

GEAR DRIVES

2) Skew Shafts (Neither parallel nor intersecting)

a) Hypoid Gears

b) Worm Gears

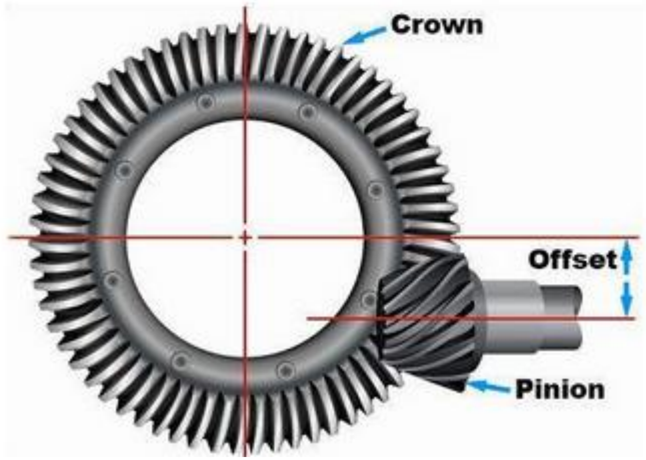
GEAR DRIVES

Hypoid Gears

- Hypoid gears are a type of spiral bevel gears, with the difference that hypoid gears have axes that are non-intersecting and not parallel.

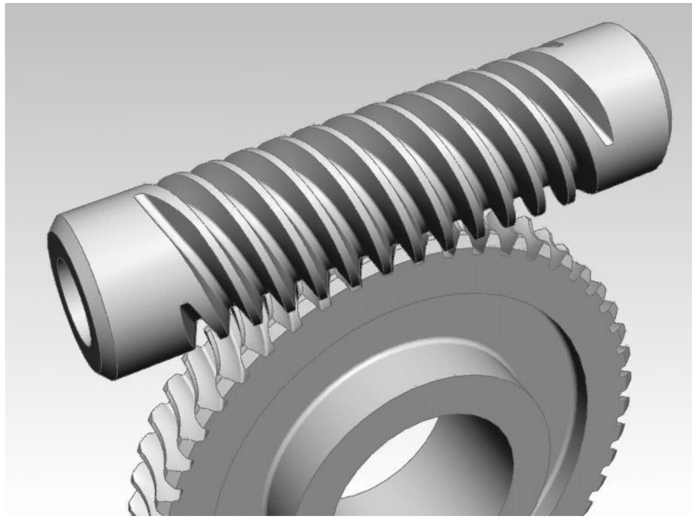
- In other words, the axes of hypoid gears are offset from one another. The basic geometry of the hypoid gear is hyperbolic, rather than having the conical geometry of a spiral bevel gear.

- The most common application for hypoid gearboxes is in the automotive industry, where they are used in rear axles, especially for large trucks.



GEAR DRIVES

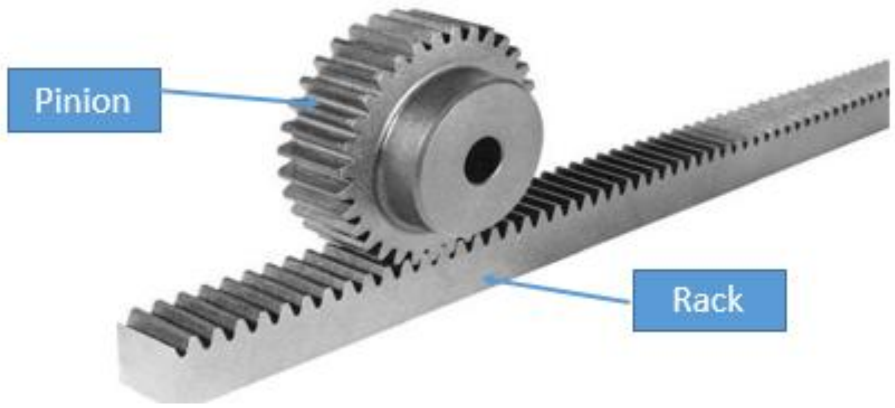
Worm Gears



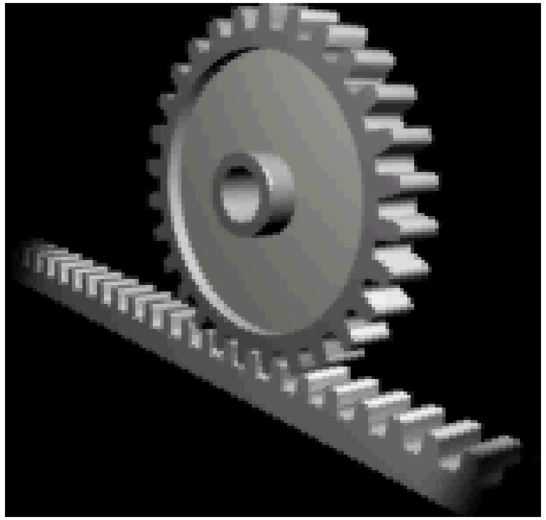
- The worm gears consist of a worm and a worm wheel.
- The worm is in the form of a threaded screw, which meshes with the matching wheel.
- Worm gear drives are used for shafts, the axes of which do not intersect and are perpendicular to each other.
- Worm gear drives are characterized by high speed reduction ratio.

GEAR DRIVES

Spur Rack and Pinion

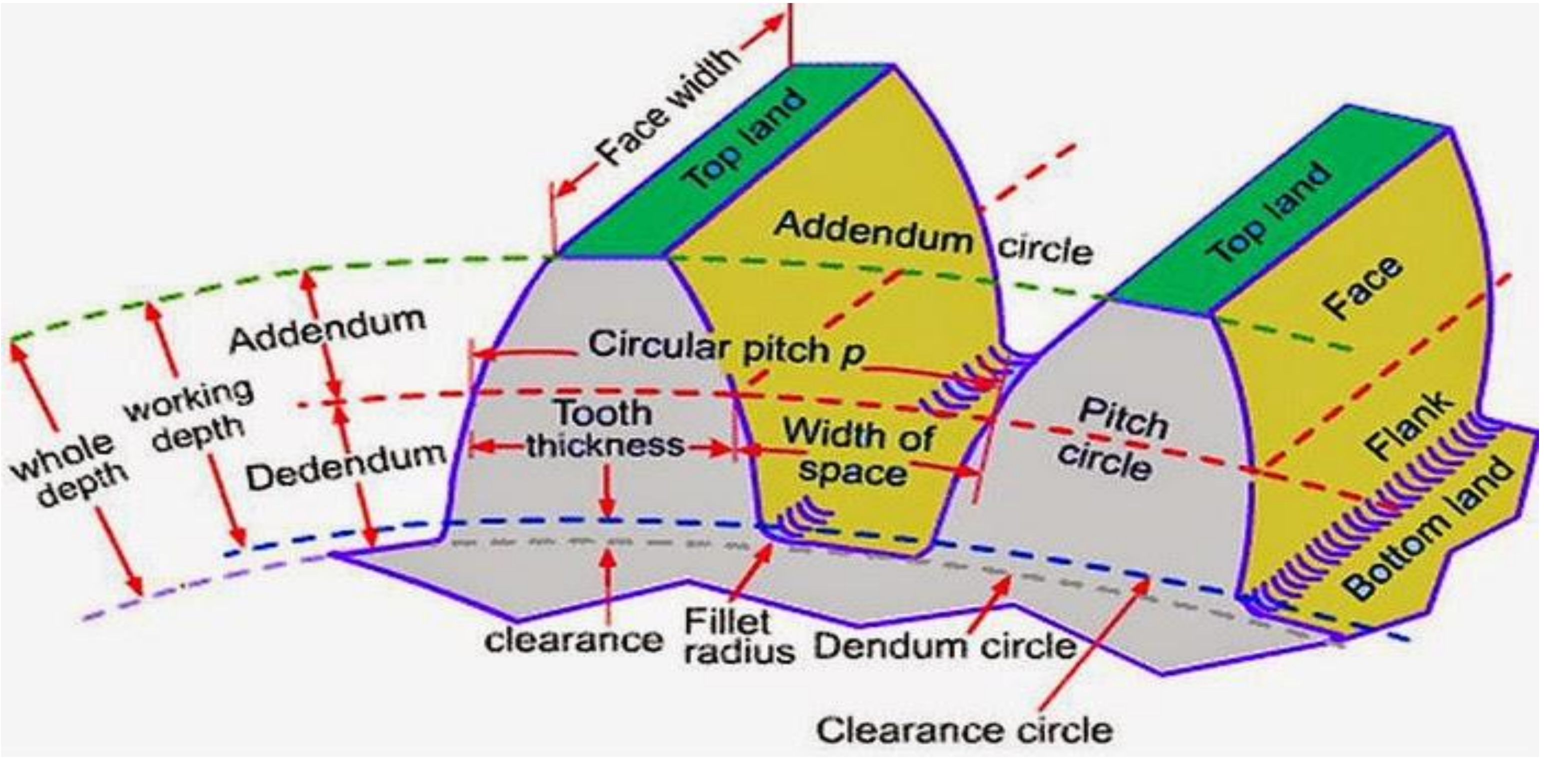


- Spur rack is a special case of a spur gear where it is made of infinite diameter.
- The spur rack and pinion combination converts rotary motion into translator motion, or vice versa.
- Example – It is used in a lathe in which the rack transmits motion to the saddle.



GEAR DRIVES

Gear Terminology



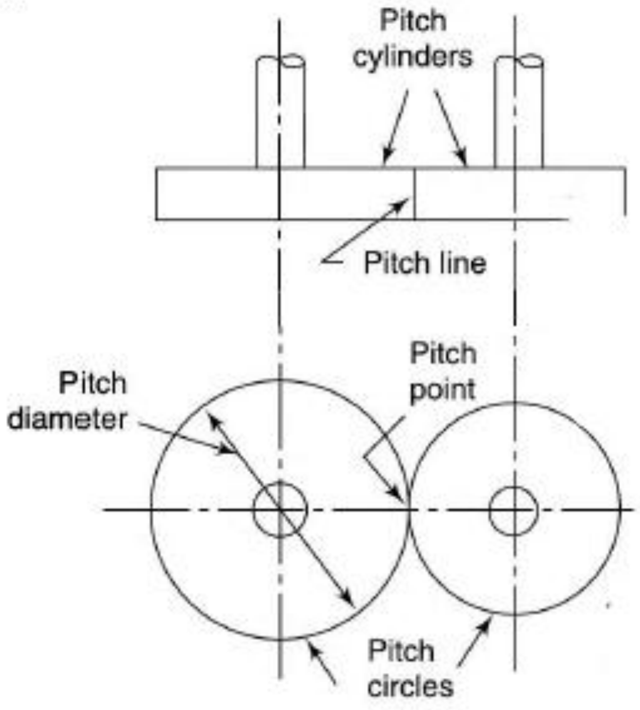
GEAR DRIVES

Gear Terminology

- **Pitch cylinders** – A pitch cylinder is an imaginary cylinder that's used as a reference surface for machining the teeth of a cylindrical gear
- Pitch cylinders of a pair of gears in mesh are the imaginary friction cylinders, which by pure rolling together, transmit the same motion as the pair of gears.

- **Pitch circle** – The pitch circle is an imaginary circle that is used to measure the size of gear teeth.
- It is the circle corresponding to a section of the equivalent pitch cylinder by a plane normal to the wheel axis.

- **Pitch diameter** – It is the diameter of the pitch circle.

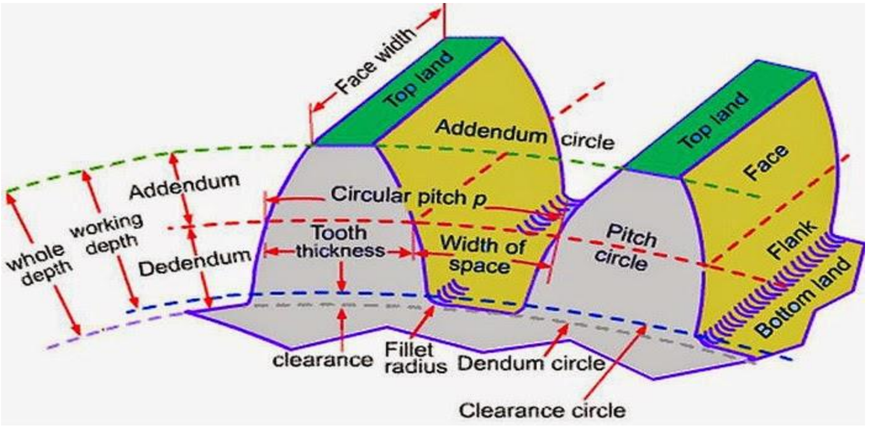


GEAR DRIVES

Gear Terminology

- **Pitch** – It is defined as follows.

a) **Circular Pitch** – It is the distance measured along the circumference of the pitch circle from a point on one tooth to the corresponding point on the adjacent tooth.



$$p = \frac{\pi d}{T}$$

where p = circular pitch; d = pitch diameter; T = number of teeth

GEAR DRIVES

Gear Terminology

- **Pitch –** It is defined as follows.

b) Diametral Pitch – It is the number of the teeth per unit length of the pitch circle diameter in inches.

$$P = \frac{T}{d}$$

It can be seen that

$$pP = \frac{\pi d}{T}\frac{T}{d} = \pi$$

The term diametral pitch is not used in SI units.

GEAR DRIVES

Gear Terminology

- **Pitch** – It is defined as follows.

c) **Module** – It is the ratio of the pitch diameter to the number of teeth. The term is used in SI units in place of diametral pitch.

$$m = \frac{d}{T}$$

Also,

$$p = \frac{\pi d}{T} = \pi m$$

Pitch of two mating gears must be same.

GEAR DRIVES

Gear Terminology

- **Velocity ratio** – The velocity ratio is defined as the ratio of the angular velocity of the driven gear to the angular velocity of the driving gear.

  Let **d = pitch diameter, T = number of teeth, ω = angular velocity (rad/s), N = angular velocity (rpm);** Subscript 1 = driving gear (driver), Subscript 2 = driven gear (follower)

$$\text{VR} = \frac{\text{angular velocity of follower}}{\text{angular velocity of driver}}$$

$$= \frac{\omega_2}{\omega_1}$$

$$= \frac{N_2}{N_1} \qquad (\omega = 2\pi N)$$

$$= \frac{d_1}{d_2} \qquad (\because \pi d_1 N_1 = \pi d_2 N_2)$$

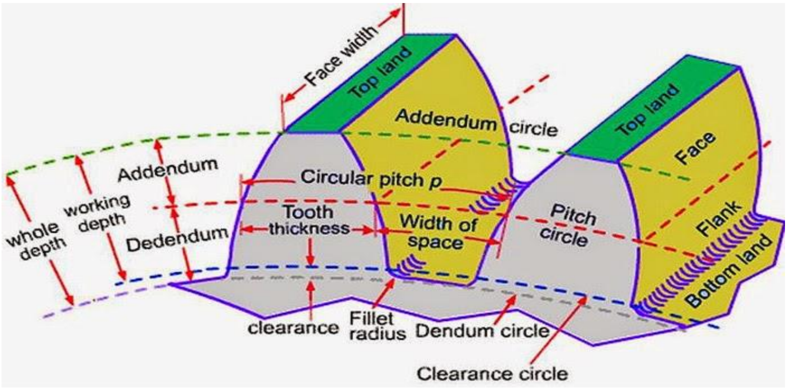
$$= \frac{T_1}{T_2} \qquad \left(p = \frac{\pi d_1}{T_1} = \frac{\pi d_2}{T_2}\right)$$

GEAR DRIVES

Gear Terminology

- **Addendum Circle** – It is a circle passing through the tips of the teeth.

- **Addendum** – It is the radial height of a tooth above the pitch circle. Its standard value is one module.



- **Dedendum or Root Circle** – It is a circle passing through the roots of the teeth.

- **Dedendum** – It is the radial depth of a tooth below the pitch circle. Its standard value is 1.157m.

- **Clearance** – Radial difference between the addendum and the dedendum of a tooth.

GEAR DRIVES

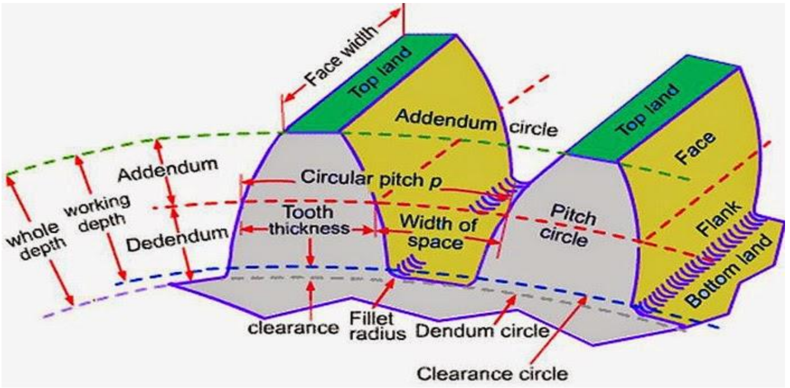
Gear Terminology

- **Full Depth of Teeth (Whole Depth)** – It is the total radial depth of the tooth space.
  Full depth = Addendum + Dedendum

- **Working Depth of Teeth** – The maximum depth to which a tooth penetrates into the tooth space of the mating gear is the working depth of teeth.
  Working depth = Sum of addendums of the two gears.

- **Space Width** – It is the width of the tooth space along the pitch circle.

- **Tooth thickness** – It is the thickness of the tooth measured along the pitch circle.



GEAR DRIVES

Gear Terminology

- **Backlash** – It is the difference between the space width and the tooth thickness along the pitch circle.

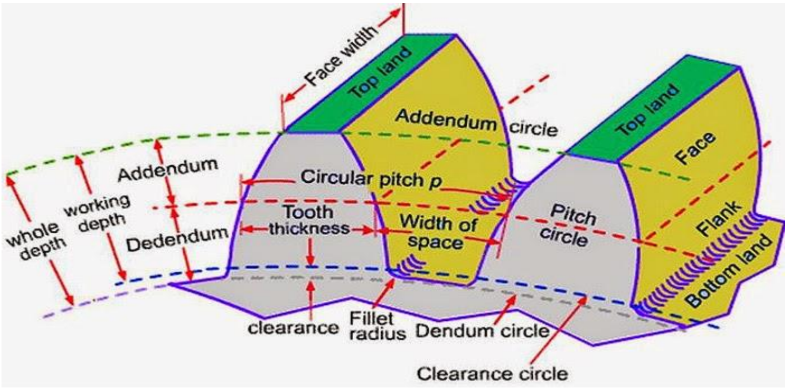
- **Face Width** - The length of the tooth parallel to the gear axis is the face width.

- **Top land** – It is the surface of the top of the tooth.

- **Bottom land** – The surface of the bottom of the tooth between the adjacent fillets.

- **Face** – Tooth surface between the pitch circle and the top land.

- **Flank** – Tooth surface between the pitch circle and the bottom land including the fillet.



GEAR DRIVES

Gear Trains

- A gear train is a combination of gears used to transmit motion from one shaft to another.

- It becomes necessary when it is required to obtain large speed reduction within a small space.

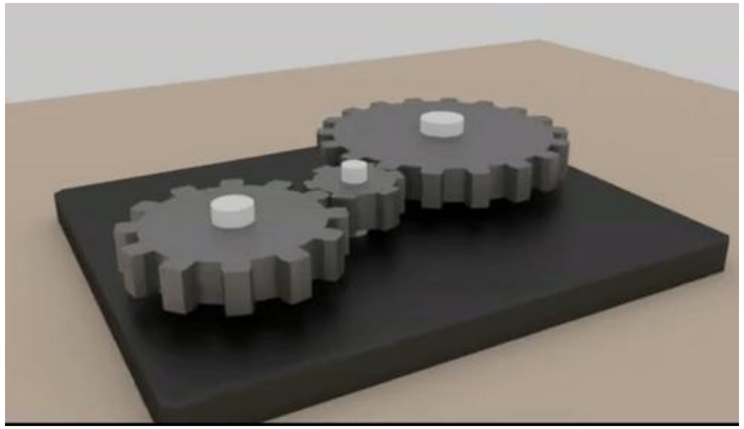
- Main types of gear trains –
  1) **Simple gear train**
  2) **Compound gear train**
  3) **Reverted gear train**
  4) **Planetary or epicyclic gear train**

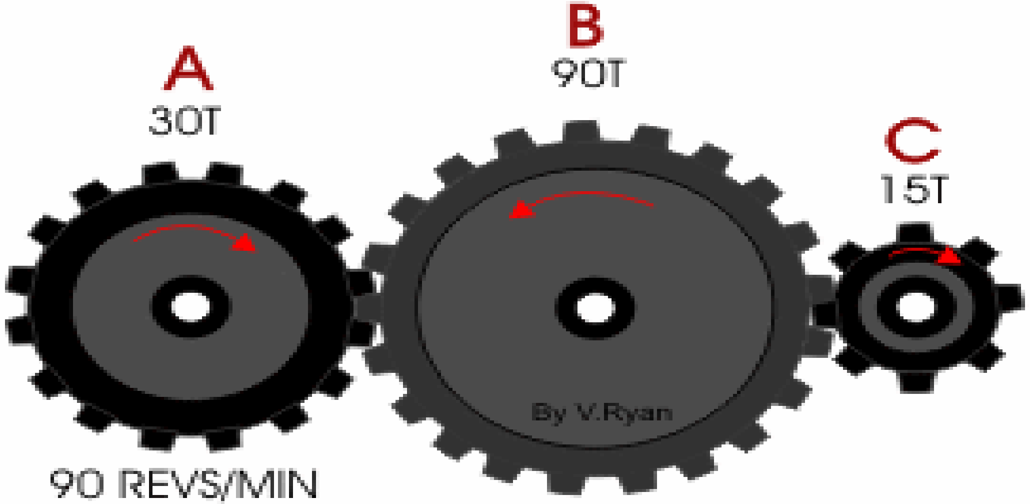
GEAR DRIVES

Simple Gear Train

- A series of gears, capable of receiving and transmitting motion from one gear to another is called a simple gear train.

- In the simple gear train, the gear axes remain fixed relative to the frame and each gear is on a separate shaft.

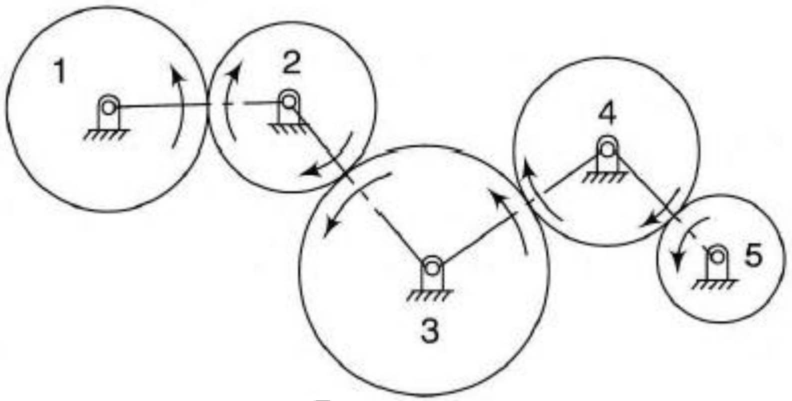




GEAR DRIVES

Simple Gear Train

- **Speed ratio of a gear train** – It is the ratio of the speed of the driving to that of the driven shaft.



- Let T = number of teeth on a gear; N = speed of gear in rpm

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} \qquad \left[\text{Also } \frac{\omega_2}{\omega_1} = \frac{2\pi N_2}{2\pi N_1} = \frac{N_2}{N_1}\right]$$

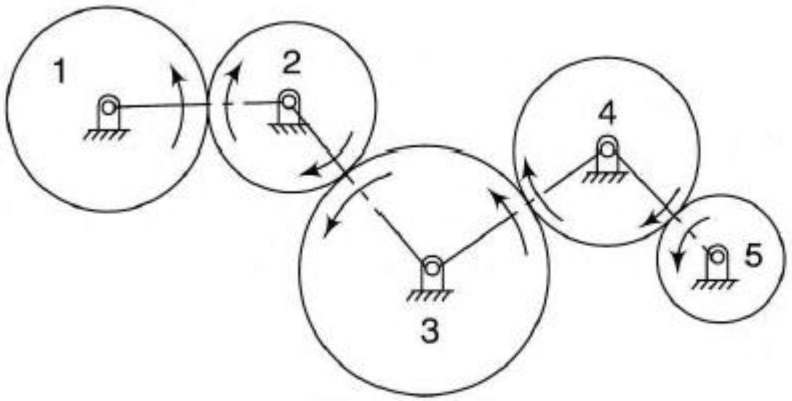
and
$$\frac{N_3}{N_2} = \frac{T_2}{T_3}, \frac{N_4}{N_3} = \frac{T_3}{T_4} \text{ and } \frac{N_5}{N_4} = \frac{T_4}{T_5}$$

Multiplying,

$$\frac{N_2}{N_1} \times \frac{N_3}{N_2} \times \frac{N_4}{N_3} \times \frac{N_5}{N_4} = \frac{T_1}{T_2} \times \frac{T_2}{T_3} \times \frac{T_3}{T_4} \times \frac{T_4}{T_5}$$

GEAR DRIVES

Simple Gear Train



- Speed ratio is given by,

$$\frac{N_1}{N_5} = \frac{T_5}{T_1}$$

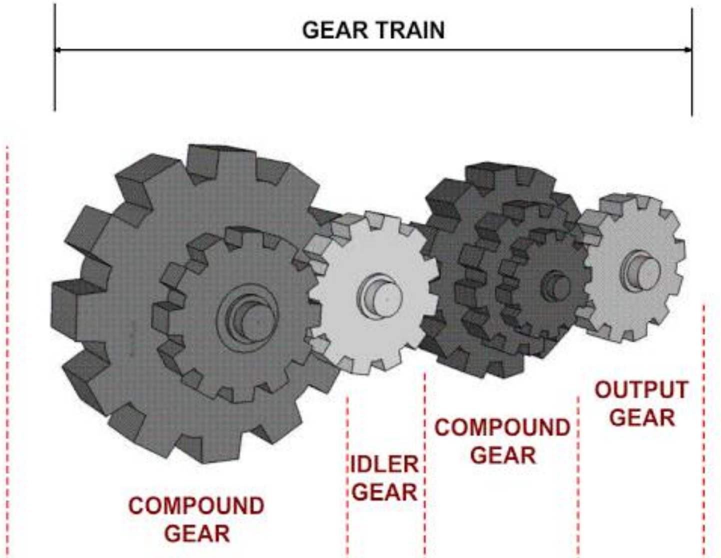
- Thus it is seen that the intermediate gears have no effect on the speed ratio and therefore they are known as ***idlers***.

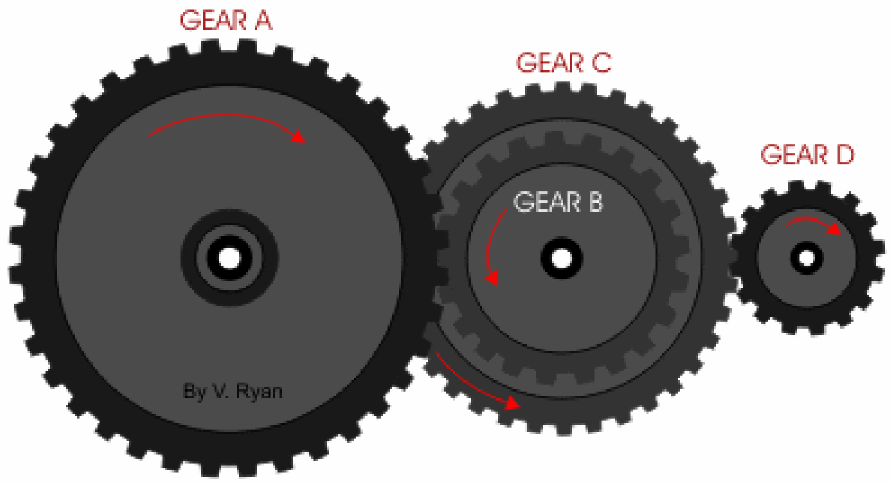
GEAR DRIVES

Compound Gear Train

- When a series of gears are connected in such a way that two or more gears rotate about an axis with the same angular velocity, its known as compound gear train.

- In this type, some of the intermediate shafts, i.e., other than the input and the output shafts, carry more than one gear.





GEAR DRIVES

Compound Gear Train

$$\frac{N_2}{N_1} = \frac{T_1}{T_2}, \ \frac{N_4}{N_3} = \frac{T_3}{T_4} \text{ and } \frac{N_6}{N_5} = \frac{T_5}{T_6}$$

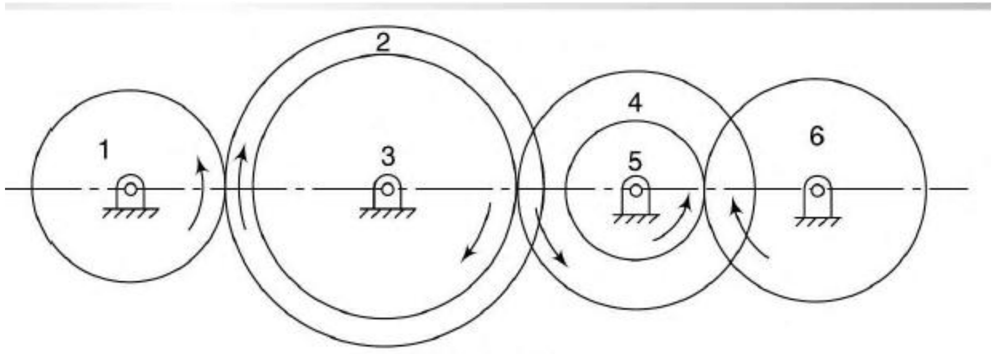
or

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} \times \frac{N_6}{N_5} = \frac{T_1}{T_2} \times \frac{T_3}{T_4} \times \frac{T_5}{T_6}$$

or

$$\frac{N_2}{N_1} \times \frac{N_4}{N_2} \times \frac{N_6}{N_4} = \frac{T_1}{T_2} \times \frac{T_3}{T_4} \times \frac{T_5}{T_6}$$

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

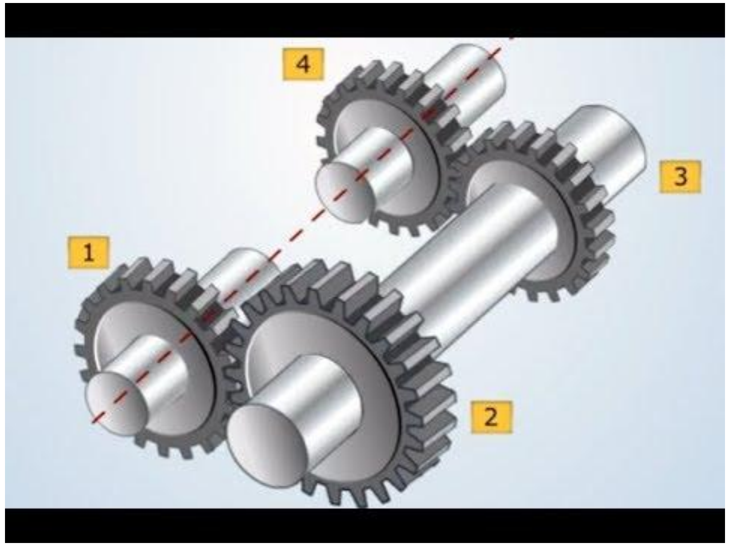


GEAR DRIVES

Reverted Gear Train

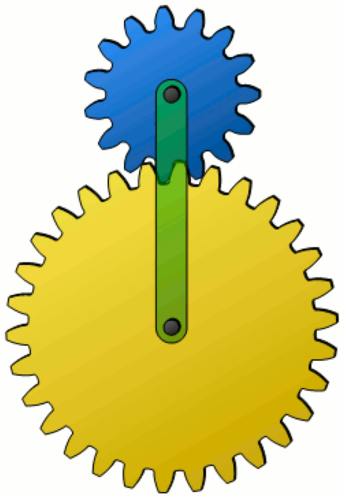
- If the axes of the first and the last wheels of a compound gear coincide, it is called a reverted gear train.

- Such an arrangement is used in clocks and in simple lathes where back gear is used to give a slow speed to the chuck.



GEAR DRIVES

Planetary or Epicyclic Gear Train



- A gear train having a relative motion of axes is called a ***planetary*** or an ***epicyclic gear train***.

- In an epicyclic gear train, the axis of at least one of the gears also moves relative to the frame.

- Usually the wheel that rolls outside is known as **epicyclic** wheel. The term epicyclic emerges from the fact that the wheel traces an epicyclic path.

- Large speed reductions are possible with epicyclic gears and if the fixed wheel is annular, a more compact unit could be obtained. Important applications are in transmission, computing devices etc.

GEAR DRIVES

Numericals

1) The following data relate to two meshing gears –
   Velocity ratio – 1/3
   Module = 4 mm
   Centre distance = 200mm
   Determine the number of teeth of both the gears.

GEAR DRIVES

Numericals

Solution

(i) $$VR = \frac{N_2}{N_1} = \frac{1}{3} = \frac{T_1}{T_2} \quad \text{or} \quad T_2 = 3T_1$$

and $$C = \frac{d_1 + d_2}{2} = \frac{m\,(T_1 + T_2)}{2}$$

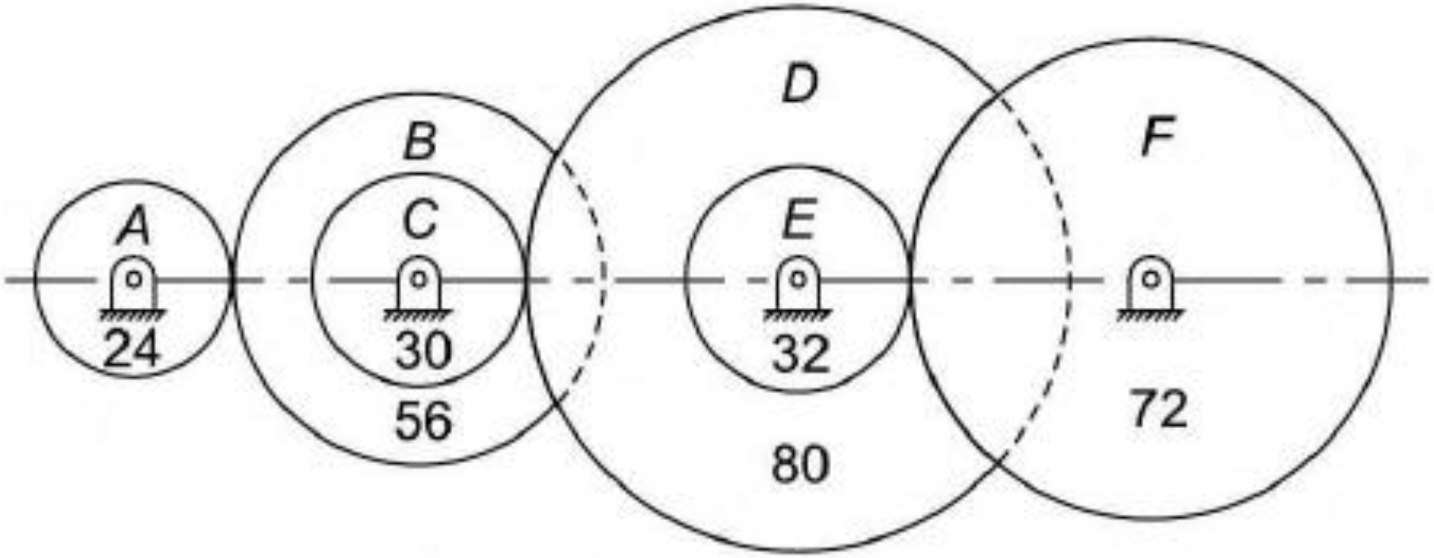
or $$200 = \frac{4\,(T_1 + 3T_1)}{2} = 8T_1$$

or $$T_1 = 25 \text{ and } \qquad T_2 = 25 \times 3 = 75$$

GEAR DRIVES

Numericals

2) A compound gear train shown in the figure consists of compound gears B – C and D – E. All gears are mounted on parallel shafts. The motor shaft rotating at 800 rpm is connected to the gear A. The number of teeth on gears A, B, C, D, E and F are 24, 56, 30, 80, 32 and 72 respectively. Determine the speed of the gear F.



GEAR DRIVES

Numericals

Solution

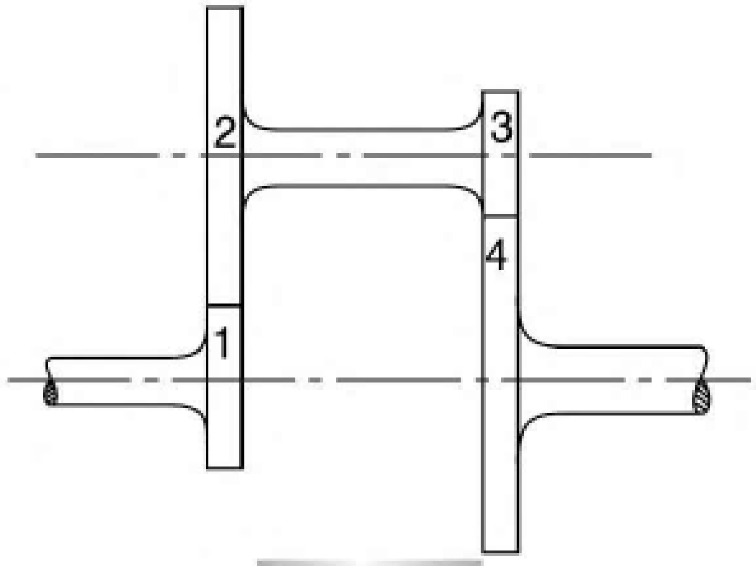
$$\frac{N_F}{N_A} = \frac{T_A}{T_B}\frac{T_C}{T_D}\frac{T_E}{T_F} = \frac{24}{56} \times \frac{30}{80} \times \frac{32}{72}$$

$$= 0.07143 \text{ or } N_F = 0.07143 \times 800 = 57.14 \text{ rpm}$$

GEAR DRIVES

Numericals

3) A reverted gear train shown in the figure is used to provide a speed ratio of 10. The module of gears 1 and 2 is 3.2 mm and of gears 3 and 4 is 2 mm. Determine suitable numbers of teeth for each gear. No gear is to have less than 20 teeth. The centre distance between shafts is 160 mm.



GEAR DRIVES

Numericals

Solution Let us assume that the speed ratio of the pair of gears 1 and 2 = 2.5 or $\dfrac{N_1}{N_2} = \dfrac{T_2}{T_1} = 2.5$ and speed ratio of the pair of gears 3 and 4 = 4 or

$$\frac{N_3}{N_4} = \frac{T_4}{T_3} = 4$$

$$\text{Now, } r_1 + r_2 = r_3 + r_4 = 160$$

$$\text{or } \frac{m_1 T_1}{2} + \frac{m_2 T_2}{2} = 160$$

GEAR DRIVES

Numericals

and $\frac{m_3 T_3}{2} + \frac{m_4 T_4}{2} = 160$

or $3.2(T_1 + T_2) = 320$ and $2(T_3 + T_4) = 320$

or $T_1 + T_2 = 100$ and $T_3 + T_4 = 160$

or $T_1 + 2.5T_1 = 100$ and $T_3 + 4T_3 = 160$

or $T_1 = 28.57$ say 28 and $T_3 = 32$

To ensure the same centre distance between two sets of gears,

$T_2 = 100 - 28 = 72$ and $T_4 = 160 - 32 = 128$

Exact velocity ratio

$$= \frac{T_1}{T_2} \frac{T_3}{T_4} = \frac{28 \times 32}{72 \times 128} = 10.29$$

MECHANICAL ENGINEERING SCIENCE

UNIT - 3

MANUFACTURING PROCESSES AND FASTENERS

Dr. Mantesh B Khot

Department of Mechanical Engineering

MECHANICAL ENGINEERING SCIENCE

CHAPTER-1
CASTING AND FORMING

Dr. Mantesh B Khot
Department of Mechanical Engineering

Manufacturing Process

“The Process of Converting Raw Materials Into Finished Products "or Shaping of raw materials into finished products

- Cost
- Material
- Use

CLASSIFICATION OF MANUFACTURING PROCESSES

- The various processes used in manufacturing are classified into the following five groups –

1) ***Primary shaping processes*** – Casting, Forming such as rolling, extrusion, forging etc.,

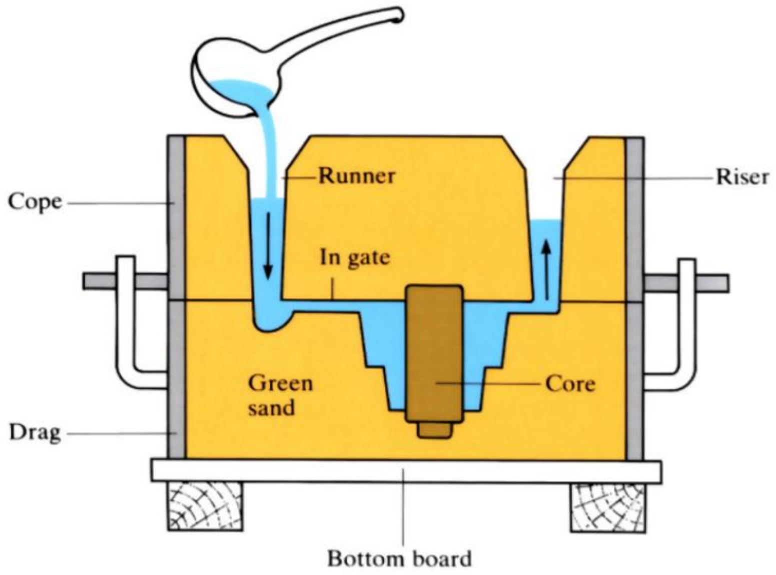
2) ***Machining processes*** – The machining operations are performed on castings, Rollings and forgings etc. in order to obtain the desired accuracy and shape. Ex – Turning, Drilling, Milling, Planning etc.

3) ***Surface finishing processes*** – These processes are used effectively to provide a good surface finish to the metal surface of the product. Ex – Buffing, Lapping, Honing, Anodising, Electroplating etc.

4) ***Joining processes*** – These processes are used for joining two or more pieces of metal parts. Ex – Welding, Soldering, Brazing etc.

5) ***Processes affecting change in properties***- These processes are used to impart certain specific properties to the metal part for specific conditions of use. Ex – Heat treatment, shot peening etc.

METAL CASTING



INTRODUCTION

- Metal casting involves pouring molten metal into a mould containing a cavity of the desired shape to produce a metal product.

- The casting is then removed from the mould and excess metal is removed.

- The product may then undergo a range of processes such as machining, heat treatment, polishing and surface coating or finishing.

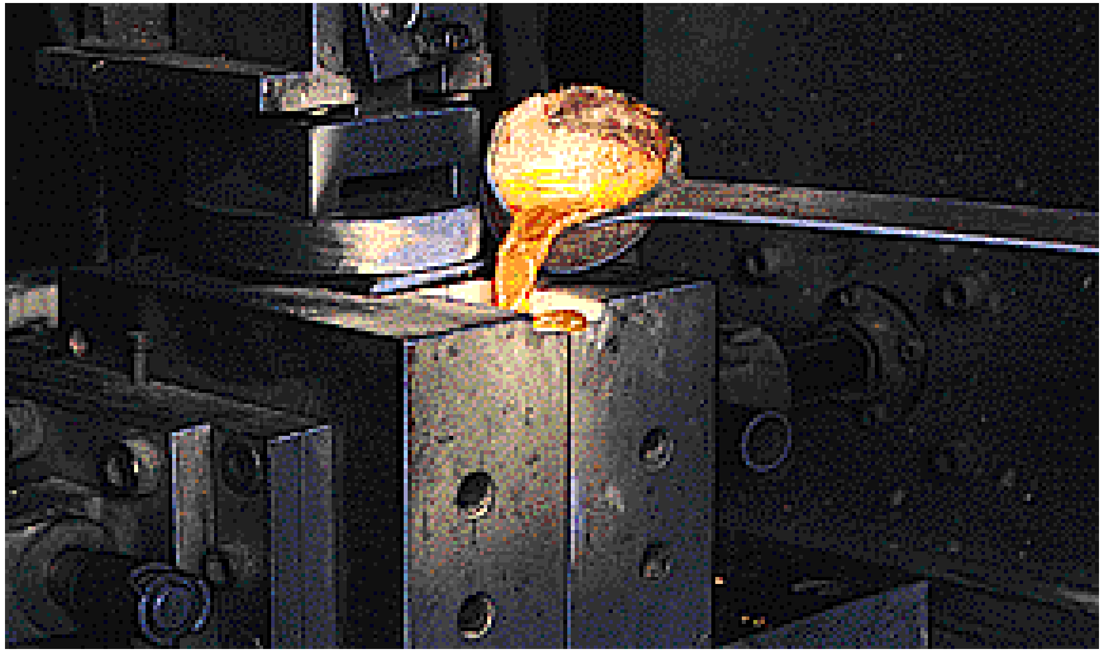
Foundry

Foundry is factory that produces castings.

Factory is a place where products (helpful to mankind) are manufactured.

STEPS INVOLVED IN CASTING

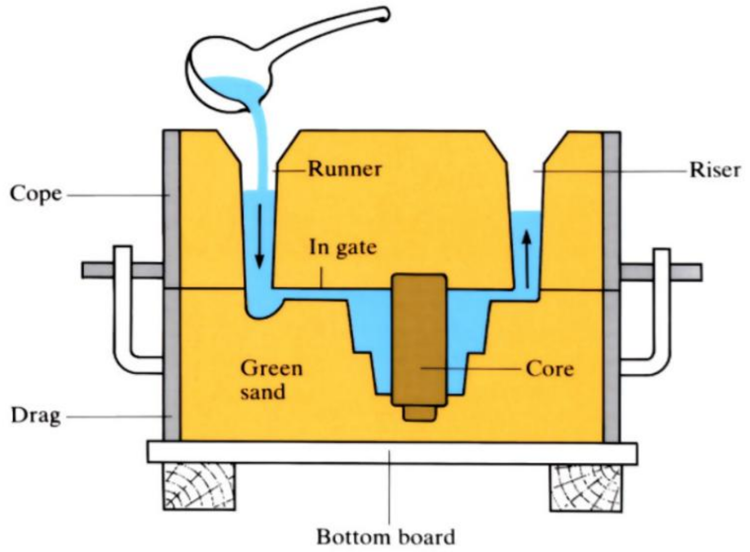
- Pattern making
- Mould making
- Melting & Pouring
- Cooling
- Sand reclamation
- Cleaning & Inspection



Used once and then discarded

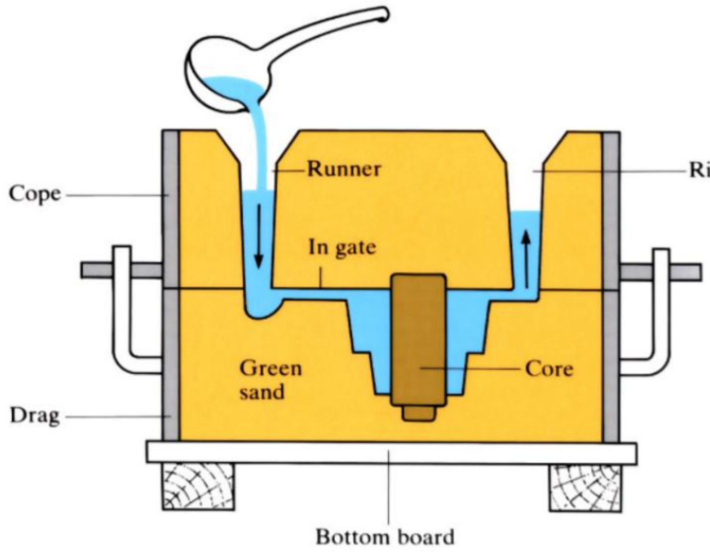
SAND MOULD MAKING – Sand is expendable moulds.

- The mould is formed in a **mould box (flask),** which is typically constructed in two halves to assist in removing the pattern.
- The bottom half of the mould (**the drag**) is formed on a molding board.
- **Cores** are required for making hollow cavity in the casting.
- After the core is inserted, the top half of the mould (the **cope**) is placed on top.
- The interface between the two mould halves is called a **parting line**.



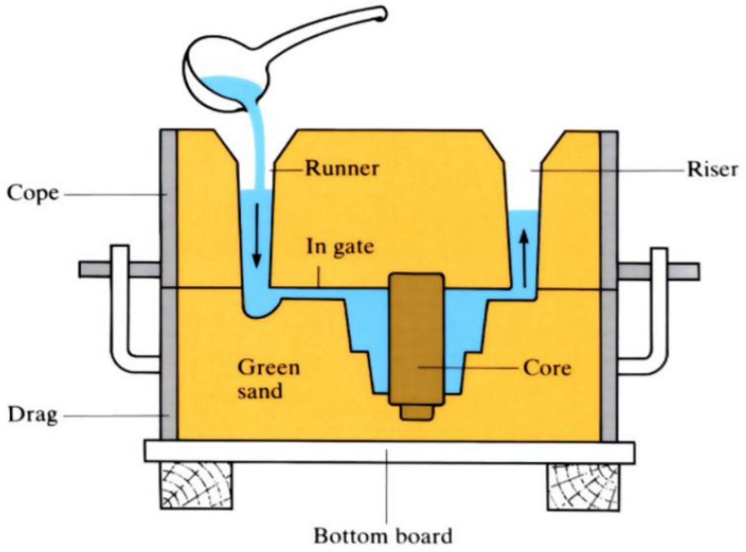
MOULD MAKING

- Mould designs include a gating system which is designed to **carry molten metal smoothly to all parts of the mould**.
- The gating system typically includes a sprue, gates, runners and risers.
- The **sprue** is where the metal is poured.
- **Runners** carry the molten metal towards the casting cavity through InGates.
- **Risers** may have several functions including vents to **allow gases to be released, reservoirs,** for avoiding solidification problems



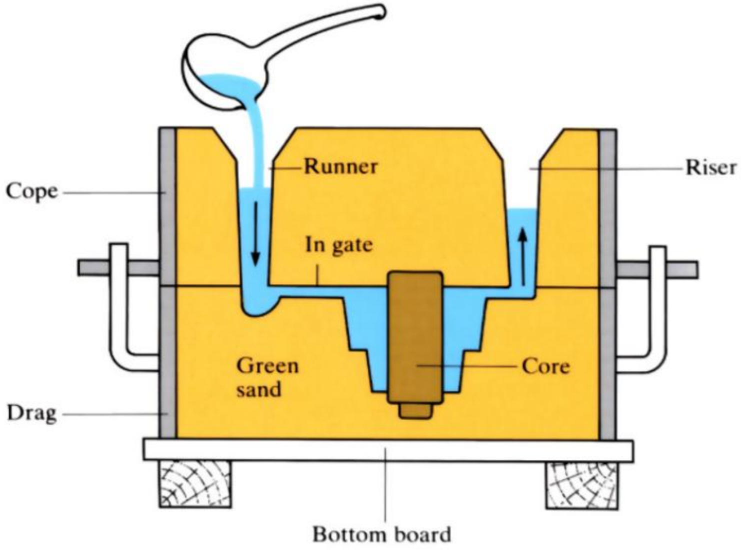
MELTING & POURING

- Molten metal is transferred from **the furnace to a ladle** and held until it reaches the desired pouring temperature.
- The molten metal is poured into the mould and allowed to solidify



Cooling and getting a final casted product

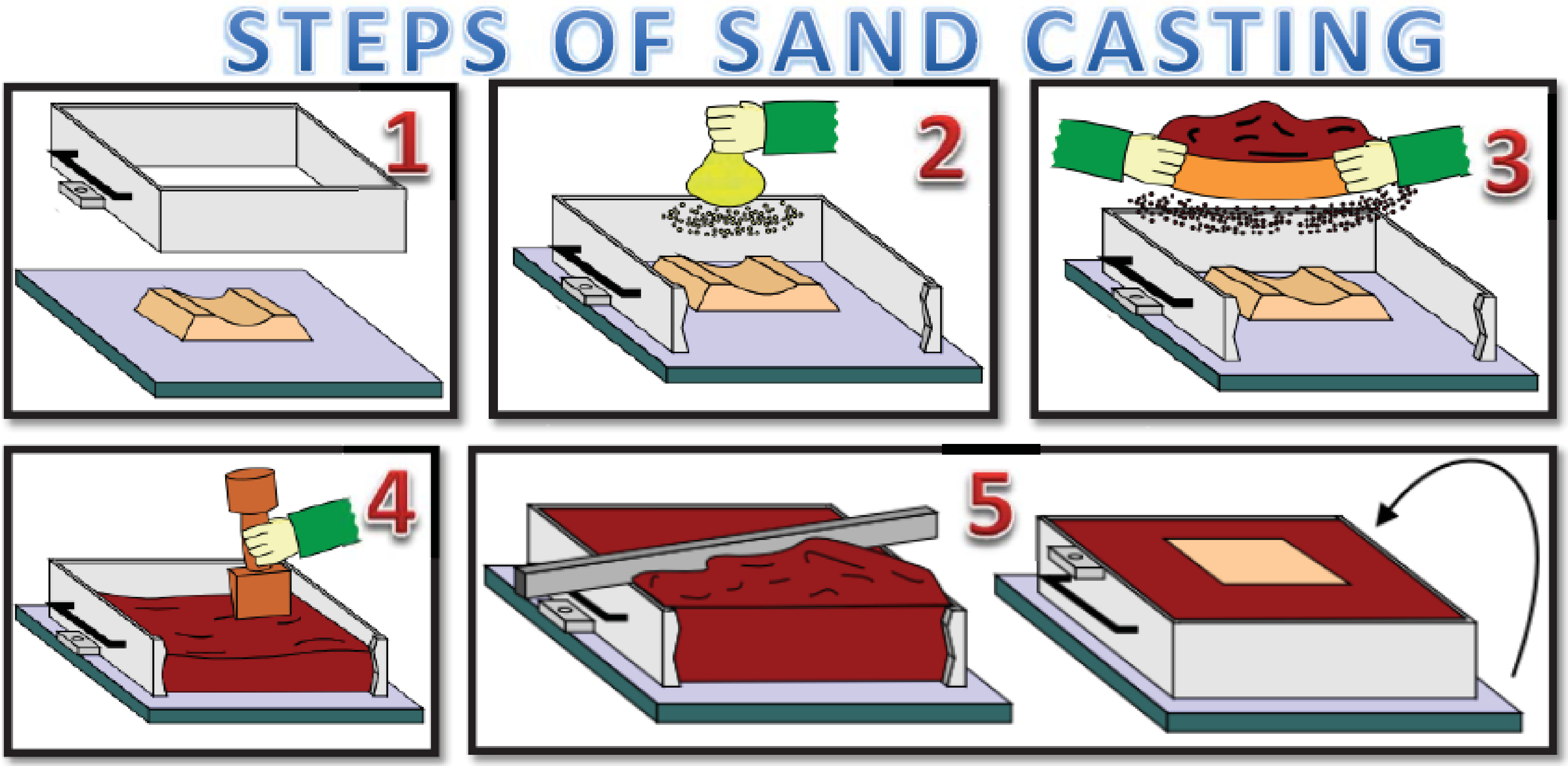
- Once the metal has been poured, the mould is cooled.
- Castings may be removed **manually** or using **vibratory tables** that shake the refractory material away from the casting.
- The casting are then heat treated for removing internal stresses and getting the desired metallurgical properties.



Cleaning and Finishing

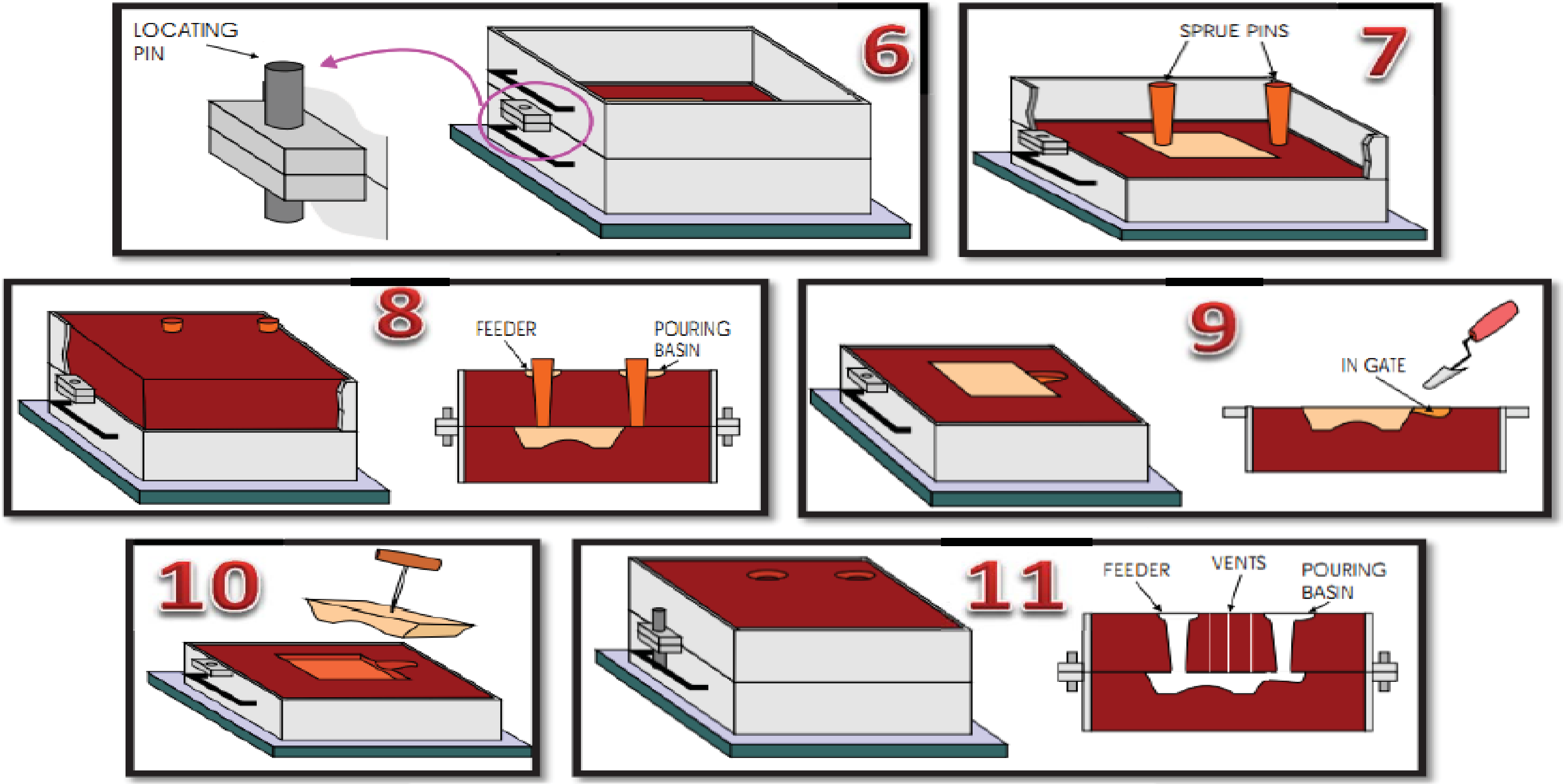
- Castings may also need to be repaired by welding, brazing or soldering to eliminate defects.
- The casting may undergo additional **grinding and polishing** to achieve the desired surface quality.
- The casting may then be coated using either a paint or a metal finishing operation such as galvanising, powder coating.

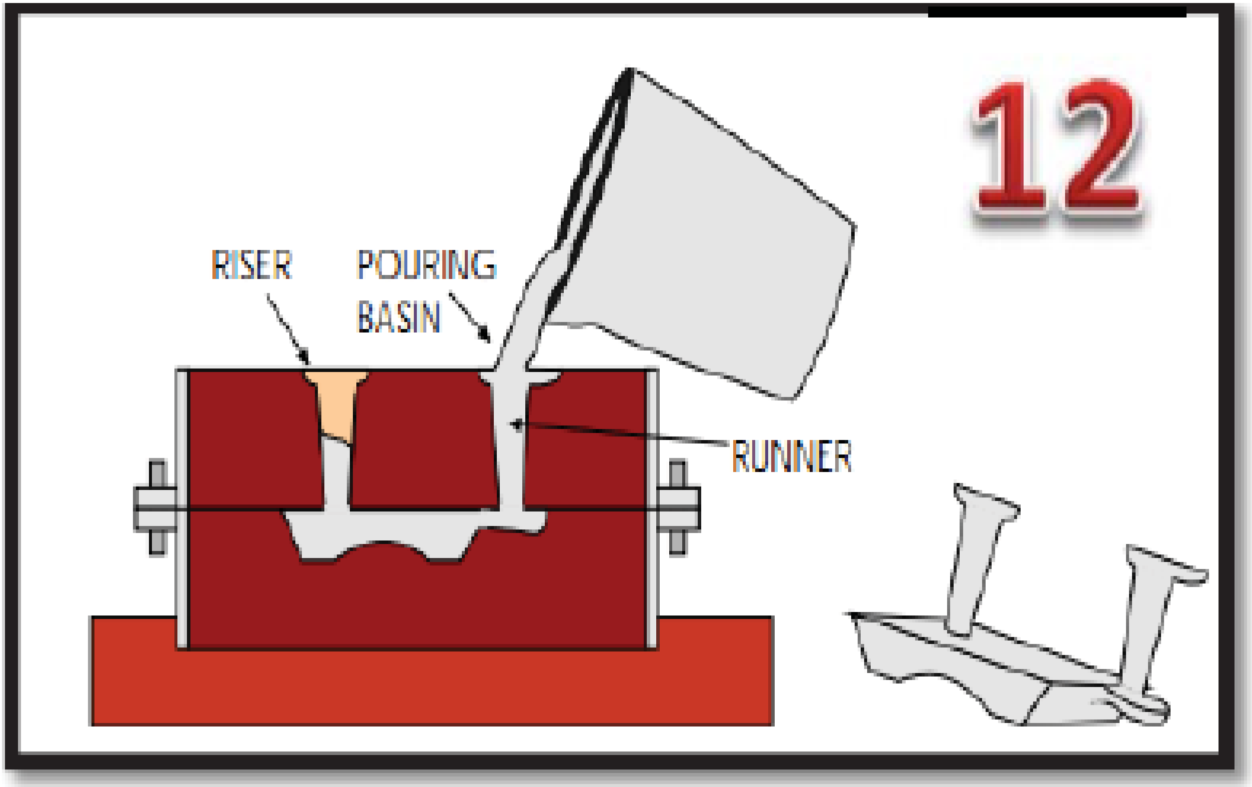
STEPS INVOLVED IN CASTING



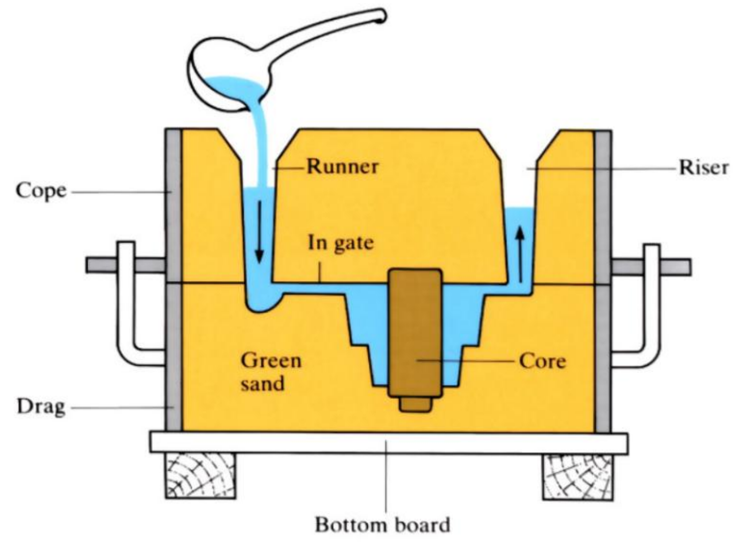
MECHANICAL ENGINEERING SCIENCES

Manufacturing processes and Fasteners

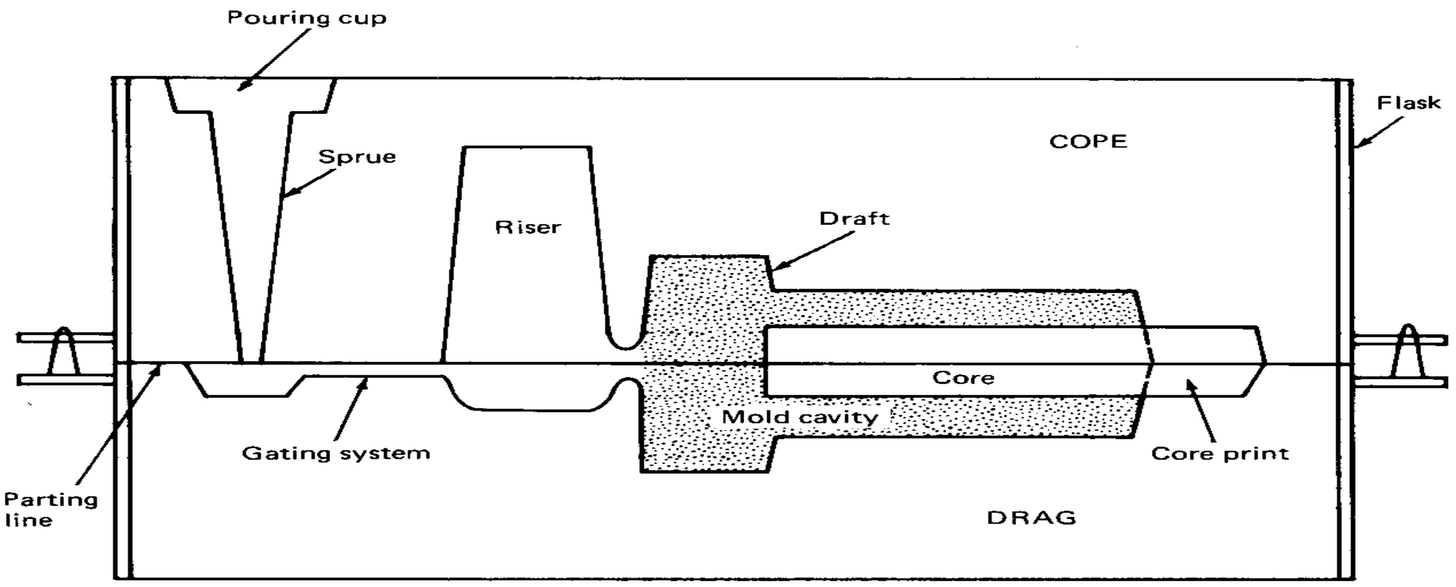


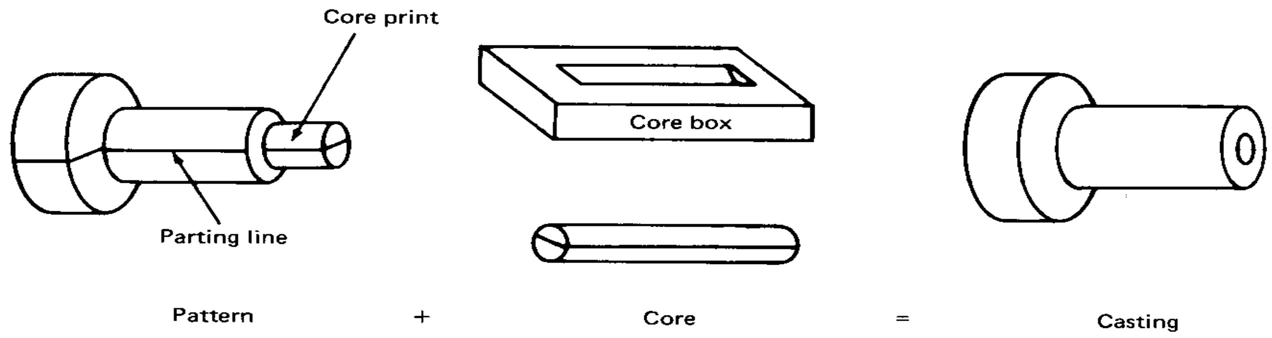


Sectional view of a casting mould

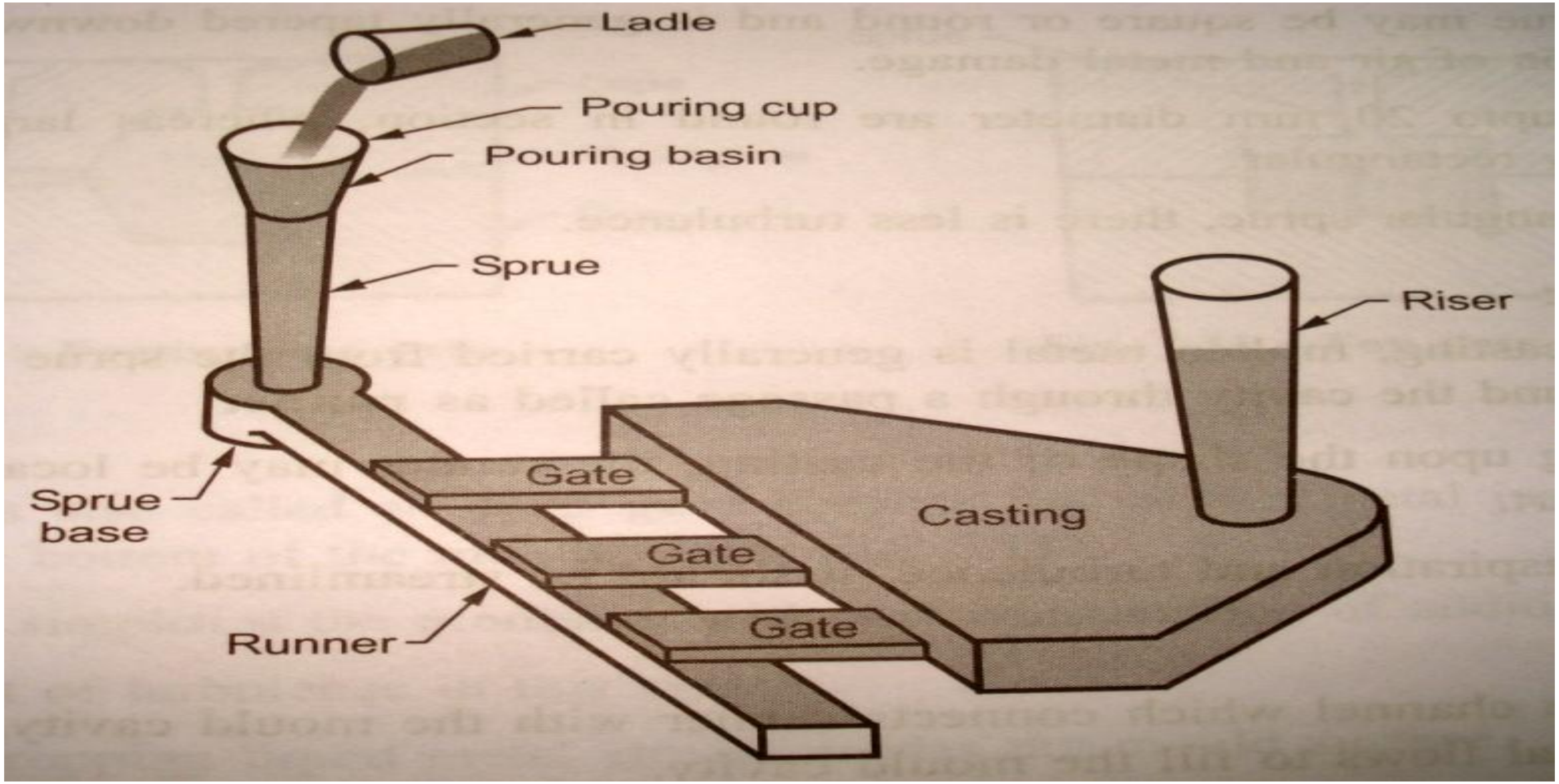


Sand Casting Terminology





Concept of Gating and Risers

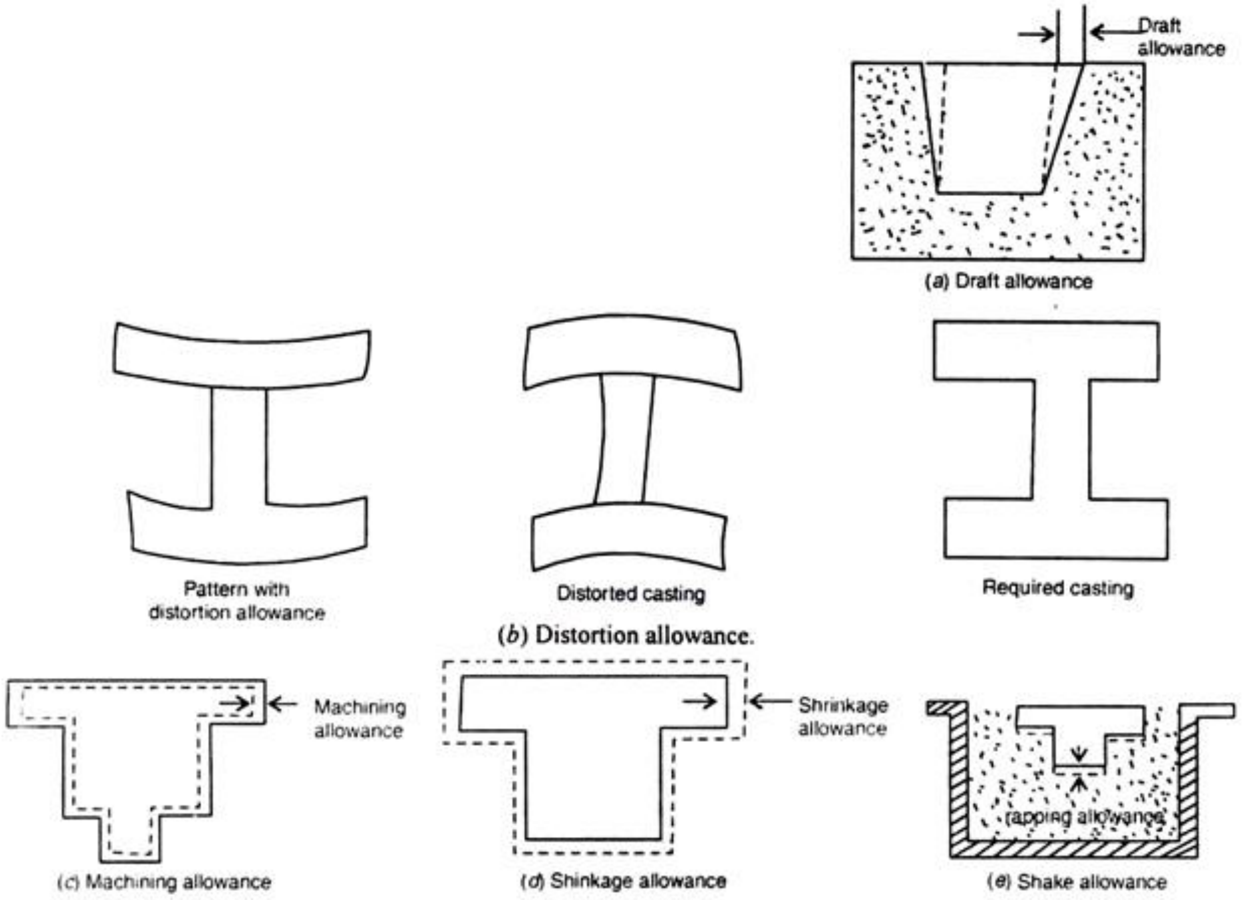


PATTERN

The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process, with some modifications.

The main modifications are the addition of pattern **allowances**, and the provision of core prints.

If the casting is to be **hollow**, additional patterns called cores are used to create these cavities in the finished product.



Pattern allowances

- Shrinkage allowance
- Machining allowance
- Distortion allowance
- Draft allowance

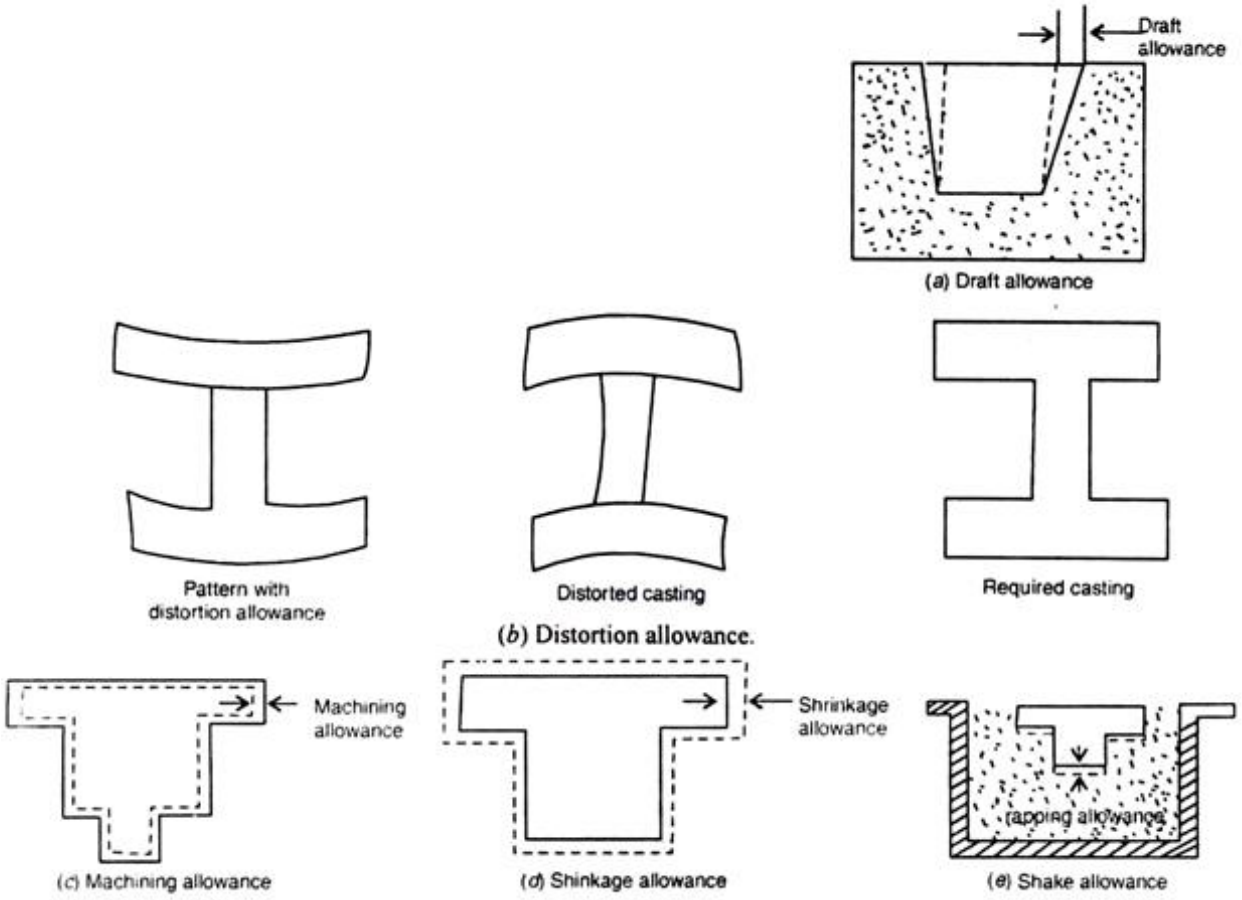
Pattern allowances

- *Shrinkage allowance:* compensates for the reduction in size that occurs during the cooling and solidification of materials, ensuring the final product achieves the desired dimensions.

- *Machining allowance:* The extra material added to certain parts of the casting to enable their machining to the required size, accuracy and surface finish.

- *Distortion allowance* compensate for the change in shape and size of the casting during the solidification process due to non-uniform cooling in uneven sections/irregular cross sections of the casting.

- *Draft allowance:* To allow removal of the pattern without damaging the mould cavity.



Functions and features of the Pattern

1. A pattern prepares a mold cavity for the purpose of making a casting.
2. A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.

   create space for the core (necessary when casting needs to be hollow. these points ensure that the core is held in correct position within mold.
3. Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
4. Patterns properly made and having finished and smooth surfaces reduce casting defects.
5. A properly constructed pattern minimizes the overall cost of the castings.

Pattern Material

Wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins.

Desirable properties of pattern material are:

1. Easily worked, shaped and joined
2. Light in weight
3. Strong, hard and durable
4. Resistant to wear and abrasion
5. Resistant to corrosion, and to chemical reactions
6. Dimensionally stable & should not cause distortion.
7. Unaffected by variations in temperature & humidity.
8. Available at low cost
9. Non hygroscopic

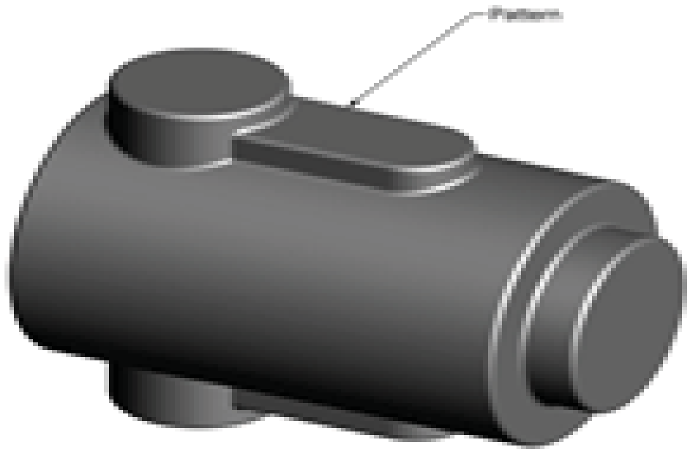
"Non-hygroscopic" refers to a substance that does not readily absorb moisture from the air

PATTERN MAKING and CORE BOX MAKING

- The quality of the casting produced depends upon the material of the pattern, its design, and construction.
- Pattern making is the first stage for developing a new casting.
- Pattern making is a highly skilled and precise process that is critical to the quality of the final product.
- Pattern can be used for one or more casting.
- Cores are produced in conjunction with the pattern to form the interior surfaces of the casting.

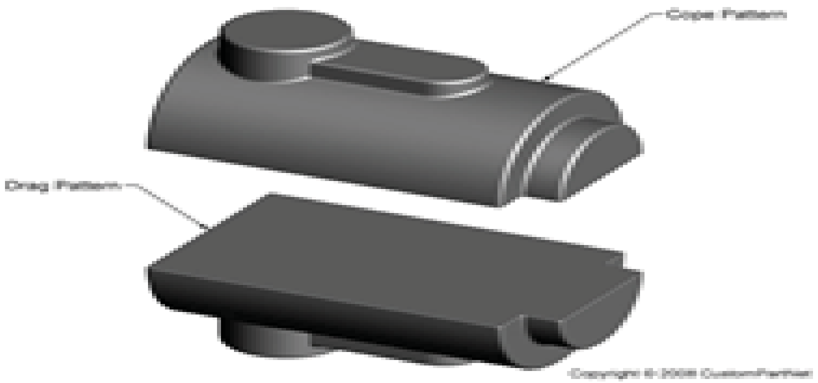
Types of Pattern

Solid pattern *- A solid pattern is a model of the part as a single* piece. It is the easiest to fabricate, but can cause some difficulties in making the mold.
The parting line and runner system must be determined separately. Solid patterns are typically used for geometrically simple parts that are produced in low quantities.



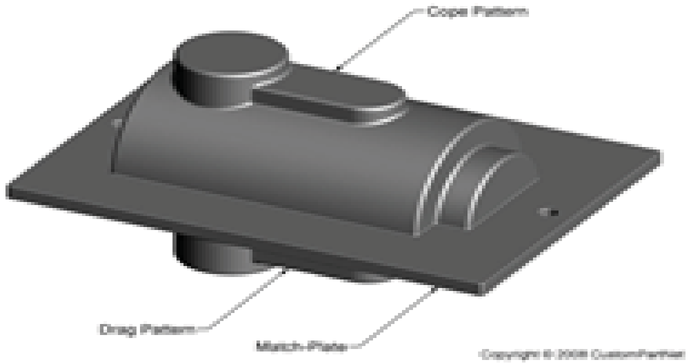
Split pattern

- *Split pattern models the part as two separate pieces that* meet along the parting line of the mold.
- Using two separate pieces allows the mold cavities in the cope and drag to be made separately and the parting line is already determined.
- Split patterns are typically used for parts that are geometrically complex and are produced in moderate quantities.



Match plate pattern

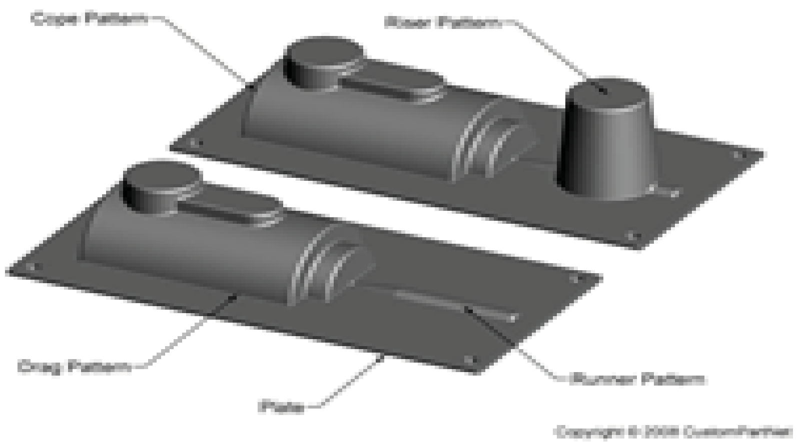
- A match-plate pattern is similar to a split pattern, except that each half of the pattern is attached to opposite sides of a single plate.
- This pattern design ensures proper alignment of the mold cavities in the cope and drag and the runner system can be included on the match plate.
- Match-plate patterns are used for larger production quantities and are often used when the process is automated.



Cope and drag pattern

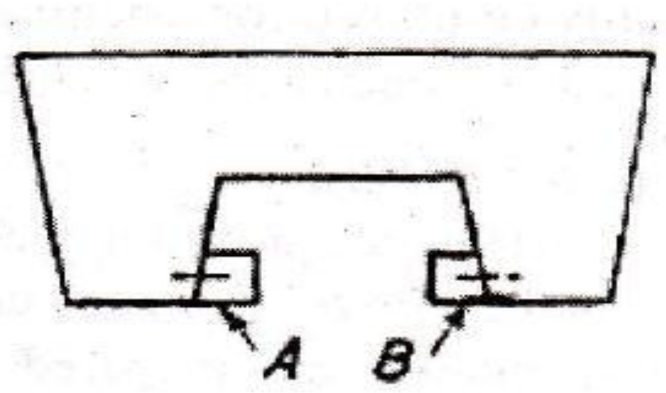
- *A cope and drag pattern is similar to a* match plate pattern, except that each half of the pattern is attached to a separate plate and the mold halves are made independently.

- Just as with a match plate pattern, the plates ensure proper alignment of the mold cavities in the cope and drag and the runner system can be included on the plates.
- Cope and drag patterns are often desirable for larger castings

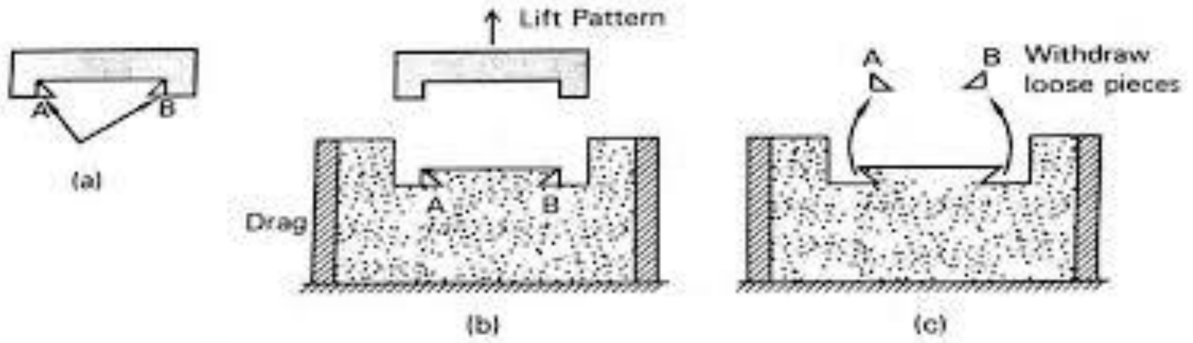


Loose-piece pattern

- Patterns with complicated shapes which cannot be withdrawn easily.
- Loose pieces remains attached with the main body by using dowel pins.



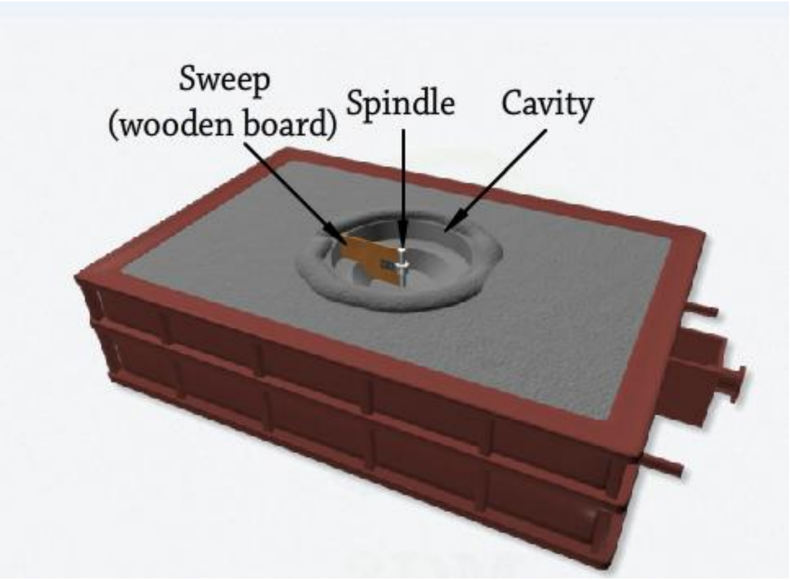
Loose piece pattern.



Loose piece pattern

Sweep pattern

- Sweeps can be advantageously used for preparing moulds of large symmetrical castings, particularly of circular cross section.
- The full equipment consists of a base, suitably placed in the sand mass, a vertical spindle and a wooden template called sweep.
- The outer end of sweep carries the contour corresponding to the shape of the desired casting. The sweep is rotated about the spindle to form the cavity.



Advantages of Sand Casting

- Process is suitable for both ferrous and non-ferrous metal castings.
- Handles a more diverse range of products than any other casting method.
- Produces both small precision castings and large castings of up to 1 tonne.
- Can achieve very close tolerances if uniform compaction is achieved.
- Mould preparation time is relatively short in comparison to many other processes.
- High levels of sand reuse are achievable

Limitations of Sand Casting

- The dimensional accuracy and surface finish achieved by normal sand casting process would not be adequate for final application in many cases.

- The sand casting process is labour intensive to some extent and therefore many improvements are aimed at it like machine moulding and foundry mechanisation.

- With some materials it is often difficult to remove defects arising out of the moisture present in sand castings.

Applications of Sand Casting

Cylinder blocks

Liners

Machine tool beds

Pistons and piston rings

Mill rolls

Wheels

Housings

Properties of molding sand

- Green strength
- Dry strength
- Permeability or porosity
- Cohesiveness
- Adhesiveness
- Collapsibility
- Flow ability
- Refractoriness

Properties of Moulding materials

1) Refractoriness - It is the ability of the moulding material to withstand the high temperatures of the molten Metal.

2) Green Strength - The moulding sand that contains moisture is termed as green sand. The green sand should have enough strength so that the constructed mould retains its shape.

3) Dry Strength - When the moisture in the moulding sand is completely expelled, it is called dry sand. When molten metal is poured into a mould, the sand around the mould cavity is quickly converted into dry sand as the moisture in the sand immediately evaporates due to the heat in the molten metal.

4) Permeability - During the solidification of a casting, large amounts of gases are to be expelled from the mould. The moulding sand should be sufficiently porous so that the gases are allowed to escape from the mould. **This gas evolution capability of the moulding sand is termed as permeability.**

Properties of Moulding materials

5) Cohesiveness - Cohesiveness is known as the strength of the moulding sand. Cohesiveness is that property of the moulding sand which enables the sand particles to stick together. Following factors may affect the strength or cohesiveness of the moulding sand.

- Shape and size of the grain
- Bonding material and its distribution
- Moisture

6) Adhesiveness - Adhesiveness can be defined as the property of moulding sand, which enables the sand particles to stick with other objects such as moulding box.

Properties of Moulding materials

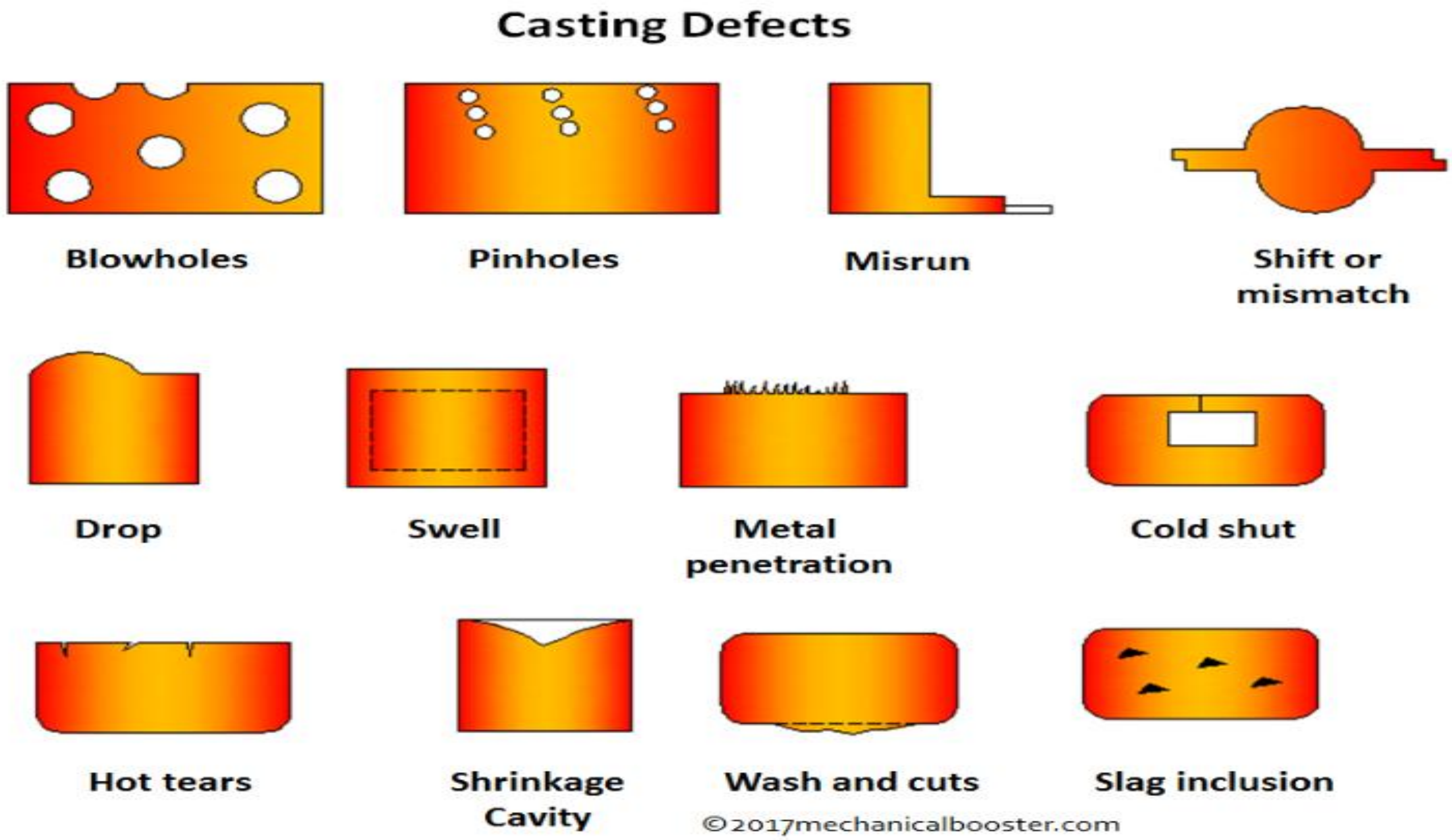
7) Flowability - Flowability is the property of moulding sand to properly pack the moulding box all around the pattern. Good flowability ensures the moulding sand to flow all over the pattern when the mould is rammed.

8) Collapsibility - The ability of the sand mixture to collapse under force. Collapsibility is that property of the moulding sand, which will permit easy break down of the sand mass and its subsequent use after the casting has been taken out of the mould

Casting Defects

Types

1. **Gas Porosity:** Blowholes, open holes, pinholes
2. **Shrinkage defects:** shrinkage cavity
3. **Mold material defects:** Cut and washes, swell, drops, metal penetration, rat tail
4. **Pouring metal defects:** Cold shut, misrun, slag inclusion
5. **Metallurgical defects:** Hot tears, hot spot


Casting Defects
Blowholes
Pinholes
Misrun
Shift or mismatch
Drop
Swell
Metal penetration
Cold shut
Hot tears
Shrinkage Cavity
Wash and cuts
Slag inclusion
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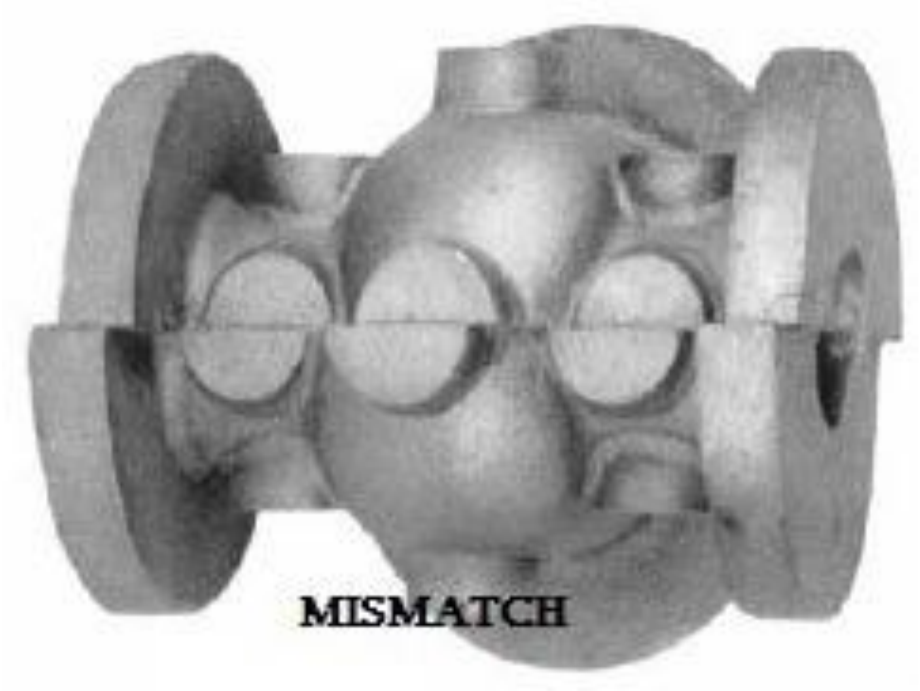
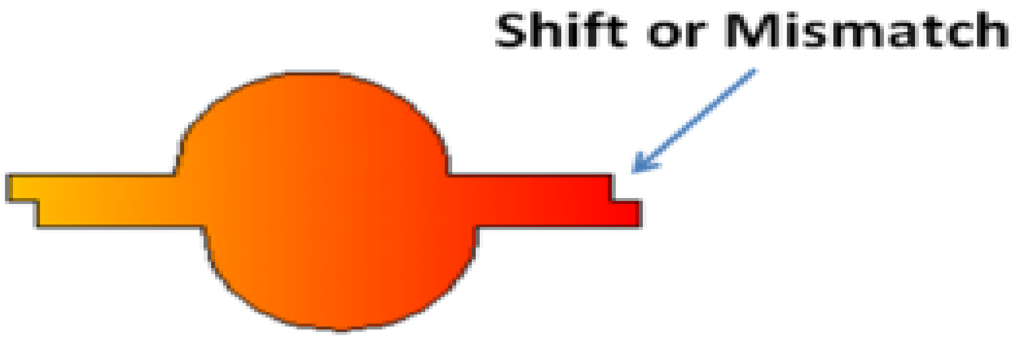
Shift or Mismatch

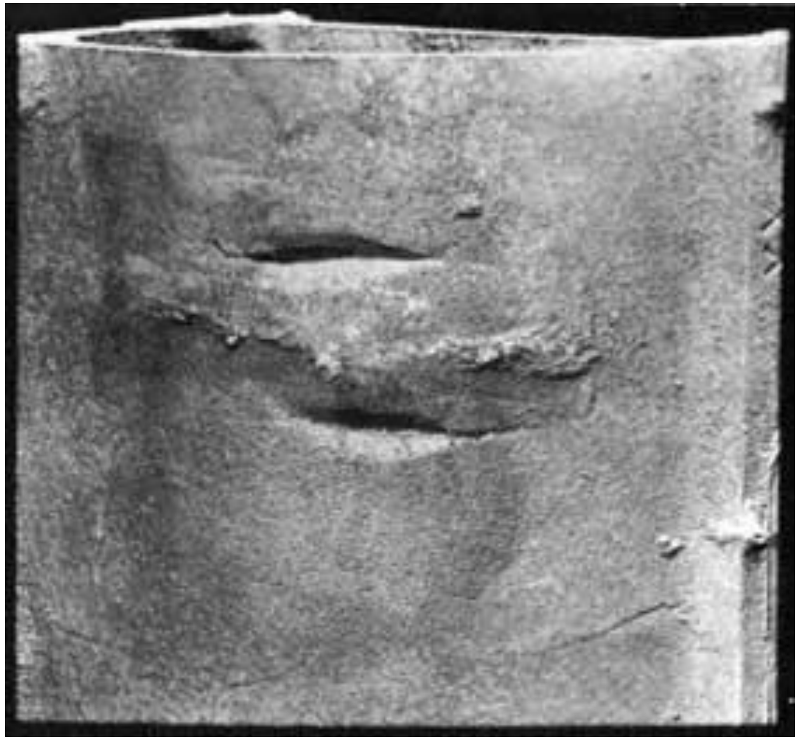
The defect caused due to misalignment of upper and lower part of the casting and misplacement of the core at parting line

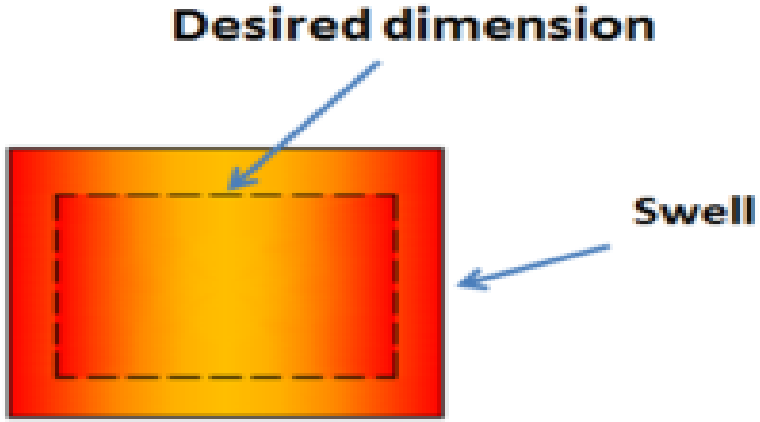




Swell

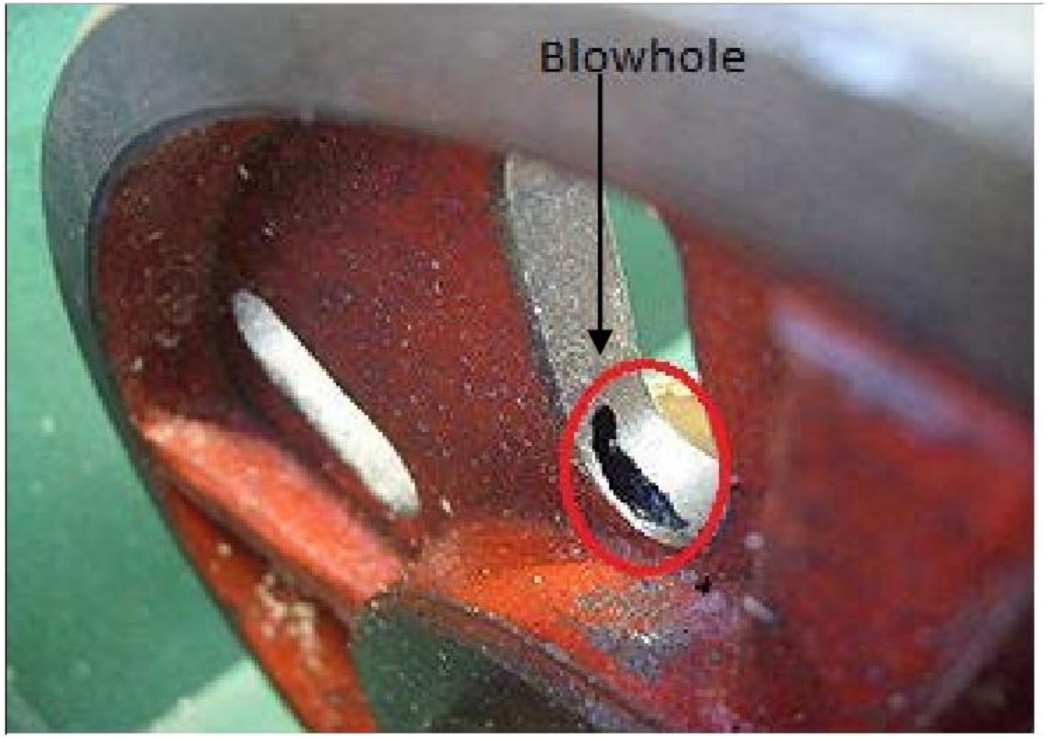
It is the enlargement of the mold cavity because of the molten metal pressure, which results in localized or overall enlargement of the casting.

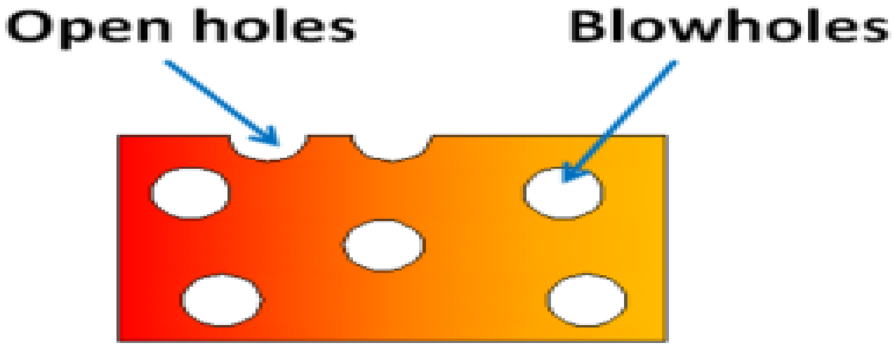




Blowholes

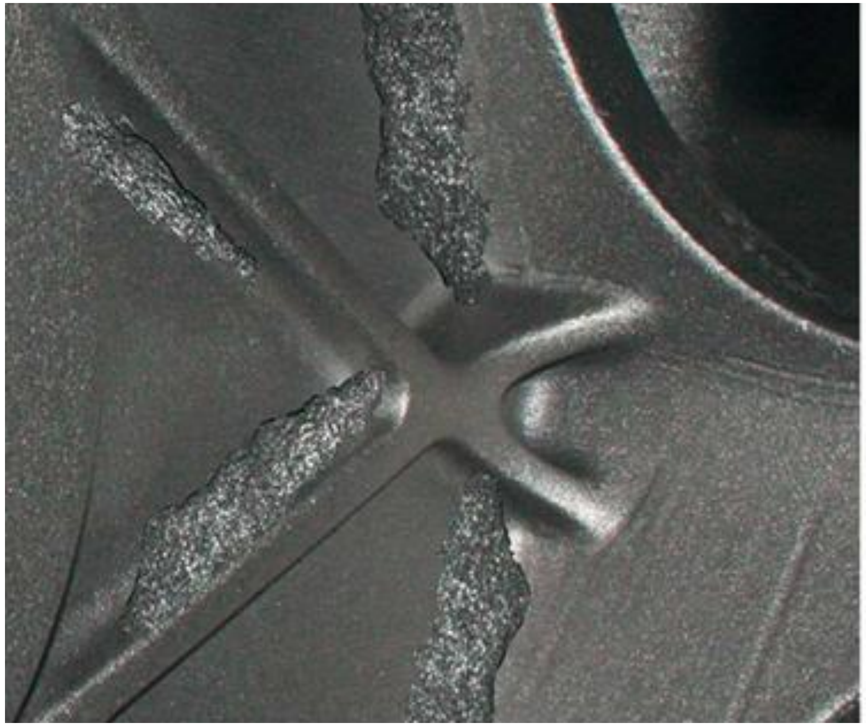
When gases entrapped on the surface of the casting due to solidifying metal, a rounded or oval cavity is formed called as blowholes. These defects are always present in the cope part of the mold

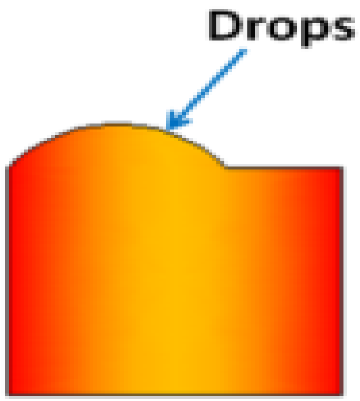




Drop

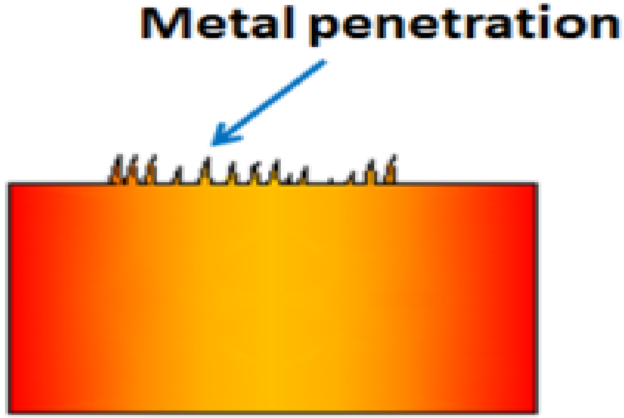
Drop defect occurs when there is cracking on the upper surface of the sand and sand pieces fall into the molten metal.





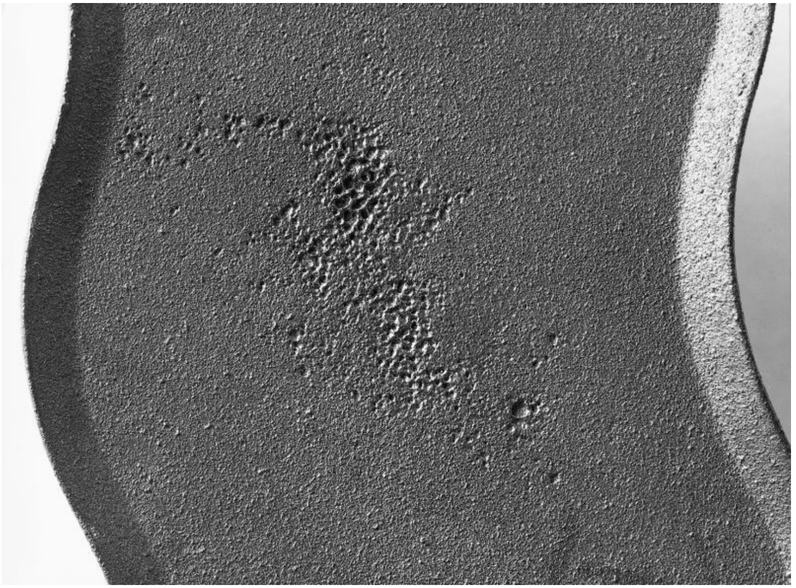
Metal Penetration

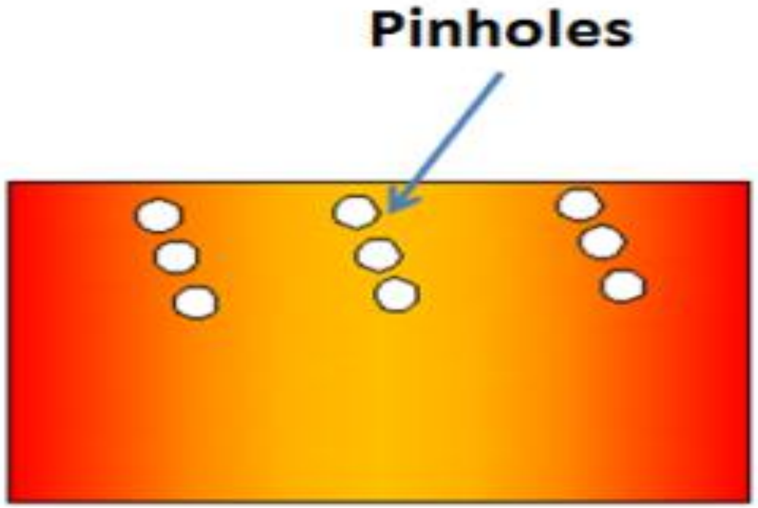
These casting defects appear as an uneven and rough surface of the casting. When the size of sand grains is larges, the molten fuses into the sand and solidifies giving us metal penetration defect.



Pinholes

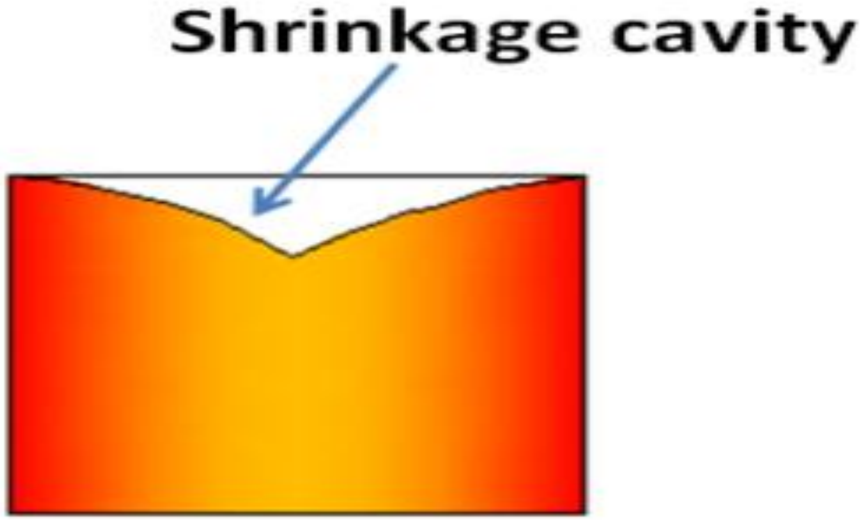
- They are very small holes of about 2 mm in size which appears on the surface of the casting.
- This defect happens because of the dissolution of the hydrogen gases in the molten metal.
- When the molten metal is poured in the mold cavity and as it starts to solidify, the solubility of the hydrogen gas decreases and it starts escaping out the molten metal leaves behind small number of holes called as pinholes.





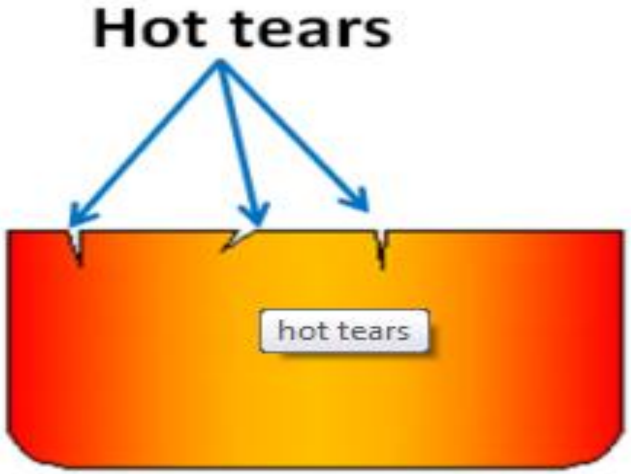
Shrinkage Cavity

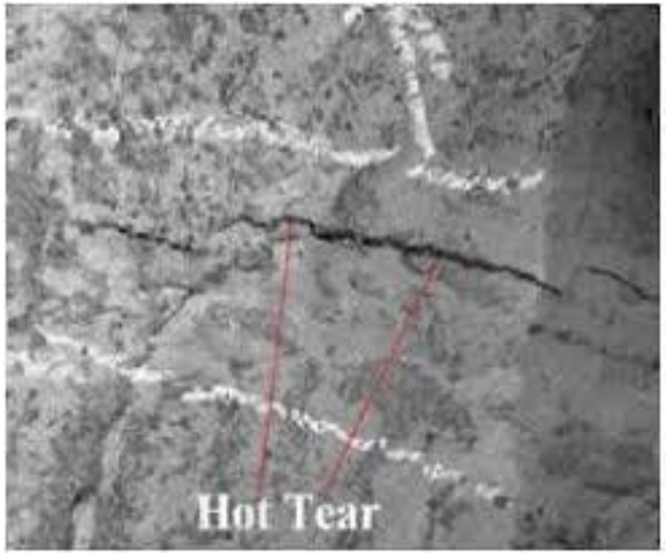
The formation of cavity in the casting due to volumetric contraction is called as shrinkage cavity.

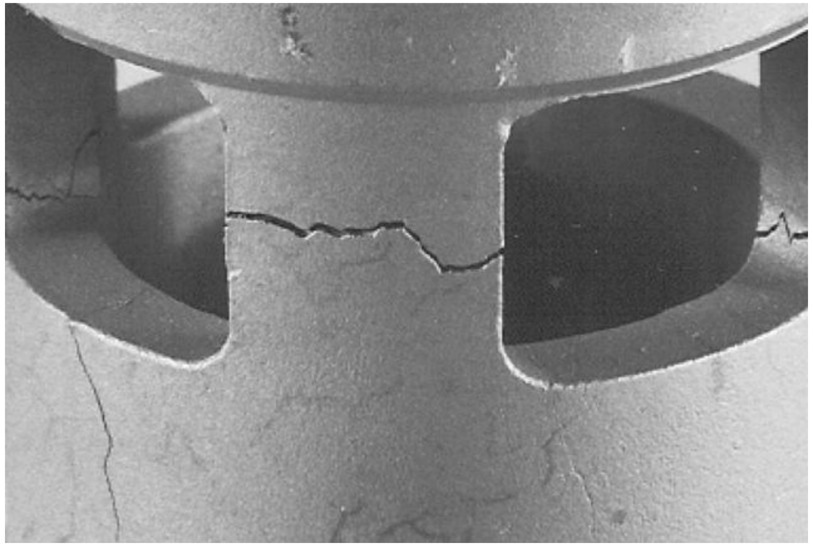


Hot Tears or Hot Cracks

when the metal is hot it is weak and the residual stress (tensile) in the material cause the casting fails as the molten metal cools down. The failure of casting in this case is looks like cracks and called as hot tears or hot cracking.







Cold Shut

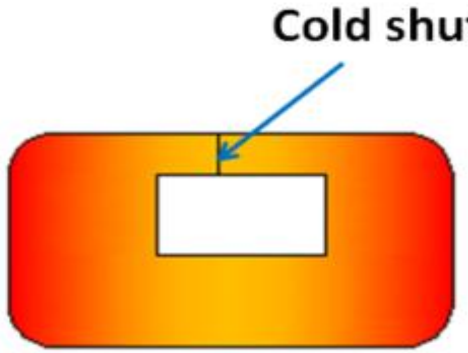
It is a type of surface defects and a line on the surface can be seen. When the molten metal enters into the mold from two gates and when these two streams of molten metal meet at a junction with low temperatures than they do not fuse with each other and solidifies creating a cold shut (appear as line on the casting). It looks like a crack with round edge

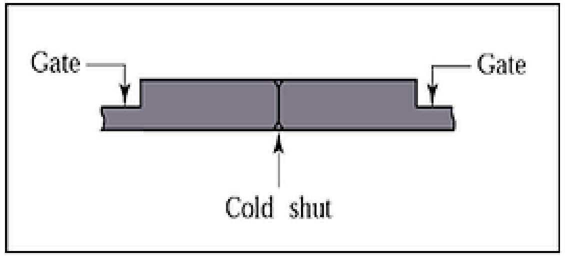
Causes

- Poor gating system
- Low melting temperature
- Lack of fluidity

Remedies

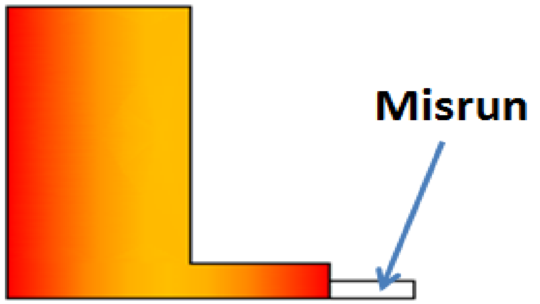
- Improved gating system.
- Proper pouring temperature.





Misrun

When the molten metal solidifies before completely filling the mold cavity and leaves a space in the mold called as misrun.



Causes

(i) Low fluidity of the molten metal.
(ii) Low temperature of the molten metal which decreases its fluidity.
(iii) Too thin section and improper gating system.

Remedies

(i) Increasing the pouring temperature of the molten metal increases the fluidity.
(ii) Proper gating system

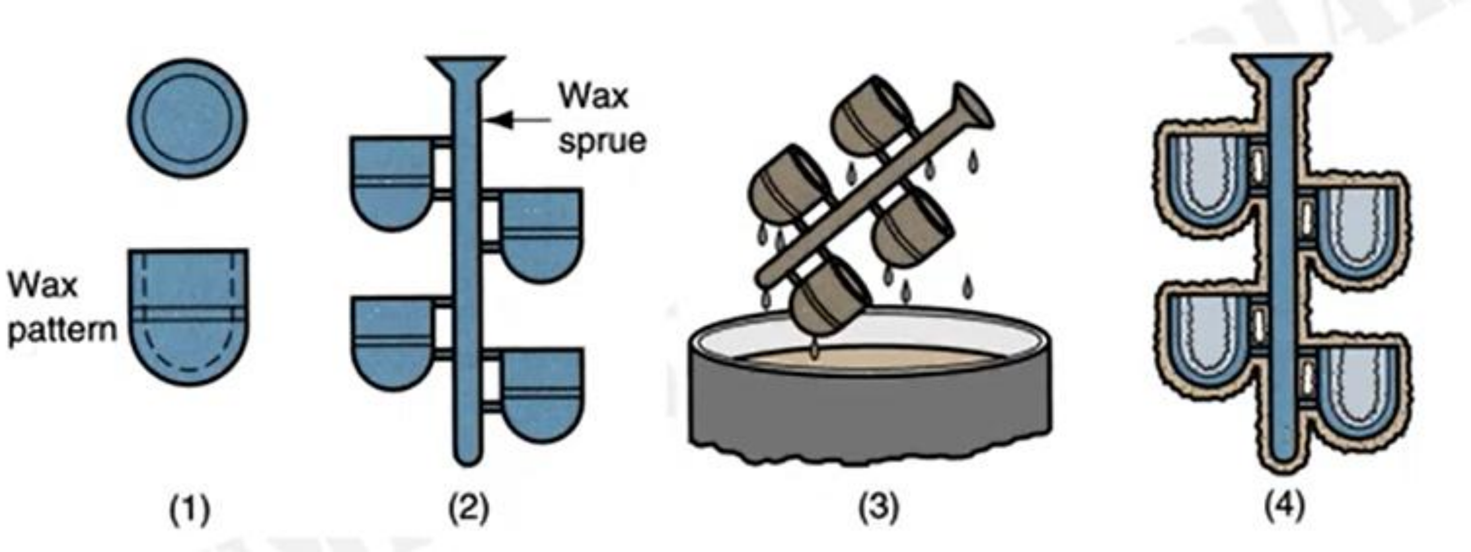
Special Casting Processes

- Sand casting processes described so far are not suitable and economical in many applications. In such situations special casting processes would be more appropriate.

- The following two special casting processes are discussed in the following sections –

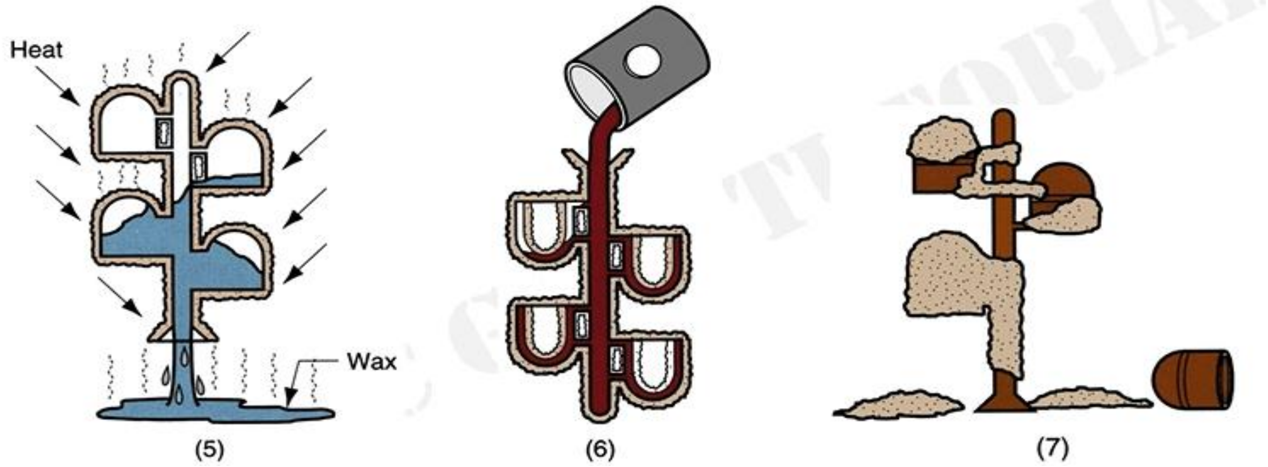
1) Precision Investment Casting

2) Centrifugal Casting



Precision Investment Casting

1. Wax patterns are produced
2. Several patterns are attached to a sprue to form a pattern tree
3. The pattern tree is coated with a thin layer of refractory material
4. The full mold is formed by covering the coated tree with sufficient refractory material to make it rigid



Precision Investment Casting

5. The mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity
6. The mold is preheated to a high temperature, which ensures that all contaminants are eliminated from the mold.
   It also permits the liquid metal flow more easily into the detailed cavity.
   The molten metal is poured and it solidifies.
7. The mold is broken away from the finished casting.
   Parts are separated from the sprue.

Special Casting Processes

Precision Investment Casting

Applications –

- This process was used in the olden days for the preparation of jewellery and surgical instruments.

- Presently the products made by this process are vanes and blades for gas turbines, shuttle eyes for weaving, pawls and claws for movie cameras, wave guides for radars, bolts and triggers for fire arms, stain less steel valve bodies and impellers for turbo chargers.

Special Casting Processes

Centrifugal Casting

- This is a process where the mould is rotated rapidly about its central axis as the metal is poured into it.

- Because of the centrifugal force, a continuous pressure will be acting on the metal as it solidifies. The slag, oxides and other inclusions being lighter, gets separated from the metal and segregates toward the centre.

- There are three main types of centrifugal casting processes. They are:
  - **True centrifugal casting**,
  - Semi centrifugal casting, and
  - Centrifuging

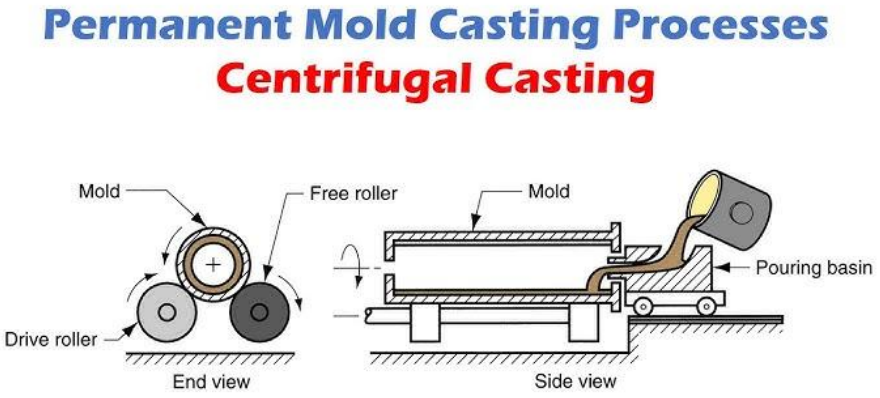
True Centrifugal Casting

- This is normally used for the making of hollow pipes, tubes, hollow bushes, etc., which are axi-symmetric with a concentric hole.

- Since the metal is always pushed outward because of the centrifugal force, no core needs to be used for making the concentric hole. The axis of rotation can be horizontal, vertical or any angle in between.

- First, the moulding flask is properly rammed with sand to confirm to the outer contour of the pipe to be made.

- Then the flask is dynamically balanced so as to reduce the occurrence of undesirable vibrations during the casting process. The finished flask is mounted in between the rollers and the mould is rotated slowly.

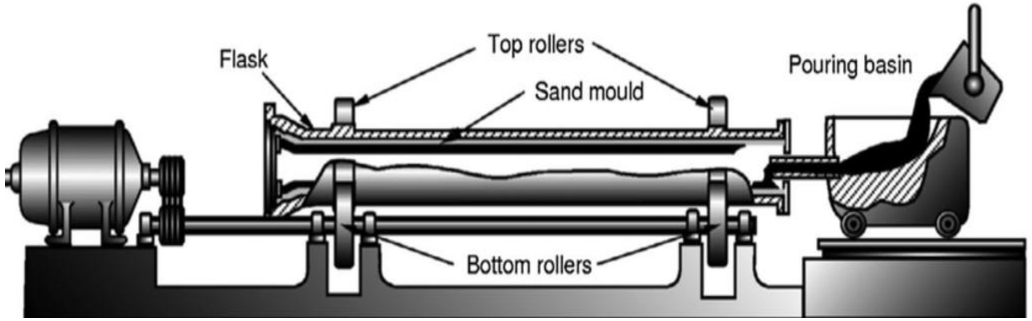


Special Casting Processes

True Centrifugal Casting

- Now the molten metal in requisite quantity is poured into the mould through the movable pouring basin. The amount of metal poured determines the thickness of the pipe to be cast.

- After the pouring is completed, the mould is rotated at its operational speed till it solidifies, to form the requisite tubing. Then the mould is replaced by a new mould machine and the process continues.



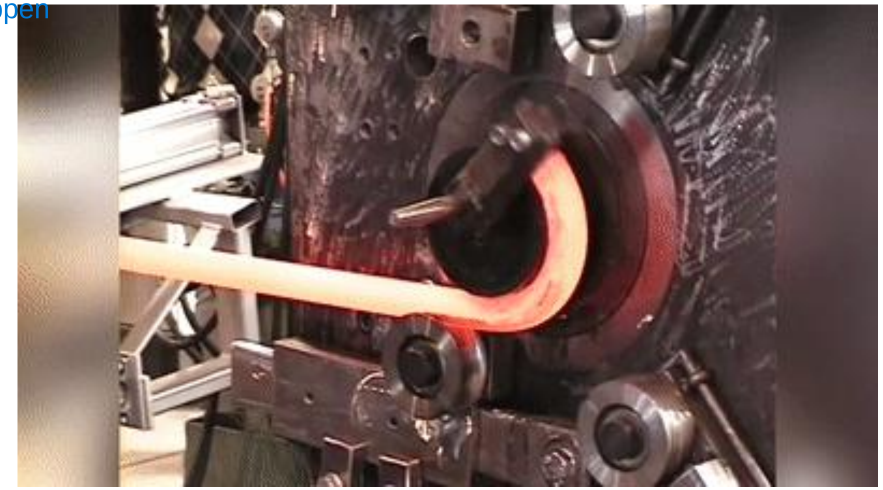
Metal Forming

Metal forming is a process where materials are subjected to **Plastic deformation with pressure, with or without the application of heat.**

Forging , Rolling, Extrusion, Wire drawing and deep drawing.

- The metal-working processes are traditionally divided into **hot working and cold-working processes**. The division is on the basis of the amount of heating applied to the metal before applying the mechanical force.

temp at which new strain free gains happen



- Those processes, working above the **recrystallisation temperature**, are termed as hot-working processes whereas those below are termed as cold-working processes.

- Under the action of heat and the force, when the atoms reach a certain higher energy level, the new crystals start forming which is termed as recrystallisation. Recrystallisation temperature as defined by American Society of Metals is "**the approximate minimum temperature at which complete recrystallisation of a coldworked metal occurs within a specified time**".

- The recrystallisation temperature generally varies between **one third to one half the melting point** of most of the metals.

HOT WORKING AND COLD WORKING

- **Advantage of Hot Working**: As the material is above the recrystallisation temperature, any amount of working can be imparted since there is no strain-hardening taking place.

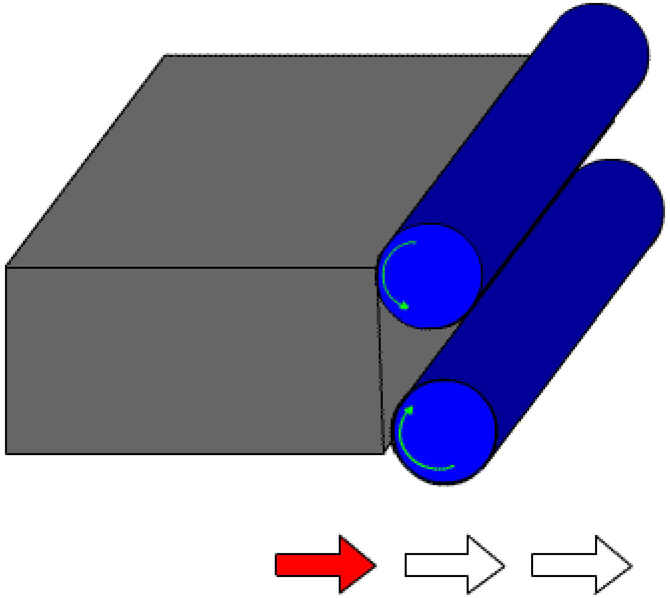
- **Limitations of Hot Working**:
  1) Higher temperatures of metal give rise to scaling of the surface and as a result, the surface finish obtained is poor.
  2) Because of the thermal expansion of metals, the dimensional accuracy in hot working is difficult to achieve since it is difficult to control the temperature of work pieces.
  3) Handling and maintaining of hot metal is difficult.

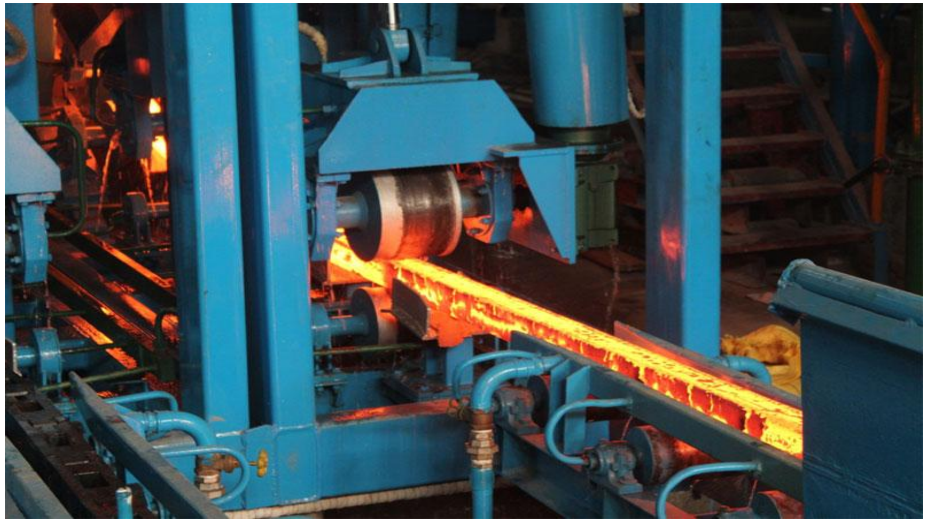
- **Advantage of Cold Working**: Cold working increases the strength and hardness of the material due to strain hardening which would be beneficial in some situations.

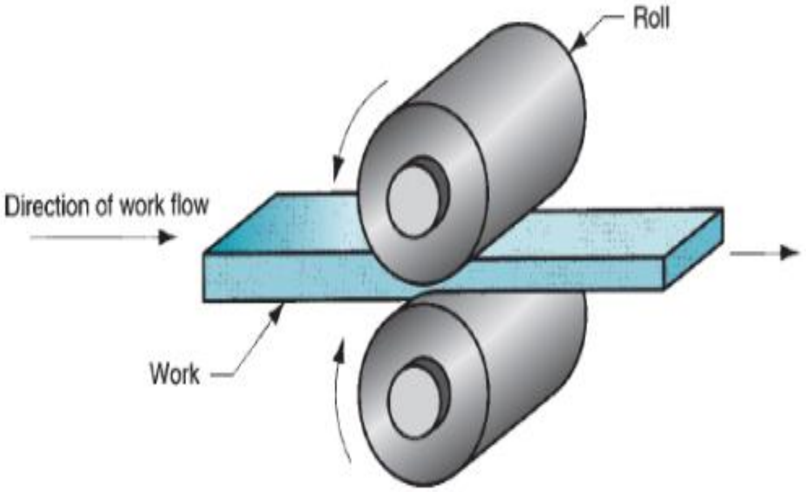
- **Limitation of Cold Working**: Since the material has higher yield strength at lower temperatures, the amount of deformation that can be given to is limited by the capability of the presses or hammers used.

Rolling

- It is the process of reducing the thickness or changing the cross section of a long work piece by compressive forces applied through a set of rolls.
- Most rolling is carried out by hot working, called hot rolling, owing to the large amount of deformation required.
- Hot-rolled metal is generally free of residual stresses, and its properties are isotropic.







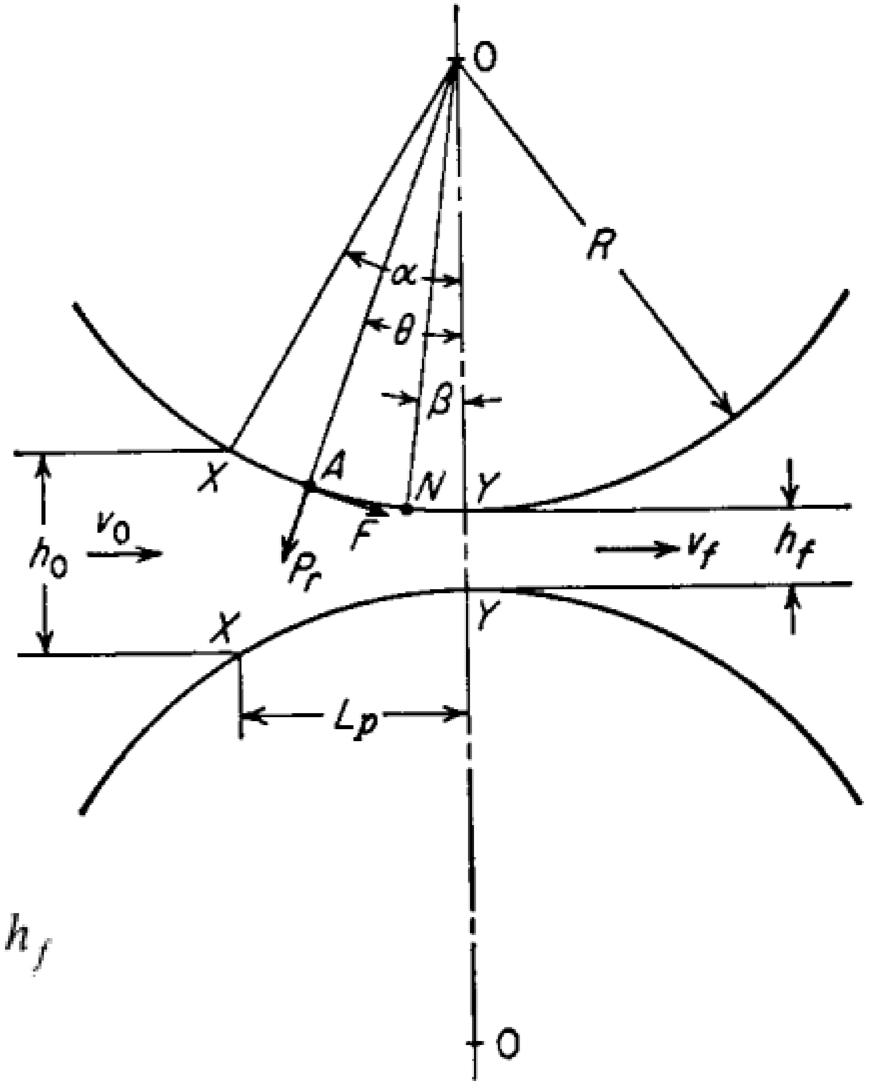
FORCES ACTING DURING ROLLING

- A metal sheet with thickness h_0 enters the rolls at the entrance plane XX with a velocity v_0. It passes through the roll gap and leaves the exit plane YY with a reduced thickness hf.

- Vertical compression of the metal is translated into an elongation in the rolling direction. Since equal volumes of metal must pass a given point per unit time, we can write

$$bh_0v_0 = bhv = bh_fv_f$$

where b = width of sheet
v = its velocity at any thickness h intermediate between h_0 and h_f



FORCES ACTING DURING ROLLING

- Speed of metal at entry is less than roller surface speed

- Speed of metal at exit is more than roller surface speed

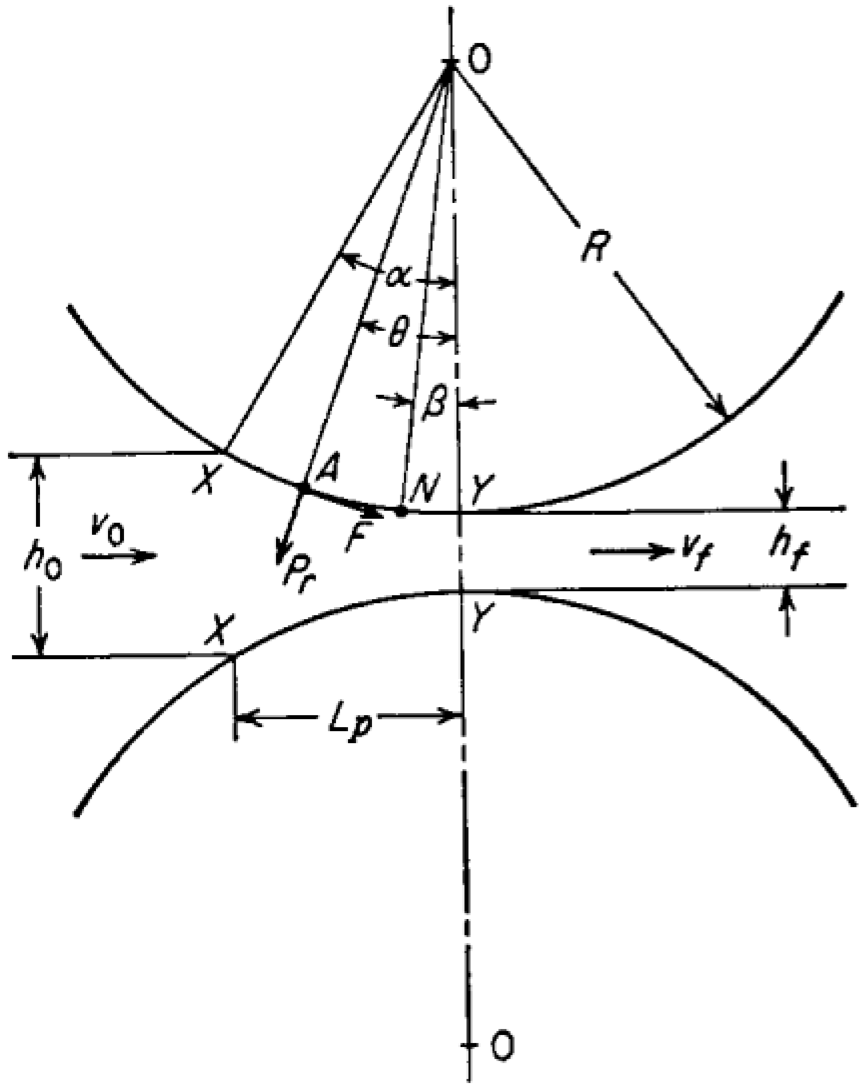
- *Neutral point* is speed of metal equal to rollers surface speed.

FORCES ACTING DURING ROLLING

- At any point along the surface of contact, such as point A, two forces act on the metal. These are a radial force Pr and a tangential frictional force F.

- The vertical component of Pr is called the rolling load P. It is the force with which the rolls press against the metal.

- The specific roll pressure p is the rolling load divided by the contact area.



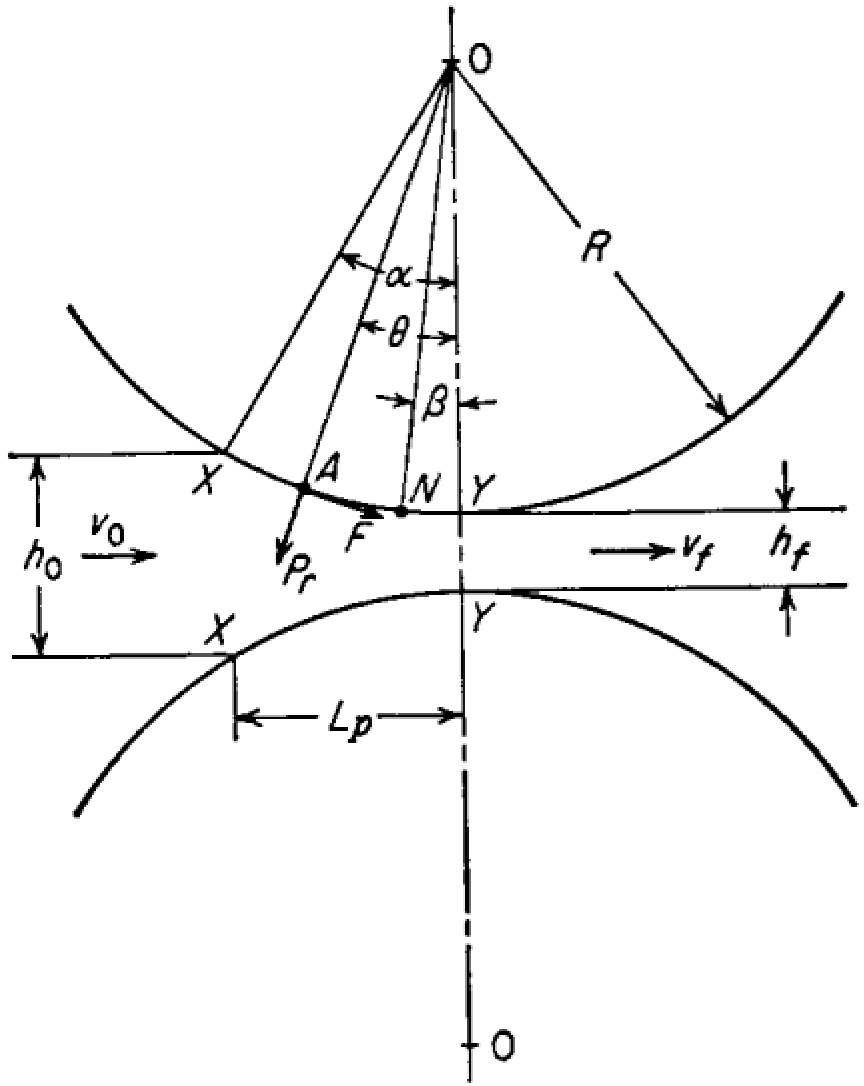
FORCES ACTING DURING ROLLING

- The contact area between the metal and the rolls is equal to the product of the width of the sheet b and the projected length of the arc of contact Lp.

- The angle α between the entrance plane and the centerline of the rolls is called the angle of contact or angle of bite. It can be shown that,

$$\mu = \tan \alpha$$

- The workpiece can be drawn into rolls if the tangent of the contact angle exceed the coefficient of friction.



FORCES ACTING DURING ROLLING

- Referring to the figure, we can write,

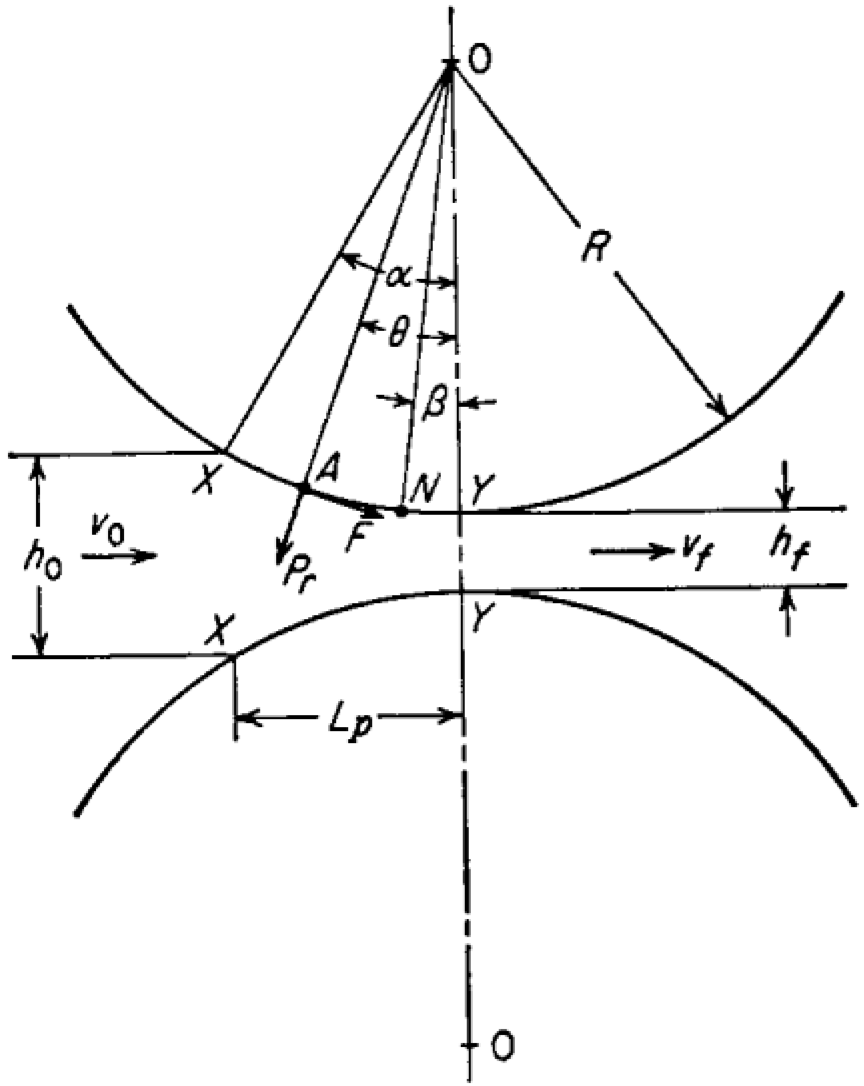
$$L_p \approx \sqrt{R\Delta h}$$

where Δh = the "draft" taken in rolling

$$\tan\alpha = \frac{L_p}{R - \Delta h/2} \approx \frac{\sqrt{R\Delta h}}{R - \Delta h/2} \approx \sqrt{\frac{\Delta h}{R}}$$

From Eq. (17-4), $\mu \geq \tan\alpha = \sqrt{\Delta h/R}$

or $$(\Delta h)_{max} = \mu^2 R$$



FORCES ACTING DURING ROLLING

Example Determine the maximum possible reduction for cold-rolling a 300 mm-thick slab when $\mu = 0.08$ and the roll diameter is 600 mm. What is the maximum reduction on the same mill for hot rolling when $\mu = 0.5$?

FORCES ACTING DURING ROLLING

$$\tan \theta_{max} = \mu \qquad \alpha = \theta_{max} = \tan^{-1}(0.08) = 4.6^\circ$$

From Fig. 17-5 $\sin \alpha = L_p/R = \sqrt{R\Delta h}/R$, $\Delta h = 1.91$ mm. Note that the same result would be obtained from Eq. (17-5).

$$(\Delta h)_{max} = \mu^2 R = (0.08)^2(300) = 1.92 \text{ mm}$$

For hot rolling

$$(\Delta h)_{max} = (0.5)^2(300) = 75 \text{ mm}$$

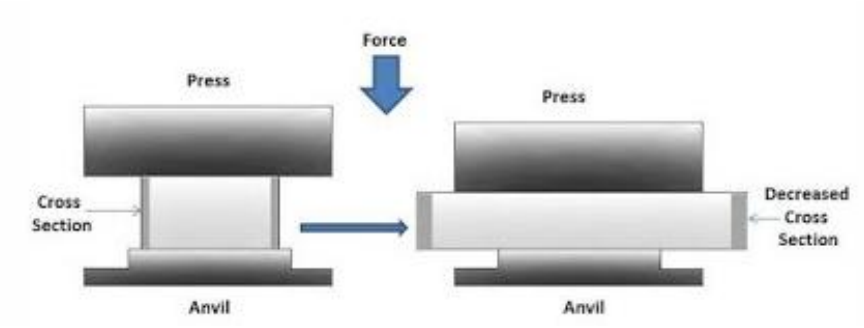
FORGING

- Forging is the operation where the metal is heated and then a force is applied to manipulate the metal in such a way that the required final shape is obtained.

- Two types of operations are used in forging in order to arrive at the final object configuration. They are

Drawing Out

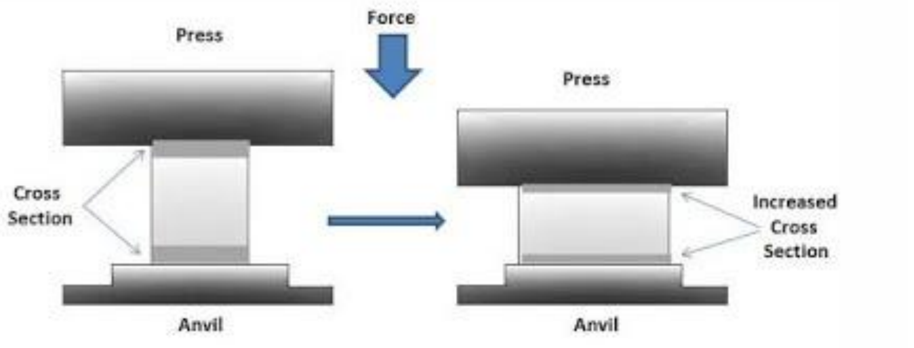
- This is the operation in which the metal gets elongated with a reduction in the cross-sectional area.
- For this purpose, the force is to be applied in a direction, perpendicular to the length axis.



FORGING

Upsetting

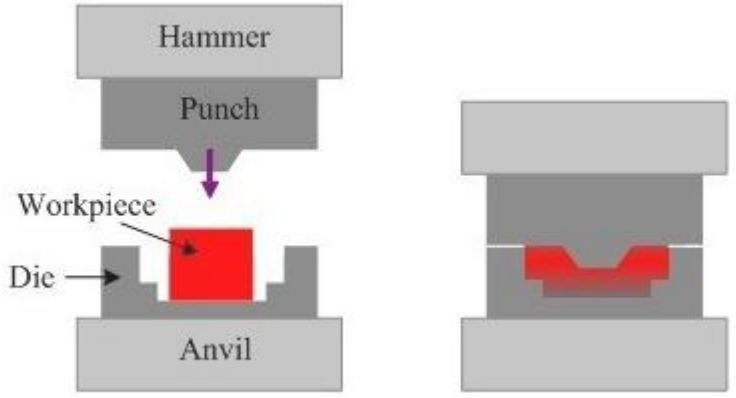
- This is applied to increase the cross-sectional area of the stock at the expense of its length.
- To achieve the upsetting, force is applied in a direction parallel to the length axis.



Forging Types

Smith Forging - This is the traditional forging operation done openly or in open dies by the village blacksmith or modern shop floor by manual hammering or by power hammers.

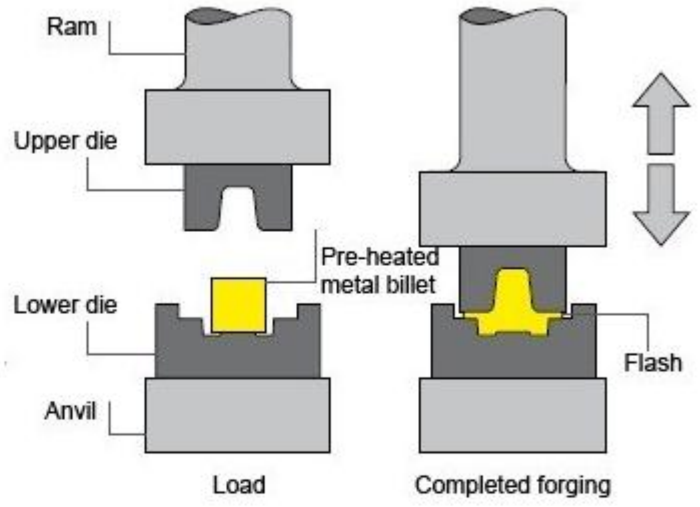
Drop Forging - This is the operation done in closed impression dies by means of the drop hammers. Here the force for shaping the component is applied in a series of blows.



FORGING

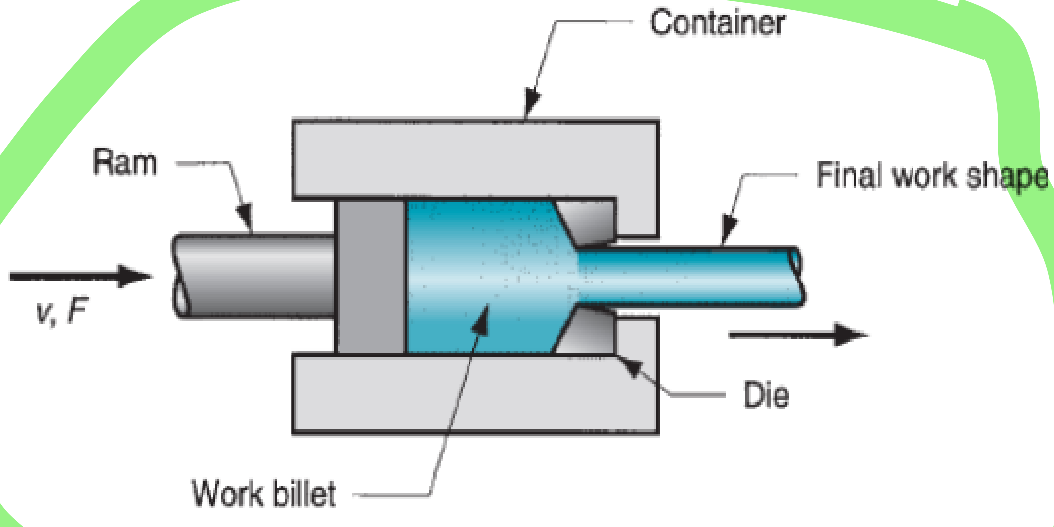
Press Forging - Similar to drop forging, the press forging is also done in closed-impression dies with the exception that the force is a continuous squeezing type applied by the hydraulic presses.

Machine Forging - the process of forging in a forging machine where the metal is moved into the die impression by pressure applied in a horizontal direction by the moving die in the ram.

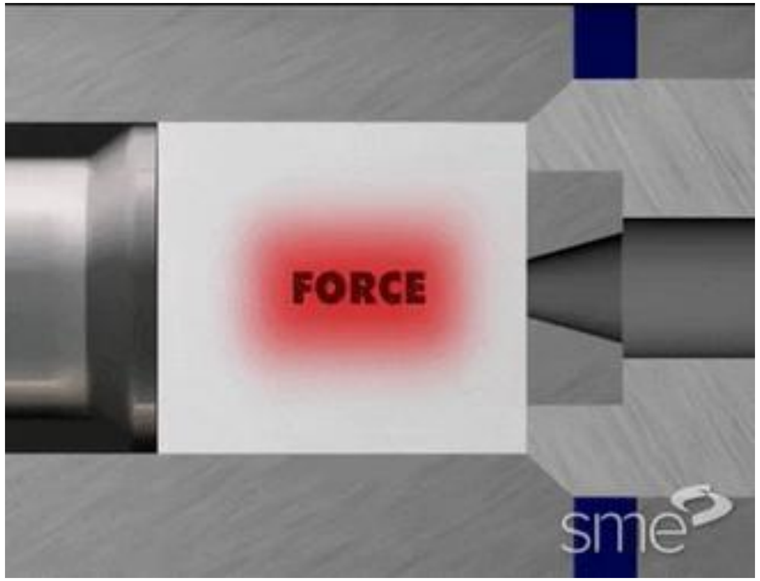


Extrusion

- Extrusion is the process of confining the metal in a closed cavity and then allowing it to flow from only one opening so that the metal will take the shape of the opening.
- This process has ability to create very complex cross-sections,
- The equipment consists of a cylinder or container, Ram or plunger and heated metal billet.



Extrusion process (direct extrusion)



FORWARD EXTRUSION

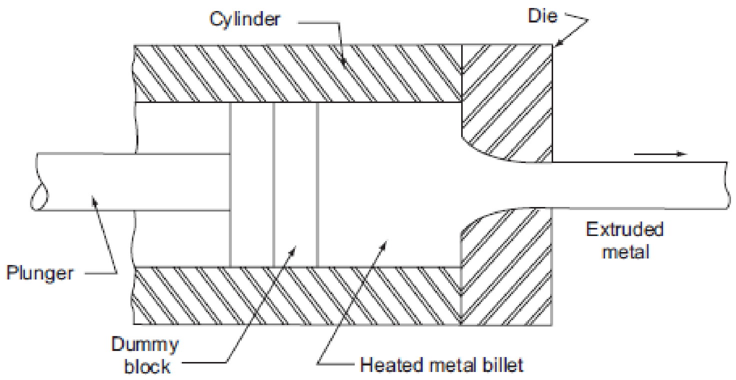
- The process represented in Fig. is called the forward extrusion, signifying the flow of metal in the forward direction, i.e. the same as that of the ram.

- In forward extrusion, the problem of friction is prevalent because of the relative motion between the heated metal billet and the cylinder walls.

- This is particularly severe in the case of steels because of their higher extrusion temperatures.

- To reduce this friction, lubricants are to be used.

- To reduce the damage to equipment, extrusion is finished quickly and the cylinder is cooled before further extrusion.



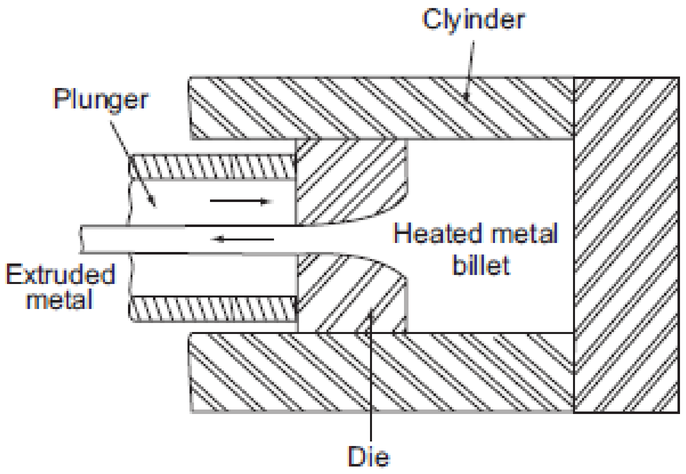
BACKWARD EXTRUSION

- In order to completely overcome the friction, the backward extrusion, as shown in Fig. is used.
- It is termed backward because of the opposite direction of the flow of metal to that of ram movement.

- The ram which houses the die, also compresses the metal against the container, forcing it to flow backwards through the die in the hollow plunger or ram.

- Thus, the billet in the container remains stationary and hence no friction.

- Though advantageous, this process is not extensively used because of the problem of handling extruding metal coming out through the moving ram.



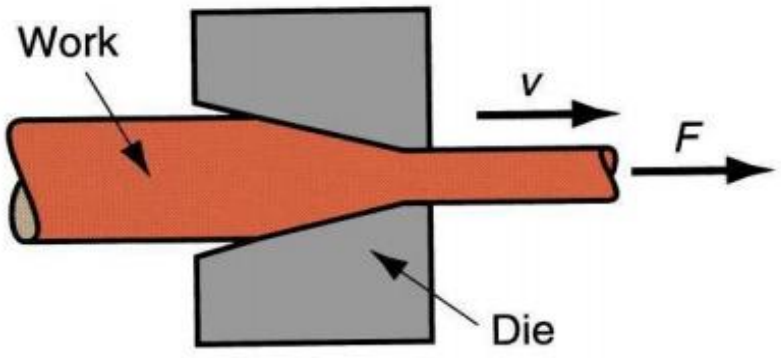
WIRE DRAWING

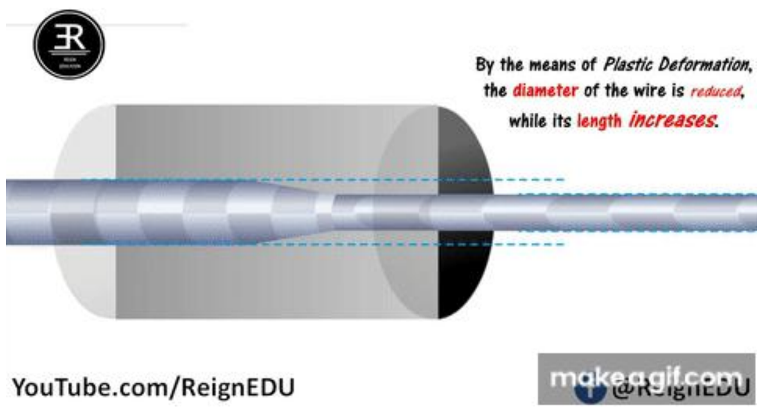
- A wire by definition, is circular with small diameters so that it is flexible. The process of wire drawing is to obtain wires from rods of bigger diameter through a die.

- Wire drawing is always a cold-working process.

- This is done by pulling the metal through a series of drawing dies, which are tools with a specific shape and size that gradually reduce the size of the wire as it passes through them.

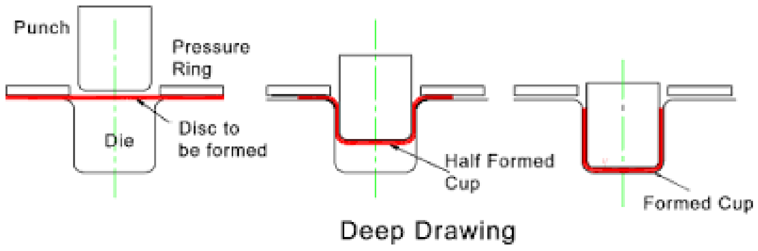
- The process is typically used for producing wires, cables, and rods from metals such as copper, aluminum, steel, or brass.

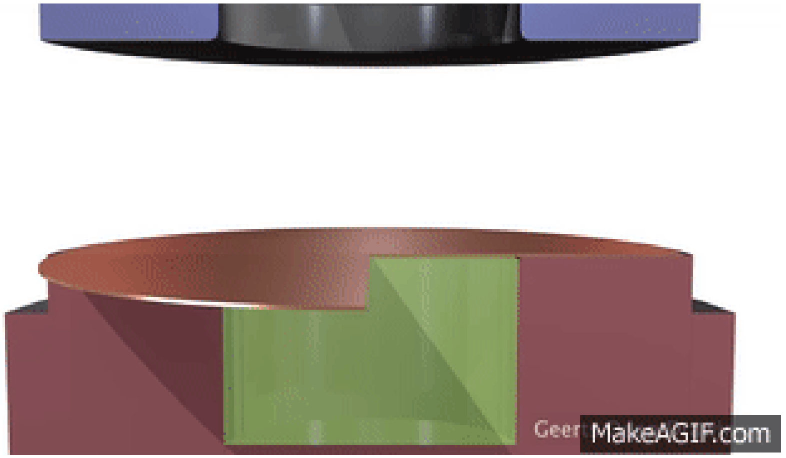




SHEET METAL DRAWING

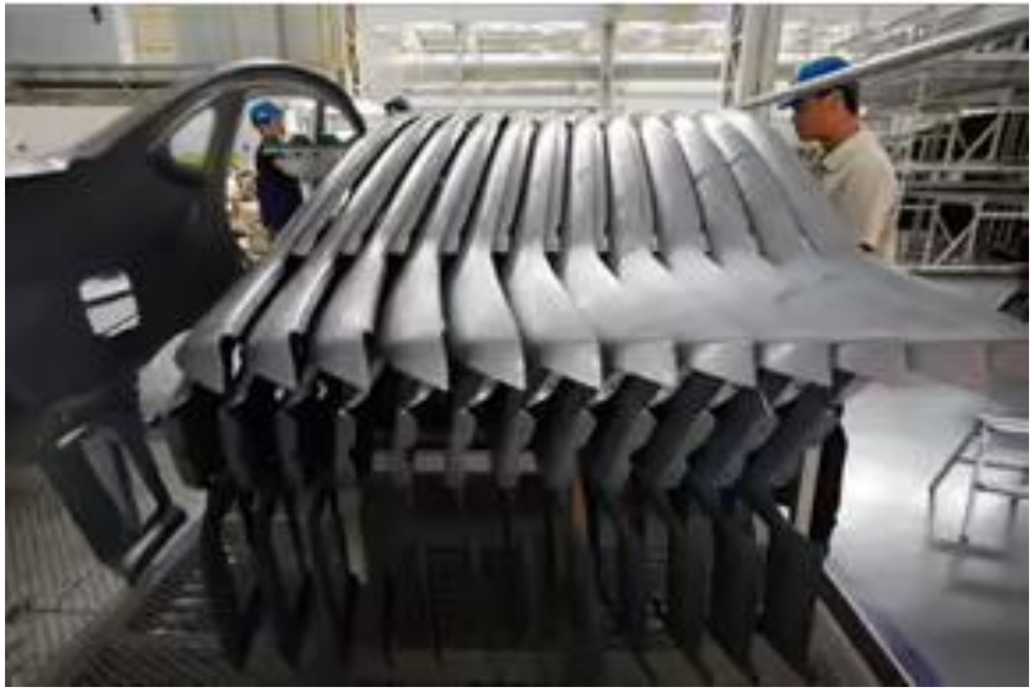
- Sheet metal is generally considered to be a plate with thickness less than about 5 mm.
- Sheet metal operations are mostly cold working operations that manufacture low cost parts with very high volumes and at a fast rate.
- Sheet metal drawing is the process of making cups, shells and similar articles from metal sheet blanks.
- Shallow drawing is defined as where the cup height is less than half the diameter. Otherwise it is referred to as deep drawing.





APPLICATIONS OF METAL FORMING

- **Automotive Manufacturing: Automobile body panels**
- **Aerospace Engineering: Airplane fuselage, wings and engine components**
- **Construction: Pipelines**



Chapter 2: Joining Processes

JOINING PROCESSES

- Joining two or more elements to make a single part.
- A fairly large number of industrial components are made by joining processes.
- Common examples are aircraft and ship bodies, bridges, building trusses, welded machine frames, sheet metal parts, etc.
- The joining process is often, the most economical method and relies on raw material obtained from one of the primary manufacturing processes.
- The various joining processes can be classified as follows:
  - **Mechanical joining by means of bolts, screws and rivets.**
  - **Adhesive bonding by employing synthetic glues such as epoxy resins.**
  - **Welding, brazing and soldering.**

JOINING PROCESSES

Temporary, Semi – Permanent and Permanent joining processes

- Joining obtained by bolts and screws is **temporary** in nature and can be disassembled whenever necessary.
- Rivets are **semi permanent** fastening devices and the joint can be separated only by destroying the rivet without harming the parent elements.
- Welding produces a **permanent** joint as a welded part needs to be broken to dismantle it.

Welding

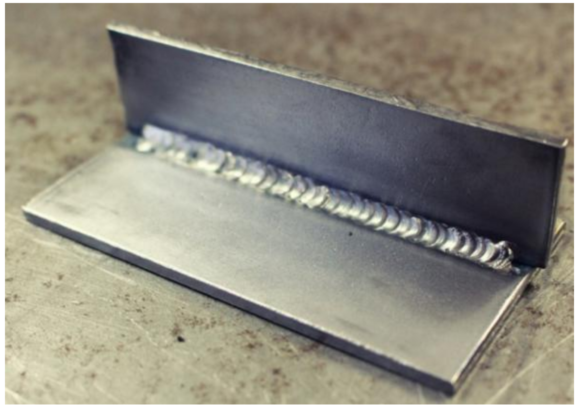
- Welding is a metallurgical joint of two metals pieces together to produce essentially a single piece of metal.

➢ Based on the use of pressure, welding can be mainly classified as

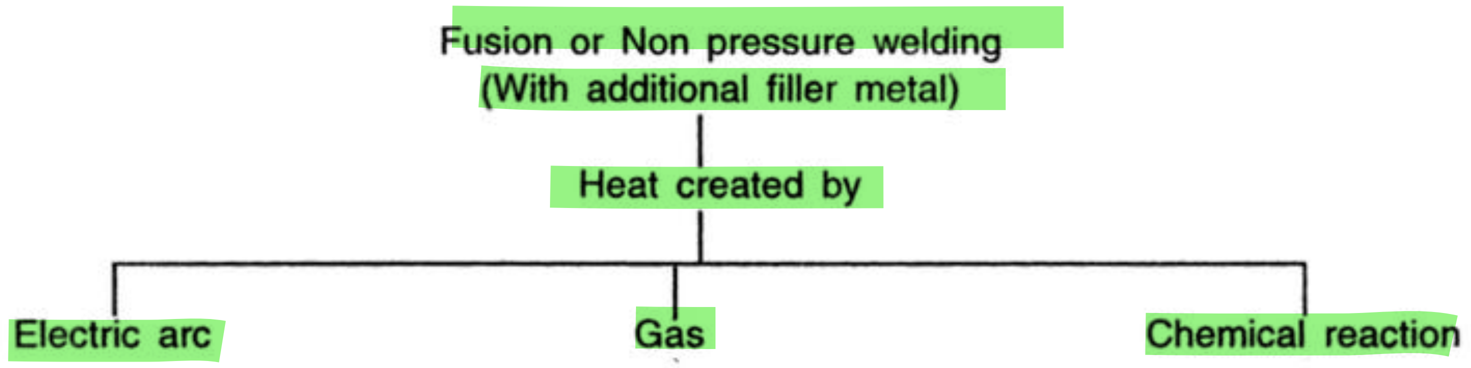
soft and pliable, but not fully melted

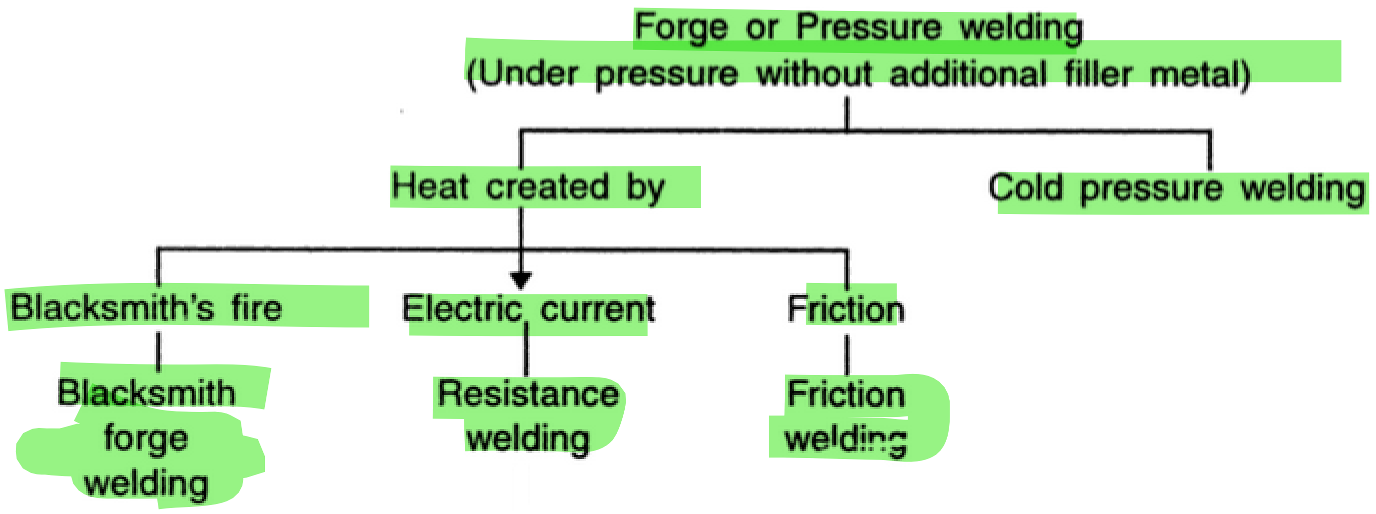
➢ **Plastic Welding** – Here parts being joined are heated to their plastic states and then joined together by applying external pressure.

➢ **Fusion Welding** - Here, the interface of the two parts to be joined is brought to a temperature above the melting point and then allowed to solidify so that joining takes place.



WELDING

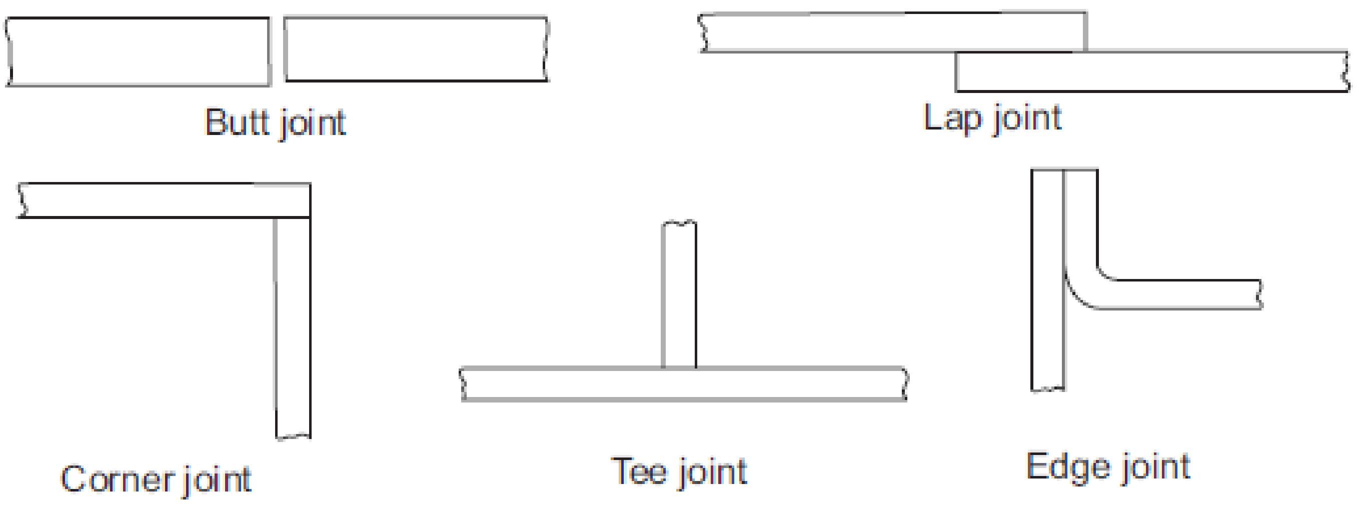

Fusion or Non pressure welding
(With additional filler metal)
Heat created by
Electric arc
Gas
Chemical reaction


Forge or Pressure welding
(Under pressure without additional filler metal)
Heat created by
Cold pressure welding
Blacksmith's fire
Electric current
Friction
Blacksmith forge welding
Resistance welding
Friction welding

GENERAL CONSIDERATIONS

Types of Joints

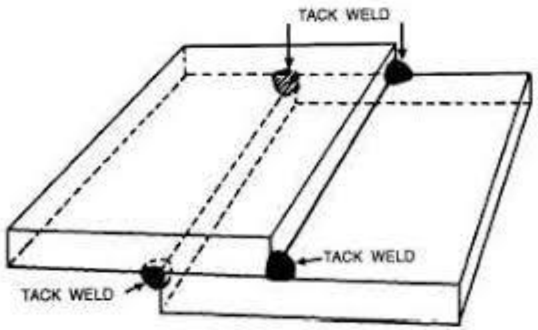
- Different types of welding joints are classified as **butt, lap, corner, tee and edge** joints. The choice of the type of joint depends on the weldment being made and the sheet thickness.

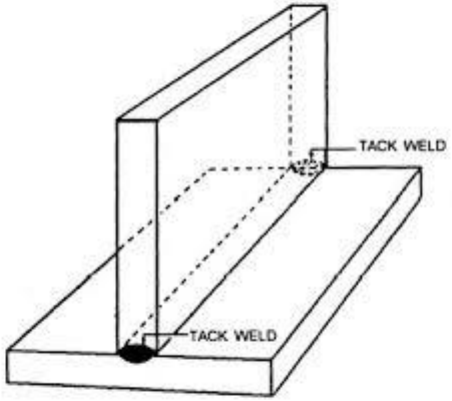


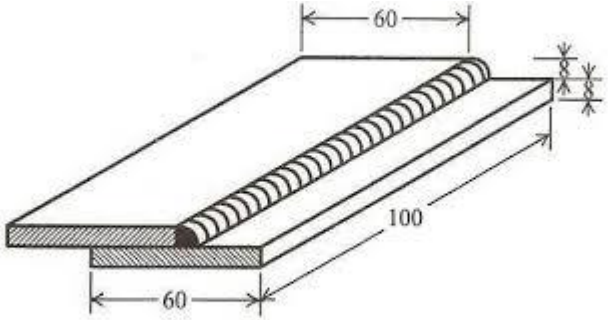
Fusion welding : Electric Arc welding

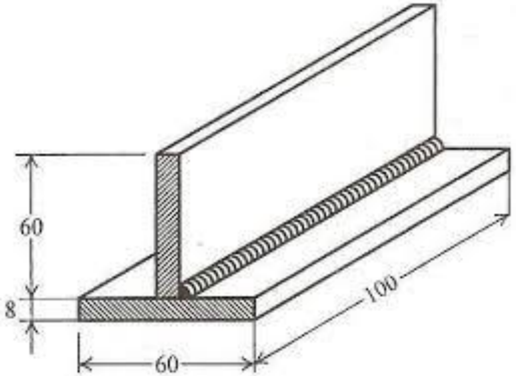
Steps involved in welding

- Step 1: Cleaning
- Step 2: Edge Preparation
- Step 3: Check for safety devices
- Step 4: Initial tack weld
- Step 5: Final welding
- Step 6: Excess material removal









ELECTRIC ARC WELDING

- The electric arc welding process makes use of the **heat produced by the electric arc** to fusion weld metallic pieces.

- This is one of the most widely used welding process, mainly because of the ease of use and high production rates that can be achieved economically.

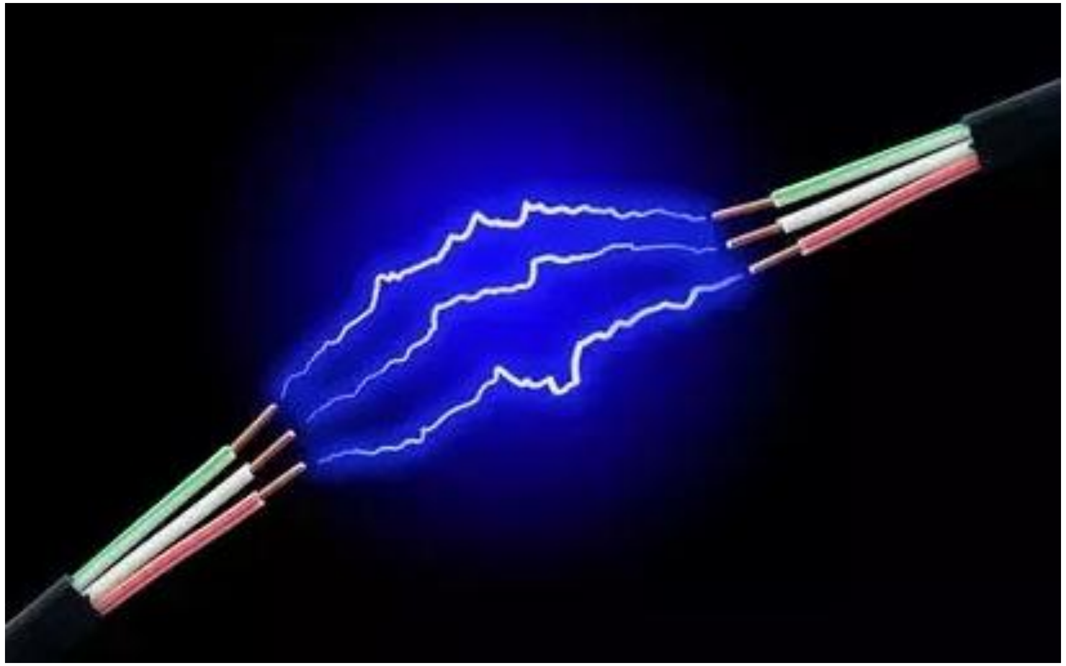
Principle of Arc

- An arc is generated between two conductors of electricity, cathode and anode, when they are touched to establish the flow of current and then separated by a small distance.

- An arc is a sustained electric discharge through the ionised gas column called plasma between the two electrodes.

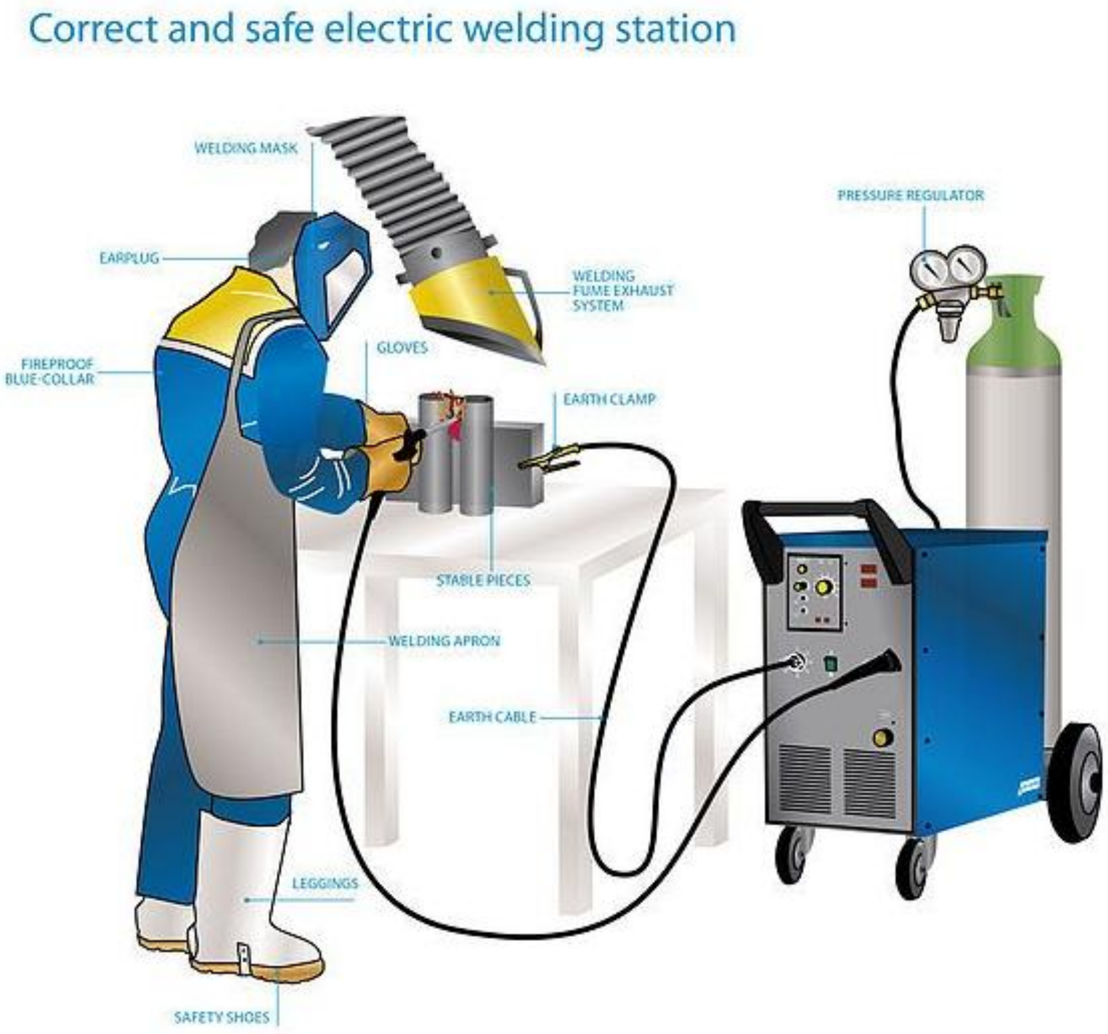
- It is generally believed that electrons liberated from the cathode move towards the anode and are accelerated in their movement. When they strike the anode at high velocity, large amount of heat is generated.

- A temperature of the order of 6000°C is generated at the anode.



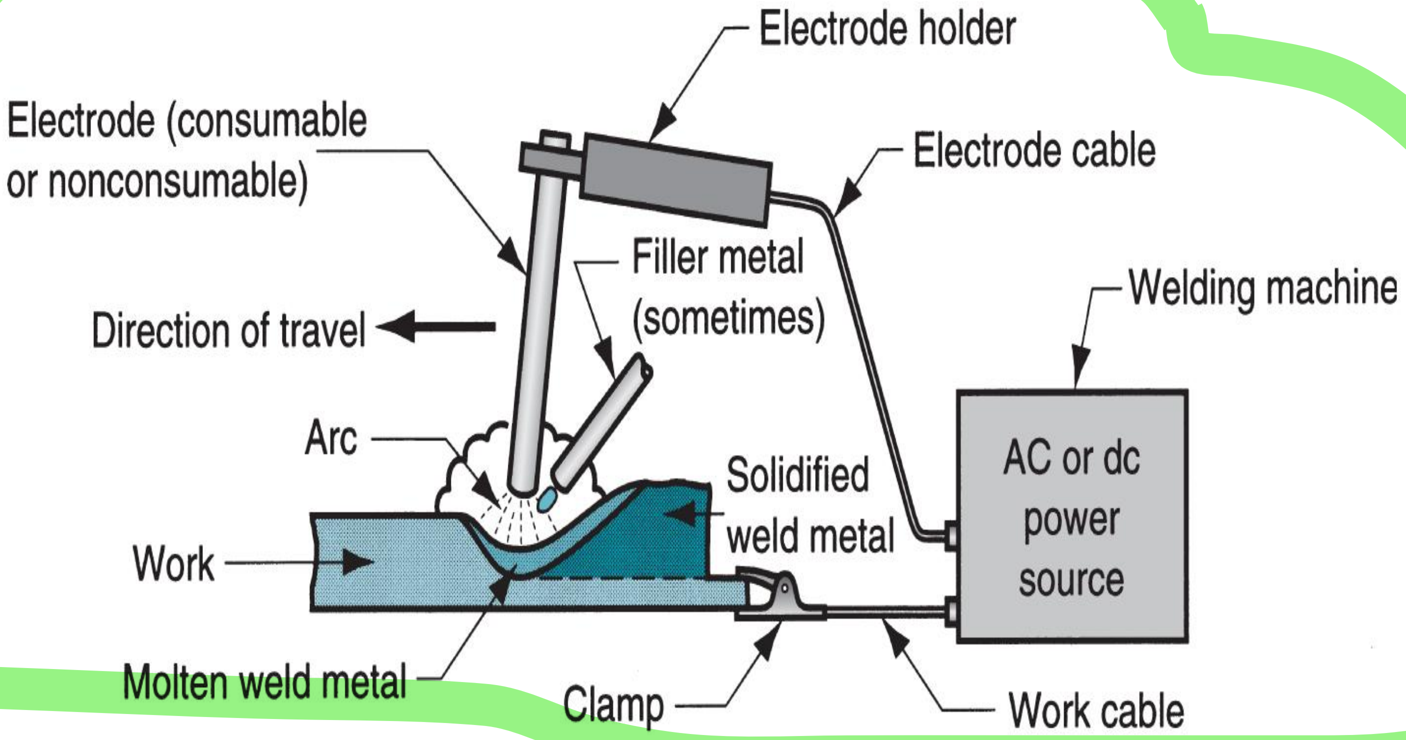
Arc welding equipment and accessories

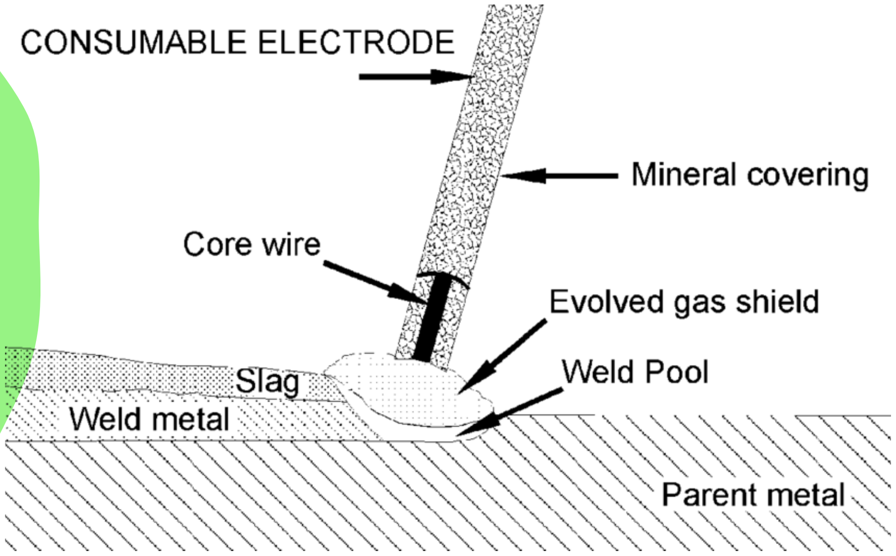
- AC or DC machine
- Electrode and electrode holder
- Chipping hammer
- Earthing clamps
- Wire brush
- Helmet
- Safety goggles, Hand gloves, etc.



Arc welding (Metal arc)

- Arc welding → fusion welding process → ends of the metal pieces joined by electric arc. Used for welding steel, Cu, Cu alloys, etc.



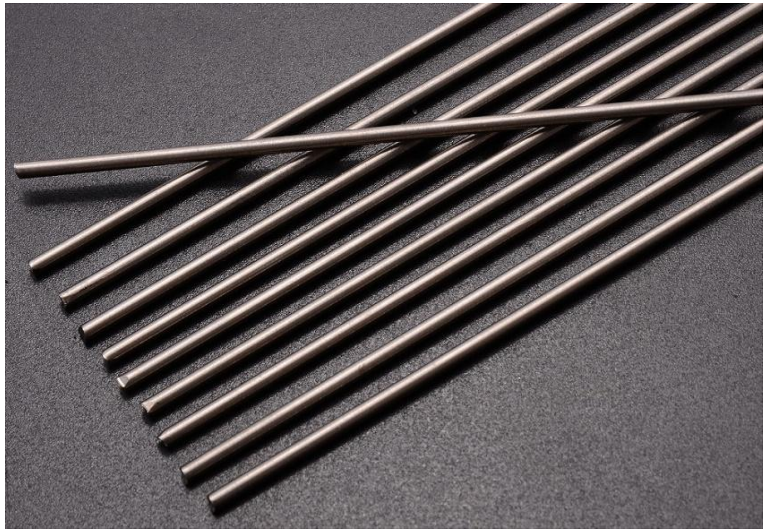


Electrodes used for arc welding

Non-consumable electrodes

- Does not consume during welding process
- **Non-consumable electrodes** made of carbon, graphite or tungsten. The carbon and graphite electrodes are used only in DC welding, whereas tungsten electrodes are used for both AC and DC welding.

Consumable electrodes



- Consume during welding process
- Both rod and wire forms, electrode is consumed by the arc and added to weld joint as filler metal.
- Made of mild steel, Al, lead-bronze, phosphor-bronze, etc.

Types → (1) Bare or non-coated electrodes

(2) Coated electrodes

Functions of coated electrodes.

- Protect molten metal from oxidation by producing gas shield around the arc and weld pool
- Provide the formation of slag
- Controls the weld bead
- Stabilize the arc

Fluxes

Fluxes are added/coated over the surfaces of parent metal → protect the weld metal from oxidation

Flux applied in the form of paste/powder/liquid/gas

Typical fluxes

- SiO_2, TiO_2, FeO, MgO, Al_2O_3, quartz sand, calcium oxide, calcium fluoride, calcined borax, borax, lithium etc
- Produces a gaseous shield to prevent contamination.

GAS WELDING

- As the name implies, gas welding also called as oxy-fuel gas welding (OFW), derives the heat from the **combustion of a fuel gas** such as acetylene in combination with oxygen.

- The process is a fusion welding process wherein the joint is completely melted to obtain the fusion. The heat produced by the combustion of gas is sufficient to melt any metal and as such is universally applicable.

- The fuel gas generally used is acetylene because of the high temperature generated in the flame. This process is called **oxy-acetylene welding** (OAW).

Advantages of Arc Welding

- The electric arc welding is the suitable welding process for high speed welds.
- Apparatus required for arc welding is very simple and portable.
- The electric arc welding gives superior temperature at the point of welding.
- Electric arc welding can work on both AC and DC supply.
- It is inexpensive to install.

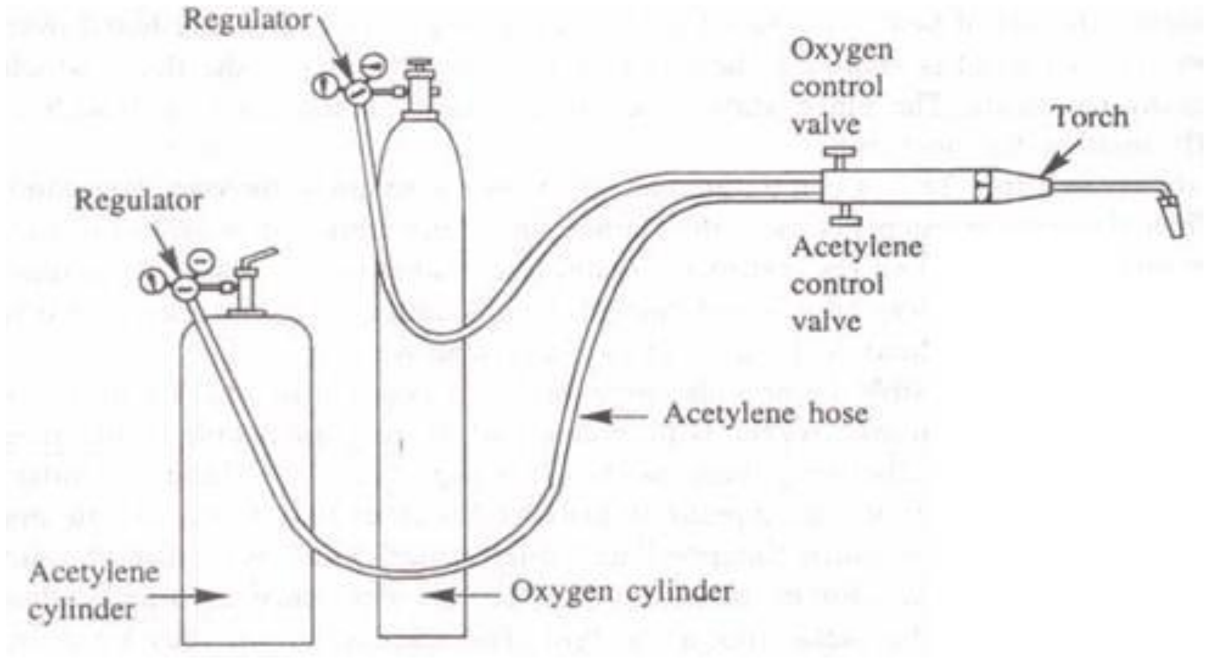
Disadvantages of Electric Arc Welding

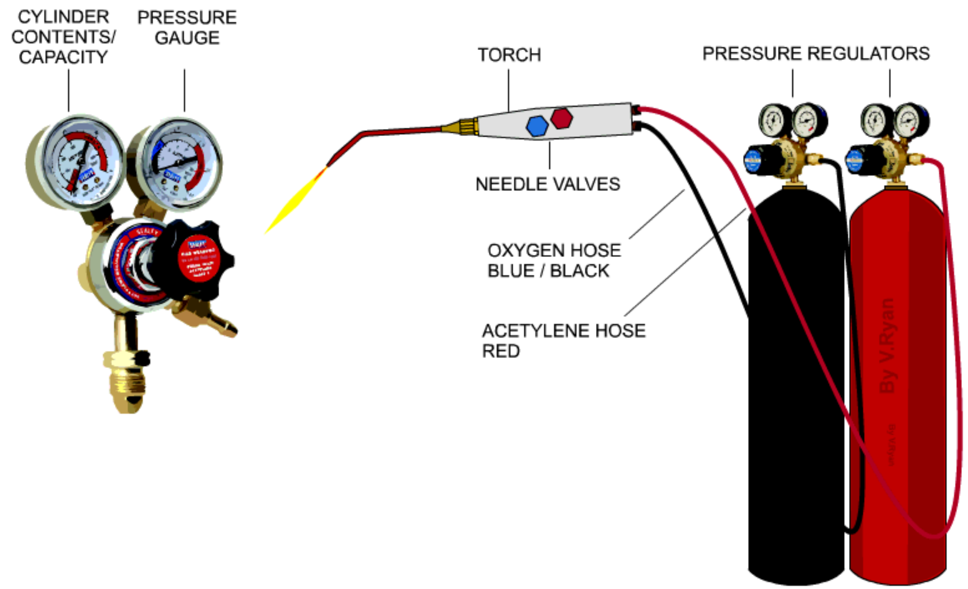
- The welding process with electric arc welding requires skilled operators.
- Electric arc welding cannot be used for welding of reactive metals such as aluminium, titanium, etc.
- Electric arc welding is not suitable for welding thin metals.

Gas Welding

Gas welding is a fusion welding method of welding, in which a strong gas flame is used to rise the temperature (3200 ˚C) of the work pieces so as to melt them

Gas Welding Setup (Oxyacetylene Gas Welding)





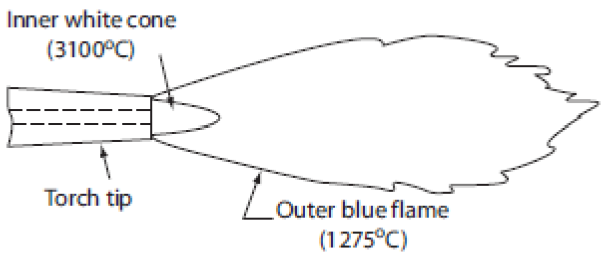
GAS WELDING

- In all the oxy-fuel gas welding processes, the combustion takes place in two stages.
- The first reaction takes place when the fuel gas such as acetylene and oxygen mixture burn releasing intense heat. This is present as a small white cone.
- For the oxy-acetylene welding, the following reaction takes place in this zone.

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + 448 \text{ kJ/mol } (18.75 \text{ MJ/m}^3 \text{ of acetylene})$$

- The carbon monoxide (CO) and hydrogen produced in the first stage further combine with the atmospheric oxygen and give rise to the outer bluish flame, with the following reaction.

$$4CO + 2H_2 + 3O_2 \rightarrow 4CO_2 + 2H_2O + 812 \text{ kJ/mol } (35.77 \text{ MJ/m}^3)$$



Gas Welding Flames

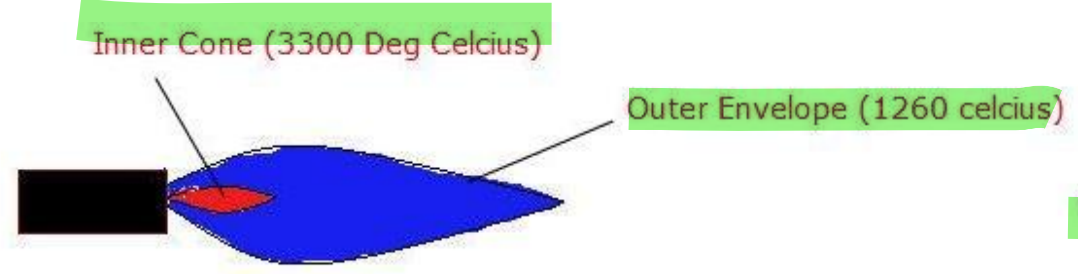
For complete combustion of acetylene, 2.5 volume of oxygen are required for 1 volume of acetylene.

Oxygen to acetylene ratio varies from 0.95 to 1.5.

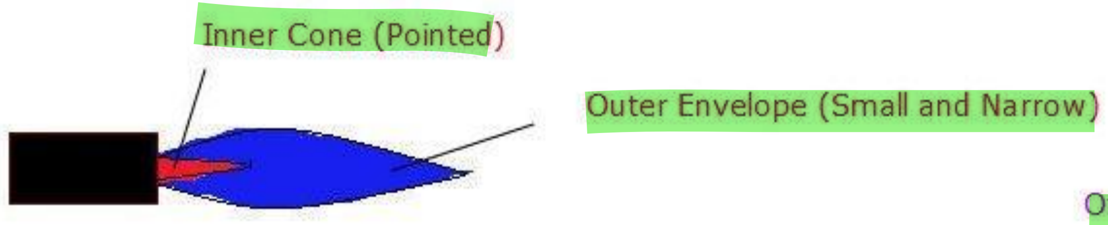
Depending on oxygen to acetylene gas ratio, it can be classified as

- Neutral Flame (0.95)
- Carburizing or reducing flames (0.95 to 1)
- Oxidizing Flame (1.15 to 1.5)

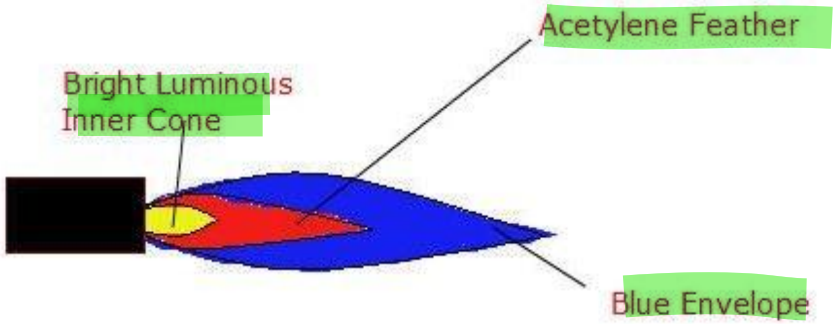
Gas Welding Flames



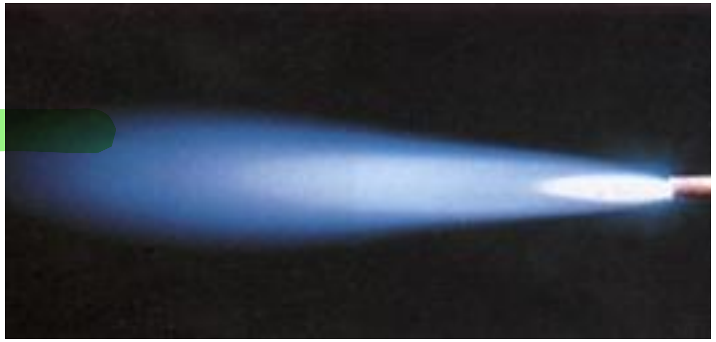
Neutral Flame



Oxidizing Flame



Carburizing or Reducing Flame



Advantages

- Process is simple and inexpensive
- Eliminates a skilled operator
- Temperature of the flame can be controlled depending on the thickness and type of material being welded

Disadvantages

- Acetylene gas is slightly costlier
- Not suitable for thick and high melting point metals
- Refractory metals like tungsten, molybdenum etc., and reactive metals like zirconium, titanium etc., cannot be gas welded.
- Acetylene gas is highly explosive. Hence precautions should be taken during its storage and welding.

RESISTANCE WELDING

- Resistance welding process is a welding process where both heat and pressure are applied on the joint but no filler metal or flux is added.

- The heat necessary is obtained by the **heating effect of the electrical resistance** of the joint and hence, the name resistance welding.

Principle:

- In resistance welding (RW), a low voltage (typically 1 V) and very high current (typically 15000 A) is passed through the joint for a very short time (typically 0.25 s).

- This high current heats the joint, due to the contact resistance at the joint and melts it.

- The pressure on the joint is continuously maintained and the metal fuses together under this pressure.

RESISTANCE WELDING

- The heat generated in resistance welding can be expressed as

$$H = kI^2Rt$$

- where, H = the total heat generated in the work, J
  I = electric current, A
  t = time for which the electric current is passing through the joint, s
  R = the resistance of the joint, ohms
  and k = a constant to account for the heat losses from the welded joint.

- The amount of heat released is directly proportional to the resistance.

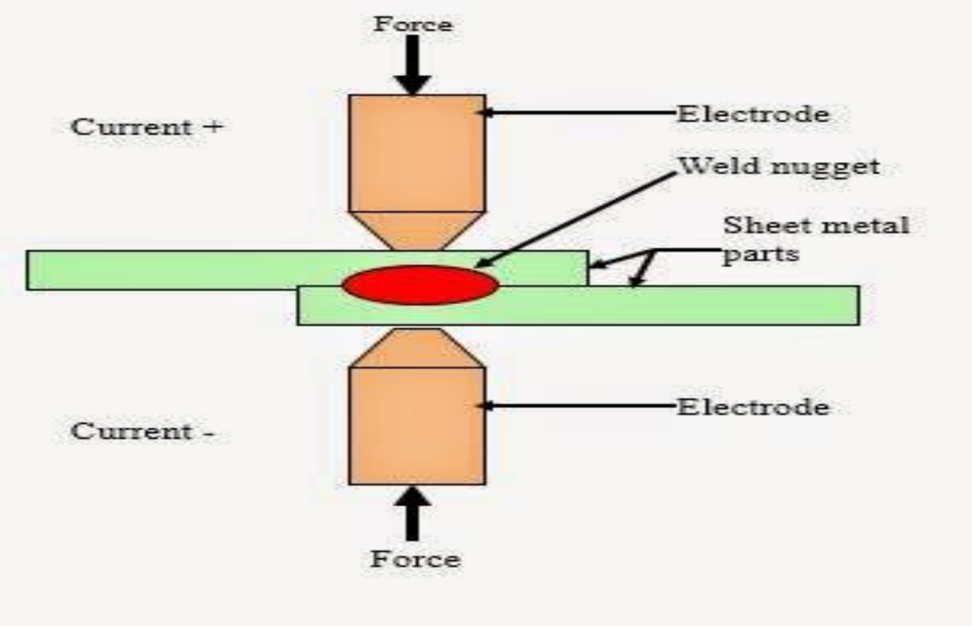
- The only place where large amount of heat is to be generated to have an effective fusion is at the interface between the two work piece plates.

RESISTANCE SPOT WELDING

- This is the most common resistance welding process. This is essentially done to join two sheet metal jobs in lap joint forming a small nugget at the interface of the two plates, as shown in Fig.

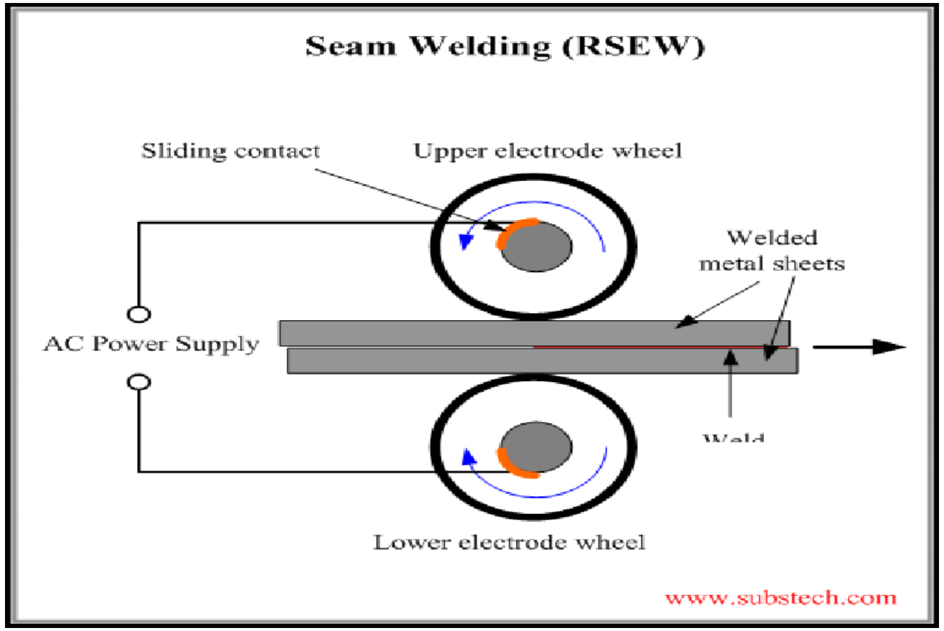
- It essentially consists of two electrodes, out of which one is fixed. The other electrode is fixed to a rocker arm (to provide mechanical advantage) for transmitting the mechanical force from a pneumatic cylinder. This is the simplest type of arrangement.

- The other possibility is that of a pneumatic or hydraulic cylinder being directly connected to the electrode without any rocker arm.



RESISTANCE SEAM WELDING

- The resistance seam welding (RSEW) is a specialised process of spot welding. Here the cylindrical electrodes are replaced by disc electrodes.
- The disc electrodes are continuously rotated so that the work pieces get advanced underneath them while at the same time the pressure on the joint is maintained.
- The electrodes need not be separated at any time



Numerical on Resistance Welding

Two steel sheets of 1.0 mm thick are resistance welded in a lap joint with a current of 10,000 A for 0.1 second. The effective resistance of the joint can be taken as 100 micro ohms. The joint can be considered as a cylinder of 5 mm diameter and 1.5 mm height. Density of steel is 0.00786 g/mm3 and heat required for melting steel be taken as 10 J/mm3. Calculate the melting efficiency.

Numerical on Resistance Welding

$$\text{Heat supplied} = 10\,000^2 \times 100 \times 10^{-6} \times 0.1\,1 = 1000 \text{ J}$$

$$\text{Volume of the joint} = \frac{\pi \times 5^2 \times 1.5}{4} = 29.452 \text{ mm}^3$$

$$\text{Heat required for melting} = 29.452 \times 10 = 294.52 \text{ J} \approx 295 \text{ J}$$

$$\text{Heat lost to surroundings} = 1000 - 295 = 705 \text{ J} = 70.5\%$$

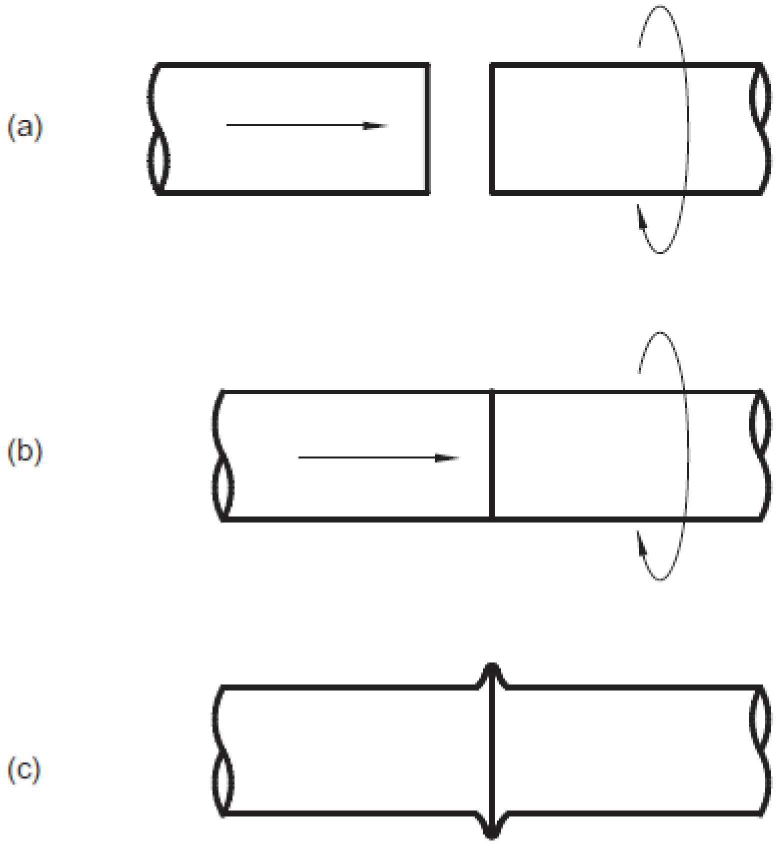
FRICTION WELDING

- The heat required for welding in this process is obtained by the **friction between the ends of the two parts** to be joined.

- One of the parts to be joined is rotated at a high speed around 3000 revolutions per minute, and the other part is axially aligned with the second one and pressed tightly against it, as shown.

- The friction between the two parts raises the temperature of both the ends.

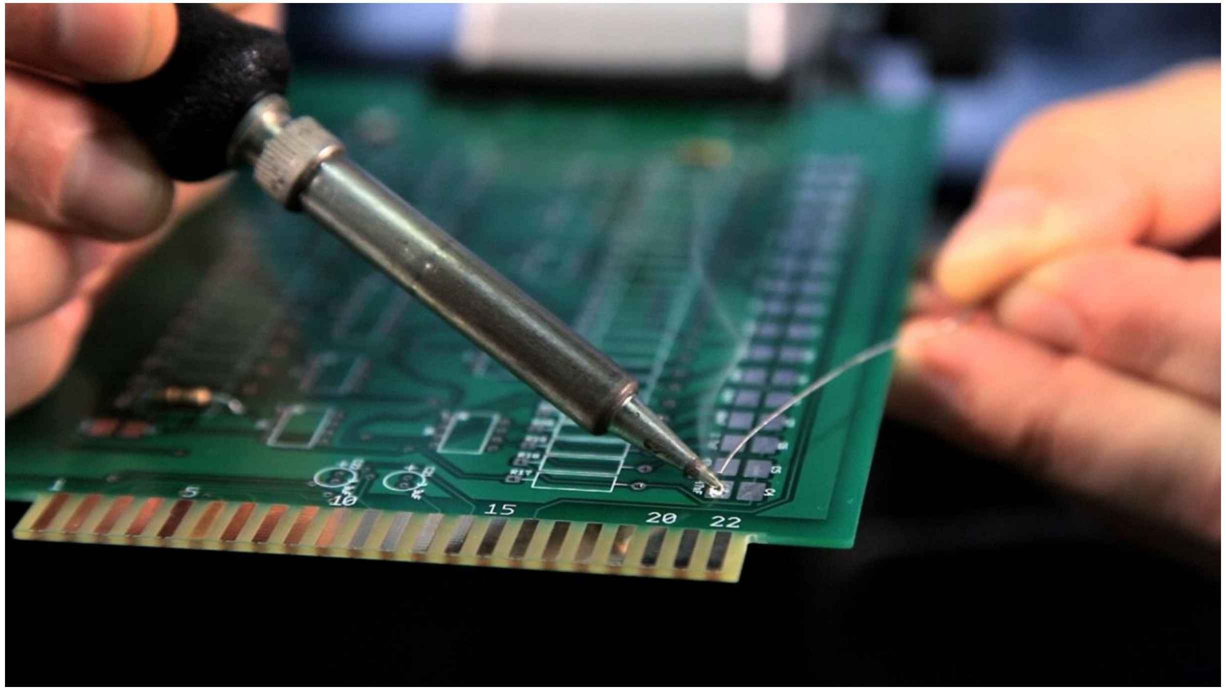
- Then the rotation of the part is stopped abruptly and the pressure on the fixed part is increased so that the joining takes place. This process is termed **Friction Welding (FRW).**



SOLDERING

- Soldering is a method of joining similar or dissimilar metals by the application of heat and using a filler metal or alloy called solder.
- The molten filler metal is made to flow between the two closely placed adjacent surfaces by the capillary action.
- Soldering mainly requires the following-

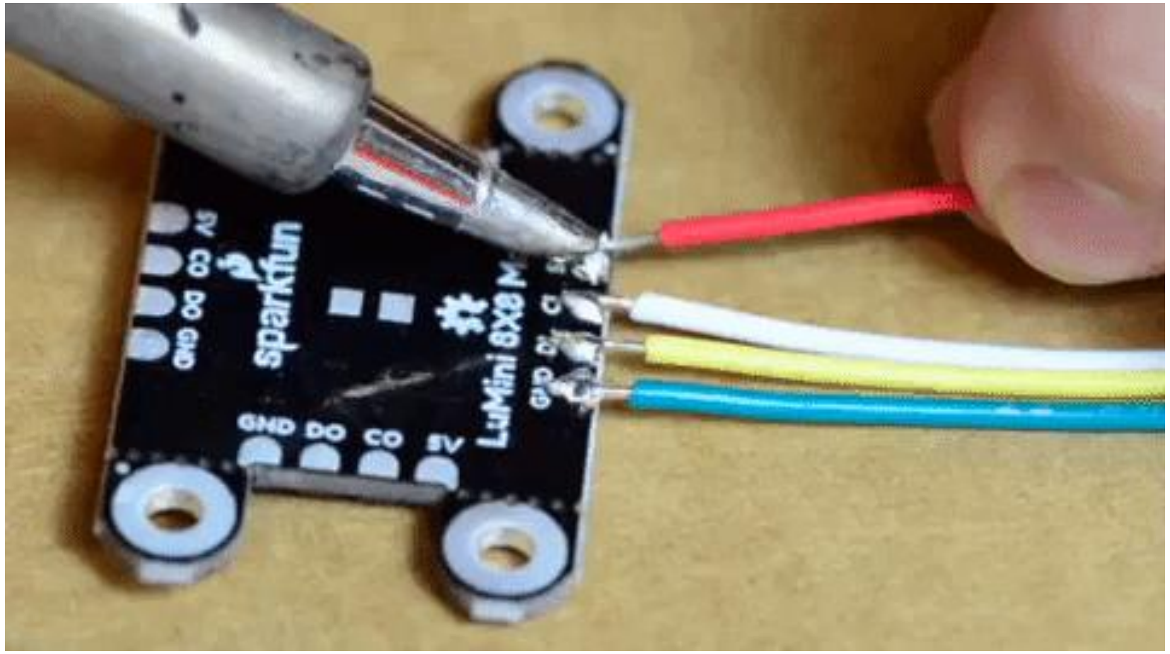
1. Soldering Iron 2. Solder (alloy)
3. Flux



Soldering Process

1.Soldering gun
2.Filler material
3.Flux

Soldering Procedure



Work Preparation

- Work pieces should be perfectly clean.
- There should be no dirt, dust, rust, paint or grease.
- Cleaning can be done with a file or sandpaper.

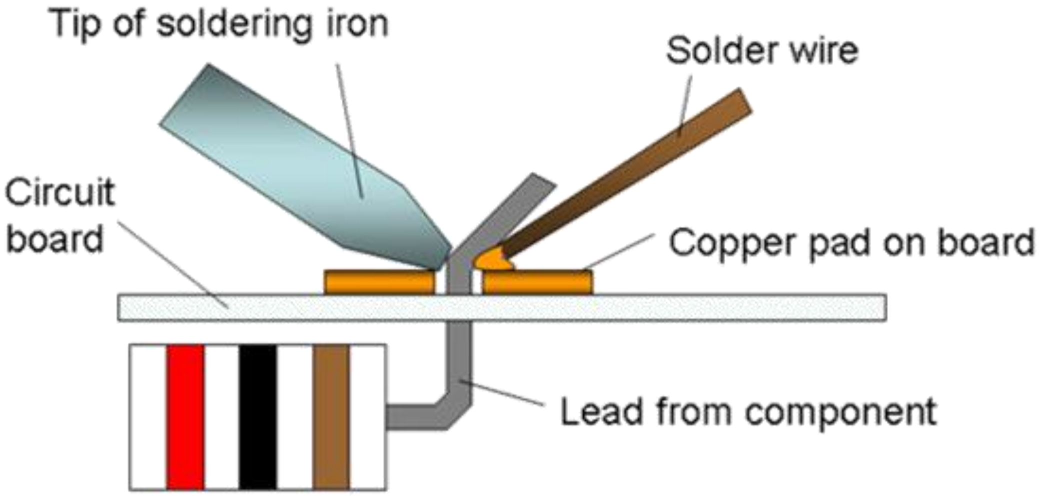
Fluxing

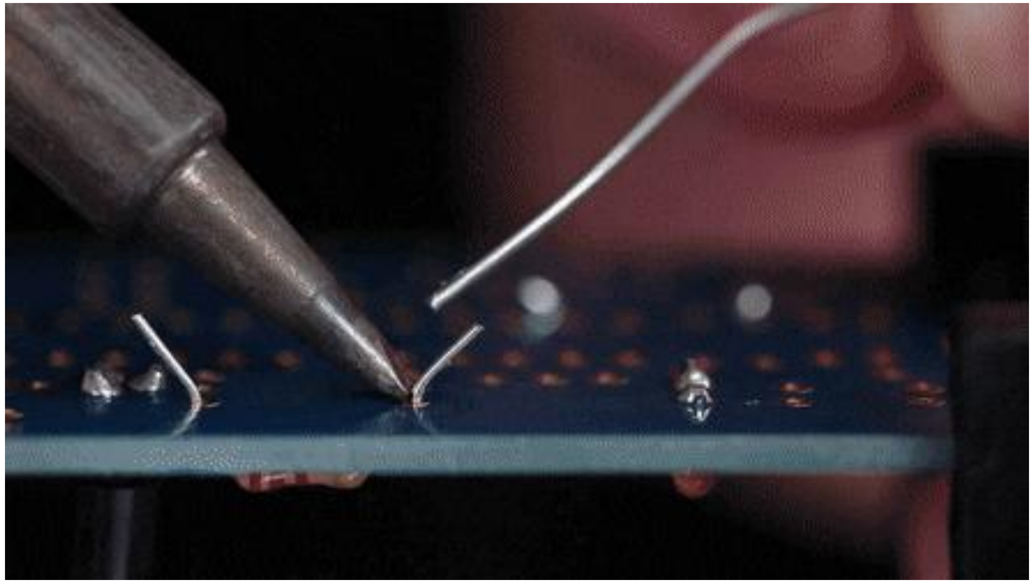
- Flux depends on the material of work piece.
- It is applied with the help of brush.
- It avoids oxidation of molten metal, helps in flow of solder

Soldering Procedure Cont..

Tinning

- Soldering bit is cleaned; application of flux is done over it.
- It is brought in contact of solder wire so the bit carriers sufficient amount of molten solder over it.
- Filling the joint with molten solder and allow to solidify





Classification of Solders

The solders can be classified into

1. **Soft Solders** (Temperature of melting 150 ˚C to 190 ˚C)

Generally composed of lead and tin

ii. **Hard Solders** (Temperature of melting 300 ˚C to 600 ˚C)

Generally composed of Copper and zinc

Fluxes

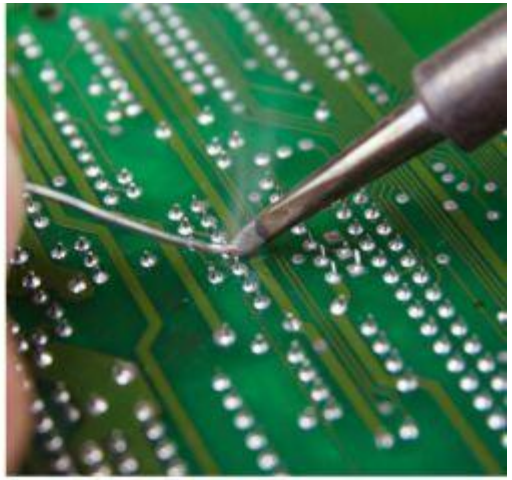
The main function of fluxes are

a. Remove oxide films from base part surfaces

b. Prevent oxidation during heating

c. Promote wetting of the faying surfaces

Faying surfaces are surfaces where parts are joined together with adhesion or welding.



Classification of Fluxes

- Organic Fluxes
- Inorganic Fluxes
- Non Corrosive Fluxes

- Chemically unstable at higher temperature but non corrosive at room temperature: Lactic acid, Benzoic acid, Stearic acid are used as flux
- Inorganic flux consists of mixture of zinc chloride and ammonia chloride
- Rosin fluxes which are non corrosive type fluxes, Rosin is a derivates of pipe trees gum. It is highly electric conductive in nature

Advantages of Soldering

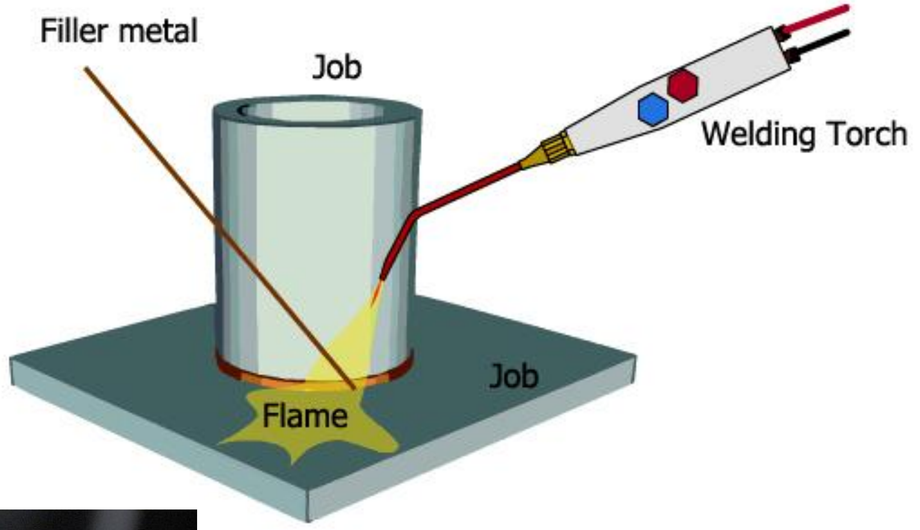
- Low cost and easy to use
- Soldered joints are easy to repair and rework.
- The soldered joint can last for a long time
- Leak proof joints can be produced
- Low energy is required.

Disadvantages of Soldering

- The strength of soldered joints is low.
- Cannot be used for high temperature applications
- Skilled and trained person is required

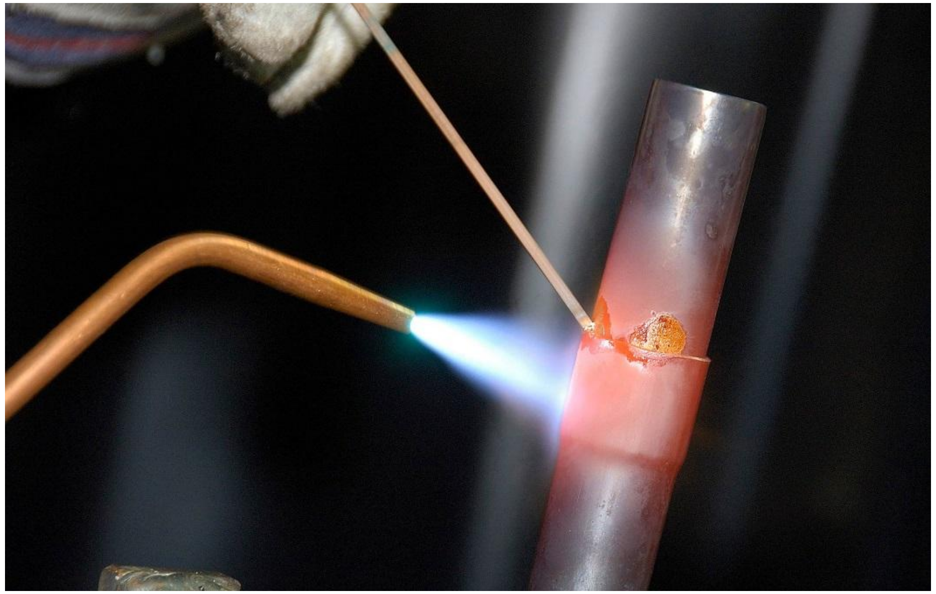
Brazing

Brazing is a joining process in which two similar or dissimilar metals joined by a special filler metal whose melting temperature is above 450 ˚C



Components in brazing

- Filler Metal (spelter)
- Flux
- Brazing Torch



Flux

Borax, boric acid, fluorides or chlorides are commonly used flux

Welding Torch

Oxyacetylene welding torch

Advantages

- Much heat is not involved in the process. Hence low thermal distortions.
- Easily automated process
- Dissimilar parts can be joined

Disadvantages

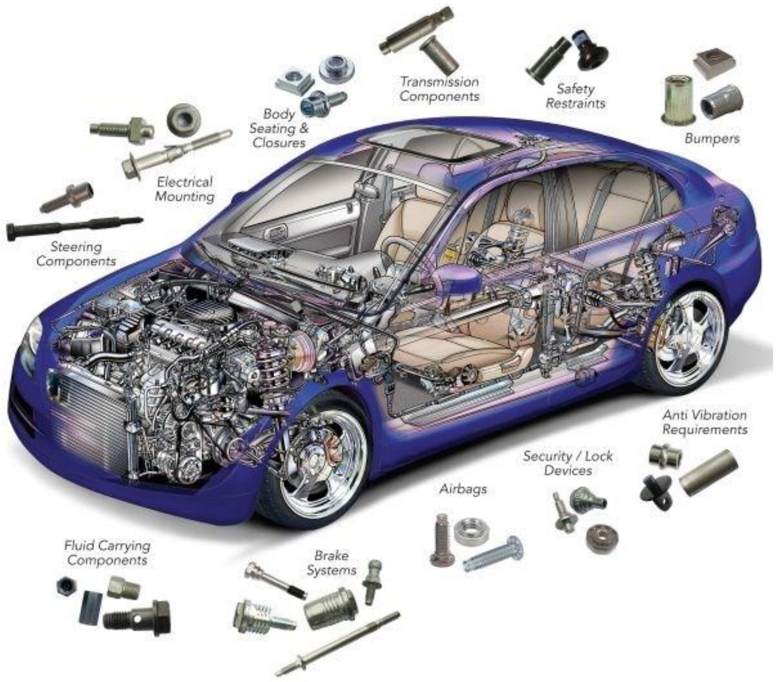
- Flux residual must be removed after brazing, otherwise which may cause corrosion
- Large and thick sections cannot be brazed efficiently
- Relatively expensive filler materials

Comparison between soldering, brazing

Soldering	Brazing
Filler metal is called solder	Filler metal is called spelter
Melting point of filler metal is below 450 ˚C	Melting point of filler metal is above 450 ˚C but below melting point of work piece
Soldered joint strength is low	Brazed joint strength is high
Solder is cheaper process (Economical Process)	Brazing is costlier process
Usually suitable for join metals with small thickness	Suitable process for joining metals for larger thickness

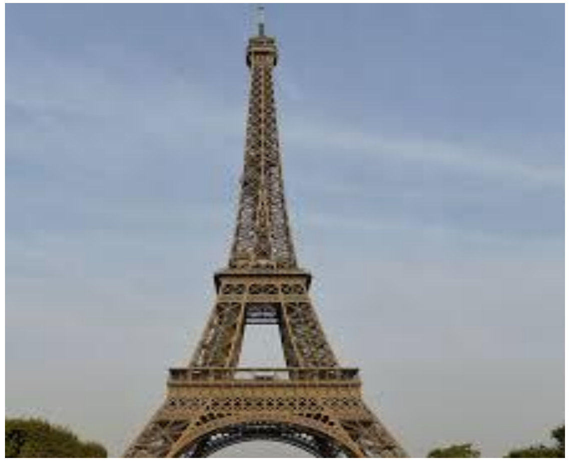
Fasteners

- Fasteners are small to large pieces of hardware that is used to affix or join objects together.
- Fasteners are everywhere. From **Smartphone to Sydney or Golden gate bridge.**
- From rivets, nuts, bolts, screws to paper clip, split clip and nails are all considered to be fasteners.



Manufacturing processes and Fasteners

- Did you know, a Boeing 747-400 has six million parts, half of which are fasteners. Around 3 million different types of nuts and bolts, rivets and screws.
- There are 18,038 iron parts and more than 25,00,000 fasteners (rivets) used to hold the Eiffel tower together.
- Examples of fasteners are wood screw, machine screws, sheet metal screws, self drilling sheet metal screws, hex bolts, flange bolts etc.



FASTENING TYPE

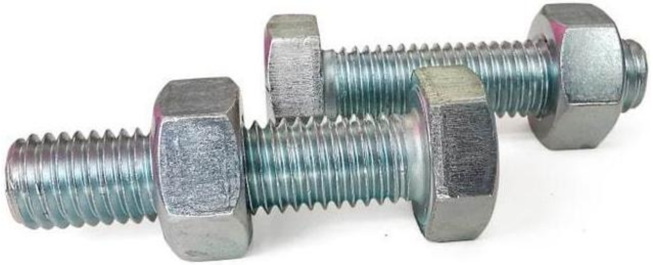
2. Temporary

2.1 ***Threaded fastener***

- bolts
- studs
- screws

2.2 ***Non-threaded fastener***

- keys
- pin



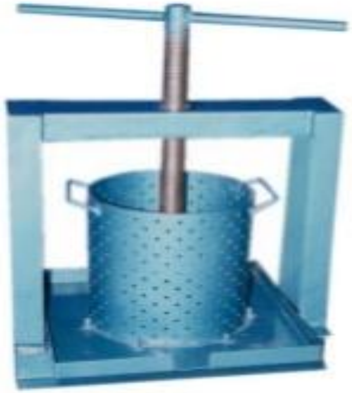
THREAD APPLICATION

1. To hold parts together.
2. To move part(s) relative to others.

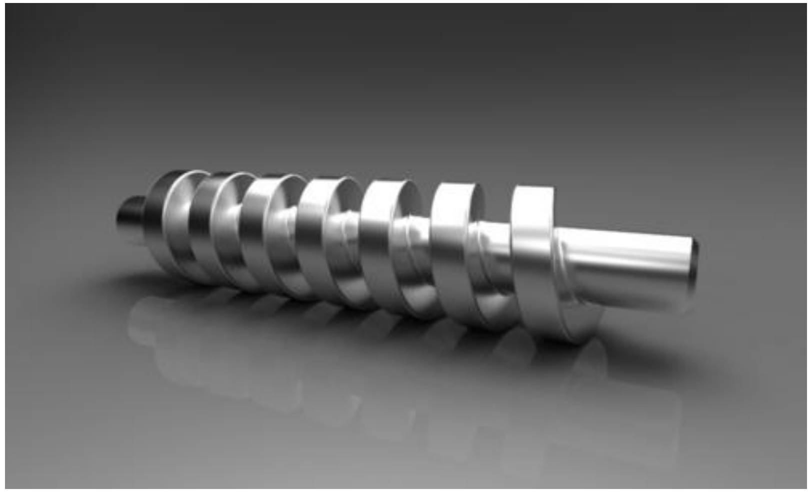
THREAD APPLICATION

1. To hold parts together.
2. To move part(s) relative to others.

Wood working vise

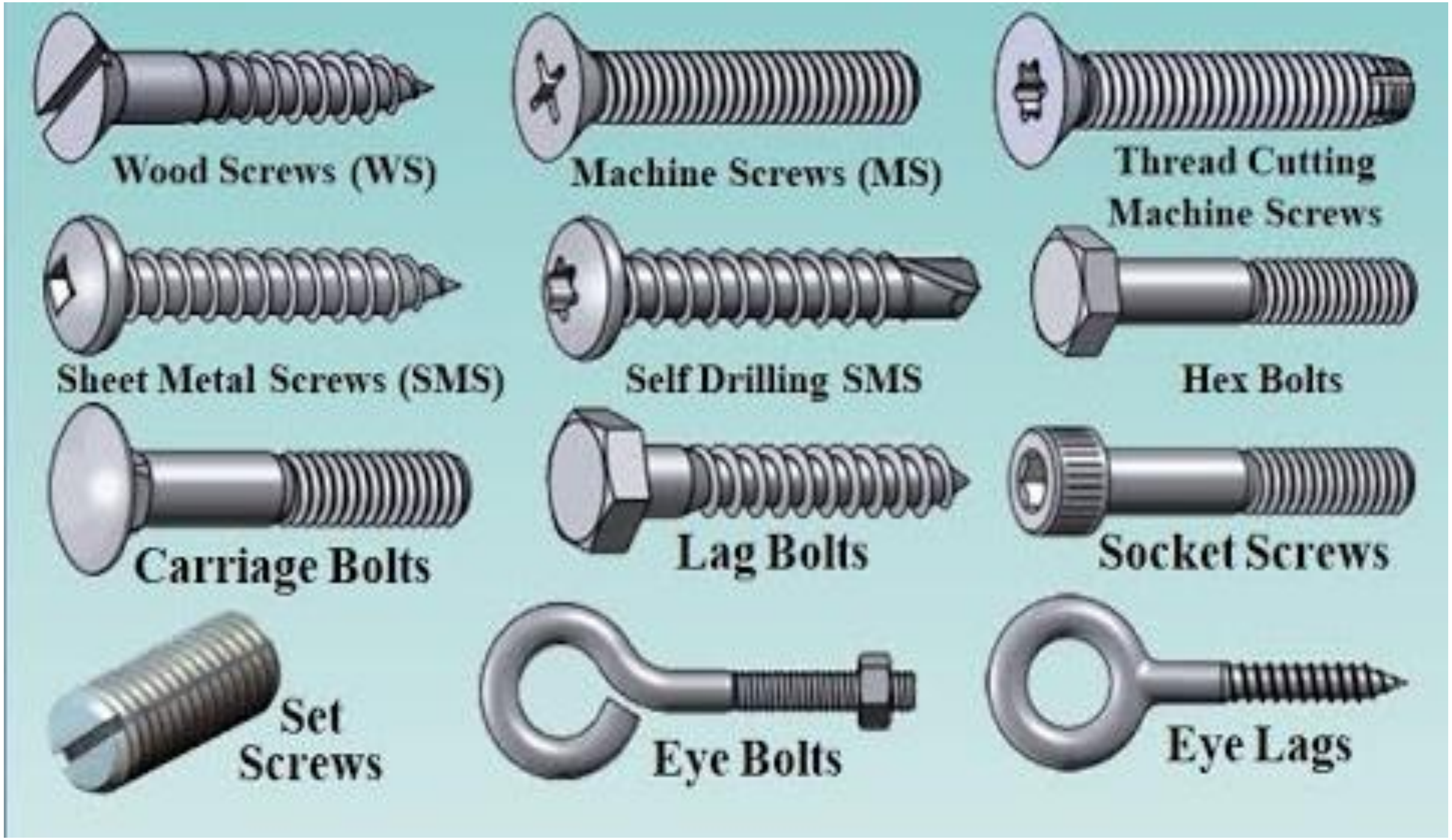


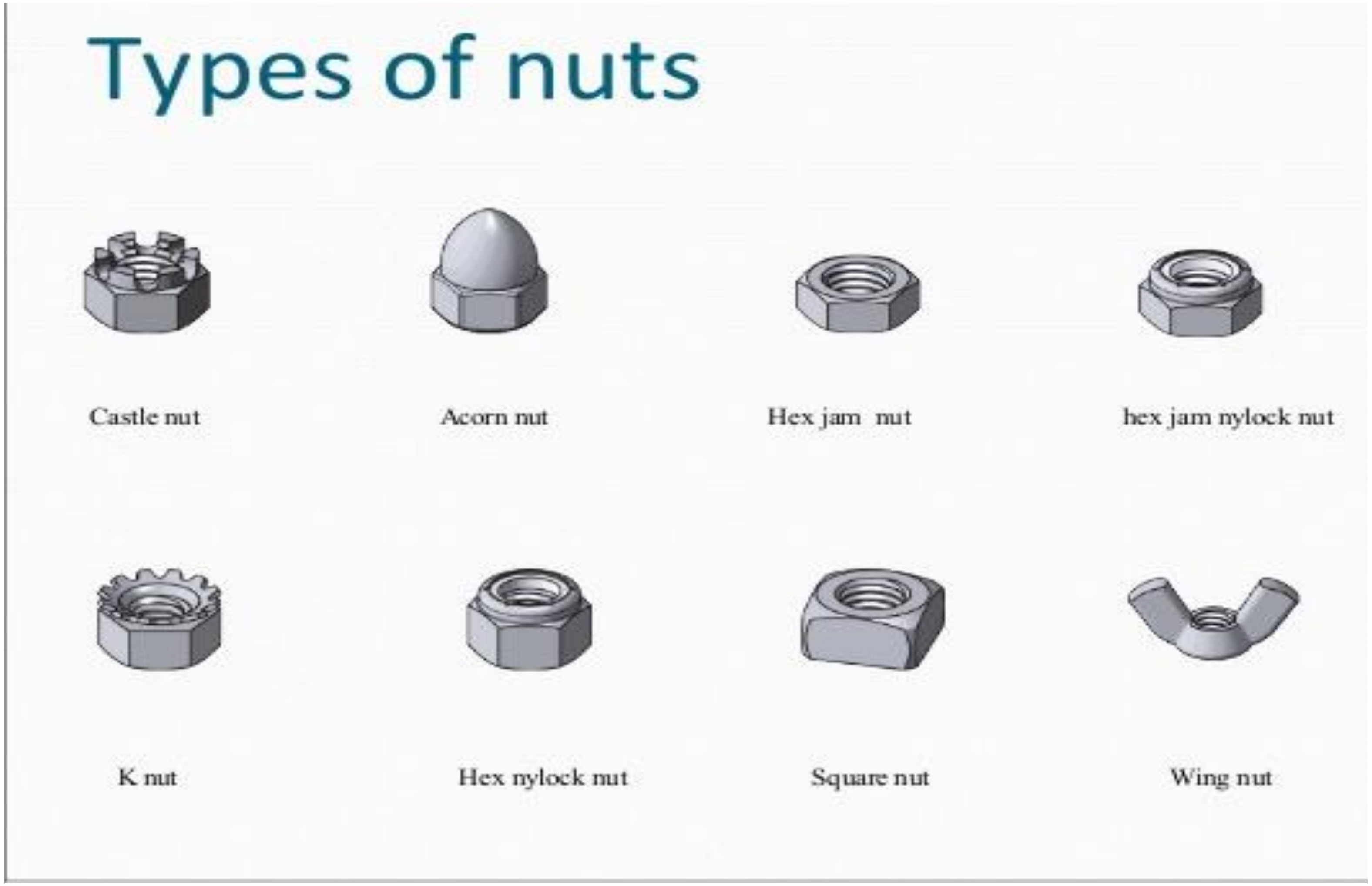
Palm fruit pressing machine



Square Screws or trapezoidal treads are used

Manufacturing processes and Fasteners



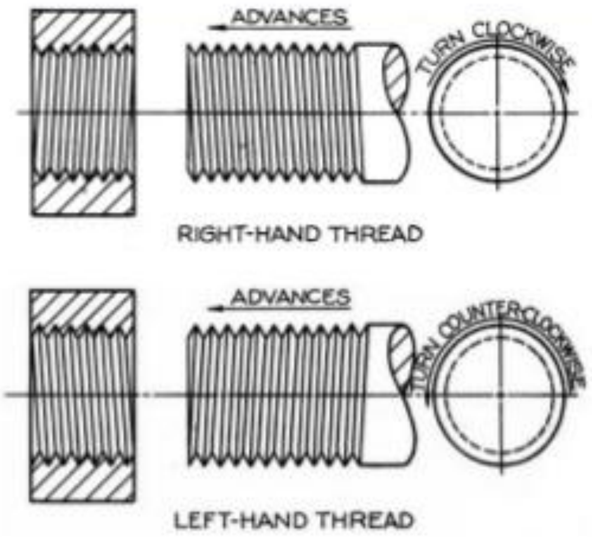

Types of nuts
Castle nut
Acorn nut
Hex jam nut
hex jam nylock nut
K nut
Hex nylock nut
Square nut
Wing nut

THREAD TERMINOLOGY

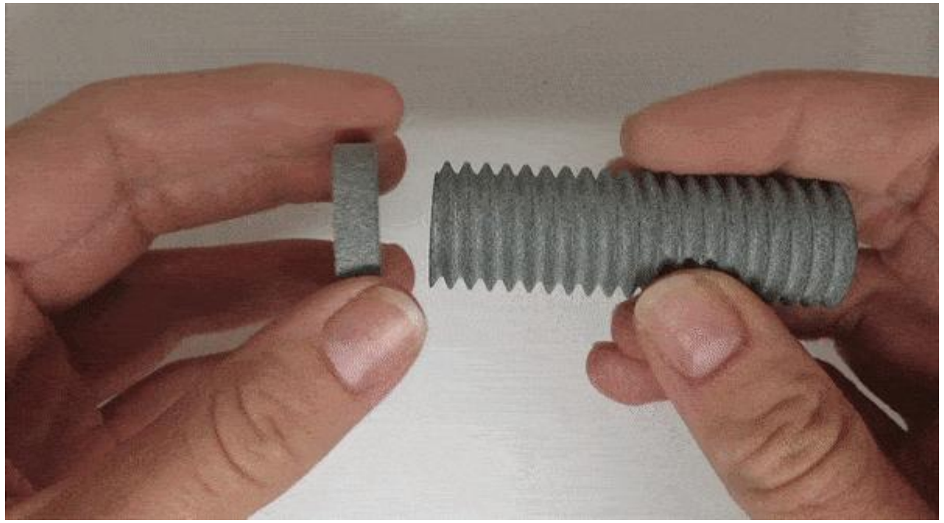
External (male) thread	A thread cut on the ***outside*** of a cylindrical body.
Internal (female) thread	A thread cut on the ***inside*** of a cylindrical body.

THREAD TERMINOLOGY

Right-hand thread	Thread that will ***assemble*** when turned ***clockwise***.
Left-hand thread	Thread that will ***assemble*** when turned ***counter-clockwise***.



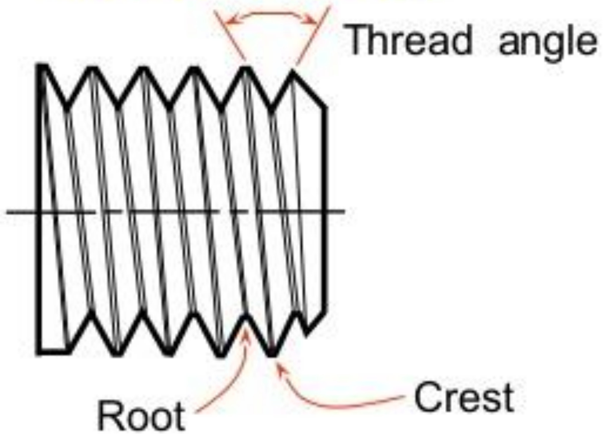
Turnbuckle use RH and LH thread at each end to double displacement.



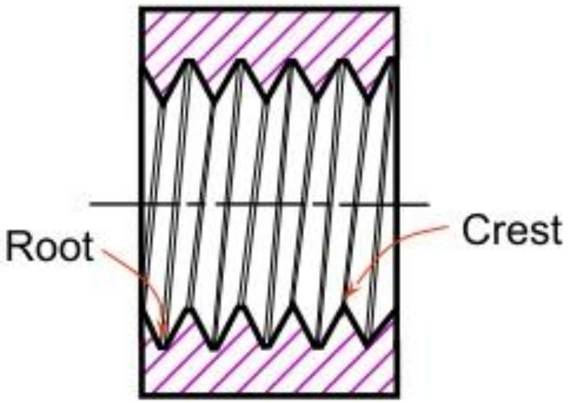
THREAD TERMINOLOGY

Crest	The ***peak edge*** of a thread.
Root	The ***bottom*** of the thread cut into a cylindrical body.
Thread angle	The angle between threads faces.

External Thread

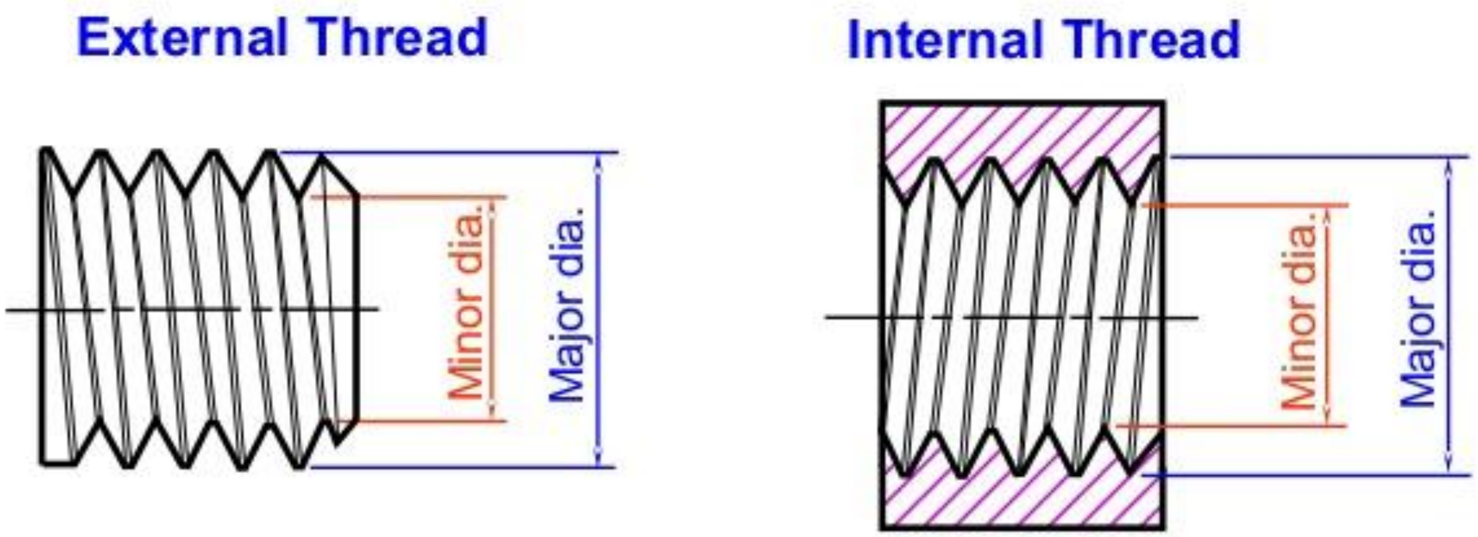


Internal Thread



THREAD TERMINOLOGY

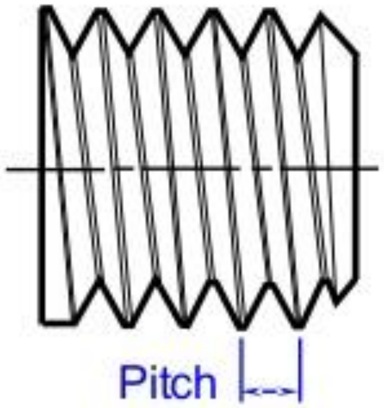
Major diameter	The ***largest diameter*** on an internal or external thread.
Minor diameter	The ***smallest diameter*** on an internal or external thread.



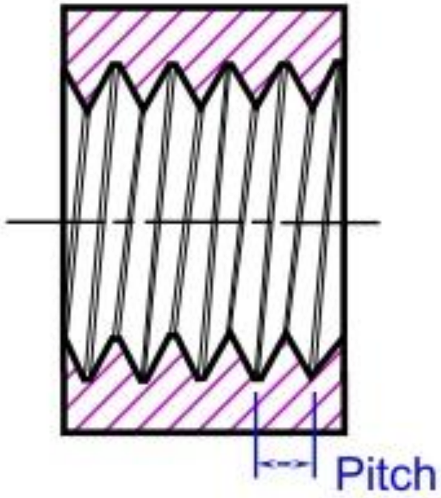
THREAD TERMINOLOGY

Pitch	The distance between crests of threads.
Lead	The distance a screw will advance when turned 360°.

External Thread

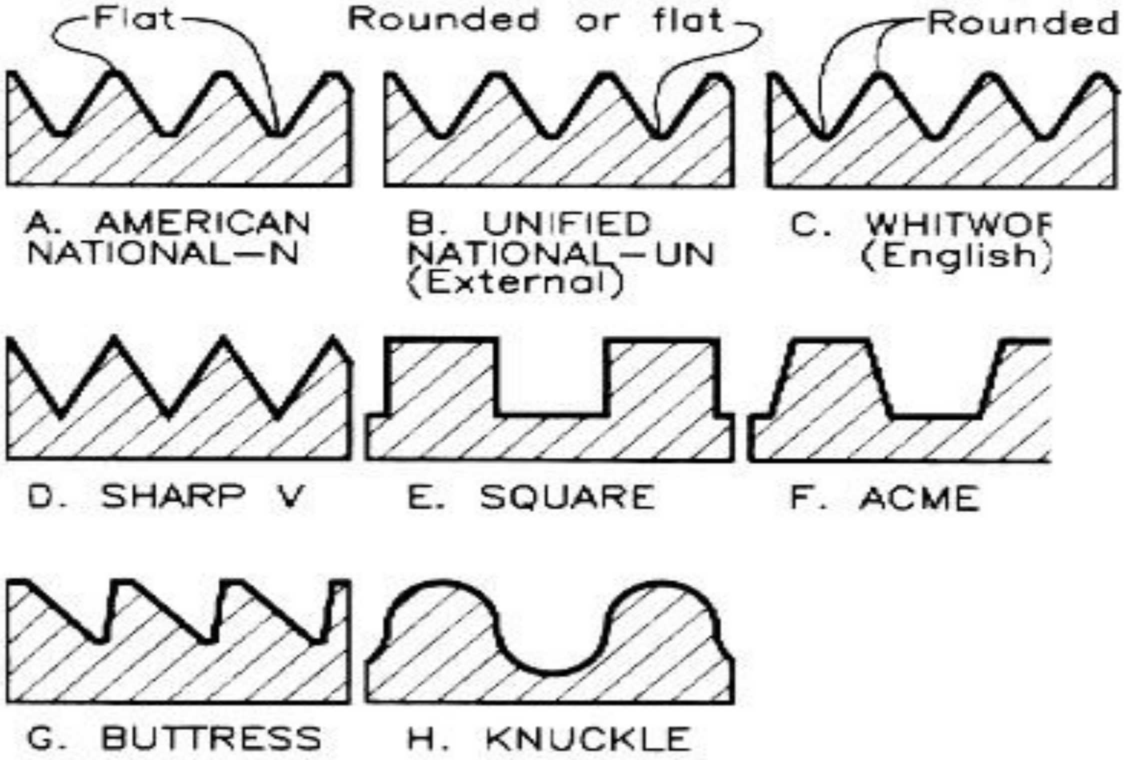


Internal Thread



THREAD TERMINOLOGY

Thread Form	Form is the profile shape of the thread.



Example :

"knuckle thread form"

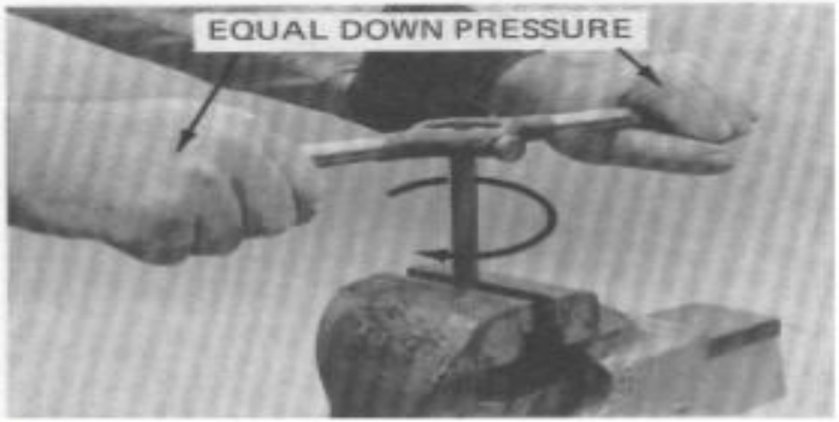
EXTERNAL THREAD CUTTING

Tools

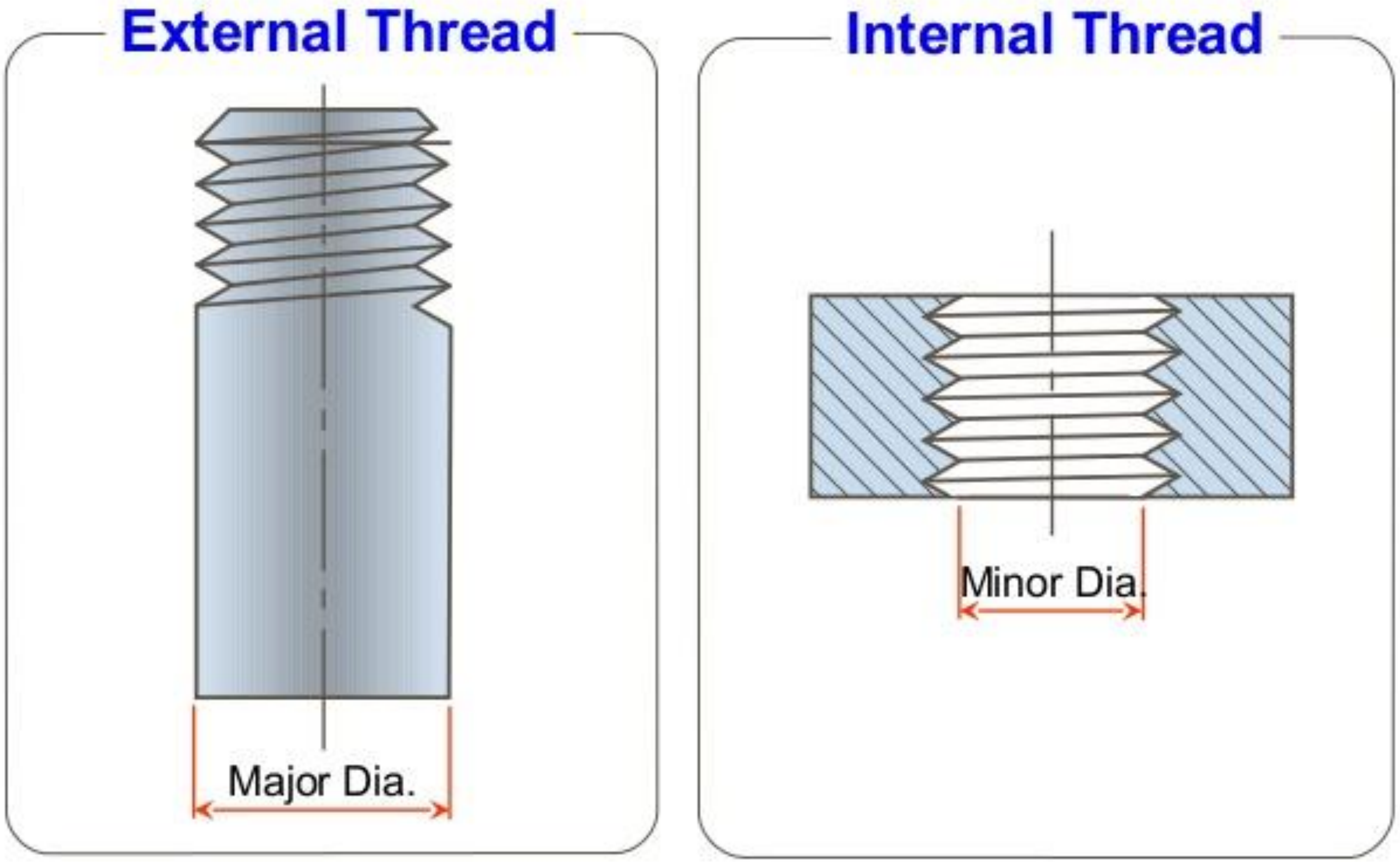
- Threading Die

- Die stock

Operation



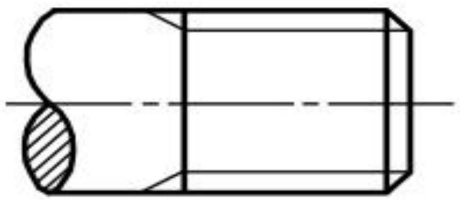
COMPARISON OF THREAD CUTTING



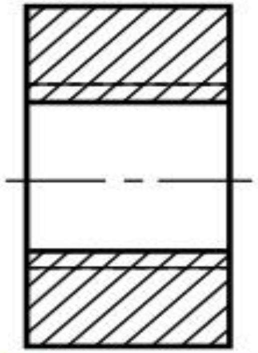
SIMPLIFIED REPRESENTATION

- Use ***thick continuous lines*** for representing ***crest*** and ***thin continuous lines*** for representing ***root*** of the thread, respectively.

External thread

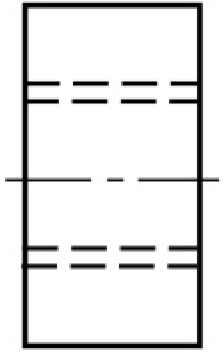


Internal thread

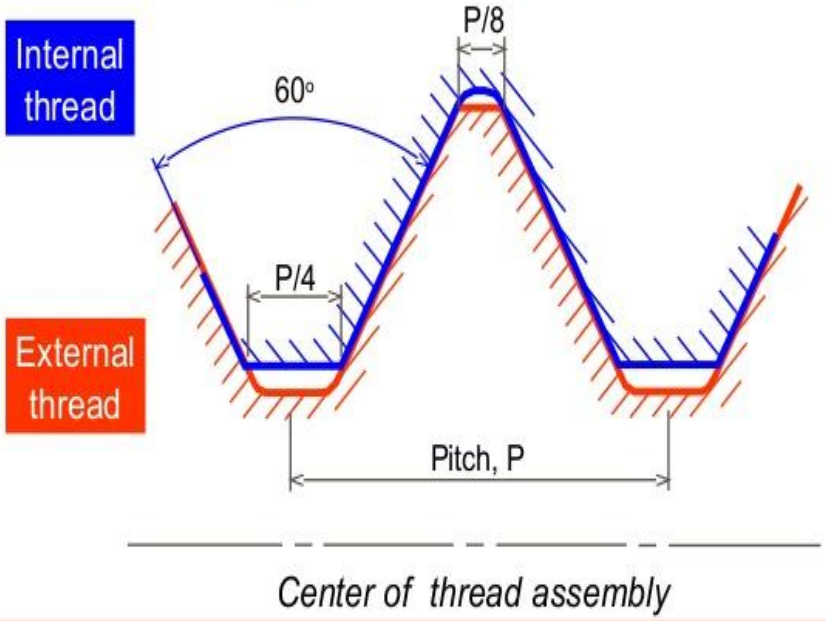


Sectional view

Internal thread



ISO (METRIC) THREAD



Thread assemble occurs if and only if both (internal & external) thread have an equal *nominal size* (*or diameter*) and *pitch*.

METRIC COARSE THREAD

[Table 9.1]

Nominal size	Major diameter	Pitch	Minor diameter	Tap drill size
M6	6.00	1.00	4.92	5.00
M8	8.00	1.25	6.65	6.75
M10	10.00	1.50	8.38	8.50
M12	12.00	1.75	10.11	10.00

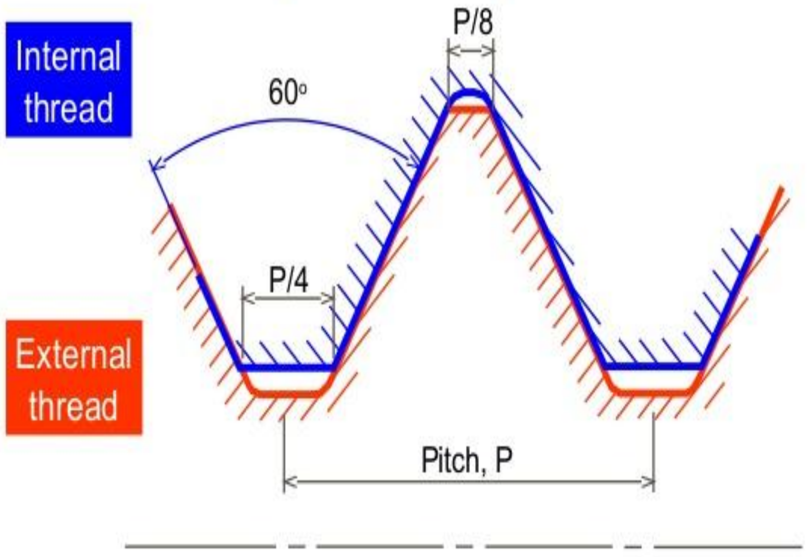
Metric thread

Minor diameter ≈ Tap drill size

In thread ***drawing***, the following relationship is used.

Minor diameter = ***Major*** diameter – Pitch

ISO (METRIC) THREAD



Thread assemble occurs if and only if both (internal & external) thread have an equal ***nominal size** (or diameter)* and ***pitch***.

METRIC FINE THREAD

[Table 9.2]

Nominal size	**Major diameter**	**Pitch**	Minor diameter	Tap drill size
M8	8.00	0.75	7.188	7.25
		1.00	6.917	7.00
M10	10.00	0.75	9.188	9.25
		1.00	8.917	9.00
		1.25	8.647	8.75

Minor diameter ≈ Tap drill size

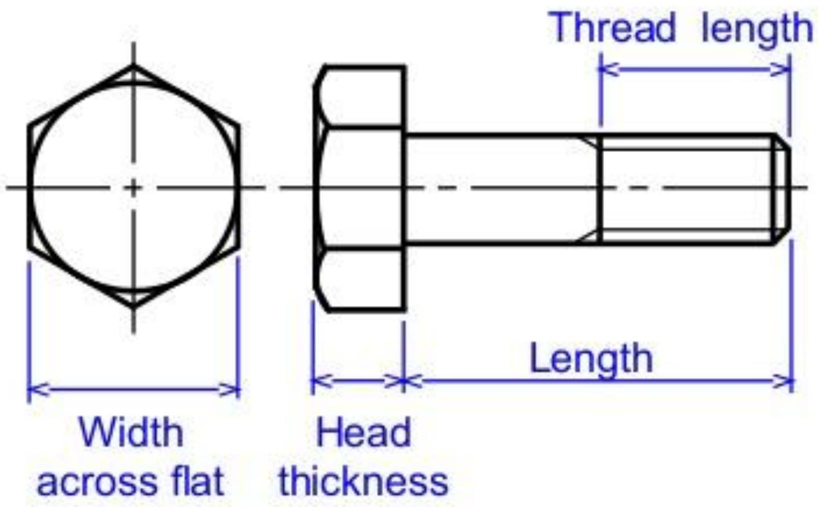
In thread ***drawing***, the following relationship is used.

***Minor** diameter = **Major** diameter – Pitch*

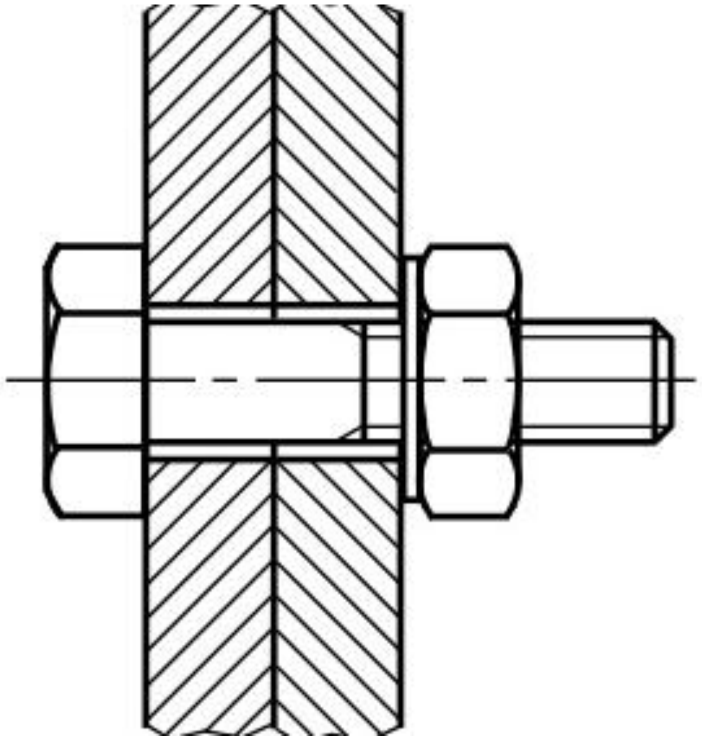
BOLT : Terminology

Bolt is a threaded cylinder with a head.

Hexagonal head bolt and nut

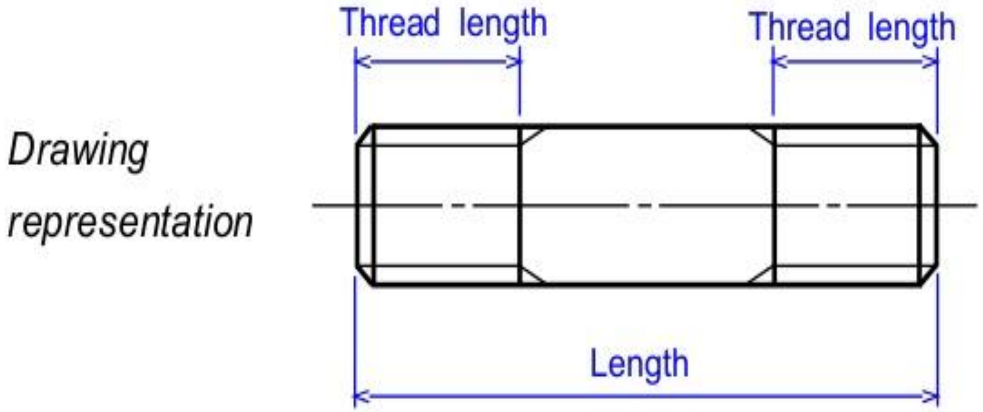


Dimensions of bolt's head are listed in table 9.4.

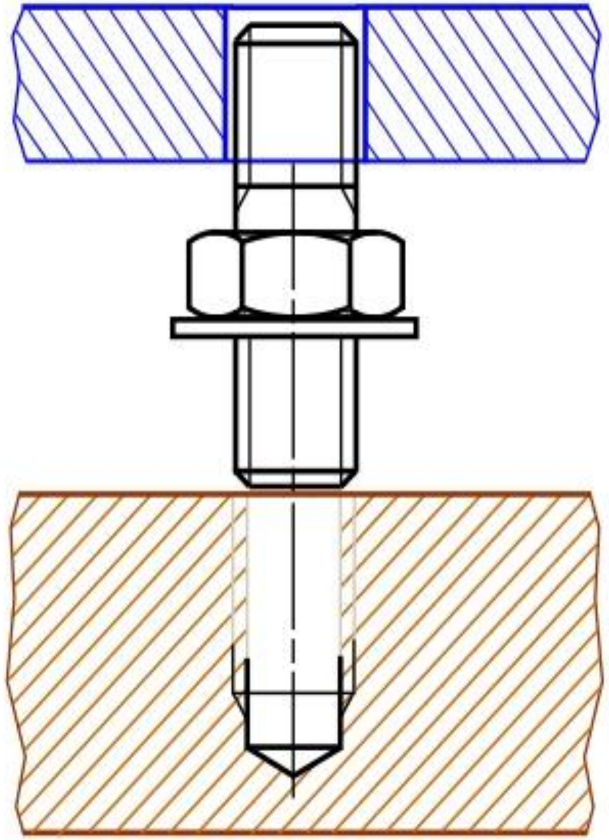


STUD : Terminology

Stud is a *headless* bolt, threaded at both ends.



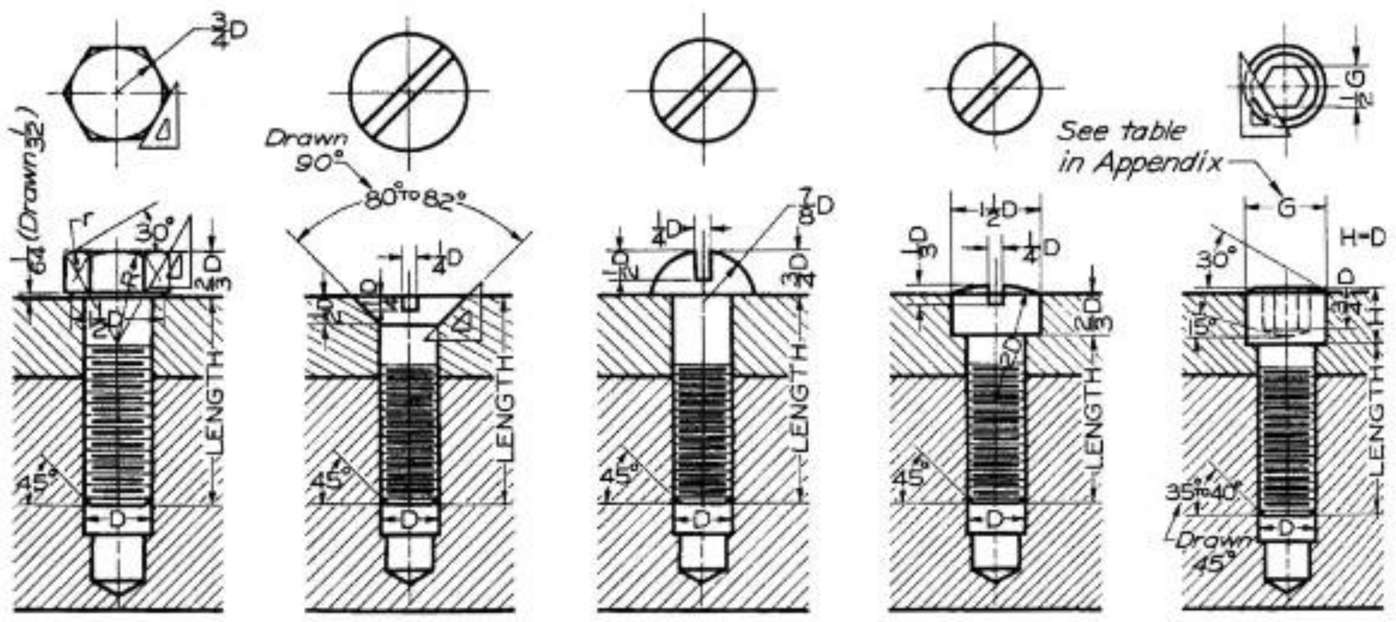
STUD : Application



1. Drill a hole.
2. Tap a hole.
3. Screw a stud.
4. Place the part to be fastened.
5. Insert washer and fastened a nut.

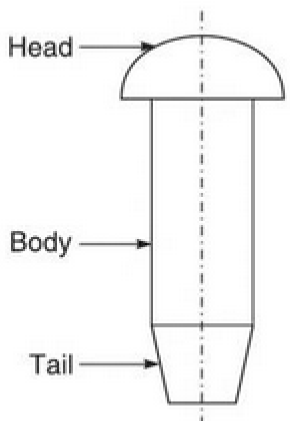
CAP SCREW : Terminology

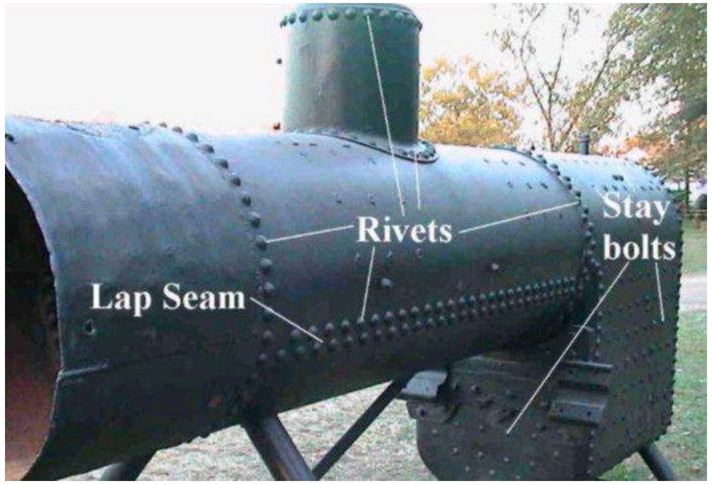
Cap screw is similar to bolt, but has a longer thread than a bolt.



RIVETS

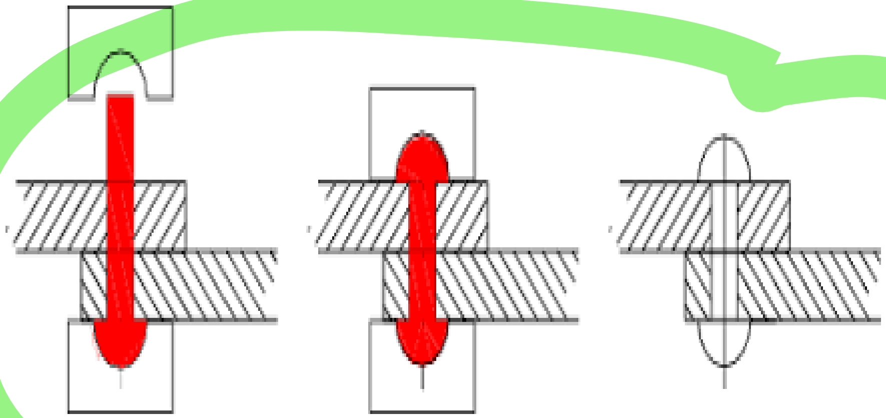
- Rivets are used as fasteners for making semi permanent joints of two or more pieces of metals.
- They are commonly used in ship building, construction of steel structures, bridges, boiler drum, tank etc.
- A rivet comprises of head, tail and shank.



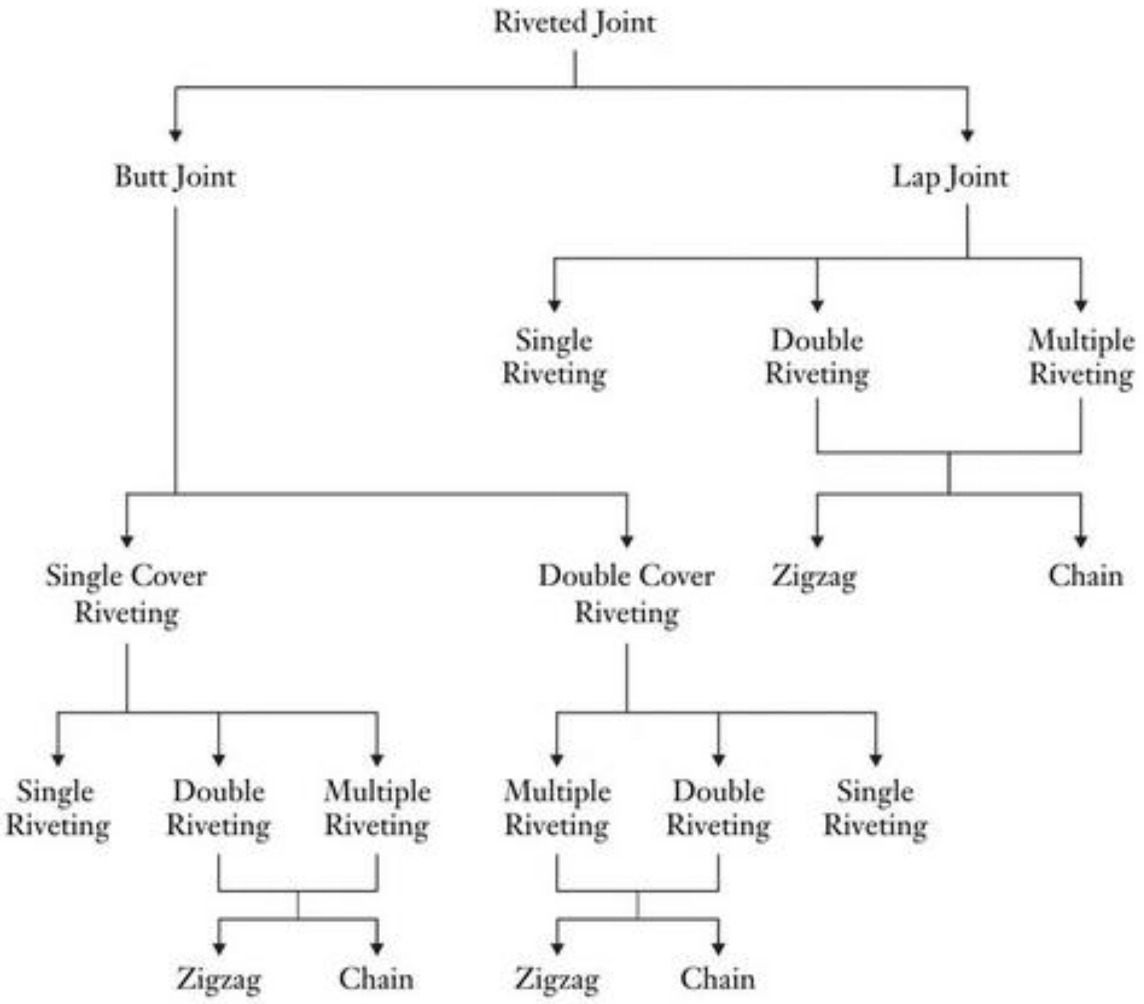


RIVETS

- First, the two metal sheets to be joined are held in proper relationship and then the holes are drilled through them.
- The diameter of the hole is kept slightly more than the shank diameter of the rivet.
- The rivet is then passed through the hole in such a way that the pre – formed head rests against an anvil.
- Next, the tail is forged to form another head.
- This is achieved by exerting the pressure on the die bar that covers the buck – tail.

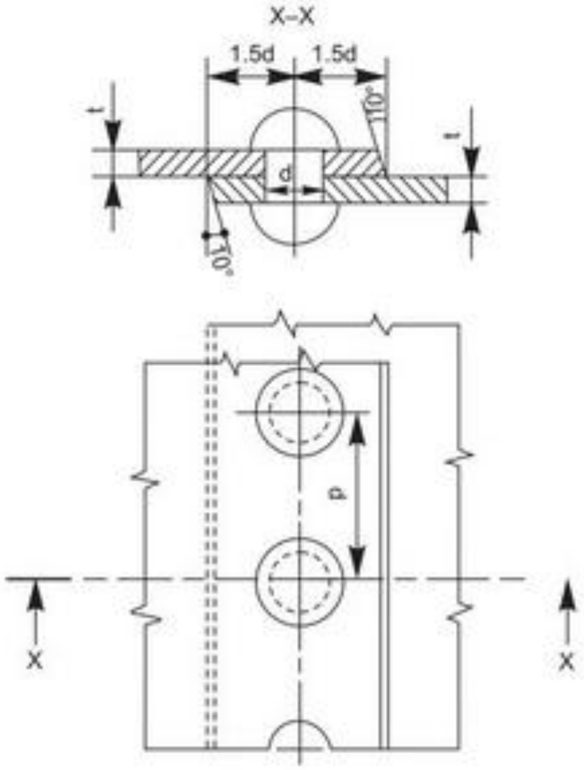


RIVETS

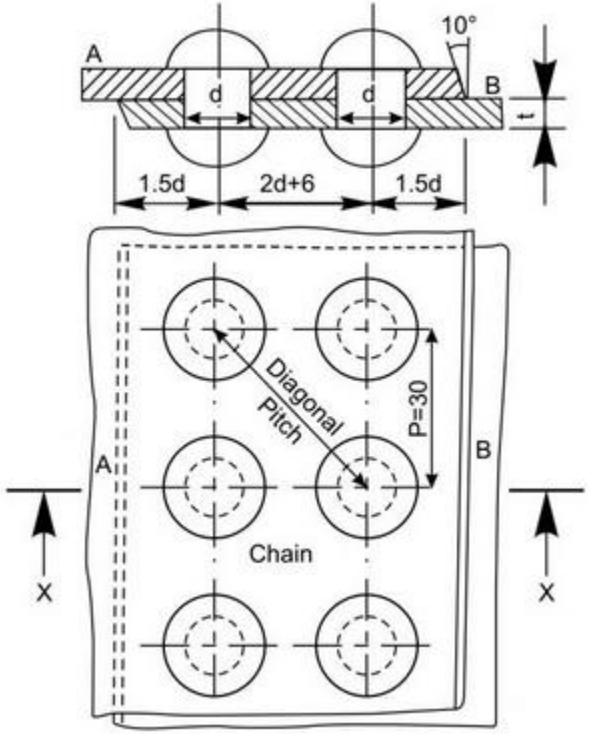

Riveted Joint
Butt Joint
Lap Joint
Single Riveting
Double Riveting
Multiple Riveting
Single Cover Riveting
Double Cover Riveting
Zigzag
Chain
Single Riveting
Double Riveting
Multiple Riveting
Multiple Riveting
Double Riveting
Single Riveting
Zigzag
Chain
Zigzag
Chain

RIVETS

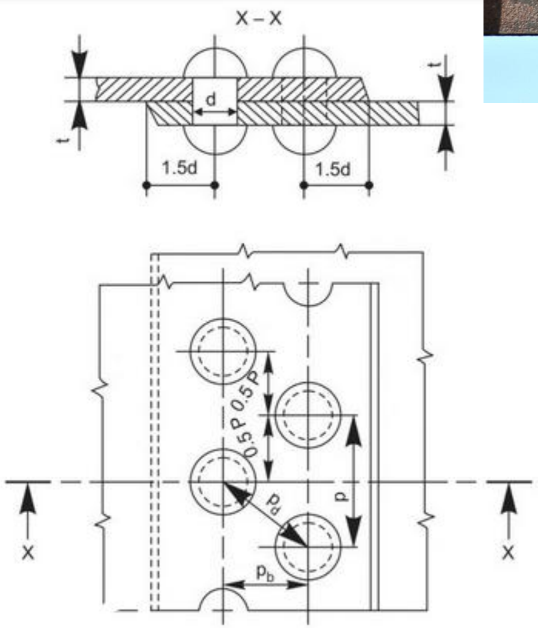
Lap joint – Here, one plate overlaps the other. All the rivets pass through the plates.



Single Riveted Lap Joint



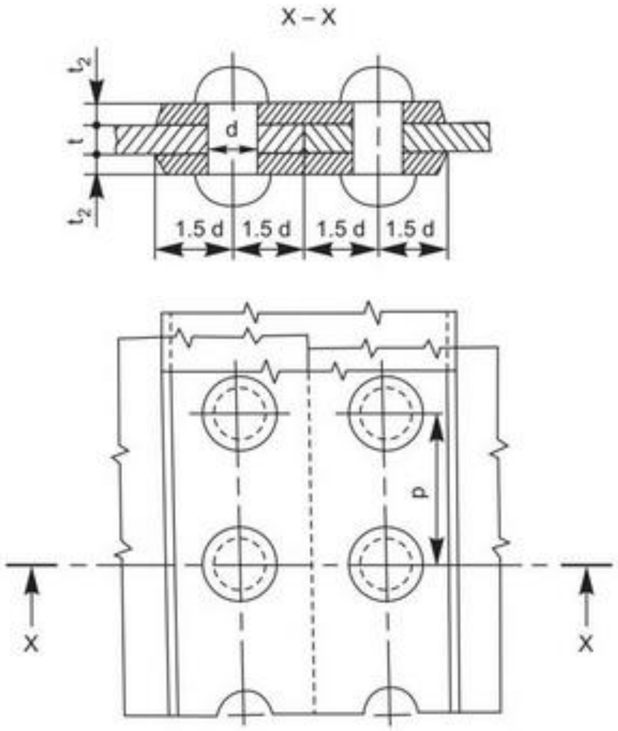
Double Riveted Lap Joint with Chain Riveting



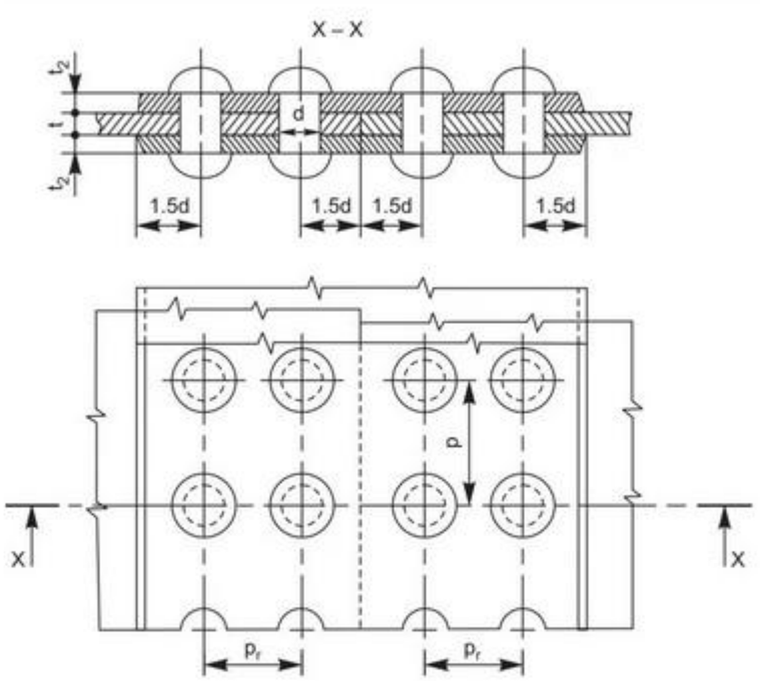
Double Riveted Lap Joint with Zigzag Riveting

RIVETS

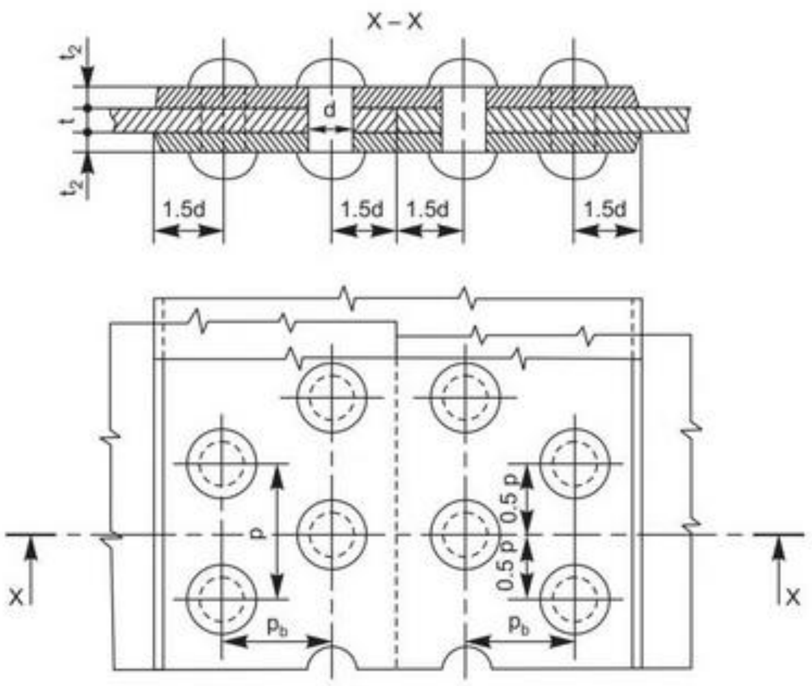
Butt joint – Here, the ends of the main plates butt up against other and may be considered as lying in the same plane. One or two strap or cover plates are placed over the joint and riveted to each plate.



Single Riveted Double Strap Butt Joint



Double Riveted Butt Joint Double Cover Plate Chain Riveting



Double Riveted Butt Joint Double Cover Plate Zigzag Riveting

Thank You

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MECHANICAL ENGINEERING SCIENCE

Unit 4
Machining and Robotics

Dr. Mantesh B Khot
Department of Mechanical Engineering

OVERVIEW

1. Machine tool
2. Machining centers
3. Robotics
4. Automation
5. Industry 4.0

MECHANICAL ENGINEERING SCIENCE

Chapter 1 – Machining Processes

Dr. Mantesh Basappa Khot

Department of Mechanical Engineering

Machining

Machining is the process of removing the excess material from the work piece in the form of chips, by forcing the cutting tool with one or more cutting edges

Machine Tool

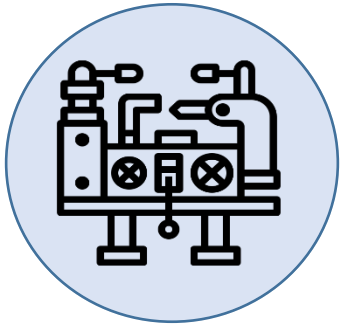
- Machine Tool is a power driven machine to perform machining

- Machine Tool performs three major functions:

  -It rigidly supports the work piece and cutting tool

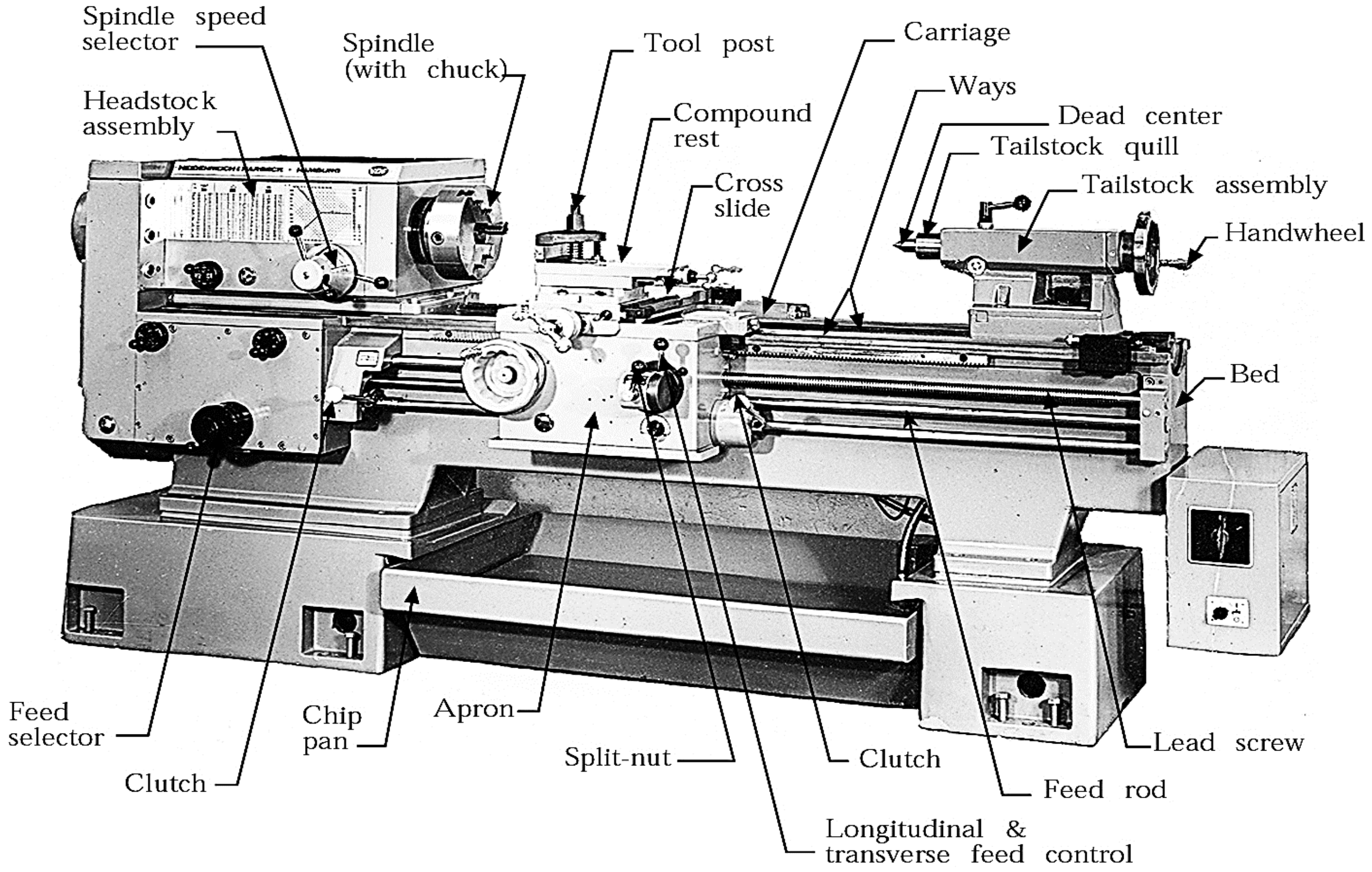
  -Provides relative motion between work piece and cutting tool

  -Provides range of speeds and feeds



1 INTRODUCTION TO LATHE

TYPICAL PARTS OF LATHE



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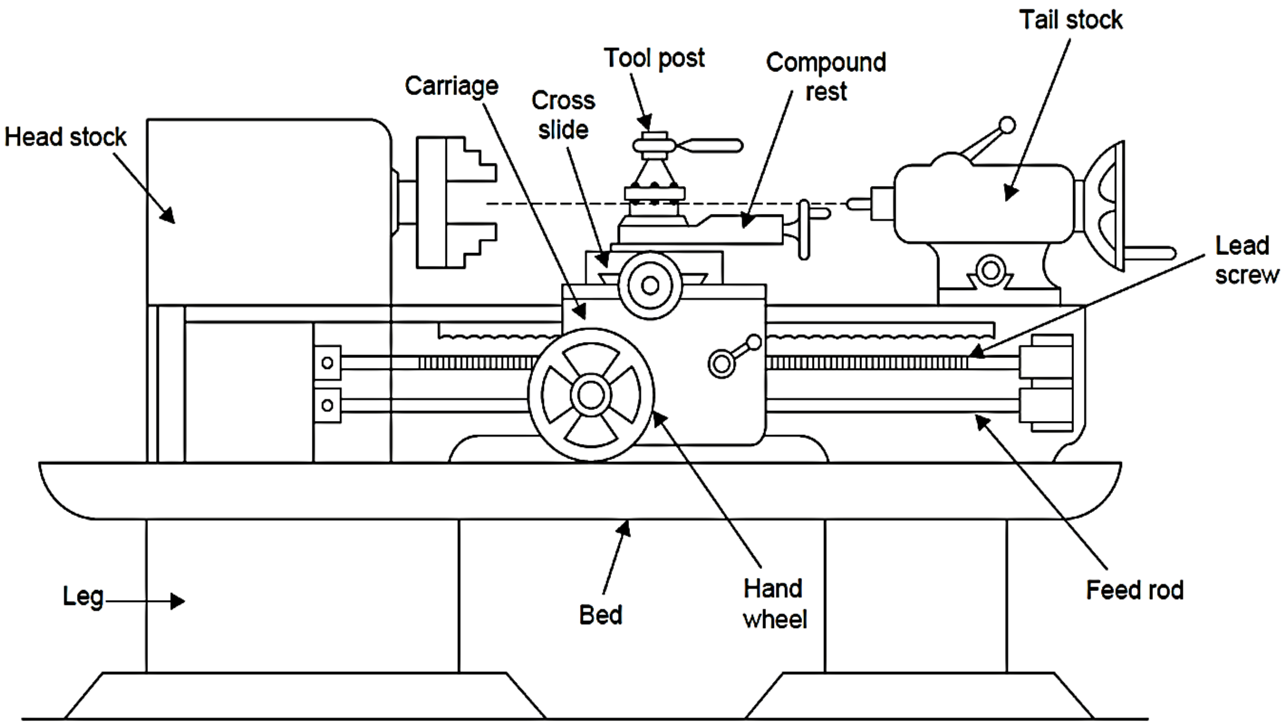
PARTS OF LATHE

- BED
- HEAD STOCK
- TAIL STOCK
- CARRIAGE ASSEMBLY
- FEED ROD
- LEAD SCREW

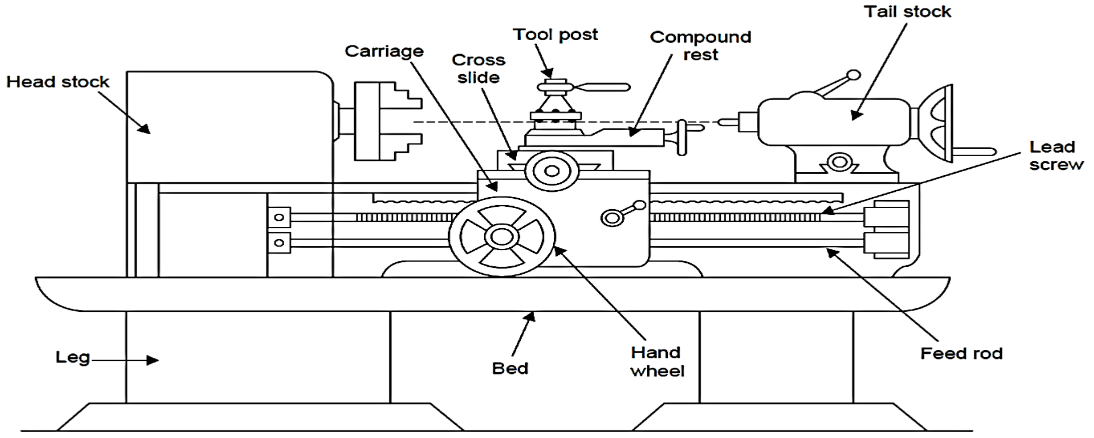


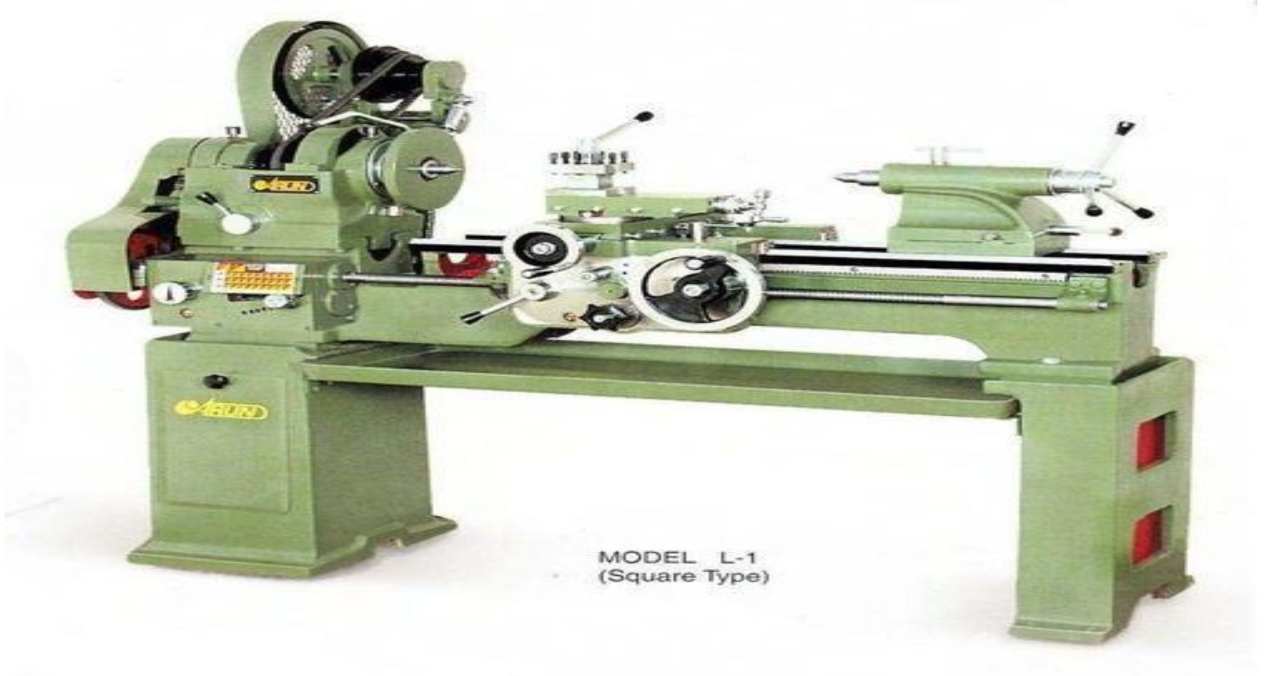
PARTS OF LATHE

BED

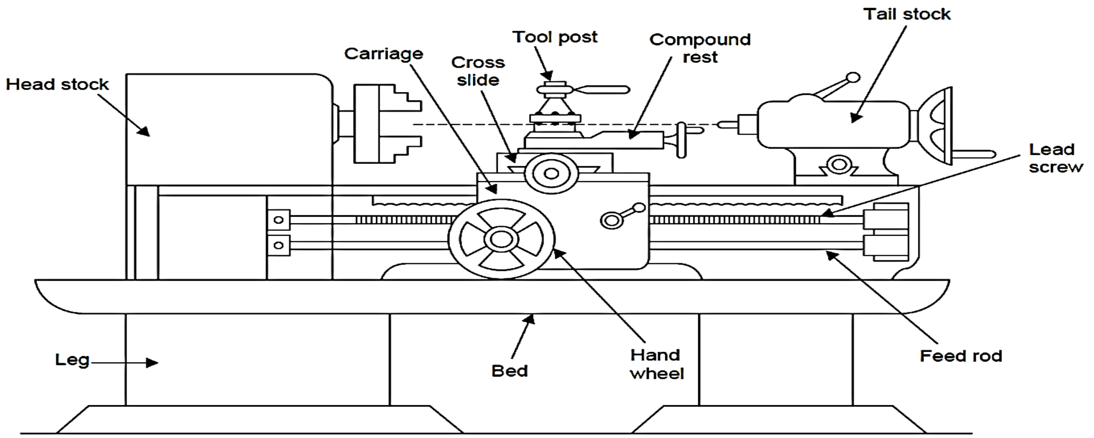
It's the backbone of the lathe upon which all other components are mounted

- At the top of the bed is formed by guide ways
- They act as a guide for accurate movement of carriage and tailstock
- Made up of cast iron because of good damping and frictional resistance





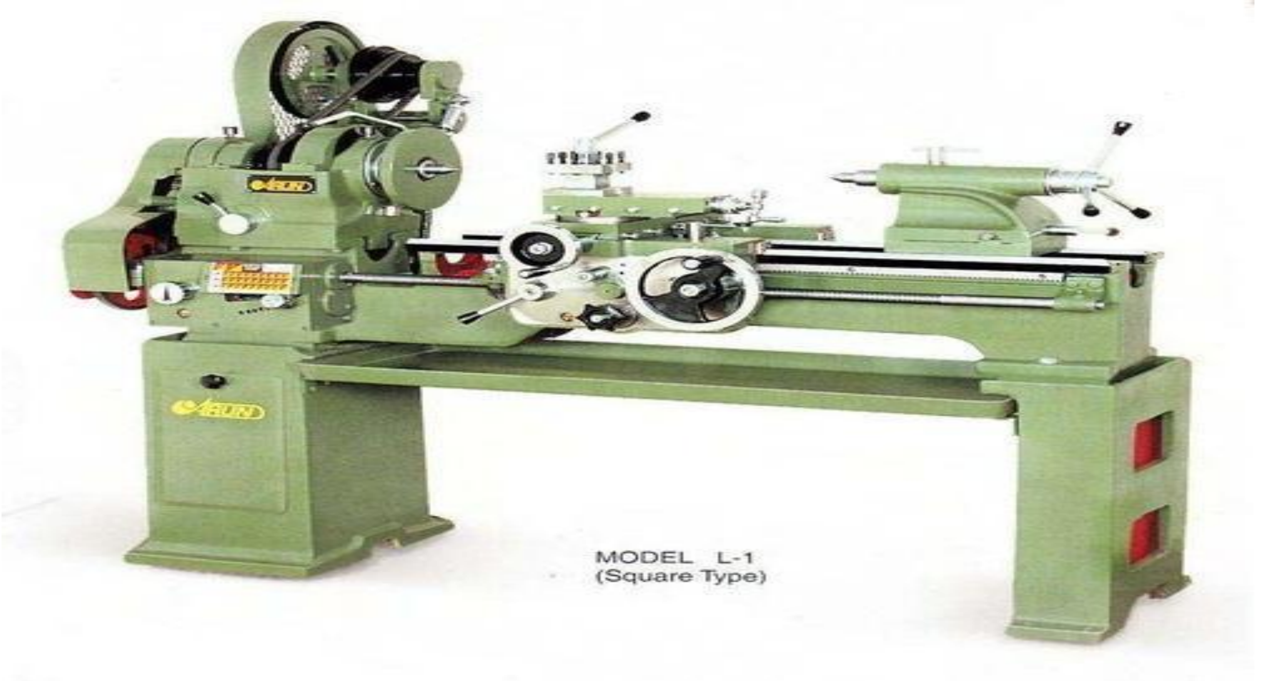
PARTS OF LATHE



HEADSTOCK

Is a box like casting mounted at the left end of the machine

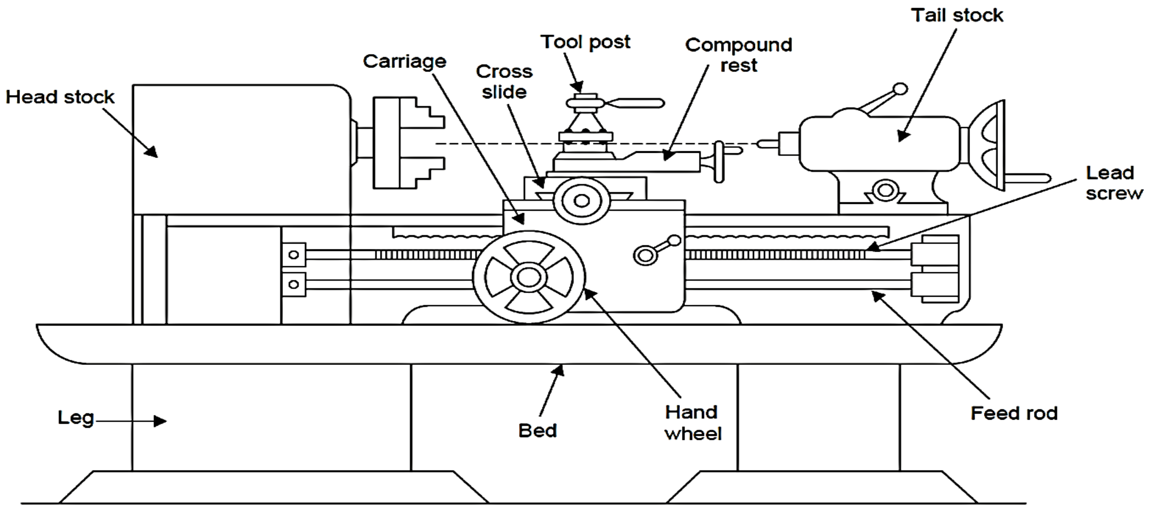
- It contains feed gear box and cone pulley enables the spindle to rotate at different speeds.
- The gear box distributes the power to the lead screw for threading or to the fed rod for turning.

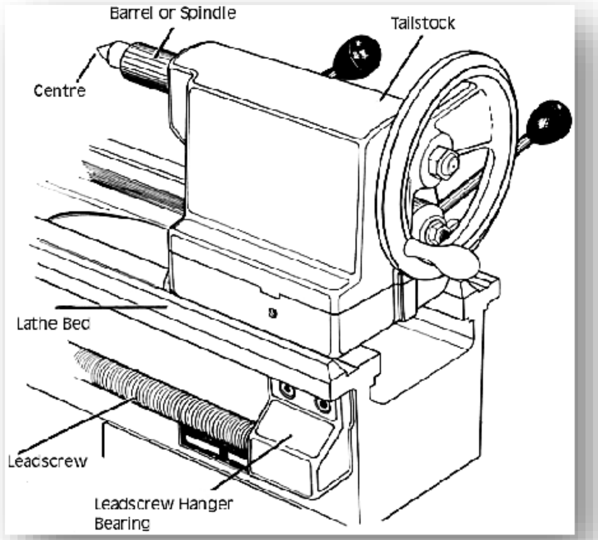


PARTS OF LATHE
TAILSTOCK

It is mounted on the right side of the machine.

- It is the movable part of the lathe that carries the dead centre in it
- It can be slide on the bed to support different length of work piece. It can be clamped on the bed at desired location
- Can be moved laterally for taper turning
- It can be used to carry tool like drill, reamer for making hole





- The carriage supports and feed the tool against the work during the operation on the lathe
- The carriage slides along the bed ways and consists of the following main parts

CARRIAGE ASSEMBLY

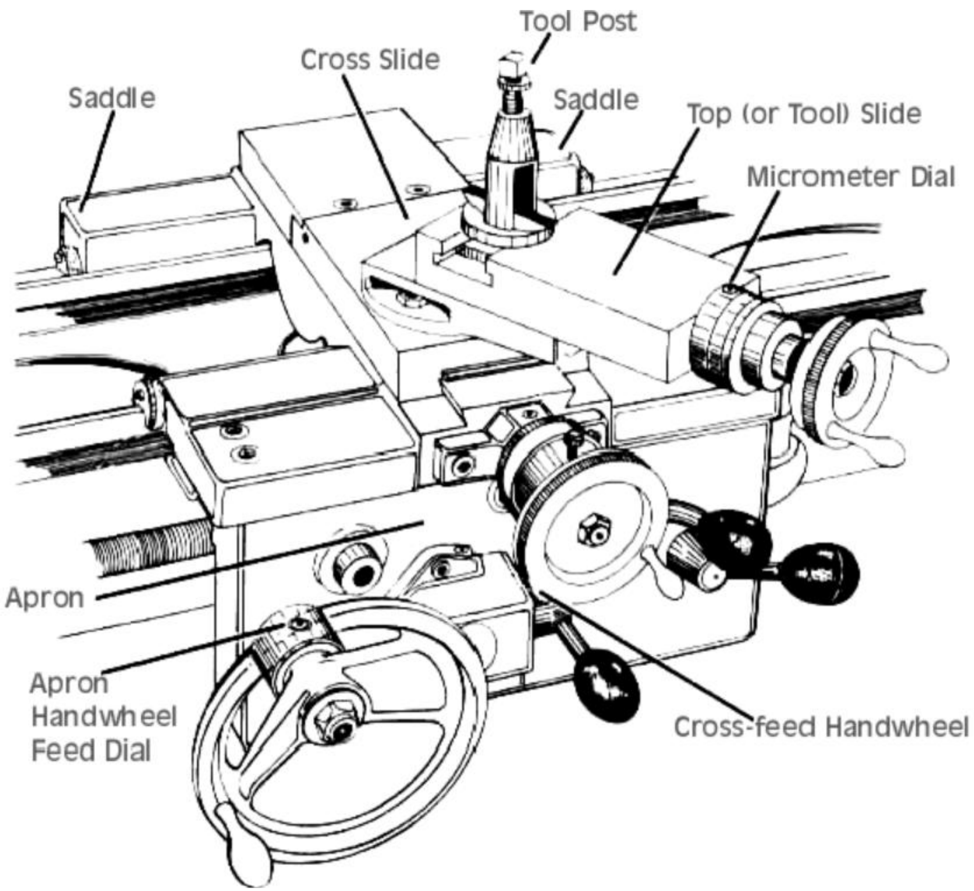
SADDLE

CROSS SLIDE

COMPOUND REST

TOOL POST

APRON

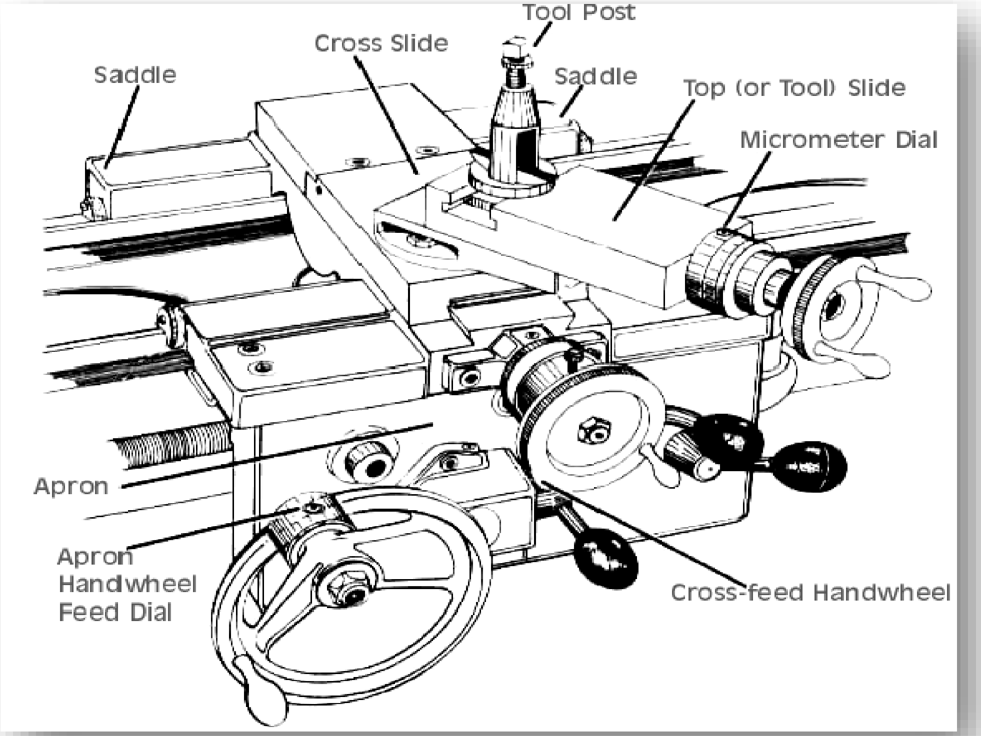


PARTS OF LATHE

CARRIAGE ASSEMBLY

SADDLE:

It is free to slide back and forth along the bed slide ways so that the tool will move parallel to the spindle axis



CROSS SLIDE:

On the upper surface of the saddle is the cross slide. This moves the tool at right angle to spindle axis.

It can either be operated by the means of the cross slide hand wheel or may be given power feed through the apron mechanism

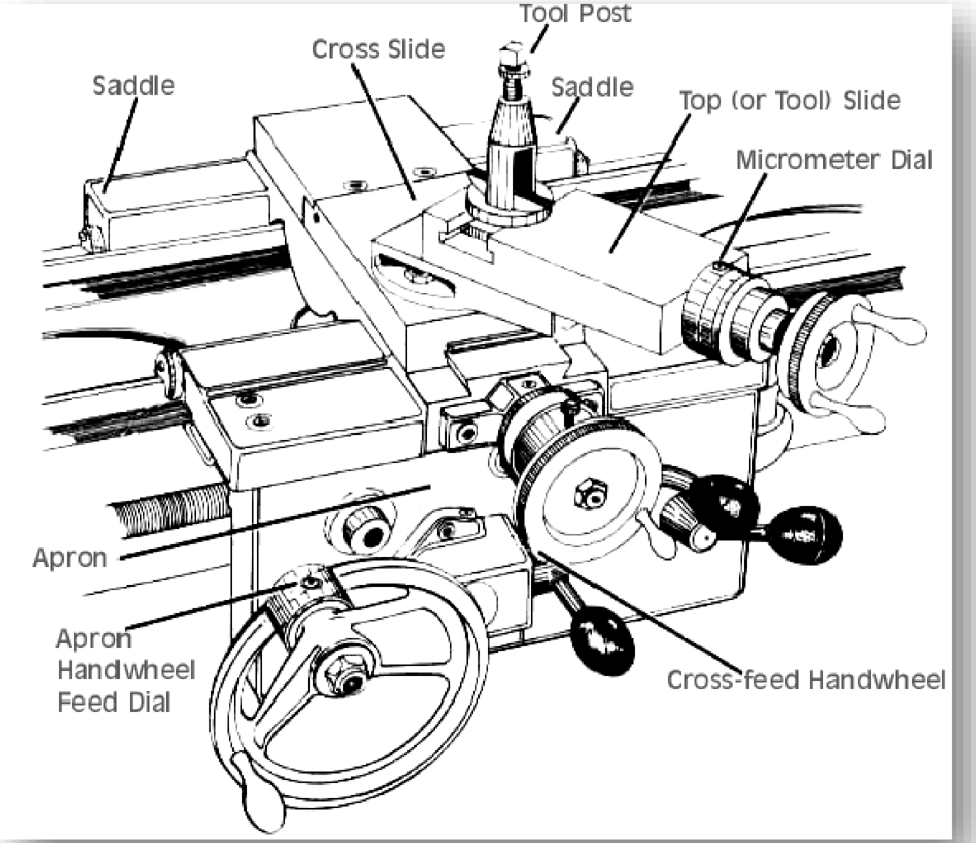
PARTS OF LATHE

CARRIAGE ASSEMBLY

COMPOUND REST:

The compound slide is mounted on the upper surface of the cross slide.

This can be swiveled so that the tool can move at an right angle to the spindle axis



TOOL POST:

This is mounted on the compound slide and carries the cutting tool

PARTS OF LATHE

Feed rod:

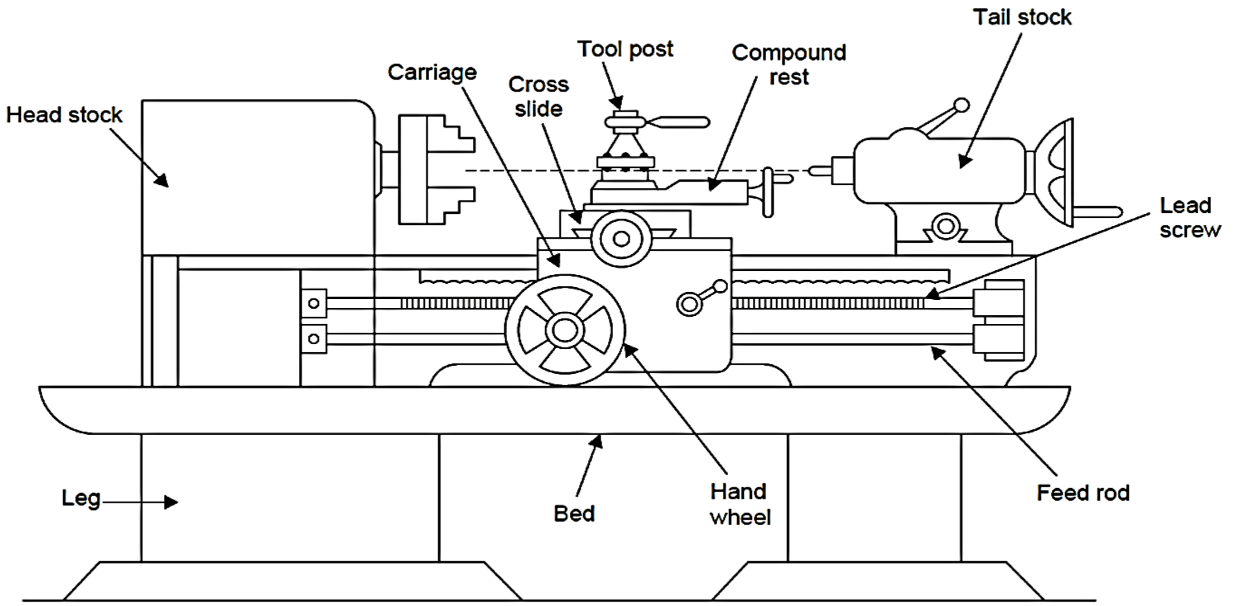
Feed rod is long shaft used to drive the apron mechanism for cross and longitudinal power feed during turning.

It is powered by the set of gears from the headstock

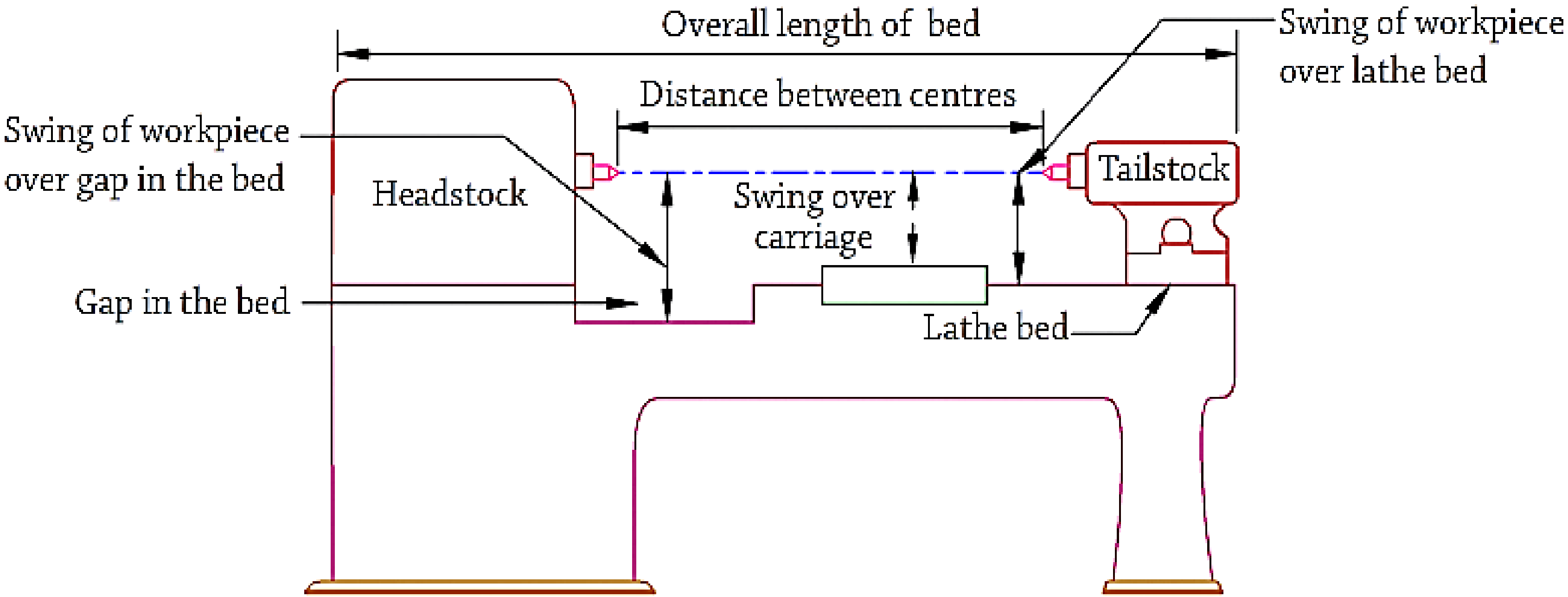
Lead Screw:

Is a long-threaded shaft geared to the headstock.

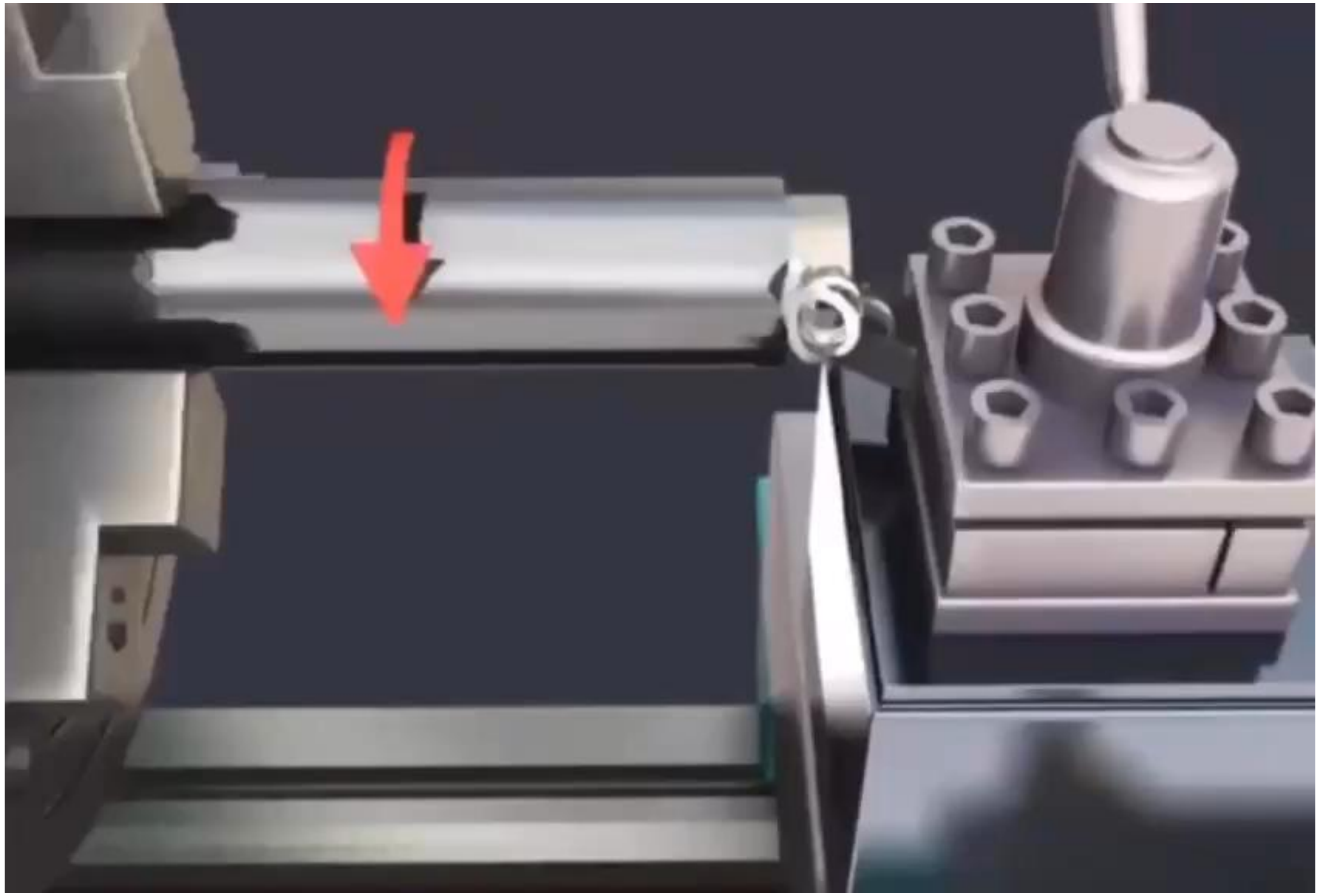
The lead screw is used for cutting thread accurately and should be disengaged for other operations



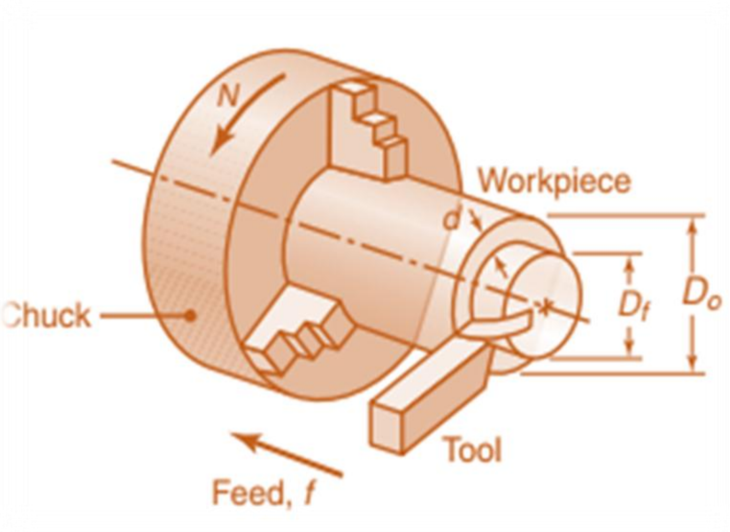
SPECIFICATION OF LATHE



Working Principle of lathe



It works on principle that a cutting tool can remove material in the form of chips from the rotating work pieces to produce circular objects



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OPERATIONS ON LATHE

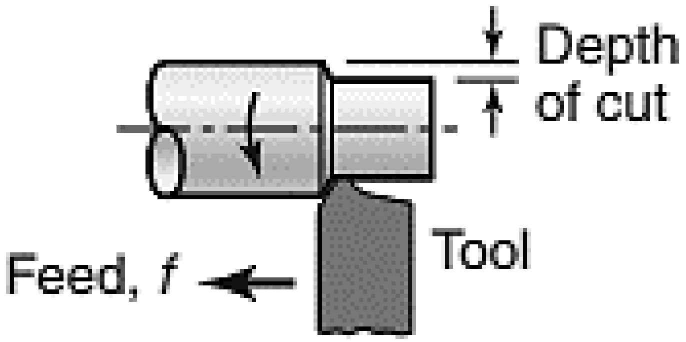
- Turning
- Eccentric Turning
- Facing
- knurling
- Grooving
- Parting
- Chamfering
- Taper turning
- Drilling
- Thread cutting

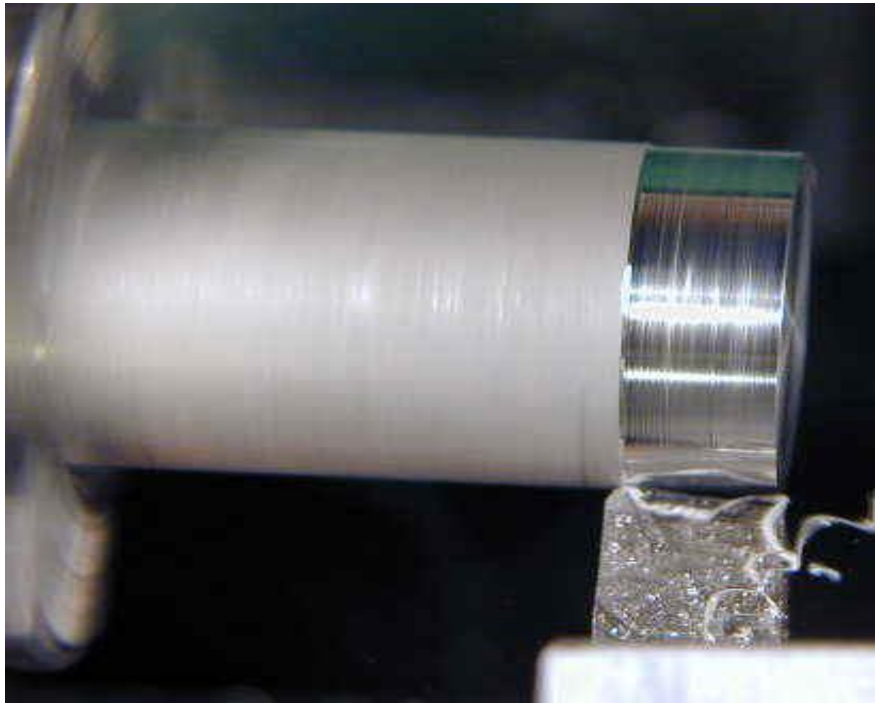
OPERATIONS ON LATHE

TURNING

- This method of machining operation in which the workpiece is reduced to the cylinder section of required diameter is called *'turning'*

- A single point cutting tool is fed perpendicular to the axis of the workpiece to a known predetermined depth of cut, and is then moved parallel to the axis of the workpiece





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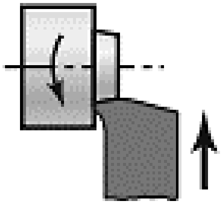
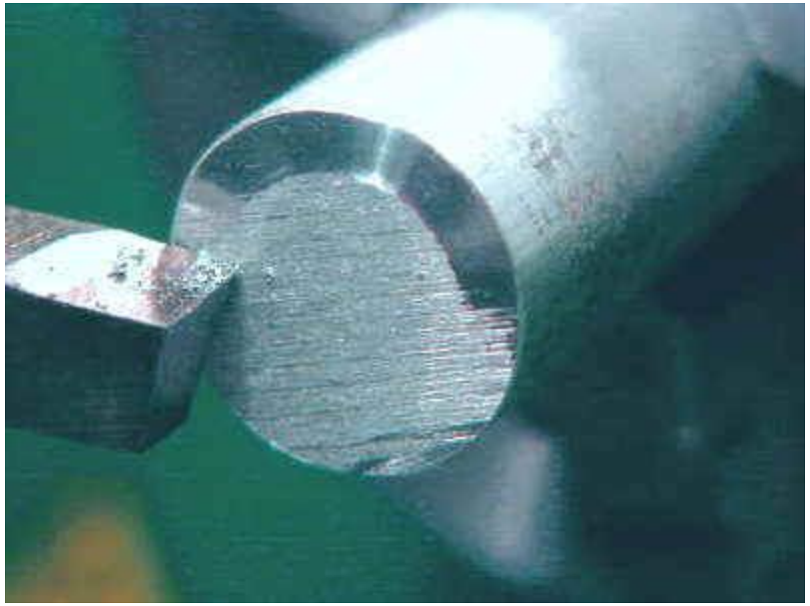
PES UNIVERSITY

OPERATIONS ON LATHE



FACING
• Facing is defined as an operation performed on the lathe to generate either flat surface or shoulders at the end of the workpiece



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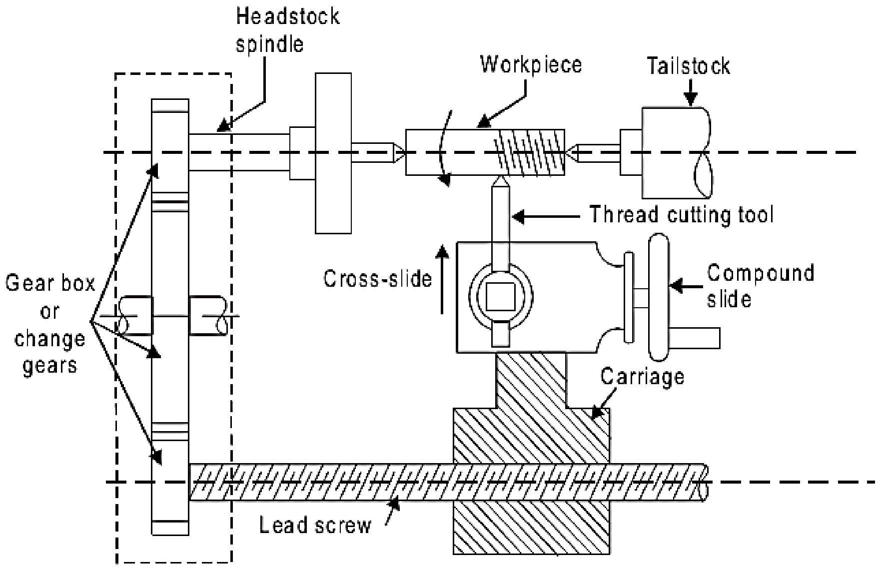
OPERATIONS ON LATHE

THREAD CUTTING

- The cutting tool, the shape of which depends on the type of thread to be cut, is mounted on a holder and moved along the length of the workpiece by the lead screw on the lathe.

- This movement is achieved by the **engagement of a split nut (also called a half nut) inside the apron of the lathe.**

- The axial movement of the tool in relation to the rotation of the workpiece determines the pitch of the screw thread.



OPERATIONS ON LATHE

THREAD CUTTING

- The axial feed is automatically generated when cutting a thread by means of the lead screw, which drives the carriage. When the lead screw rotates a single revolution, the carriage travels a distance equal to the pitch of the lead screw.

- The pitch of the resulting thread being cut, therefore, always depends upon the ratio of the rotational speeds of the lead screw and the spindle.

$$\frac{\text{Pitch of lead screw}}{\text{Desired pitch of workpiece}} = \frac{\text{rpm of workpiece}}{\text{rpm of lead screw}}$$

OPERATIONS ON LATHE

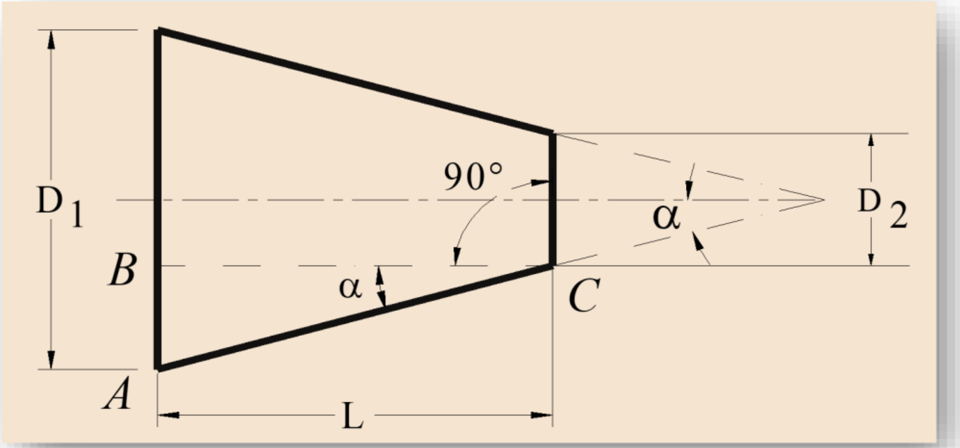
THREAD CUTTING

It is required to cut screw threads of 2 mm pitch on a lathe. The lead screw has a pitch of 6 mm. If the spindle speed is 60 rpm, then the speed of the lead screw will be

(A) 10 rpm (B) 20 rpm (C) 120 rpm (D) 180 rpm

OPERATIONS ON LATHE

Taper Turning:



$$\tan\alpha = \frac{D_1 - D_2}{2L}$$

OPERATIONS ON LATHE

Taper Turning Methods

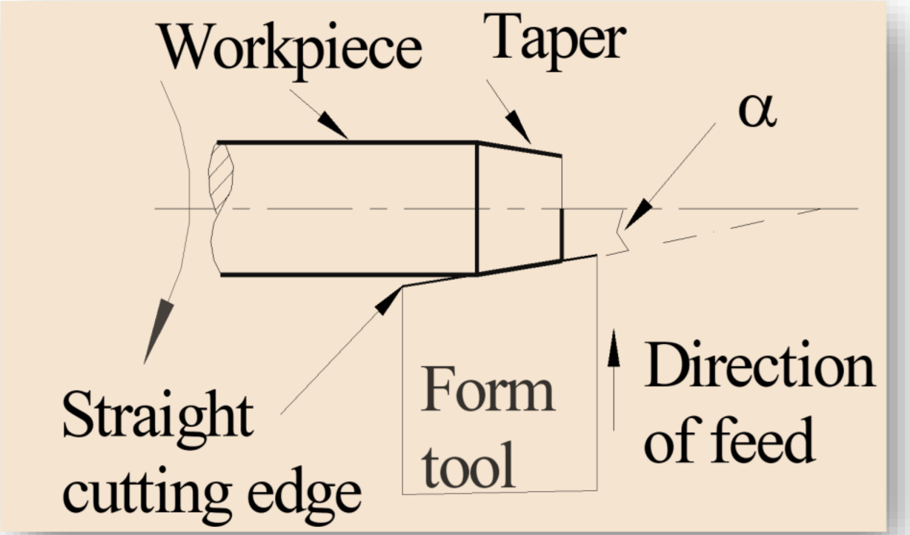
- **Form Tool**
- **Swiveling Compound Rest**
- **Tail Stock offset Method**
- **Taper Turning Attachment**

OPERATIONS ON LATHE

TAPER TURNING

Form tool method –

- A method that is normally used for production applications is the use of special form tool for generating the tapers.
- The feed is given by plunging the tool directly into the work. This method is useful for short tapers, where the steepness is of no consequence, such as for chamfering.



OPERATIONS ON LATHE

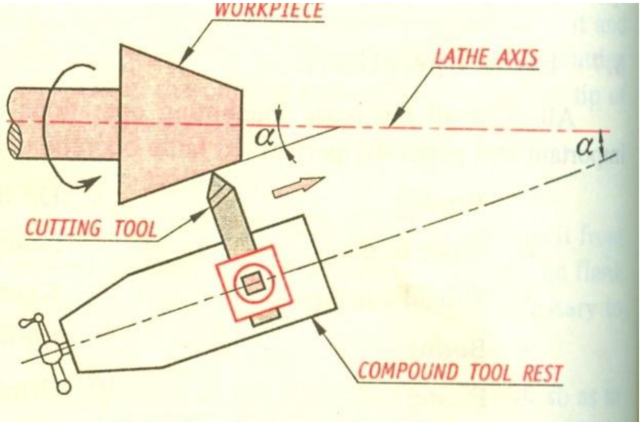
TAPER TURNING

Swivelling compound rest –

- It is possible to swivel the compound rest to the desired angle of the taper for cutting the tapers. The compound rest has a circular base graduated in degrees.

- The tool is then made perpendicular to the work piece and feed is given manually by the operator.

- Some of the features of this method are:
  - ●Short and steep tapers can be easily done.
  - ●Limited movement of the compound rest
  - ●Feeding is by hand and is non-uniform. This is responsible for low productivity and poor surface finish.



Swiveling Compound Tool Rest

OPERATIONS ON LATHE

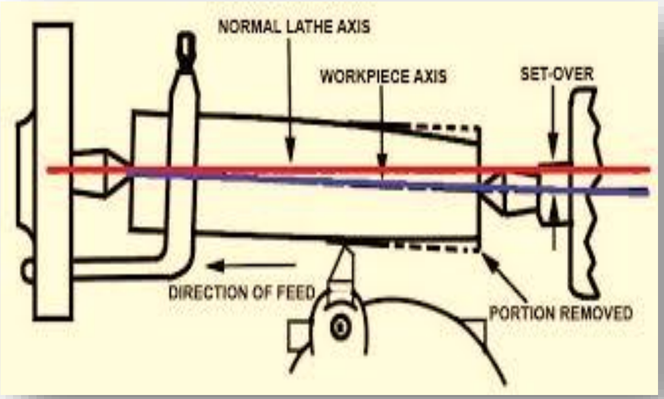
Offsetting the tailstock –

- Still another method sometimes used is the method of offsetting the tailstock from the centre position.

- By offsetting the tailstock, the axis of rotation of the job is inclined by the half angle of taper as shown in Figure.

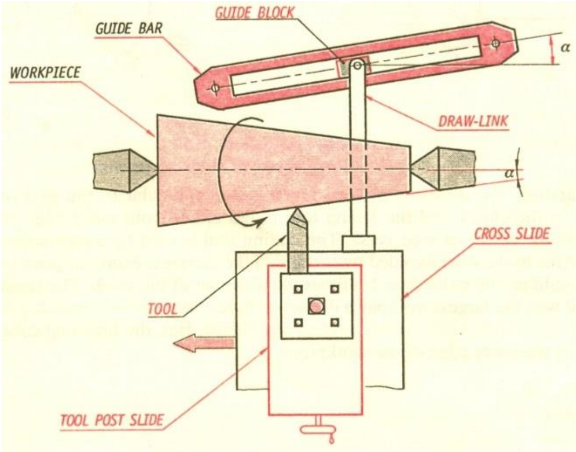
- The feed to the tool is given in the normal manner parallel to the guideways. T thus the conical surface is generated.

- The offset that is possible is generally limited, and as such this method is suitable for small tapers over a long length.



OPERATIONS ON LATHE

Taper turning attachment method –



Taper Turning Attachment

- Still another method for turning tapers over a comprehensive range is the use of taper turning attachment.

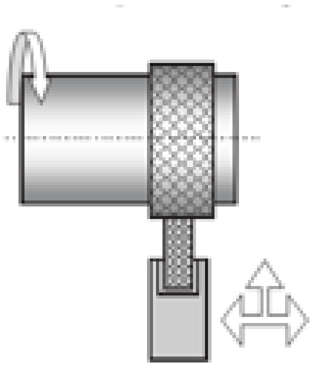
- In this method a separate slideway is arranged at the rear of the cross slide. This slide can be rotated at any angle to be setup. The block that can slide in this taper slide way is rigidly connected to the cross slide.

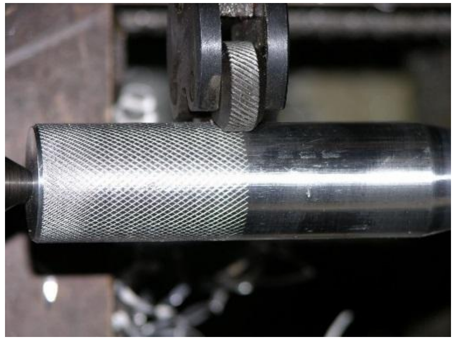
- As the carriage moves for feeding, the block moves in the inclined track of the slide, it gets the proportional cross movement perpendicular to the feed direction, the cross slide and in turn the cutting tool gets the proportional movement. Thus the tool tip follows the taper direction set in the attachment.

- This method is most commonly used for a range of tapers.

OPERATIONS ON LATHE

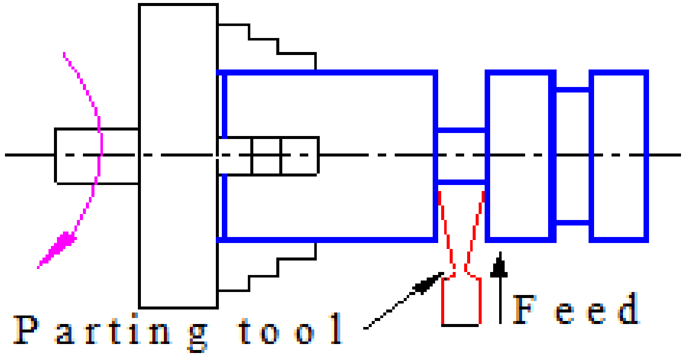
KNURLING





- Knurling is a metal working operation done in a lathe.
- In this a knurling tool having the requisite serrations is forced on to the work piece material, thus deforming the top layers. This forms a top surface, which is rough and provides a proper gripping surface.

PARTING



- Parting and grooving are similar operations. In this a flat nosed tool would plunge cut the work piece with a feed in the direction perpendicular to the axis of revolution. This operation is generally carried out for cutting off the part from the parent material.

WORK HOLDING DEVICE

- The most common form of work holding device used in a lathe is the **chuck**.
- Chucks come in various forms with a varying number of jaws. Of these the **three jaw chuck** or the **self-centering chuck** is the most common one.
- The main advantage of this chuck is the quick way in which the typical round job is centred. All the three jaws move radially inward or outward by the same amount.
- Thus, the jaws will be able to centre any job, whose external locating surface is cylindrical or symmetrical, like hexagonal.
- The independent jaw chuck has **four jaws**, which can be moved in their slots independent of each other, thus clamping any type of configuration. Since each of these jaws could move independently any irregular surface could be effectively centred.

MACHINING TIME

- To estimate the machining times, it is necessary to select the proper process parameters. For this purpose it is necessary to know the work piece material and the cutting tool material combinations to arrive at the right combination of the process parameters, cutting speed, feed and depth of cut.

- The cutting speed in turning is the surface speed of the work piece. Thus,

$$V = \frac{\pi D N}{1000}$$

where, V = cutting speed (surface), m/min

D = diameter of the work piece, mm

N = rotational speed of the work piece, rpm

- The diameter, D to be used can be either the initial diameter of the blank or the final diameter of the work piece after giving the depth of cut. However, there is practically not much change in the values obtained by using either of the values. To be realistic, the average of the two diameters would be better.

MACHINING TIME

- The time, t for a single pass is given by

$$t = \frac{L + L_o}{f\,N}$$

where L = length of the job, mm

L_o = over travel of the tool beyond the length of the job to help in the setting of the tool, mm

f = feed rate, mm/rev

MACHINING TIME

- The number of passes required to machine a component depends upon the left-over stock (stock allowance). Also depending upon the specified surface finish and the tolerance on a given dimension, the choice would have to be made as to the number of finishing passes (1 or 2) while the rest of the allowance is to be removed through the roughing passes. The roughing passes, Pr is given by

$$P_r = \frac{A - A_f}{d_r}$$

where A = Total machining allowance, mm
A_f = Finish machining allowance, mm
d_r = Depth of cut in roughing, mm

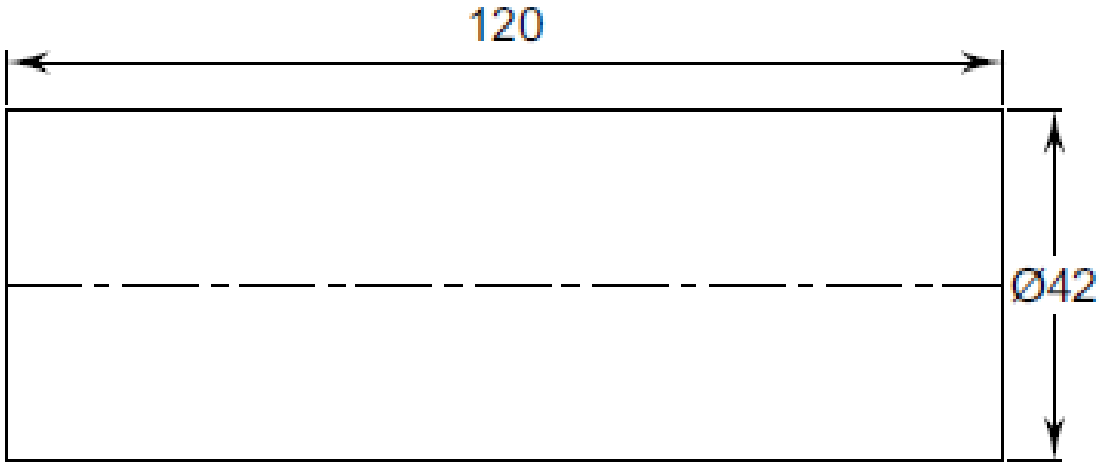
- Similarly the finishing passes, Pf is given by

$$P_f = \frac{A_f}{d_f}$$

where d_f = Depth of cut in finishing, mm

MACHINING TIME

- Estimate the actual machining time required for the component (C40 steel) shown in Fig. below. The available spindle speeds are, 70, 110, 176, 280, 440, 700, 1100, 1760 and 2800. Use a roughing speed of 30 m/min and finish speed of 60 m/min. The feed for roughing is 0.24 mm/rev while that for finishing is 0.10 mm/rev. The maximum depth of cut for roughing is 2 mm. Finish allowance may be taken as 0.75 mm. Blank to be used for machining is 50 mm in diameter.



MACHINING TIME

Solution Stock to be removed $= \dfrac{50-42}{2} = 4$ mm

Finish allowance = 0.75 mm

Roughing:

Roughing stock available = 4 – 0.75 = 3.25 mm

Since maximum depth of cut to be taken is 2 mm, there are 2 roughing passes.

Given cutting speed, $V = 30$ m/min

$$\text{Average diameter} = \frac{50+42}{2} = 46 \text{ mm}$$

$$\text{Spindle speed, } N = \frac{1000 \times 30}{\pi \times 46} = 207.59 \text{ RPM}$$

The nearest RPM available from the list is 176 RPM as 280 is very high compared to 207 as calculated.

MACHINING TIME

$$\text{Machining time for one pass} = \frac{(120+2)}{0.24\times 176} = 2.898 \text{ minutes}$$

Finishing:

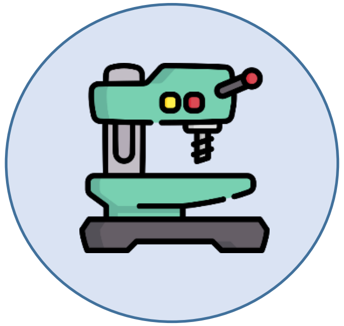
Given cutting speed, $V = 60$ m/min

$$\text{Spindle speed, } N = \frac{1000\times 30}{\pi\times 42} = 439.05 \text{ RPM}$$

The nearest RPM available from the list is 440 RPM.

$$\text{Machining time for one pass} = \frac{(120+2)}{0.10\times 440} = 2.77 \text{ minutes}$$

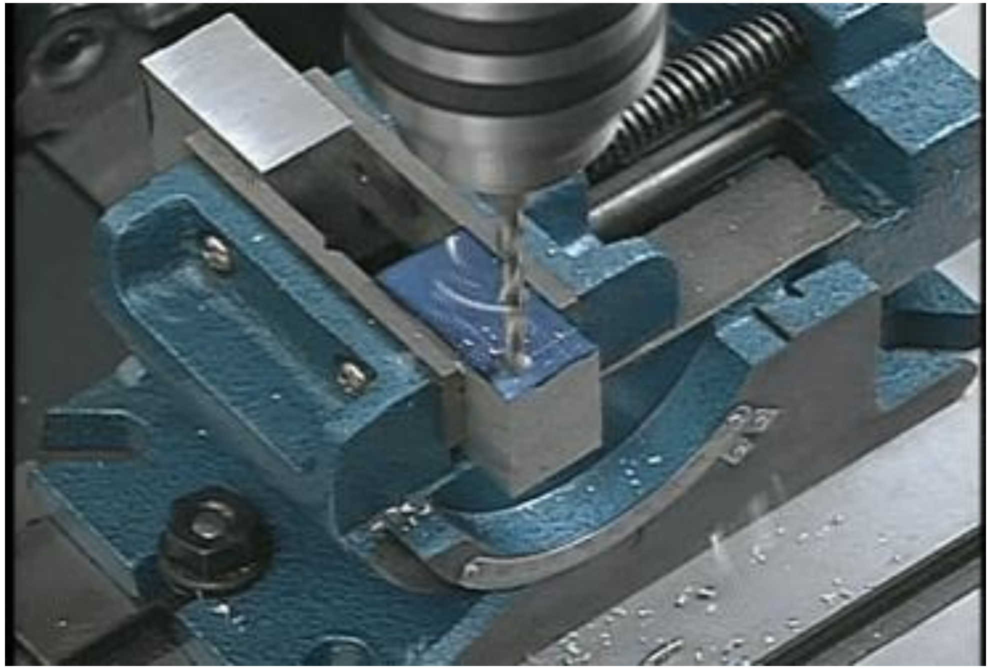
Total machining time $= 2\times 2.888 + 2.77 = 8.546$ minutes

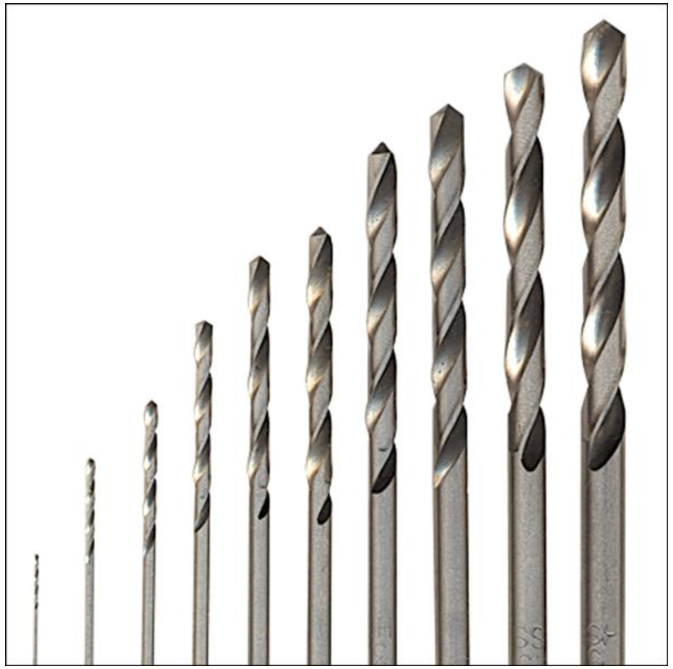


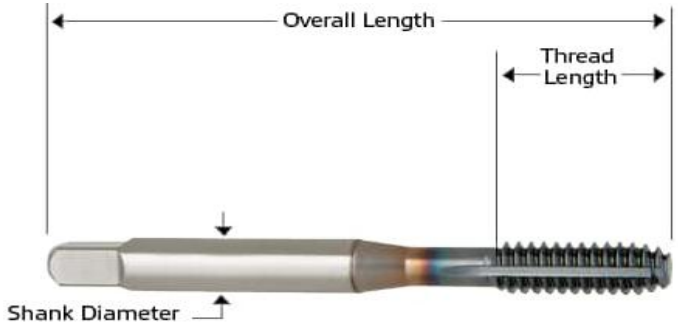
2 DRILLING

DRILLING

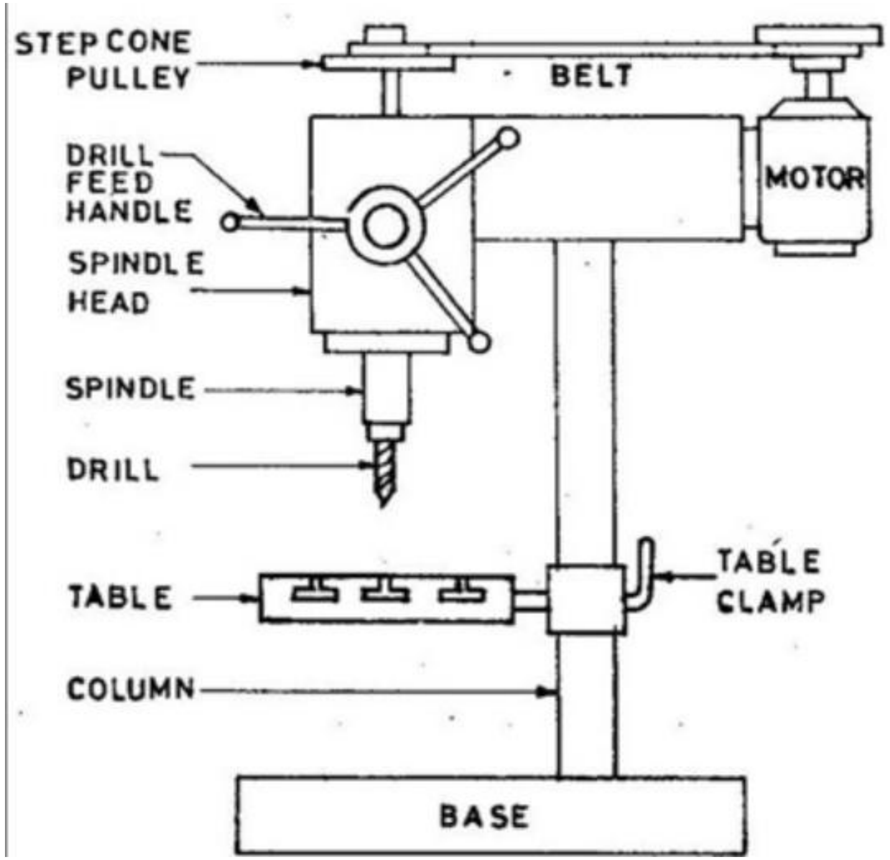
- Drilling is the operation of making primarily a hole in a workpiece using a drill bit
- Drilling machine is most common machine tool used, next to engine lathe
- The stationary work is held in a fixture and rotating tool is fed vertically to make a circular hole







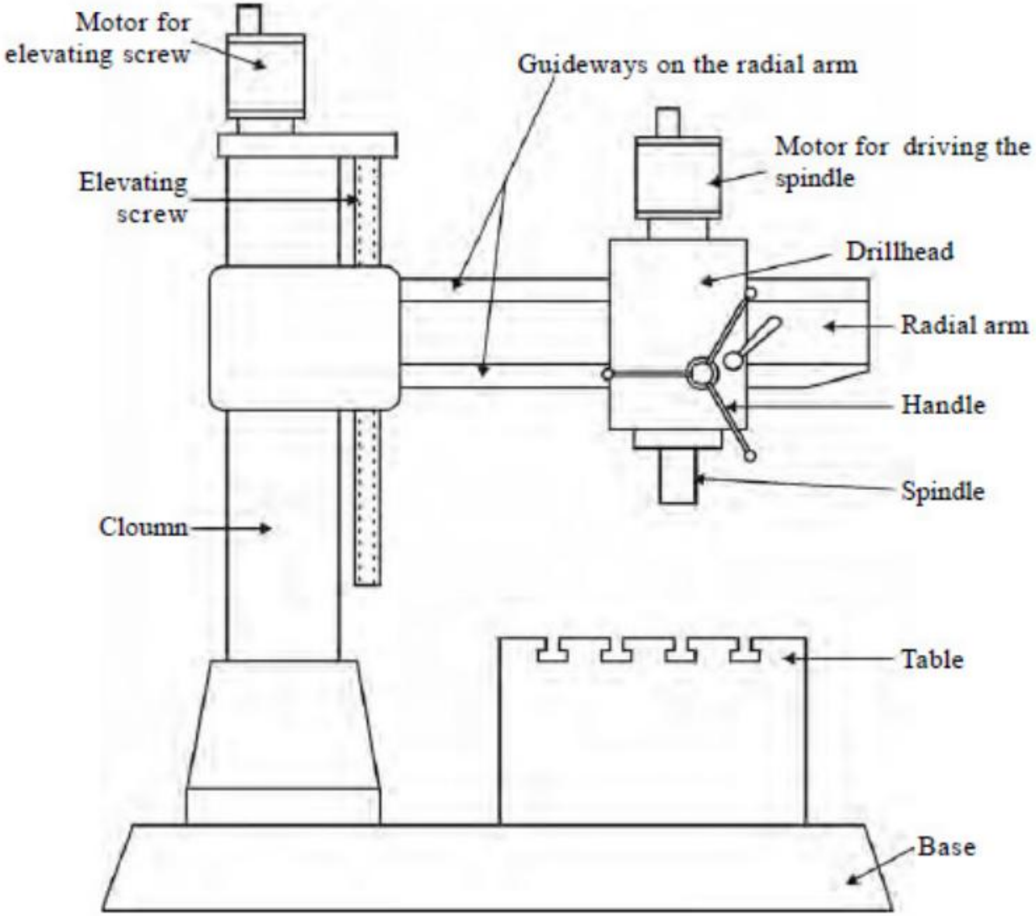
DRILLING



BENCH DRILLING MACHINE

Source: Internet

DRILLING



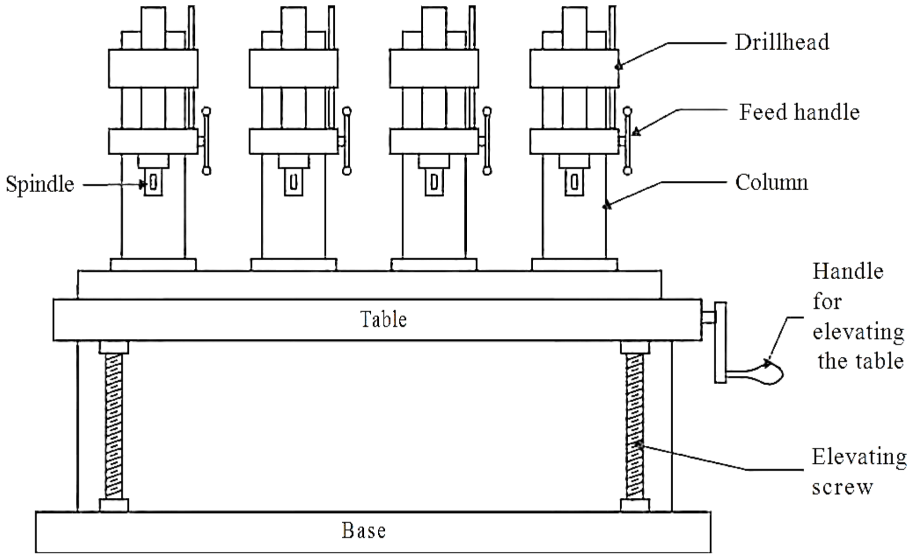
RADIAL DRILLING MACHINE

Source: Internet

DRILLING

GANG DRILL

- The machine consists of number of drill heads placed side by side in line so that more than one hole of same or different size can be drilled at the time on the same job or on different jobs
- The space between the drill spindles can be varied to suit the gap between the hole to be drilled.
- This machine is used generally to drill a large number of holes on the same job at a faster in a production job.
- The speed and feeds of the drill heads are generally controlled by individual means.

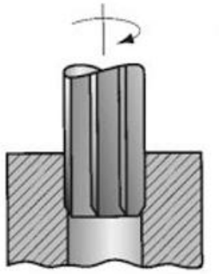


GANG DRILL

DRILLING

REAMING

- Smoothening the surface of the drilled hole. Has a straight flutes. Speed reduced to half of that of drilling



Reaming

BORING

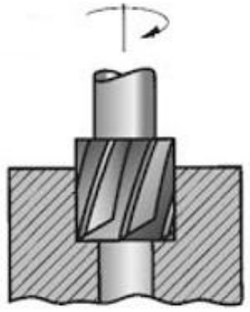
- To increase the size of an already drilled hole. It's a single point cutting tool

Boring

DRILLING

COUNTER BORING

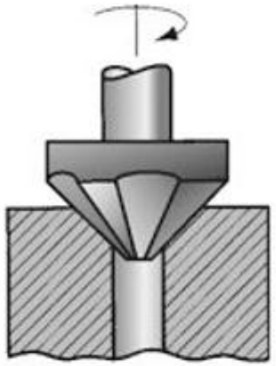
- Increase the size of the hole at one end only through a small depth. The cutting tool will have a pilot to guide the tool. Speed for counter boring must be two- third of the drilling speed



Counter boring

COUNTER SINKING

- Making the end of the hole into conical shape. Also be employed for deburring the hole. Speed should be half of that used for drilling



Counter sinking

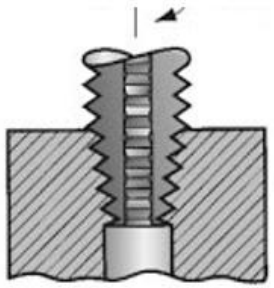
DRILLING

SPOT FACING

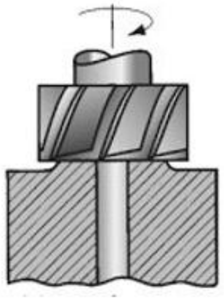
- Is a finishing operation to produce a flat round surface around a drilled hole, to give a good bearing surface for a screw or bolt head

TAPPING

- It's the process of cutting internal threads. Hole slightly smaller than the tap is drilled



Tapping



Spot facing

3 MILLING

MILLING

PRINCIPLE

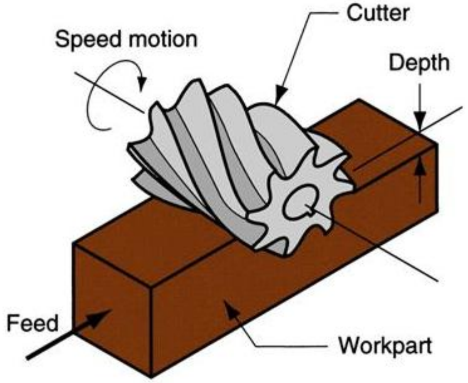
The milling cutter is a multipoint cutting tool. The workpiece is mounted on a movable work table which will be fed against the revolving milling cutter to perform the cutting operation

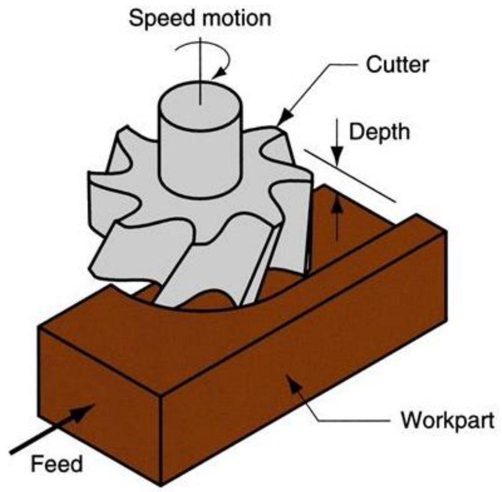
MILLING

OPERATION

- Milling operation can be classified into two broad categories: Peripheral Milling, Face Milling

- In peripheral milling the surface generated is at parallel with the axis of rotation of cutter. This type of milling is carried out in Horizontal milling machine

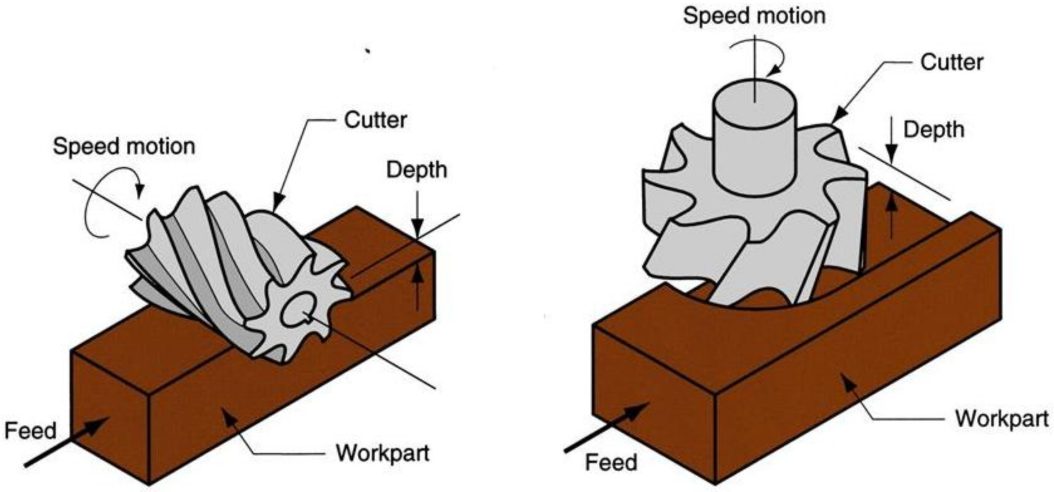




MILLING

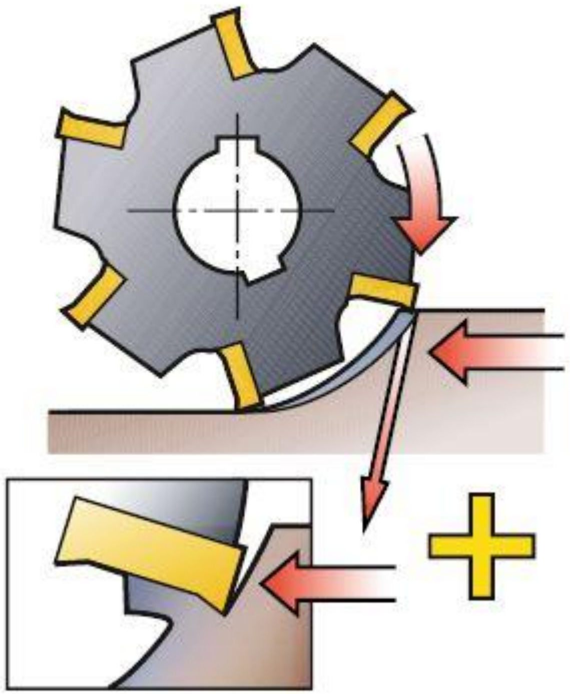
OPERATION

- In face milling surface generated is at right angle to the cutter axis. This type of milling is carried out in Vertical milling machine

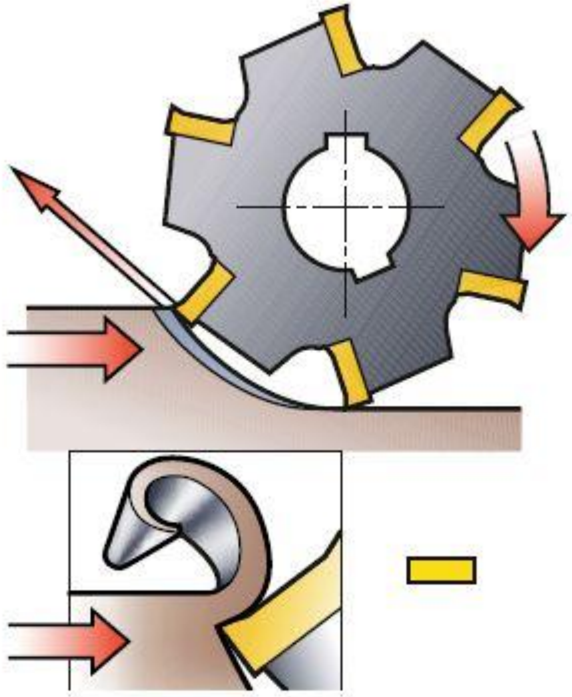


MILLING

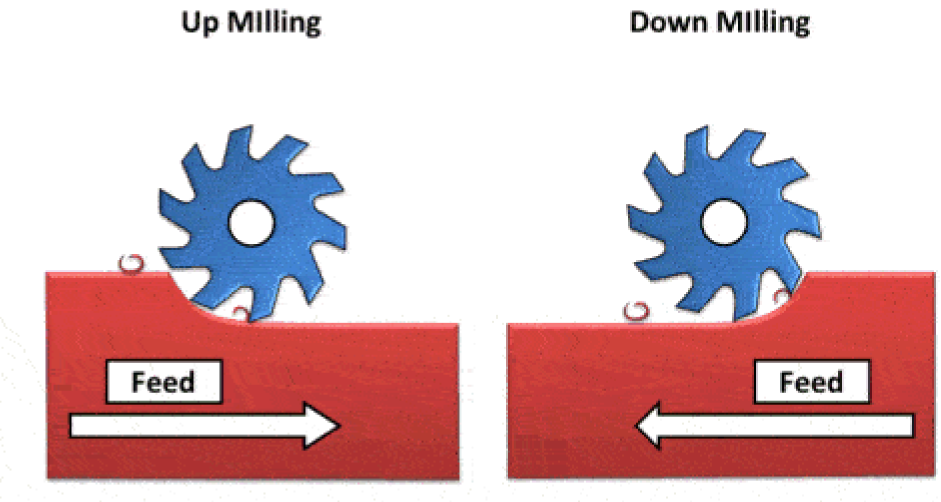
OPERATION



DOWN MILL



UP MILL



Source: Internet

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MILLING

UP MILLING	DOWN MILLING
In up milling cutter rotates against the direction of feed	Cutter rotates with the direction of feed
In this process, heat is diffused to the work piece which causes the change in metal properties	In down milling most of the heat diffuse to the chip without change the work piece properties
Progressive chip formation	Chip size is maximum at start and decreases with the feed

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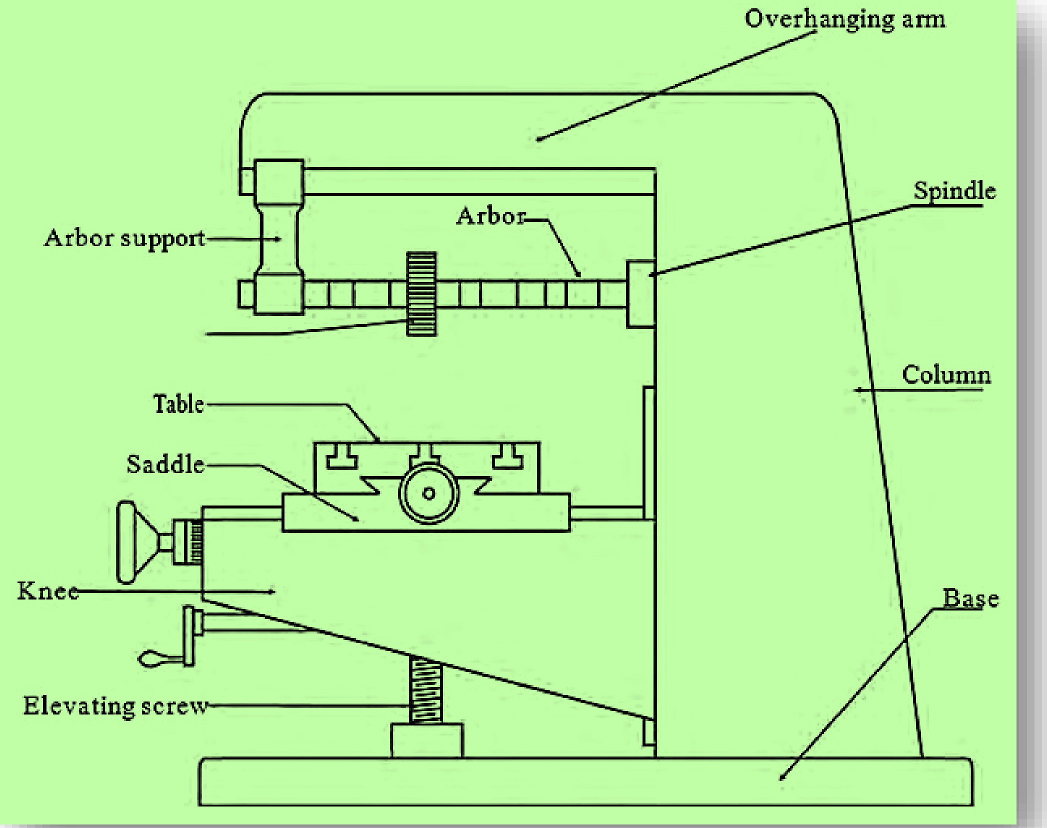
MILLING

CLASSIFICATION OF MILLING MACHINE

- HORIZONTAL MILLING MACHINE
- VERTICAL MILLING MACHINE
- UNIVERSAL MILLING MACHINE
- PLANER MILLING MACHINE
- PROFILE CUTTING MILLING MACHINE

MILLING

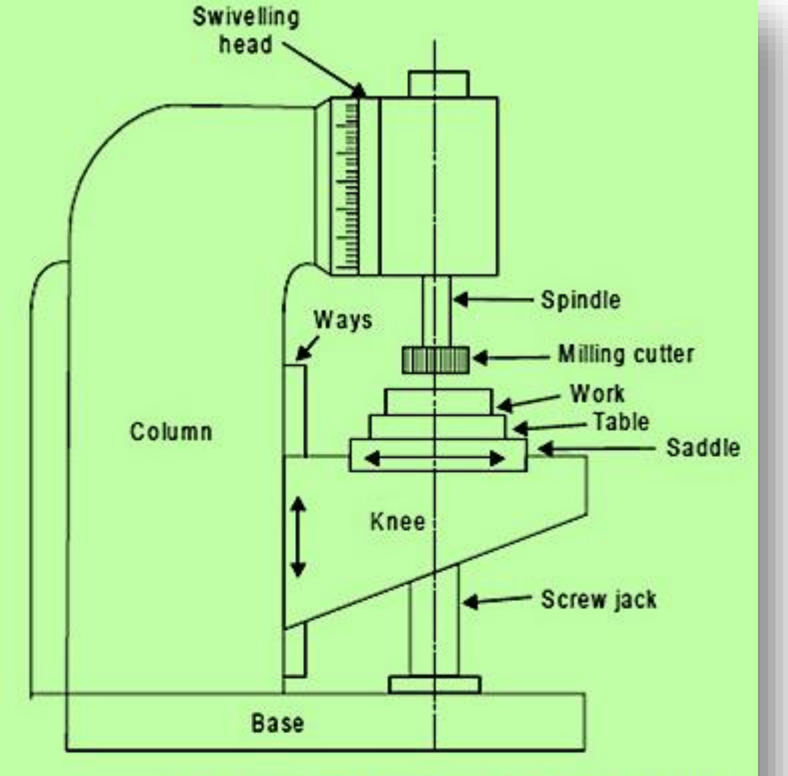
HORIZONTAL MILLING MACHINE



Source: Internet

MILLING

VERTICAL MILLING MACHINE



A column and knee type milling machine

Source: Internet

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MILLING

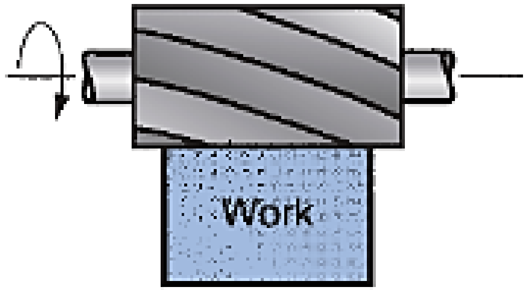
Sl No.	HORIZONTAL MILLING MACHINE	VERTICAL MILLING MACHINE
1	Spindle is horizontal and parallel to the worktable	Spindle is vertical and perpendicular to the worktable
2	Cutter cannot be moved up and down	Cutter can be moved up and down
3	Cutter is mounted on the arbor	Cutter is directly mounted on the spindle
4	Spindle cannot be tilted	Spindle can be tilted for angular cutting
5	Operation such as plan milling, gear cutting, form milling, straddle, gang milling etc.., can be performed	Operation such as slot milling, T-slots, flat milling and also different drilling operations can be performed

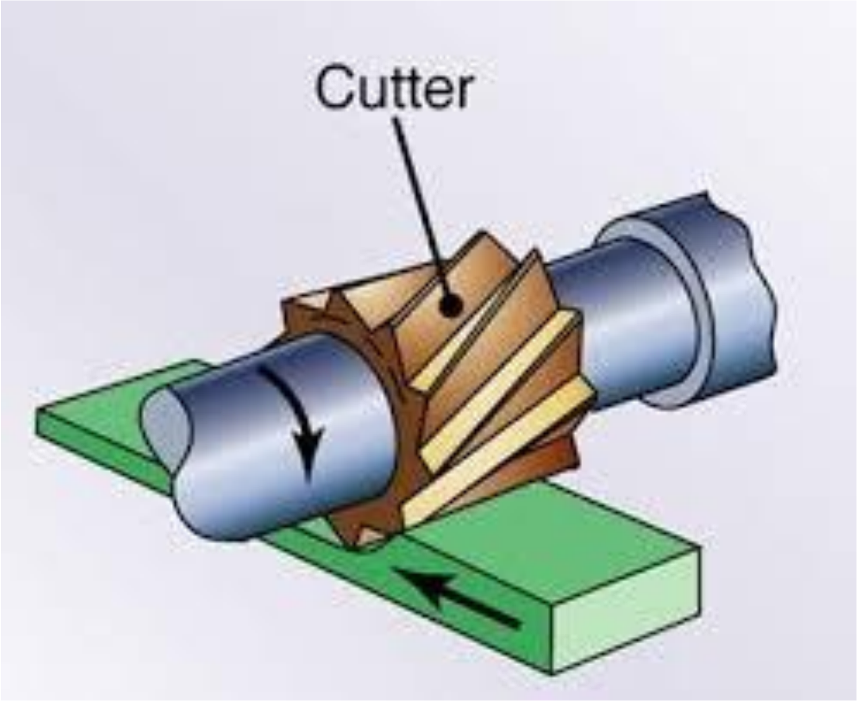
MILLING

MILLING OPERATIONS

SLAB MILLING

The basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides





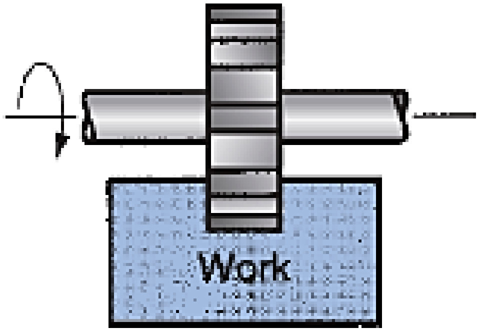
Source: Internet

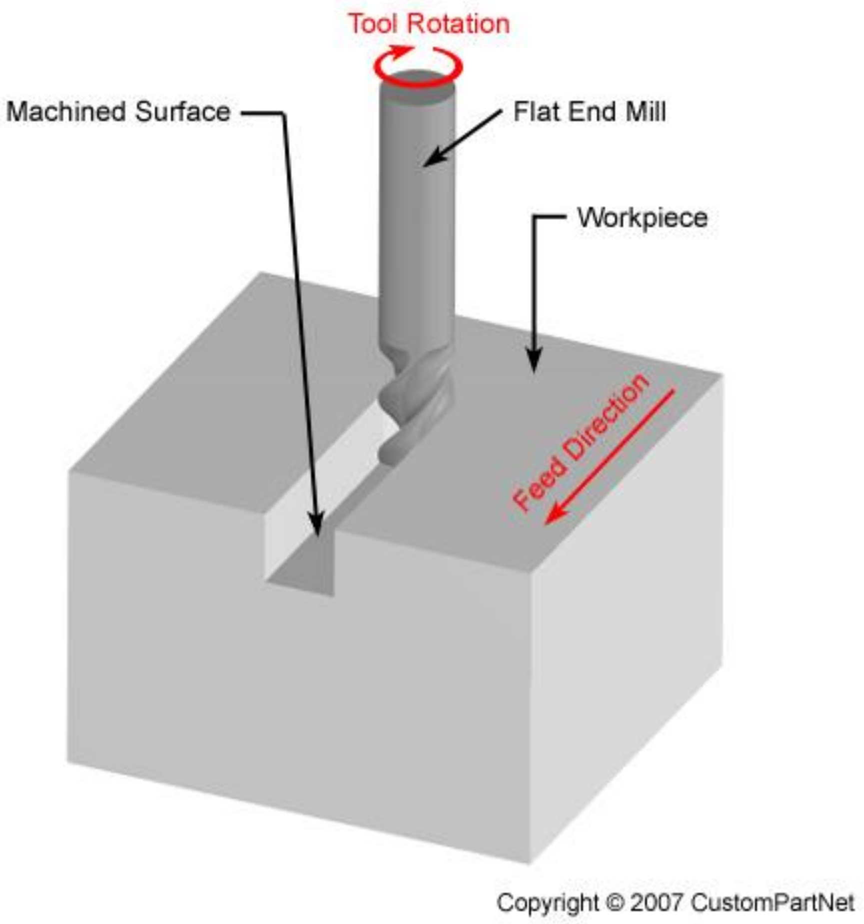
MILLING

PERIPHERAL MILLING

SLOTTING

In which the width of the cutter is less than the workpiece width, creating a slot in the work (when the cutter is very thin, this operation can be used to mill narrow slots





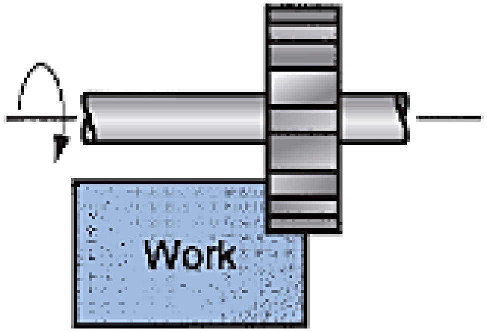
Source: Internet

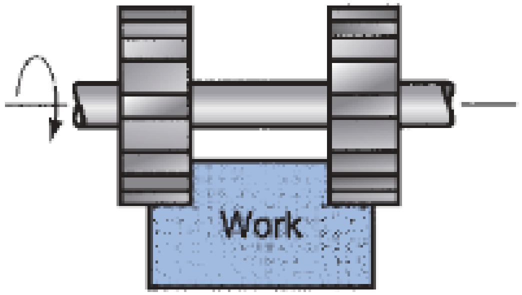
MILLING

MILLING OPERATIONS

SIDE & STRADDLE MILLING

Side milling – Cutter machines the side of the workpiece
Straddle milling – The same as side milling, only cutting takes place on both sides of the work





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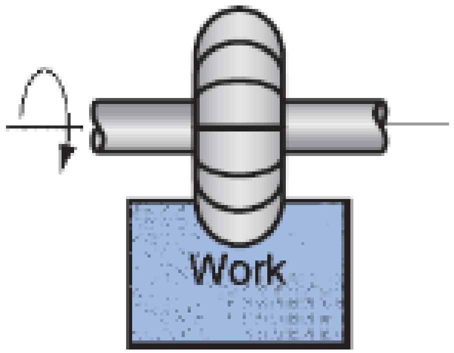
MILLING

MILLING OPERATIONS

FORM MILLING

Form milling – The milling teeth have a special profile that determines the shape of the slot that is cut in the work.



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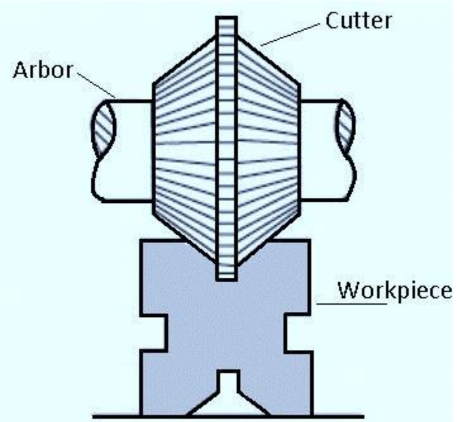
MILLING

MILLING OPERATIONS

ANGULAR MILLING

Form milling – Its operation of producing angular surface on the workpiece. a single or double cutter can be used to produce V grooves in the V- blocks



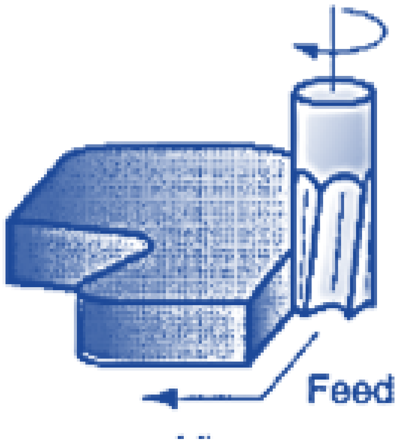
Angular Milling

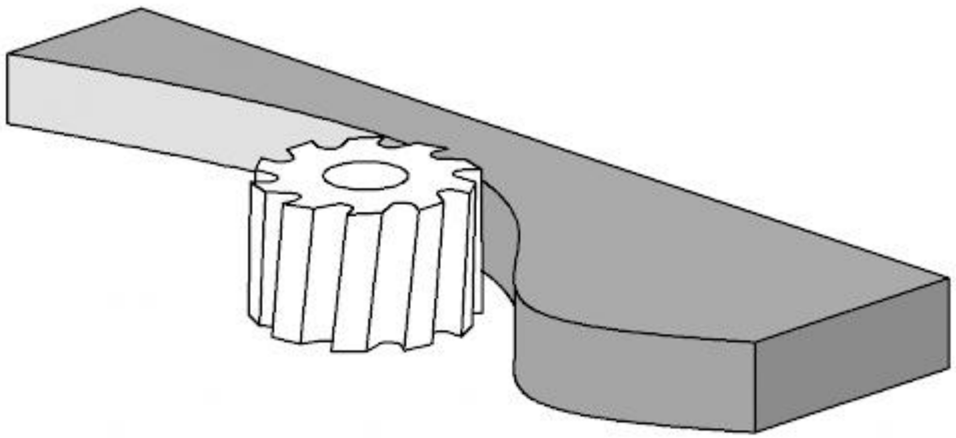
Source: Internet

MILLING

MILLING OPERATIONS

PROFILE MILLING – A form of end milling in which the outside periphery of a flat part is cut





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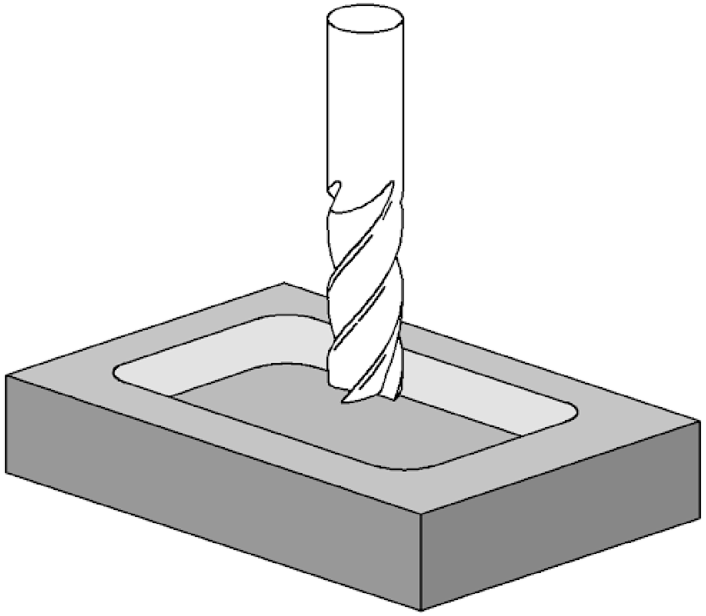
MILLING

MILLING OPERATIONS

POCKET MILLING – Another form of end milling used to mill shallow pockets into flat parts



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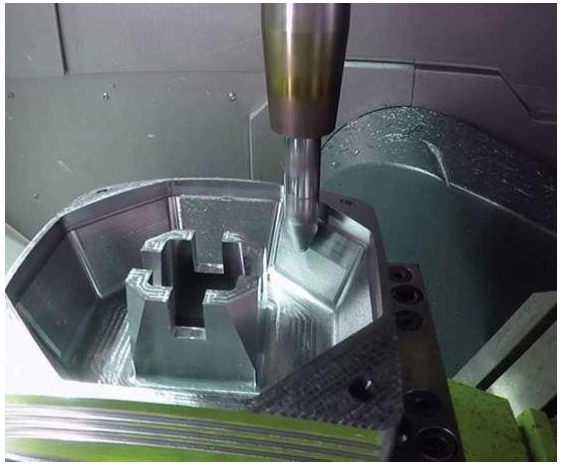
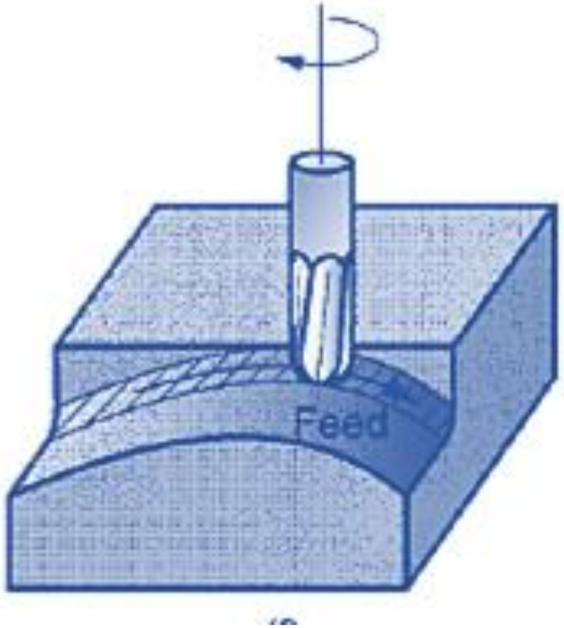
MILLING

MILLING OPERATIONS

SURFACE CONTOURING



A ball-nose cutter (rather than square-end cutter) is fed back and forth across the work along a curvilinear path at close intervals to create a three-dimensional surface form.



The same basic cutter control is required to machine the contours of mold and die cavities, in which case the operation is called die sinking.

GRINDING

- Grinding is a process carried out with a grinding wheel made up of abrasive grains for removing very fine quantities of material from the work piece surface.

- The required size of abrasive grains are thoroughly mixed with the bonding material and then pressed into a disc shape of given diameter and thickness.

- Grinding is a process used for
  - Machining materials which are too hard for other machining processes such as tool and die steels and hardened steel materials,
  - Close dimensional accuracy of the order of 0.3 to 0.5 mm, and
  - High degree of surface smoothness such as Ra = 0.15 to 1.25 mm.

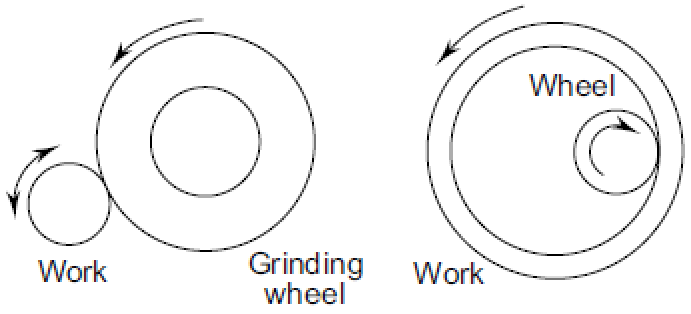
GRINDING

- Grinding operations are generally classified based on the type of surface produced. The grinding operations possible can be classified into
  - Cylindrical grinding for generating cylindrical surfaces
  - Surface grinding for generating flat surfaces, and
  - Centre less grinding for generating axi-symmetric shapes.

- The **cylindrical grinding** machine is used generally for producing external cylindrical surfaces. The machine is very similar to a centre lathe. Typical movements in a cylindrical grinding machine are shown in Fig.

- The grinding wheel is located similar to the tool post, with an independent power driven at high speed suitable for grinding operation. Both the work and the grinding wheel rotate counter clockwise.

- The work that is normally held between centres is rotated at much lower speed compared to that of the grinding wheel.

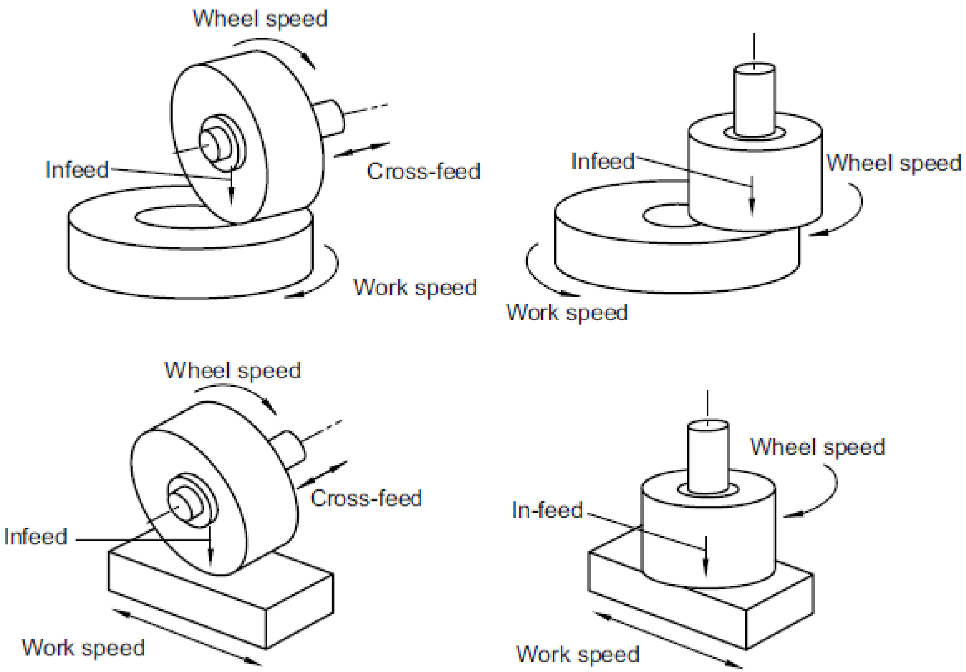


(a) Cylindrical grinding

GRINDING

- Surface grinding machines are generally used for generating flat surfaces. By far these are used for the largest amount of grinding work done in most of the machine shops.

- These machines are similar to milling machines in construction as well as motion. There are basically four types of machines depending upon the spindle direction and the table motion as shown. They are –
- Horizontal spindle and rotating table
- Vertical spindle and rotating table
- Horizontal spindle and reciprocating table
- Vertical spindle and reciprocating table



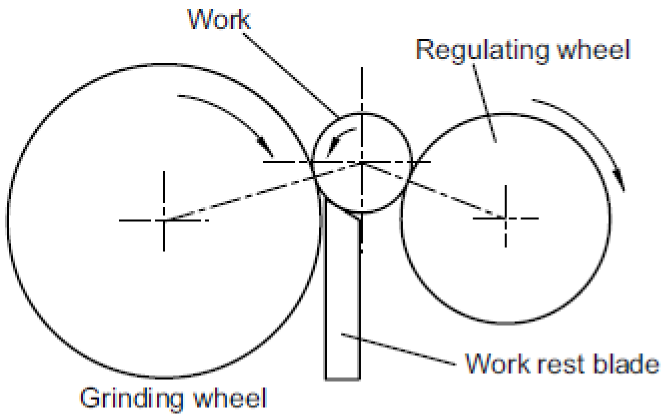
GRINDING

- Centre less grinding makes it possible to grind cylindrical work pieces without actually fixing the work piece using centres or a chuck. As a result no work rotation is separately provided.

- The process consists of two wheels, one large grinding wheel and another smaller regulating wheel. The work is held on a work rest blade. The regulating wheel is mounted at an angle to the plane of the grinding wheel.

- The centre of the work piece is slightly above the centre of the grinding wheel. The work piece is supported by the rest blade and held against the regulating wheel by the grinding force.

- As a result the work rotates at the same surface speed as that of the regulating wheel. The axial feed of the work piece is controlled by the angle of tilt of the regulating wheel.



NUMERICAL CONTROL

- Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers and symbols.

- Basically a NC machine runs on a program fed to it. The program consists of precise instructions about the methodology of manufacture as well as the movements. For example what tool to be used, at what speed, at what feed and to move from which point to which point in what path.

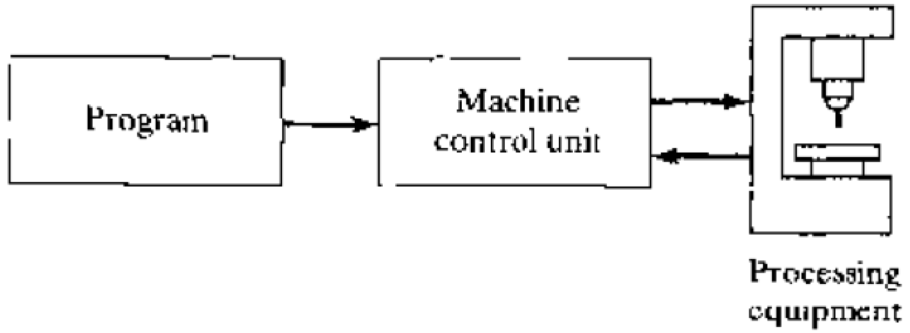
- In NC machine tools one or more of the following functions may be automatic:
  (a) starting and stopping of machine tool spindle
  (b) controlling the spindle speed
  (c) positioning the tool tip at desired locations and guiding it along desired paths by automatic control of the motion of slides
  (d) controlling the rate of movement of the tool tip (i.e. feed rate)
  (e) changing of tools in the spindle.

BASIC COMPONENTS OF NC SYSTEM

- The program of instructions is the detailed step by step commands that direct the actions of the processing equipment.

- In machine tool applications, the program of instructions is called a **part program**.

- The individual commands refer to positions of a cutting tool relative to the worktable on which the workpart is fixtured. Additional instructions are usually included such as spindle speed, feed rate, cutting tool selection and other functions.



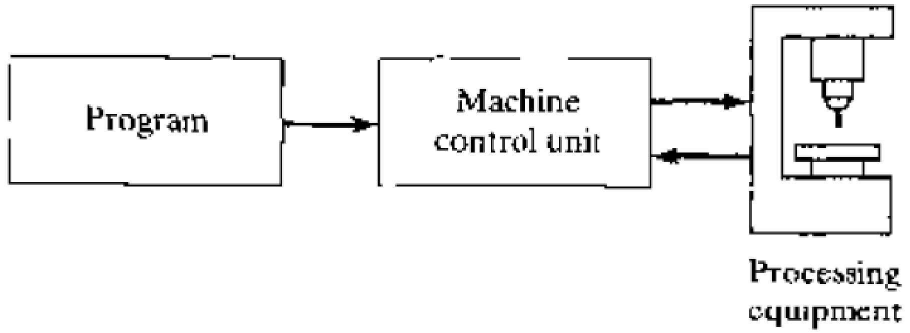
NC Part Program Code	Comments
N001 G21 G90 G92 X0 Y-050.0 Z010.0;	Define origin of axes.
N002 G00 X070.0 Y030.0;	Rapid move to first hole location.
N003 G01 G95 Z-15.0 F0.05 S1000 M03;	Drill first hole.
N004 G01 Z010.0;	Retract drill from hole.
N005 G00 Y060.0;	Rapid move to second hole location.
N006 G01 G95 Z-15.0 F0.05;	Drill second hole.
N007 G01 Z010.0;	Retract drill from hole.

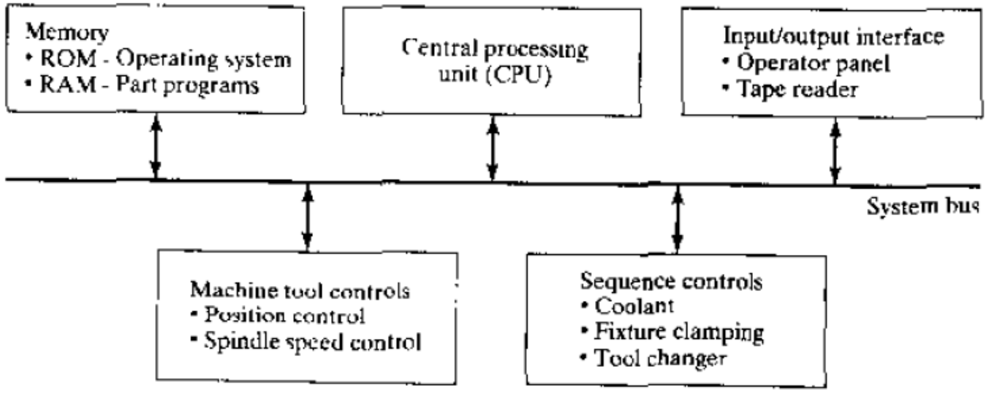
BASIC COMPONENTS OF NC SYSTEM

- Computer numerical control (CNC) is defined as an NC system whose machine control unit is based on a dedicated microcomputer rather than on a hard-wired controller.

- The MCU consists of the following components and subsystems:
  (1) central processing unit
  (2) memory,
  (3) I/O interface.
  (4) controls for machine tool axes and spindle speed and
  (5) sequence controls for other machine tool functions.

- These subsystems are interconnected by means of a system bus. as indicated in the figure.





CNC MACHINING CENTRES

- A machining centre is a computer controlled machine capable of performing a variety of cutting operations on different surfaces and directions on a workpiece.

- The CNC machining centres can be broadly categorised into two varieties:
  - Vertical axis machining centre, and
  - Horizontal axis machining centre.

MACHINING CENTRES

Accuracy and tolerances of the order +- 0.0025mm can be maintained

RPM of the order 25,000 is possible on spindles.

Takes less floor space, improved productivity, quick change over of tools etc.

Machines are equipped with tool-condition monitoring devices

Machining centres are very costly ($1 million or higher)

VERTICAL AXIS MACHINING CENTRE

- The vertical axis machining centres or VMC as is popularly abbreviated, are generally more versatile in terms of the tool being able to generate more complex surfaces compared to the horizontal axis.

- Most of the general machines come with 3 axes. Additional axes will be added to cater to the machining of more complex geometries.

- For example the spindle head can be swivelled in one or two axes (about X or Y axis). These are required for machining sculptured surfaces.

HORIZONTAL AXIS MACHINING CENTRE

- By its very configuration, the horizontal axis machining centre or popularly called HMC is sturdier than the vertical configuration and hence is used for heavier work pieces with large metal removal rates.

- Since these machines provide for heavier metal removal rates, the cutting tools used would normally be big. As a result, the tool magazine will have to provide larger place for each tool.

- This results in the tool magazines for HMC to become heavier. Also, they are normally provided with tool magazines having higher capacity.

CNC TURNING CENTRE

- Majority of the components machined in the industry are of the cylindrical shape. Hence the CNC lathes, more appropriately called turning centres, are also important machine tools.

- Most of the turning centres are also provided with a tool turret which may have a capacity of 8 to 12 tools of various types.

HOW DO YOU PRODUCE THESE COMPONENTS?

Source: Internet

MECHANICAL ENGINEERING SCIENCE

Chapter 2 – Automation, Robotics, Control Systems and Industry 4.0

Dr. Mantesh Basappa Khot
Department of Mechanical Engineering

4 ROBOTICS

ROBOTICS

An industrial robot is defined as "an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications

ROBOTICS

Some of the qualities that make industrial robots commercially and technologically important are the following:

- Robots can be substituted for humans in hazardous or uncomfortable work environments

- A robot performs its work cycle with a consistency and repeatability that cannot be attained by humans
- When the production run of the current task is completed, a robot can be reprogrammed and equipped with the necessary tooling to perform an altogether different task

- Robots are controlled by computers and can therefore be connected to other computer systems to achieve computer integrated manufacturing

ROBOTICS

ROBOT ANATOMY AND RELATED ATTRIBUTES

- In a robot, the connection of different manipulator joints is known as ***Robot Links***, and the integration of two or more link is called as ***Robot Joints***

- A robot link will be in the form of solid material, and it can be classified into two key types ***input link and output link***

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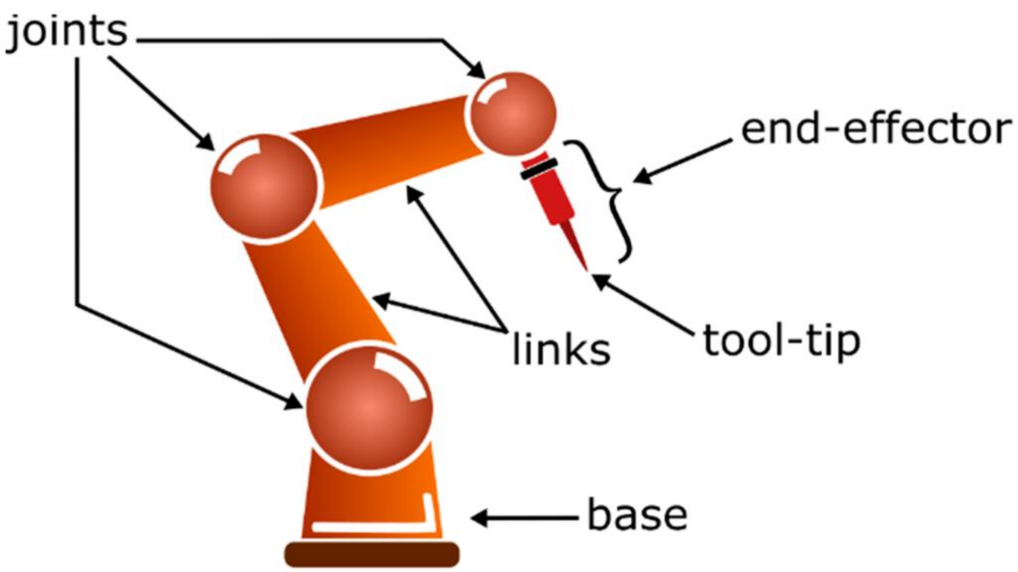
ROBOTICS

ROBOT ANATOMY AND RELATED ATTRIBUTES



ROBOTICS

ROBOT ANATOMY AND RELATED ATTRIBUTES

Nearly all industrial robots have mechanical joints that can be classified into one of five types:

Two types that provide translational motion and three types that provide rotary motion

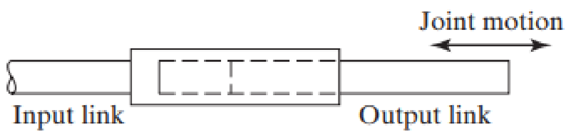
ROBOTICS

DIFFERENT TYPES OF ROBOT JOINTS

- Rotational joint
- Linear joint
- Twisting joint
- Orthogonal joint
- Revolving joint

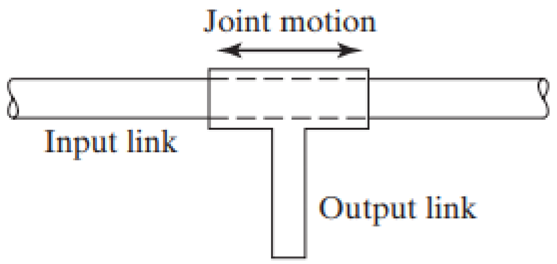
ROBOTICS

DIFFERENT TYPES OF ROBOT JOINTS

JOINT	DESCRIPTION	SCHEMATIC
Linear joint	Type L joint; the relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links parallel	

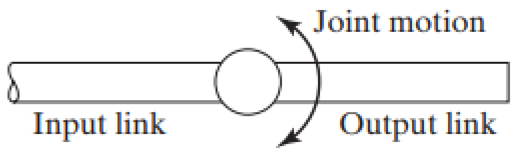
ROBOTICS

DIFFERENT TYPES OF ROBOT JOINTS

JOINT	DESCRIPTION	SCHEMATIC
Orthogonal joint	Type O joint; the relative movement between the input link and the output link is a translational sliding motion, but the output link is perpendicular to the input link	

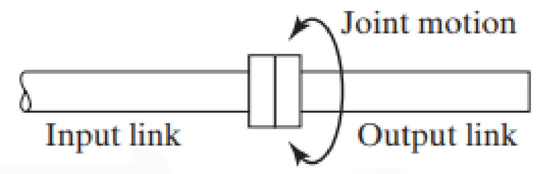
ROBOTICS

DIFFERENT TYPES OF ROBOT JOINTS

JOINT	DESCRIPTION	SCHEMATIC
Rotational joint	Type R joint; this provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links	

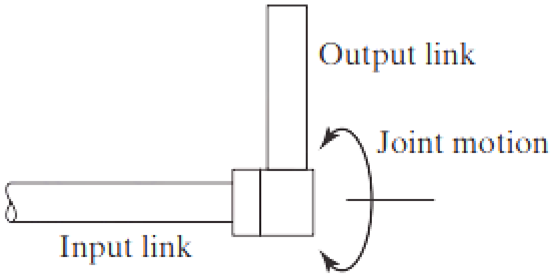
ROBOTICS

DIFFERENT TYPES OF ROBOT JOINTS

JOINT	DESCRIPTION	SCHEMATIC
Twisting joint	Type T joint; this provides rotary motion, but the axis of rotation is parallel to the axes of the two links	

ROBOTICS

DIFFERENT TYPES OF ROBOT JOINTS

JOINT	DESCRIPTION	SCHEMATIC
Revolving joint	Type V joint; the axis of the input link is parallel to the axis of rotation of the joint, and the axis of the output link is perpendicular to the axis of rotation	

Robot Configurations

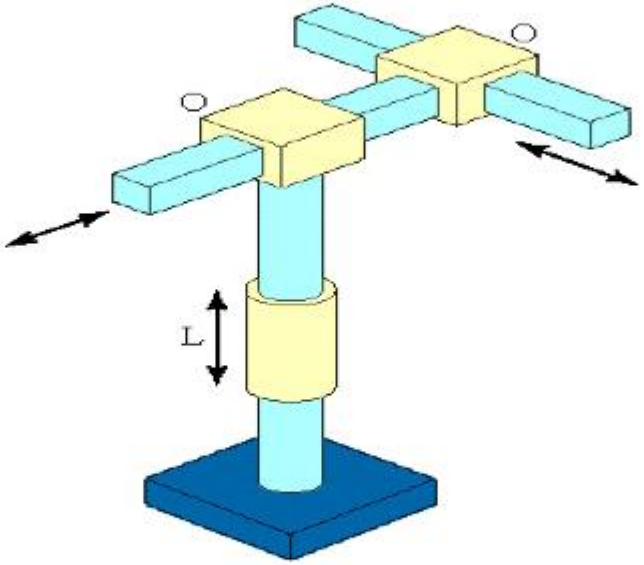
- A robot manipulator can be divided into two sections: a **body and arm assembly** and a **wrist assembly.**

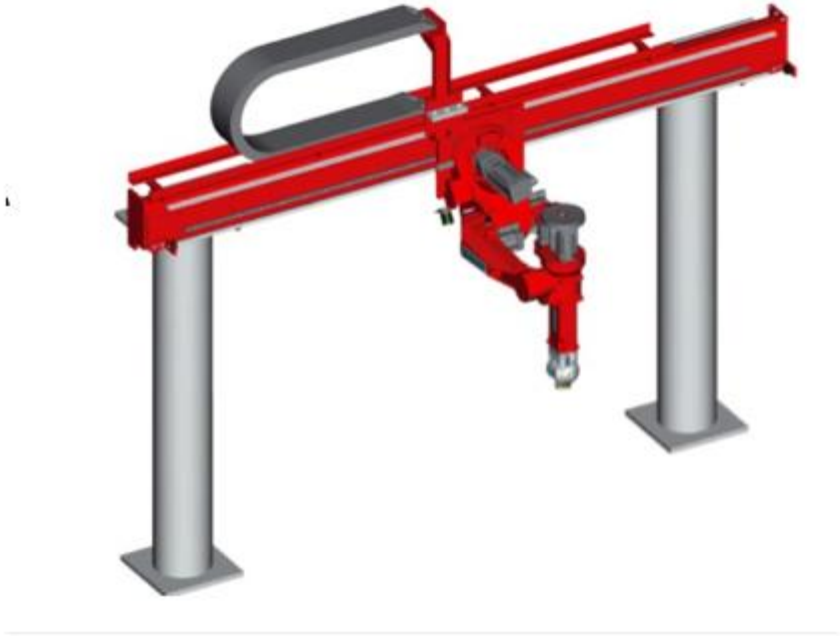
- At the end of the manipulator's wrist is a device related to the task that must be accomplished by the robot. The device called an **end effector** is usually either
  (1) a gripper for holding a work part
  (2) a tool for performing some process.

- The body and arm of the robot is used to position the end effector and the robot's wrist is used to orient the end effector.

Body and Arm Configurations

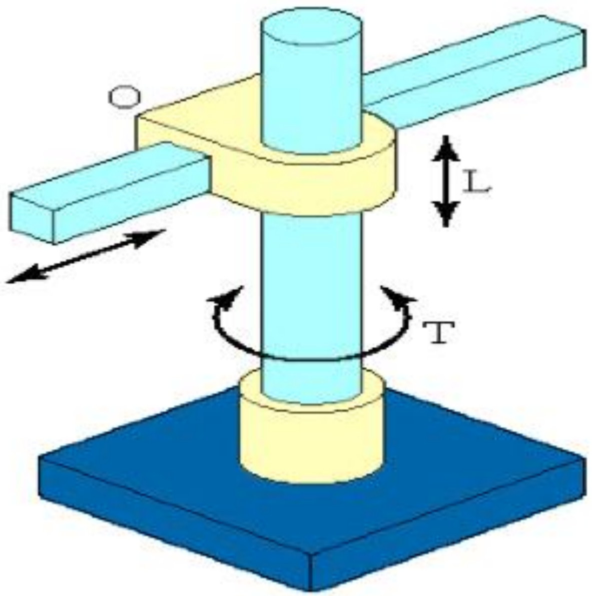
Cartesian coordinate robot – Other names for this configuration include rectilinear robot and x – y – z robot. As shown in Figure, it is composed of three sliding joints, two of which are orthogonal.





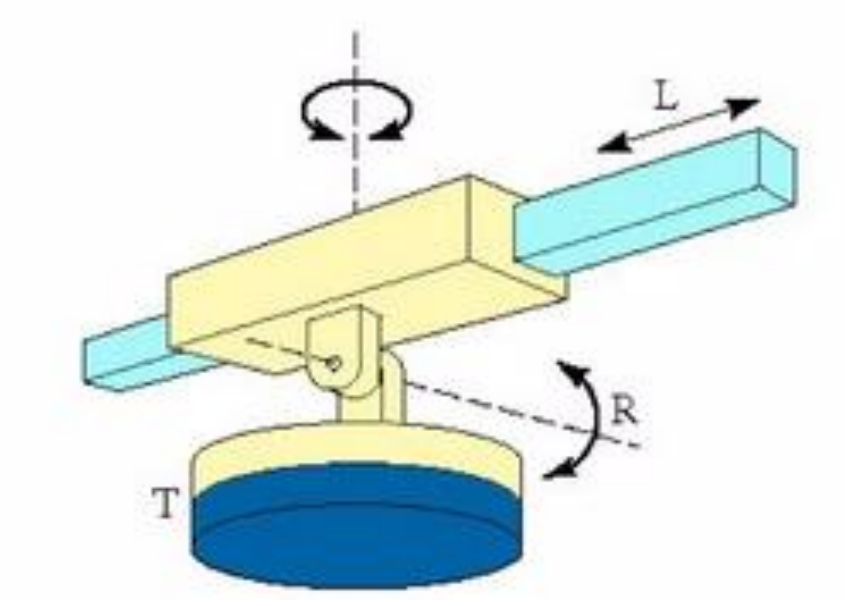
Body and Arm Configurations

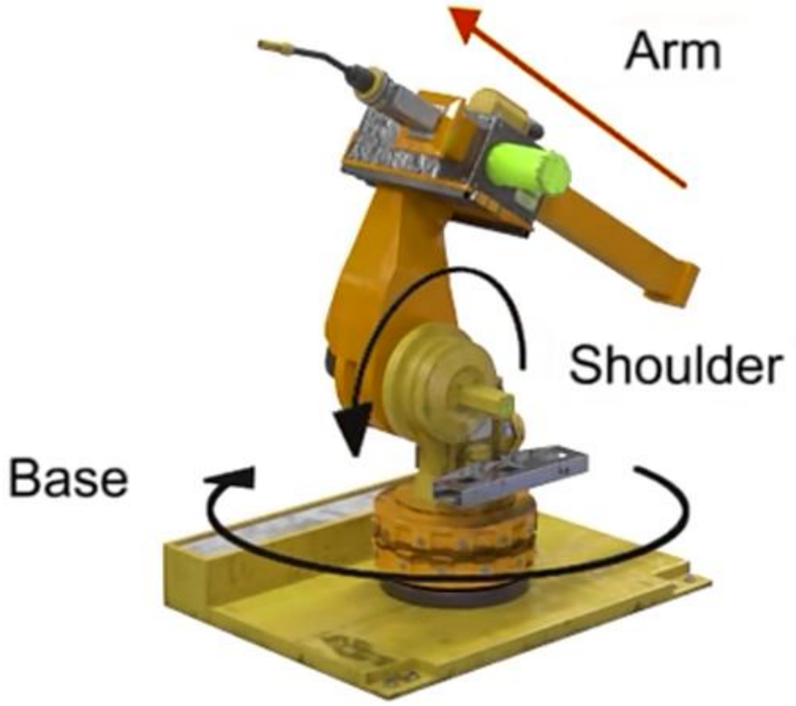
Cylindrical configuration – This robot configuration consists of a vertical column, relative to which an arm assembly is moved up or down. The arm can be moved in and out relative to the axis of the column. The column can be rotated about it's axis.



Body and Arm Configurations

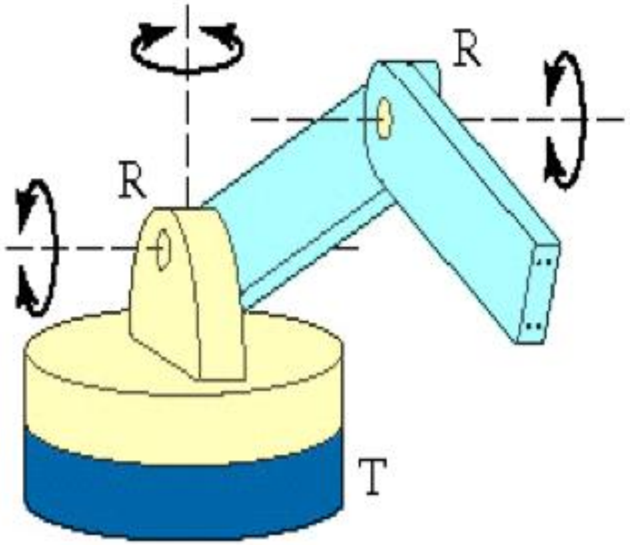
Polar configuration – This configuration consists of a sliding arm (L joint) actuated relative to the body, that can rotate about both a vertical axis (T joint) and a horizontal axis (R joint).





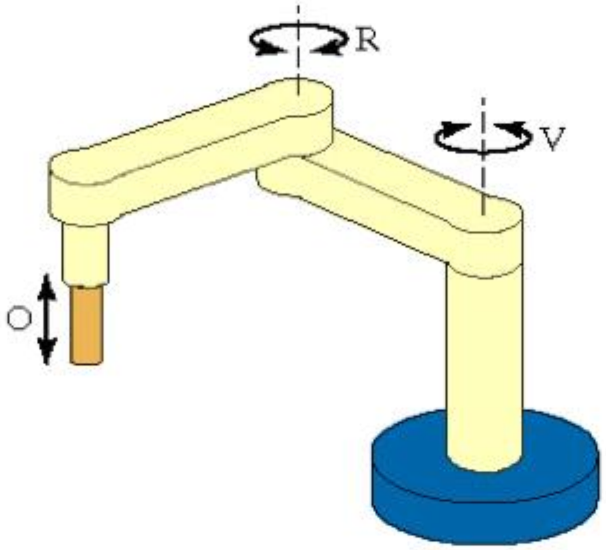
Body and Arm Configurations

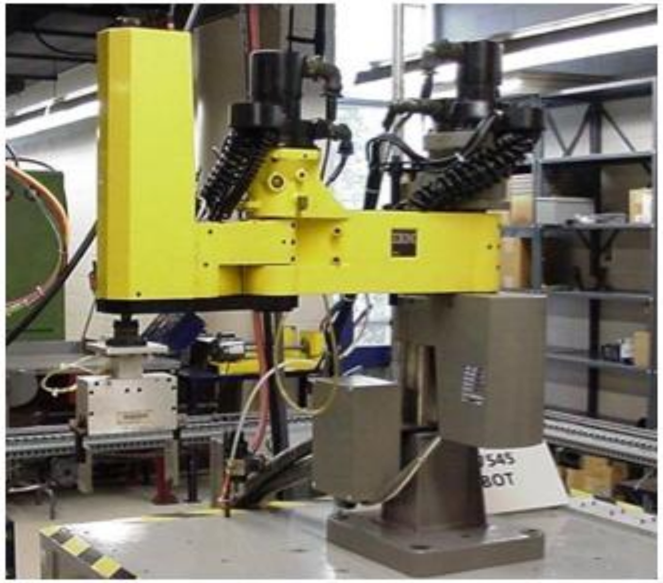
Jointed arm robot – This robot manipulator has the general configuration of a human arm. The jointed arm consists of a vertical column that swivels about the base using a T joint. At the top of the column is a shoulder joint (shown as an R joint in the figure), whose output link connects to an elbow joint (another R joint).



Body and Arm Configurations

SCARA – SCARA is an acronym for Selective Compliance Assembly Robot Arm. This configuration is similar to the jointed arm robot except that the shoulder and elbow rotational axes are vertical, which means that the arm is very rigid in the vertical direction, but compliant in the horizontal direction. This permits the robot to perform insertion tasks (for assembly) in a vertical direction, where some side to side alignment may be needed to mate the two parts properly.



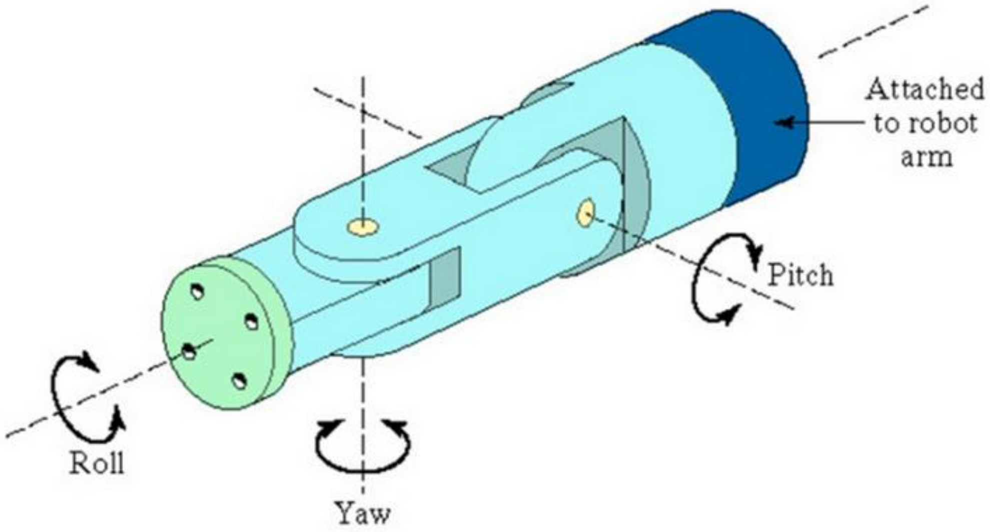


Wrist Configurations

- The robot's wrist is used to establish the orientation of the end effector.

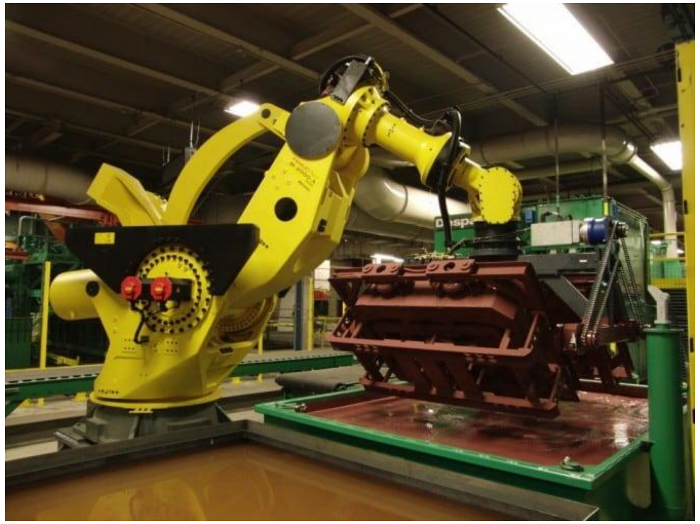
- The three joints are defined as:

1) **Roll**, using a T joint to accomplish rotation about the robot's arm axis
2) **Pitch**, which involves up and down rotation, typically using a R joint
3) **Yaw**, which involves right and left rotation, also accomplished by means of a R - joint.



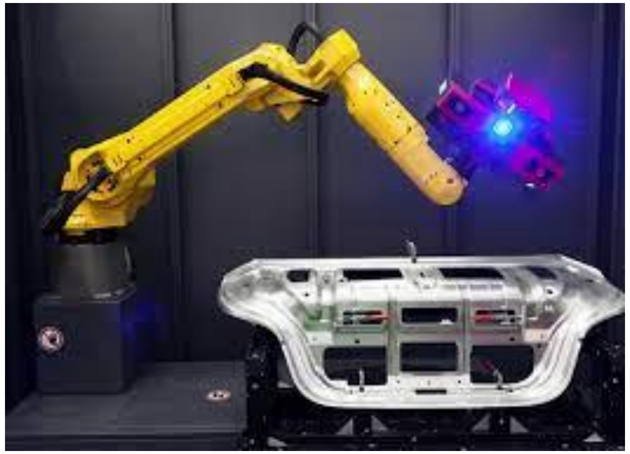
Applications

- Material handling applications –
  1) Material transfer
  2) Machine loading and/or unloading



- Processing Operations – Spot welding, Continuous arc welding, Spray painting etc.

- Assembly and Inspection



AUTOMATION

***Automation** can be defined as the technology by which a process or procedure is accomplished without human assistance*

- **To automate a process, power is required, both to drive the process itself and to operate the program and control system**
- **Although automation can be applied in a wide variety of areas, it is most closely associated with the manufacturing industries**

PES UNIVERSITY

AUTOMATION

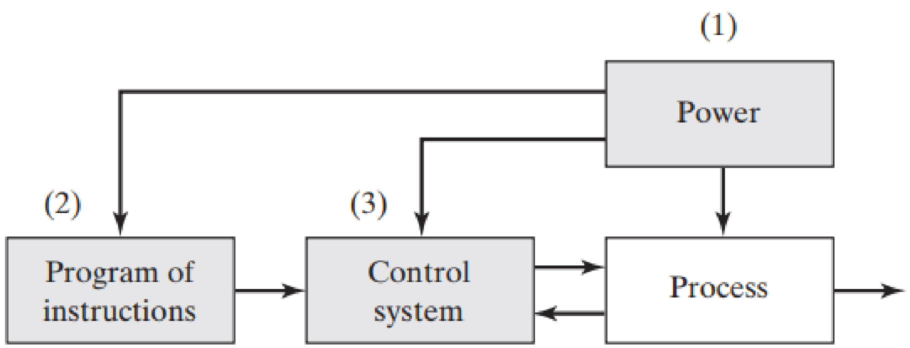
- Automated manufacturing systems operate in the factory on the physical product
- They perform operations such as processing, assembly, inspection, or material handling, in some cases accomplishing more than one of these operations in the same system

AUTOMATION

ELEMENTS OF AUTOMATED SYSTEM

An automated system consists of three basic elements:

- power to accomplish the process and operate the system
- a program of instructions to direct the process, and
- a control system to actuate the instructions



AUTOMATION

TYPES OF AUTOMATION

- *Fixed automation*
- *Programmable automation*
- *Flexible automation*

AUTOMATION

TYPES OF AUTOMATION

Fixed automation:

- Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration

The typical features of fixed automation are:

- High initial investment for custom-engineered equipment
- High production rates
- Relatively inflexible in accommodating product changes

Programmable automation:

- In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations

- New programs can be prepared and entered into the equipment to produce new products
- Automated production systems that are programmable are used in low and medium-volume production

- The parts or products are typically made in batches

- To produce each new batch of a different product, the system must be reprogrammed with the set of machine instructions that correspond to the new product

Programmable automation:

Some of the features that characterize programmable automation include:

- High investment in general-purpose equipment
- Low production rates relative to fixed automation
- Flexibility to deal with changes in product configuration
- Most suitable for batch production

Flexible automation:

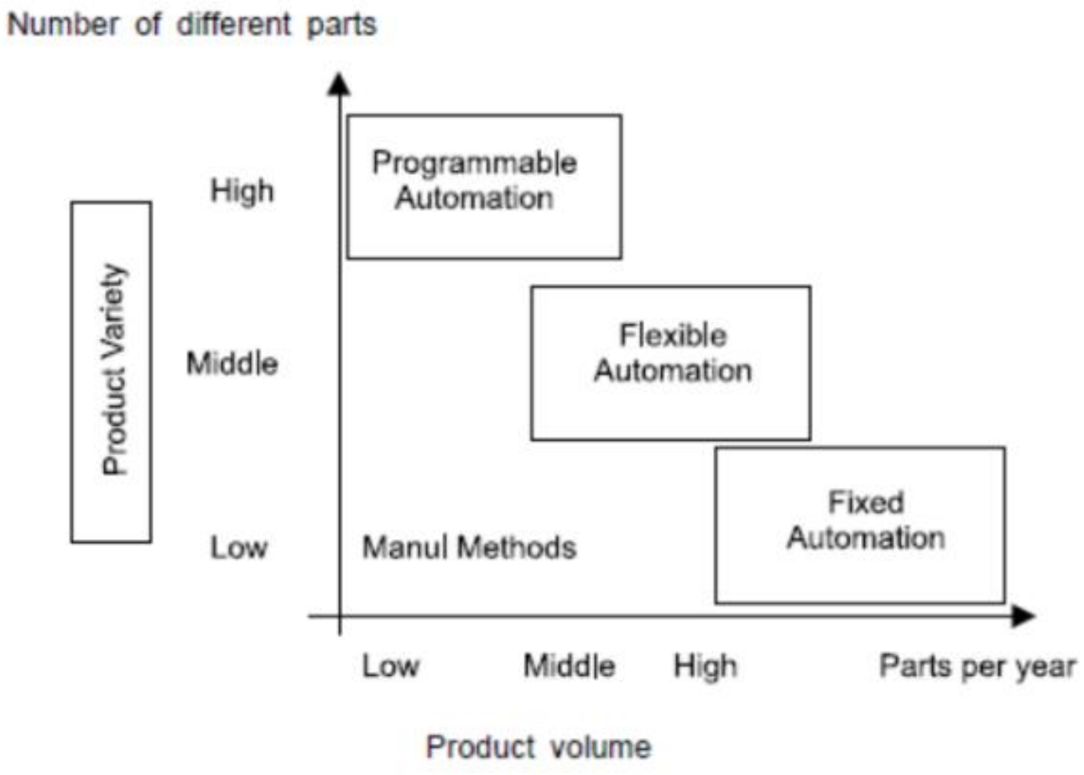
- Flexible automation is an extension of programmable automation
- A flexible automated system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeovers from one product to the next
- There is no production time lost while reprogramming the system and altering the physical setup (tooling, fixtures and machine settings)
- These features allow the automated production system to continue production without the downtime between batches that is characteristic of programmable automation

Flexible automation:

The features of flexible automation can be summarized as follows:

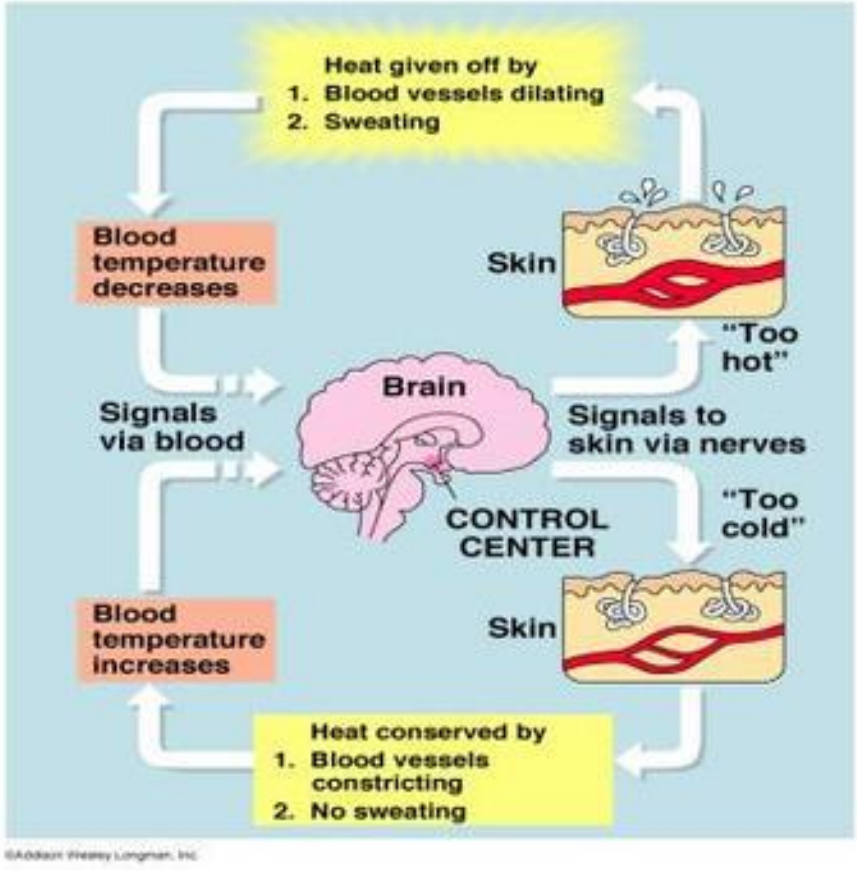
- High investment for a custom-engineered system
- Continuous production of variable mixtures of products
- Medium production rates
- Flexibility to deal with product design variations

TYPES OF AUTOMATED MANUFACTURING SYSTEMS



INTRODUCTION TO CONTROL SYSTEMS

- *The control system is that means by which any quantity of interest in a machine, mechanism or other equipment is maintained or altered in accordance with a desired manner.*



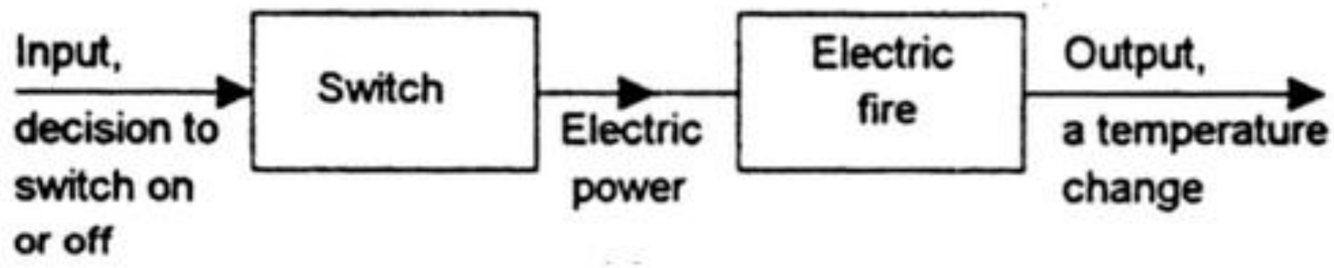
Your body temperature remains almost constant regardless of whether you are in a cold or hot environment. To maintain this constancy your body has a temperature control system. If your temperature begins to increase above the normal you sweat, if it decreases you shiver. Both these are mechanisms which are used to restore the body temperature back to its normal value. The control system is maintaining constancy of body temperature.

OPEN AND CLOSED LOOP CONTROL SYSTEMS

- There are two basic forms of control system, one being called ***open loop and the other closed loop***.

- Consider an electric fire which has a selection switch which allows a 1 kW or a 2kW element to heat a room, he or she might just switch on the 1 kW element if the room is not required to be at too high a temperature.

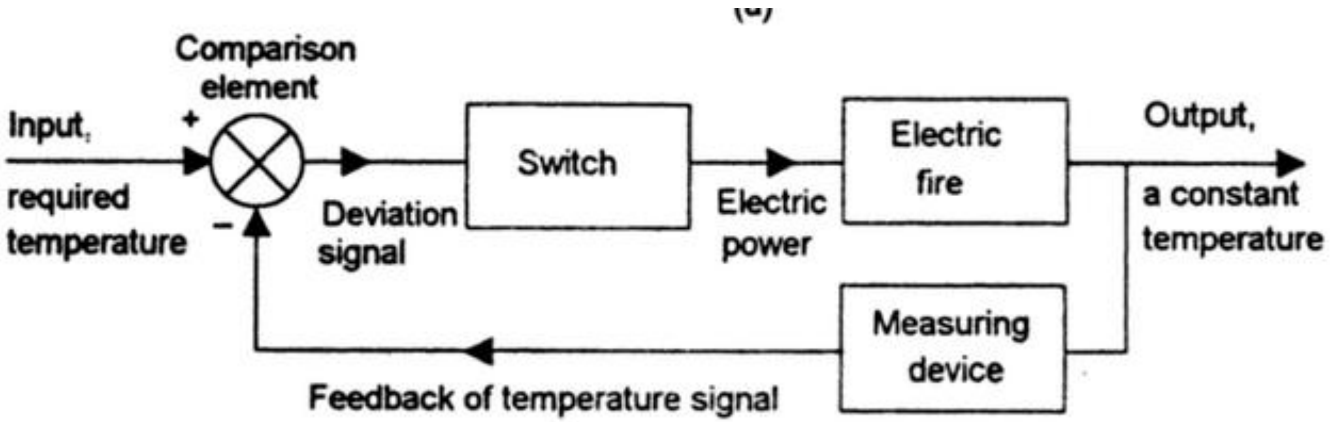
- The room will heat up and reach a temperature which is only determined by the fact the 1 kW element was switched on and not the 2 kW element. If there are changes in conditions, perhaps someone opening a window, there is no way the heat output is adjusted to compensate. This is an example of open loop control in that there is no information fed back to the element to adjust it and maintain constant temperature.



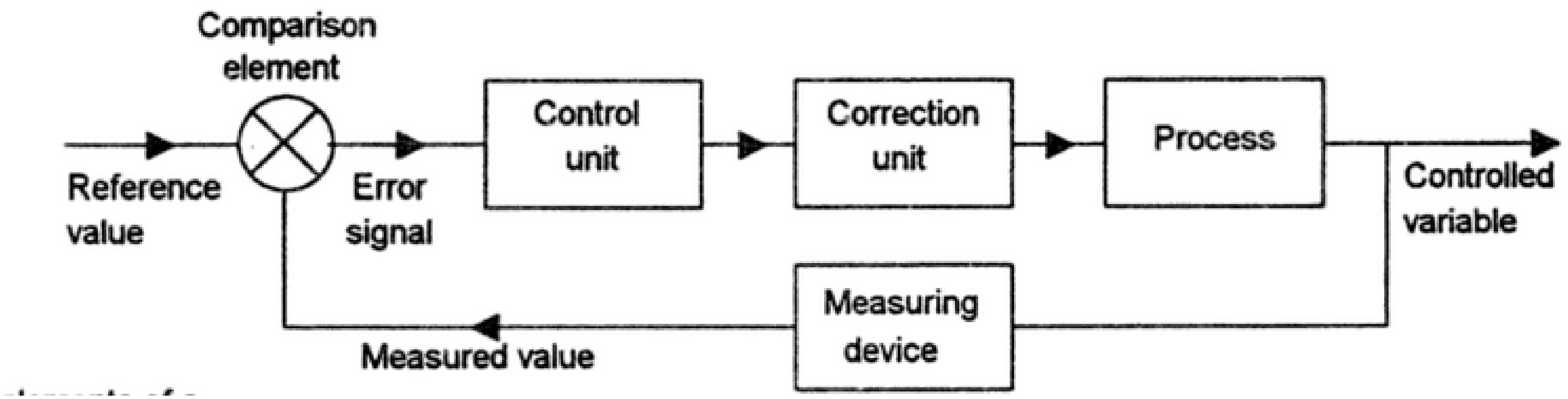
OPEN AND CLOSED LOOP CONTROL SYSTEMS

- The heating system with the heating element could be made a closed loop system if the person has a thermometer and switches the 1 kW and 2kW elements on or off, according to the difference between the actual temperature and the required temperature, to maintain the temperature of the room constant.

- In this situation, there is feedback, the input to the system being adjusted according to whether its output is the required temperature. This means that the input to the switch depends on the deviation of the actual temperature from the required temperature., the difference between them determined by a comparison element – the person in this case.



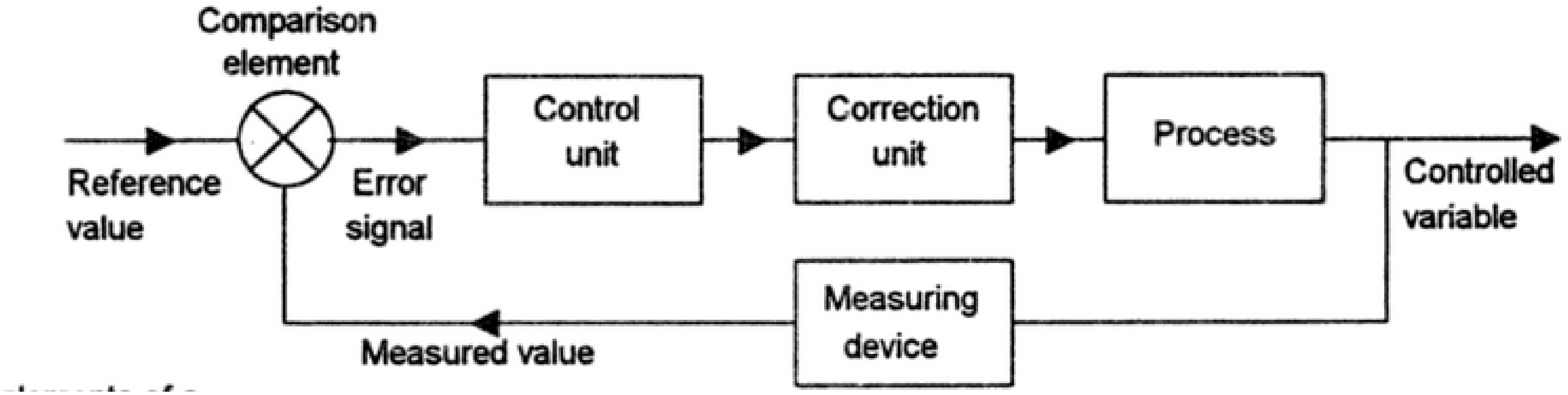
BASIC ELEMENTS OF A CONTROL SYSTEM



- ***Comparison element –*** This compares the required or reference value of the variable condition being controlled with the measured value of what is being achieved and produces an error signal.

Error signal = reference value signal – measured value signal

BASIC ELEMENTS OF A CONTROL SYSTEM

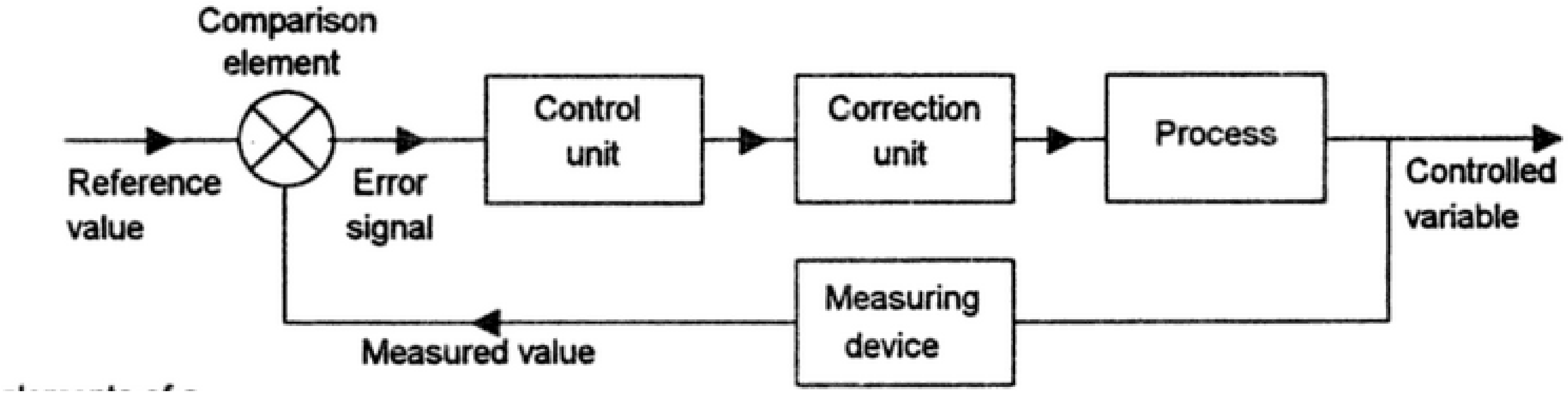


- ***Feedback loop –*** A feed back loop is a means whereby a signal related to the actual condition being achieved is fed back to modify the input signal to a process.

- ***Control unit –*** This decides what action to take when it receives an error signal.

- ***Correction unit –*** The correction unit produces a change in the process to correct or change the controlled condition.

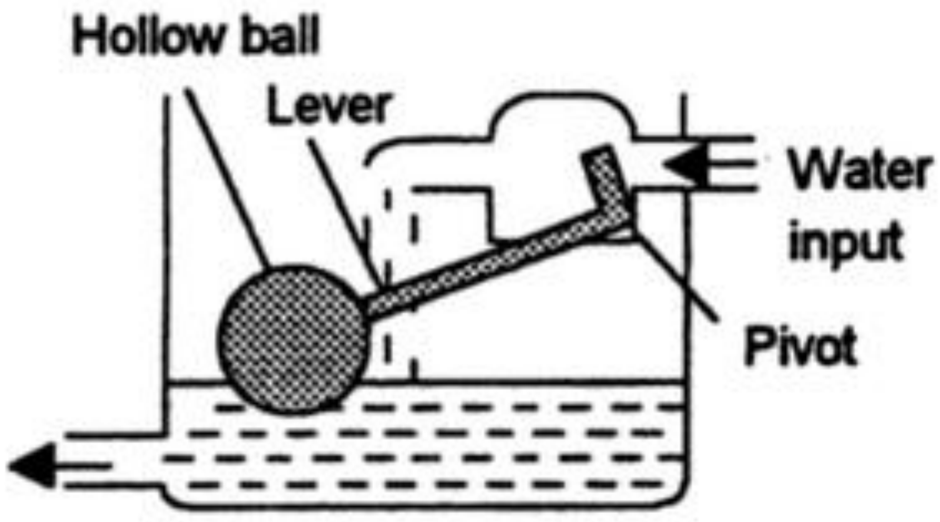
BASIC ELEMENTS OF A CONTROL SYSTEM



- ***Process unit –*** The process which is being controlled.

- ***Measurement unit –*** The measurement element produces a signal related to the variable condition of the process that is being controlled.

BASIC ELEMENTS OF A CONTROL SYSTEM



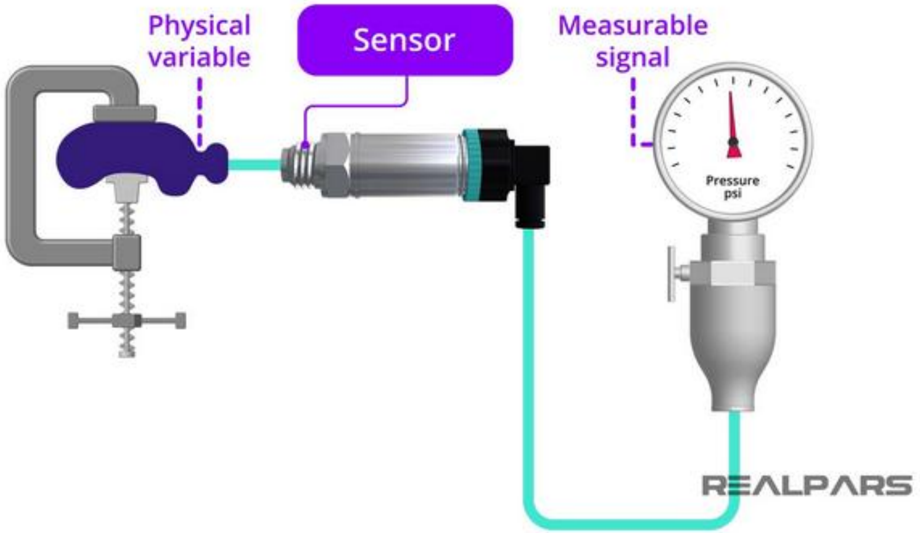
AUTOMATIC WATER LEVEL CONTROL

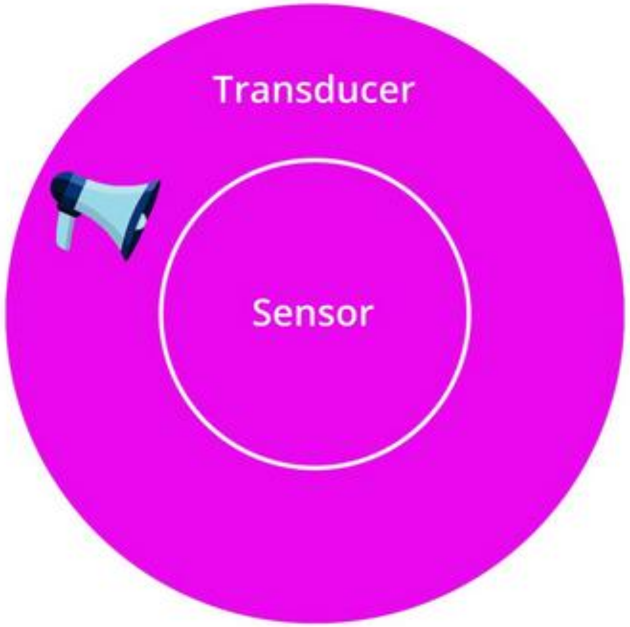
Identify controlled variable, reference value, comparison element, error signal, control unit, Correction unit, process and measuring unit????

SENSORS AND TRANSDUCERS

- The term ***sensor*** is used for an element which produces a signal relating to the quantity being measured.

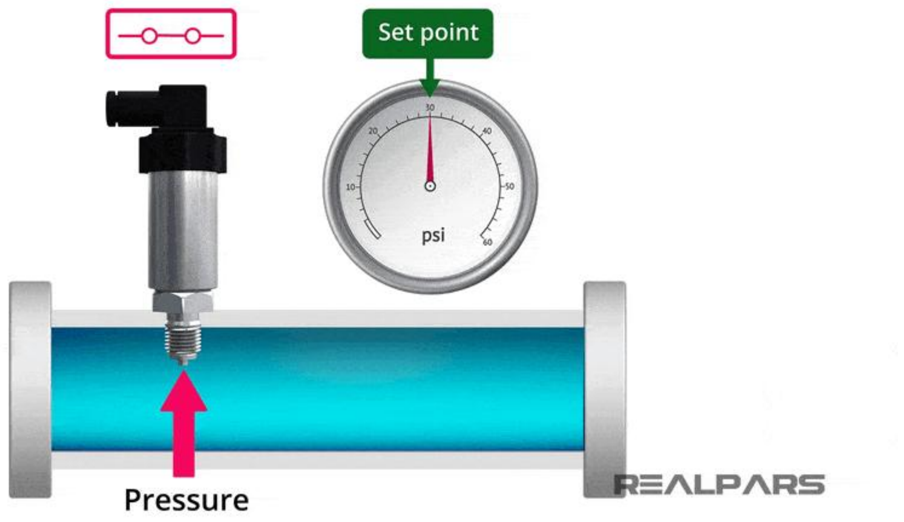
- The term ***transducer*** is defined as an element that when subject to some physical change experience a related change.

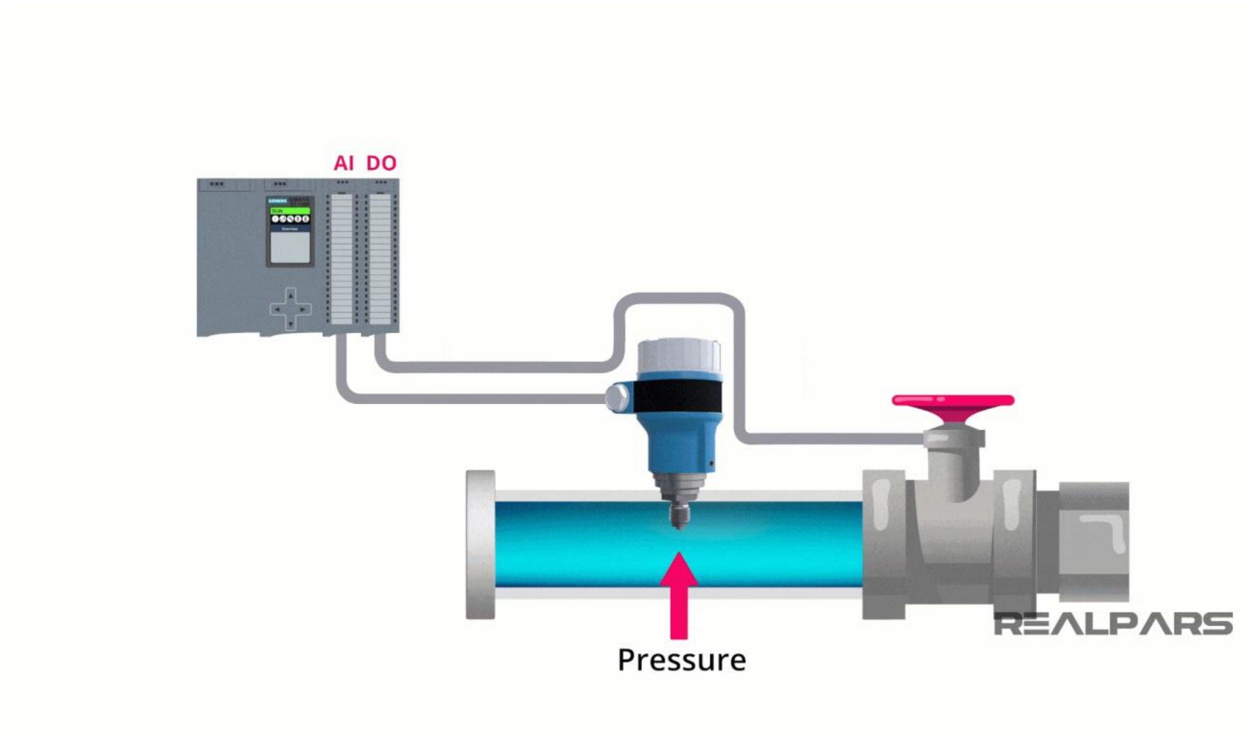




All sensors are transducers, but not all transducers are sensors.

SENSORS AND TRANSDUCERS



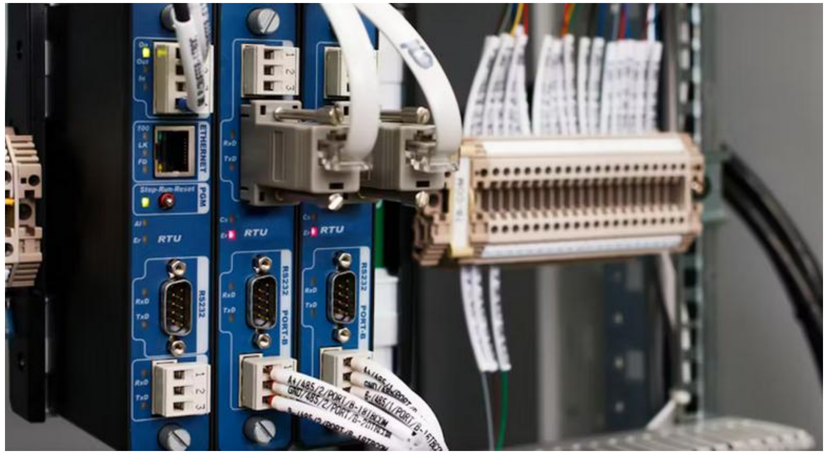


MICROPROCESSOR BASED CONTROLLERS

- Microprocessors are used in general to carry out control functions.

- In many simple systems there might be just an embedded microcontroller, this being a microprocessor with memory all integrated on one chip, which has been specifically programmed for the task concerned.

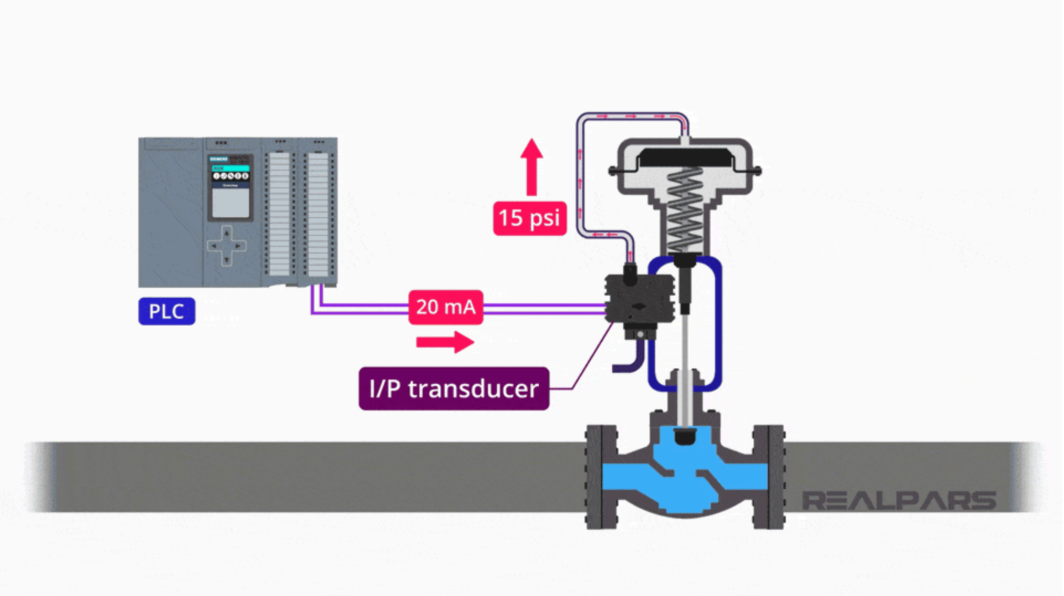
- A more adaptable form is the programmable logic controller. This is a microprocessor based controller which uses programmable memory to store instructions and to implement functions such as logic, sequence, timing counting, and arithmetic to control events and can be readily programmed for different tasks.



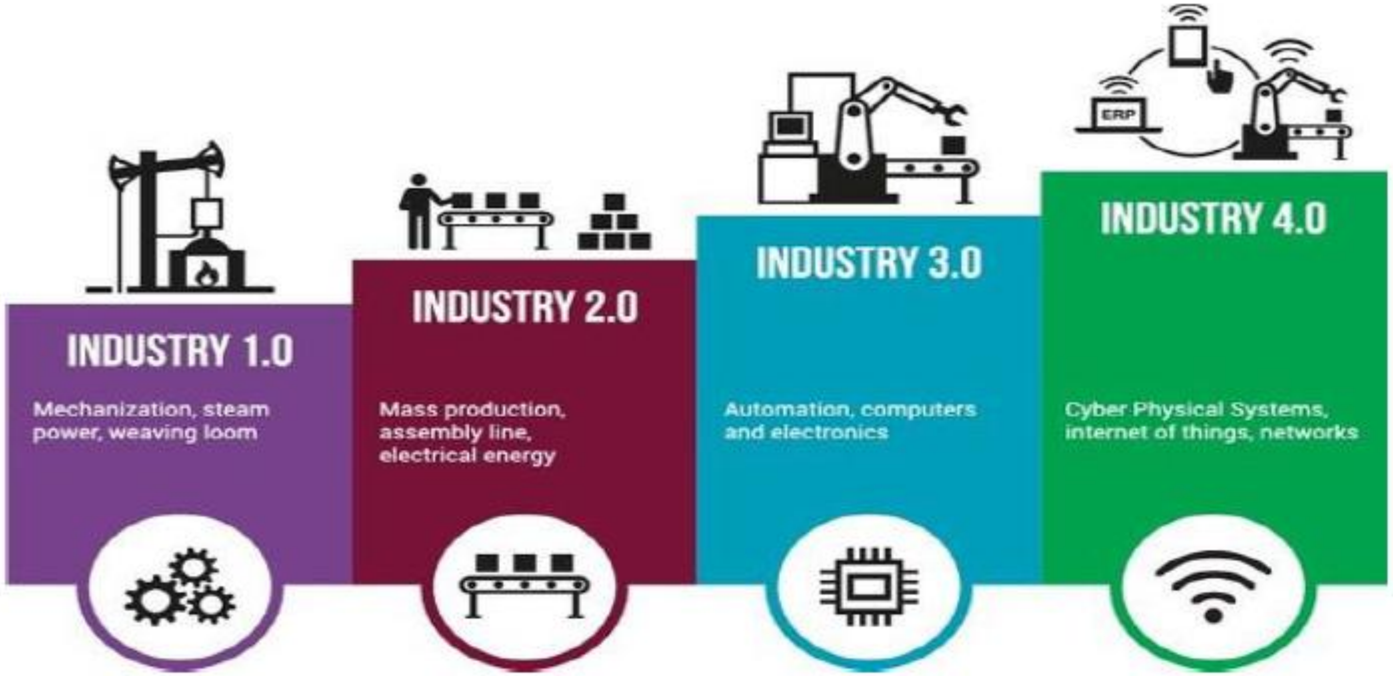
ACTUATION SYSTEMS

- ***Actuation systems are elements of control systems which are responsible for transforming the output of a microprocessor or control system into a controlling action on a machine or device.***

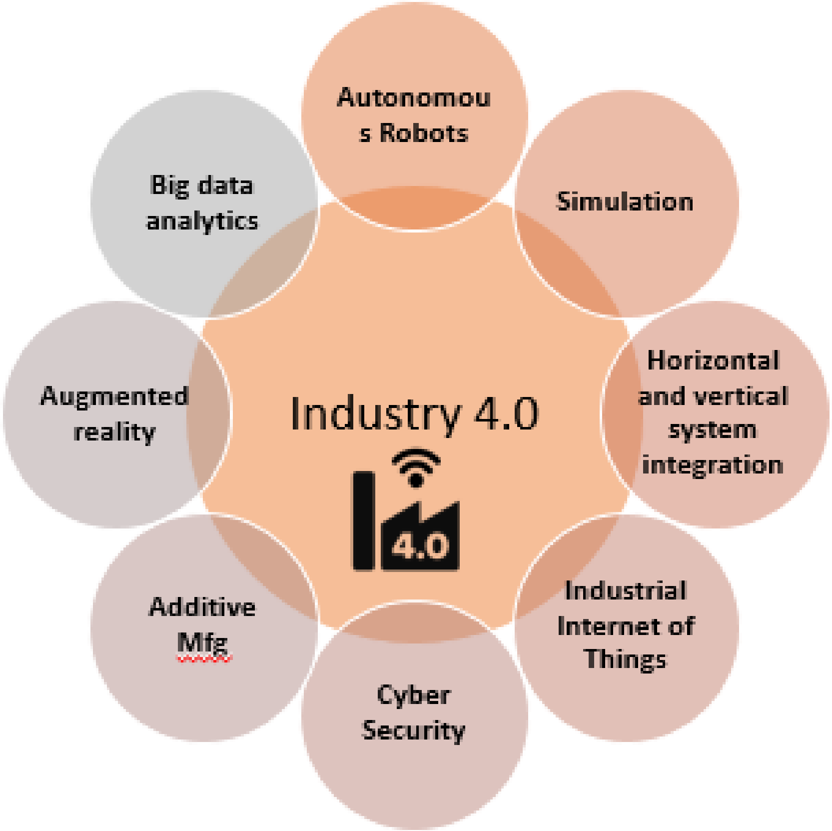
- Examples – an electrical output from the controller may have to be transformed into a linear motion to move a load, an electrical output from the controller may have to be transformed into a action which controls the amount of liquid passing along a pipe etc.



- *Industry 4.0 has been defined as **"a name for the current trend of automation and data exchange in manufacturing technologies, including cyber-physical systems, the Internet of things, cloud computing and cognitive computing and creating the smart factory".***

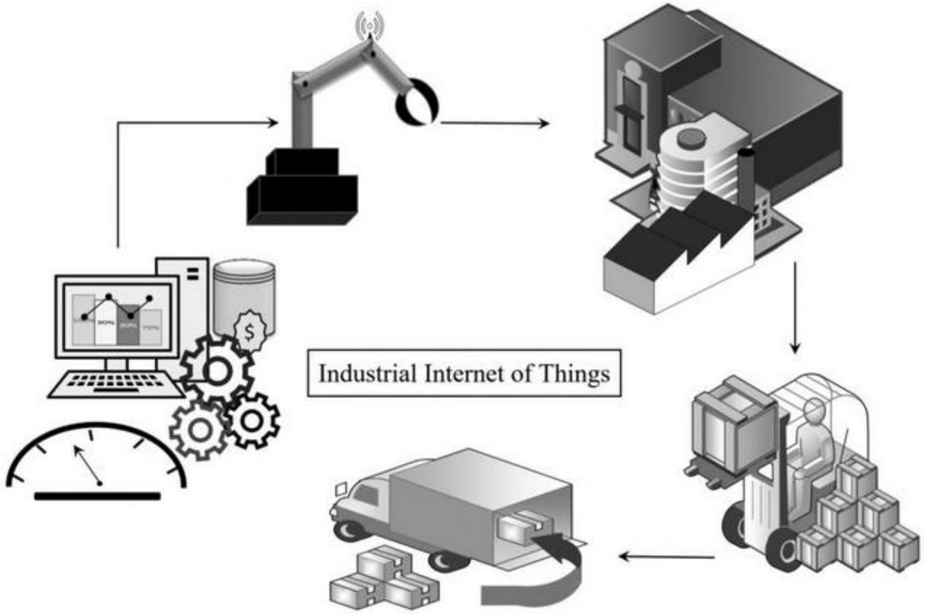


BUILDING BLOCKS OF INDUSTRY 4.0



Industrial Internet of Things (IIoT)

- IIoT can be described as an interconnection of a large number of industrial processes and systems, which communicate and coordinate among themselves.
- The real time data collected from sensor nodes are stored, processed, and analysed to improve the performance and efficiency of the overall system.
- As shown in the figure, the sensor nodes deployed at various industrial locations sense and transmit data to the server. The real time processing and complex analysis of the data help to optimize various industrial processes such as **predictive maintenance of machines, inventory management and packaging of finished products.**

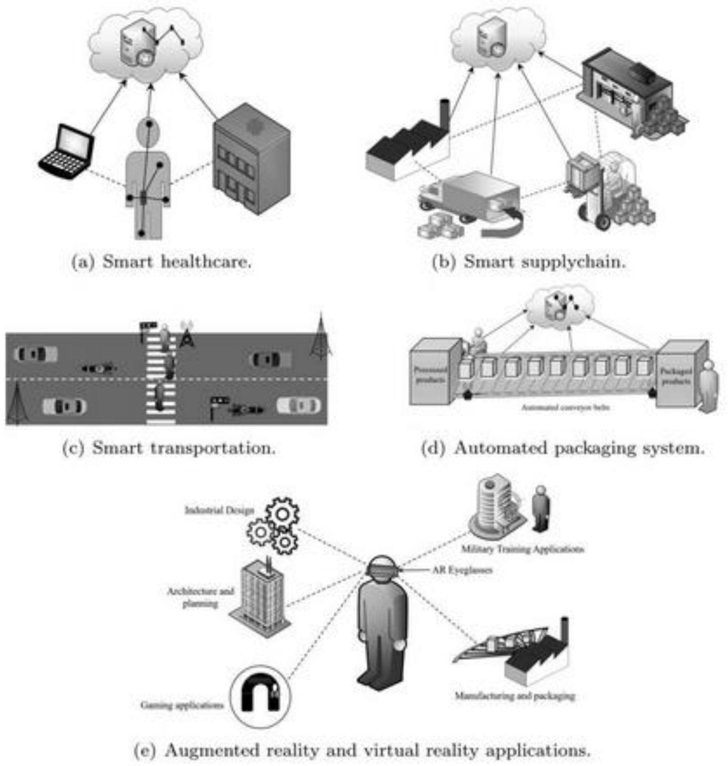


Applications of Industrial Internet of Things (IIoT)

1) ***Smart healthcare*** – Sensor nodes sense and transmit the physiological data of the patient to the local processing unit. Further, the LPU transmits the data to the local server. Medical experts can remotely observe the health conditions of the patient.

2) ***Smart supply chain*** - Proper maintenance of the raw materials, available inventory stock, details of each steps involved in the production process, proper flow of information among various stages , maintaining the time window for delivery of goods, and returning the faulty goods.

3) ***Smart transportation*** – The sensor nodes placed on the vehicles and road side units (RSU) sense and transmit data to the local server. Various real time info such as safe speed, safe distance with the neighboring vehicles, and weather conditions are conveyed to the drivers.



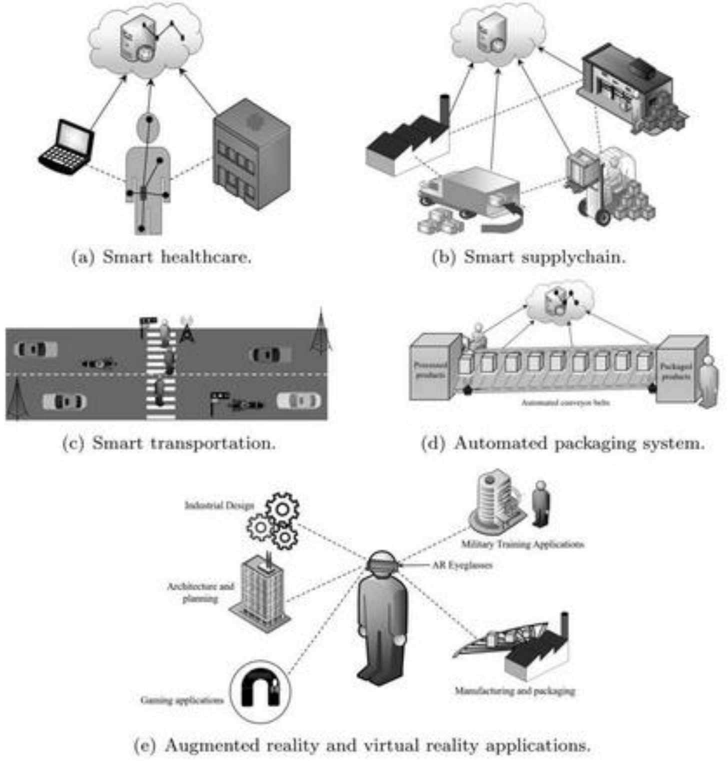
(a) Smart healthcare. (b) Smart supplychain. (c) Smart transportation. (d) Automated packaging system. (e) Augmented reality and virtual reality applications.

<u>Applications of Industrial Internet of Things (IIoT)</u>

4) Smart manufacturing system – These improve the efficiency of production and product quality, reduce the per unit cost of production and enhance the life time of machines and developed products.

e.g., Automatic packaging of a production in a manufacturing plant with minimum human intervention.

5) AR and VR applications **–** Augmented reality and virtual reality have widespread applications in the optimization stages of manufacturing industries, inventory management in warehouses, training of personnel in military, healthcare, and assembly line operations.



Additive manufacturing

- ***'Additive manufacturing fabricates parts by building them up layer-by-layer, as opposed to cutting material away or molding it'.***

- Additive manufacturing can also be viewed as a way to turn a digital model (of the object to be constructed) into a physical one since it starts as a (3D) software design.

- Additive manufacturing doesn't replace other manufacturing methods (at least not for many years to come) but leads to a wealth of new opportunities. Moreover, some objects would be almost impossible to make without additive manufacturing.

- ***Additive manufacturing and 3D printing are used in multiple domains (healthcare, the construction industry, defense, retail, pharma, automotive industry, aerospace, making parts in close to any area you can imagine, including human tissue and food, smart manufacturing). They are also the subject of intensive research and development (methods, materials, new techniques, application areas, etc.).***

Different 3D Printing Processes

- A total of seven different types of additive manufacturing processes have been established and identified. These seven 3D printing processes brought forth ten different types of 3D printing technology that 3D printers use today.

- 3DPrinting Process: Material Extrusion
  - Fused Deposition Modeling (FDM)
- 3D Printing Process: Vat Polymerization
  - Stereolithography (SLA)
  - Digital Light Processing (DLP)
- 3D Printing Process: Powder Bed Fusion
  - 3D Printing Process: Powder Bed Fusion (Polymers)
    - Selective Laser Sintering (SLS)
  - 3D Printing Process: Powder Bed Fusion (Metals)
    - Direct Metal Laser Sintering (DMLS)/Selective Laser Melting (SLM)
  - Electron Beam Melting (EBM)
- 3D Printing Process: Material Jetting
  - Material Jetting (MJ)
  - Drop on Demand (DOD)
- 3D Printing Process: Binder Jetting
  - Sand Binder Jetting
  - Metal Binder Jetting
- Sheet Lamination
- Directed Energy Deposition

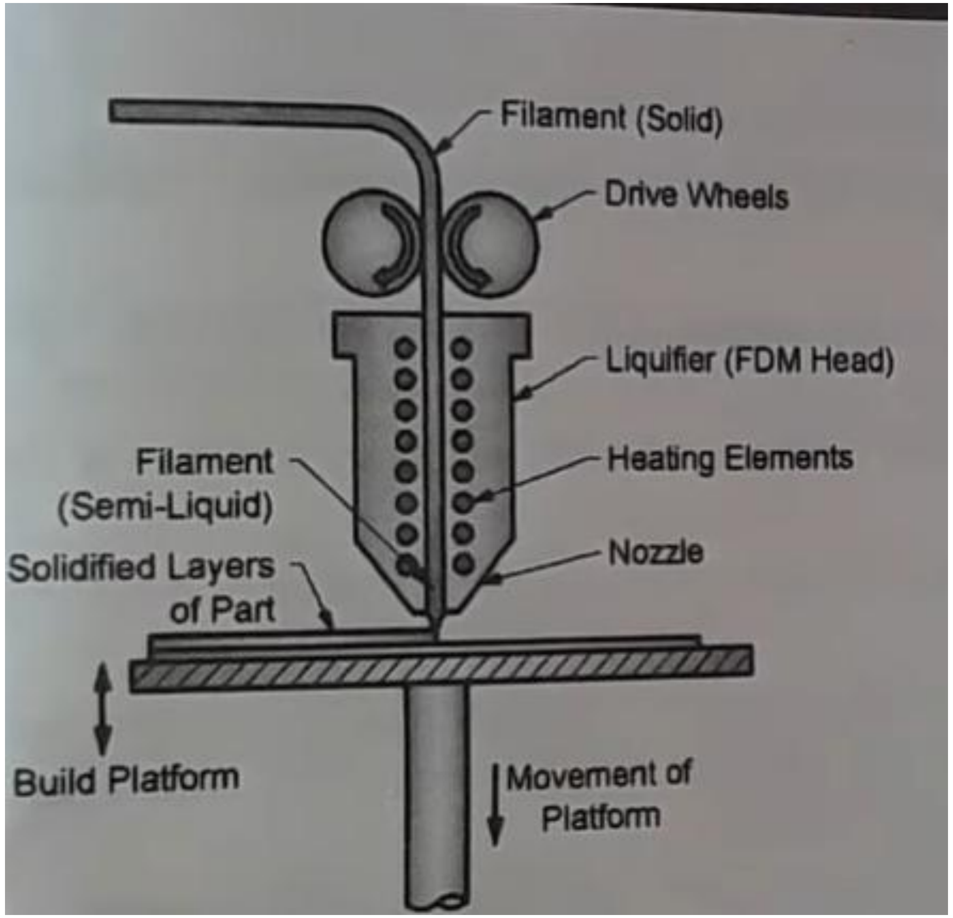
Material Extrusion – Fused Deposition Modelling

- Material extrusion is a 3D printing process where a filament of solid thermoplastic material is pushed through a heated nozzle, melting it in the process.

- The printer deposits the material on a build platform along a predetermined path, where the filament cools and solidifies to form a solid object.

- **Types of 3D printing technology**: Fused deposition modeling (FDM), sometimes called fused filament fabrication (FFF)
- **Materials**: Thermoplastic filament (PLA, ABS, PET, TPU)
- **Dimensional accuracy**: ±0.5% (lower limit ±0.5 mm)
- **Common applications**: Electrical housings; Form and fit testings; Jigs and fixtures; Investment casting patterns
- **Strengths**: Best surface finish; Full color and multi-material available
- **Weaknesses**: Brittle, not sustainable for mechanical parts; Higher cost than SLA/DLP for visual purposes

Material Extrusion – Fused Deposition Modelling

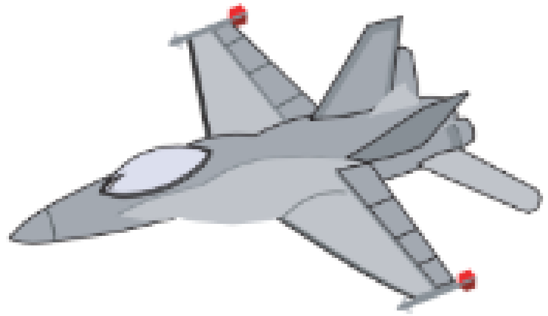


- Raw material : Plastic wire (1.75mm dia) Polylactic acid, Nylon, polycarbonate etc
- The nozzle will usually have a diameter of between 0.3 mm and 1.0 mm

1) Part preparation: The initial stage is to import the design file and choose options for the build, such as layer height, orientation and infill percentage.

2) FDM Machine setup
3) FDM printing
4) FDM part removal

RAPID PROTOTYPING

A prototype is the first or original example of something that has been or will be copied or developed; it is a model or preliminary version; e.g.: A prototype supersonic aircraft.	

RAPID PROTOTYPING

The general definition of the prototype contains three aspects of interests:

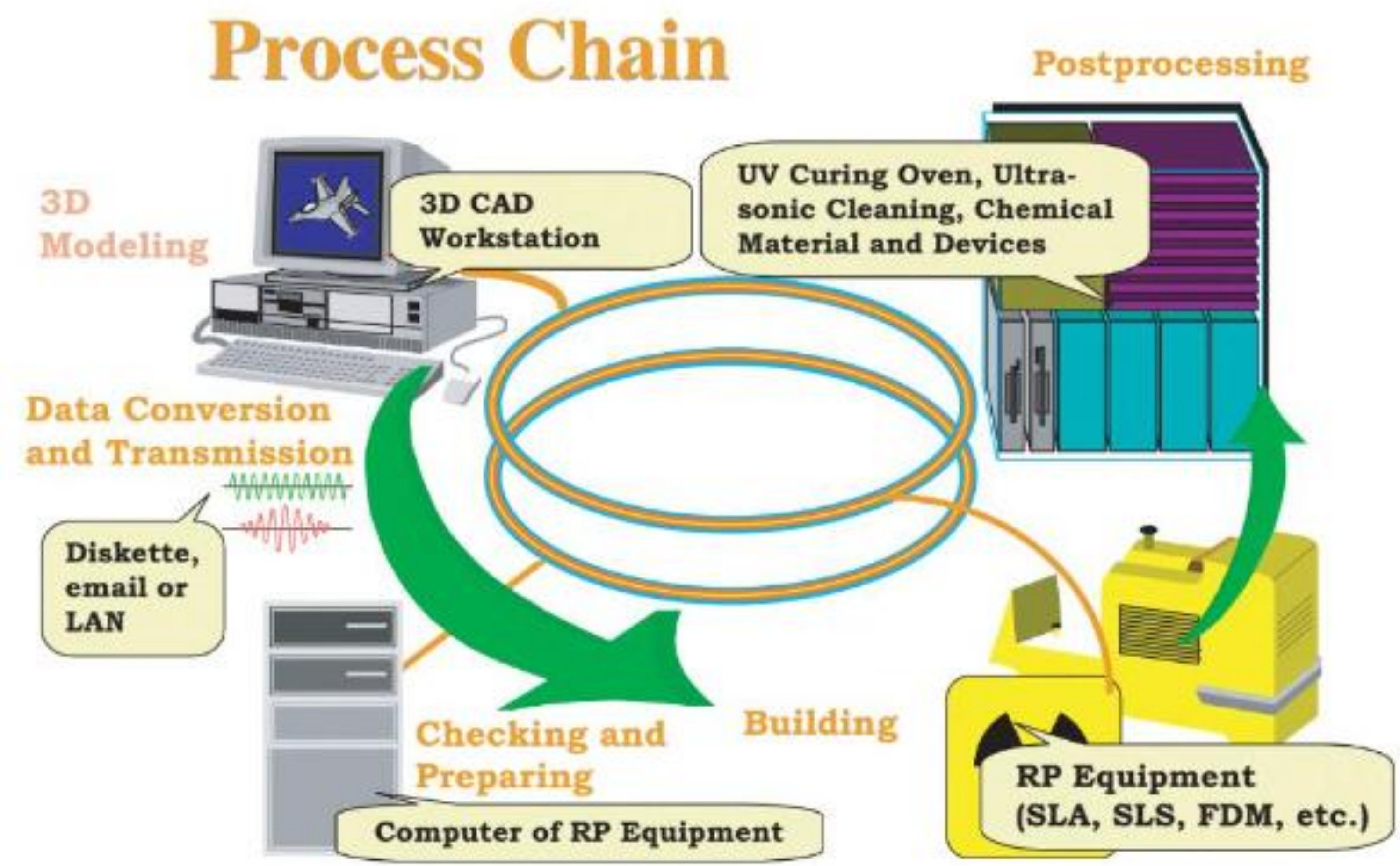
(1) the implementation of the prototype; from the entire product (or system) itself to its subassemblies and components,
(2) the form of the prototype; from a virtual prototype to a physical prototype and
(3) the degree of the approximation of the prototype; from very rough representation to exact replication of the product.

RAPID PROTOTYPING

Prototypes play several roles in the product development process. They include the following:

(1) experimentation and learning,
(2) testing and proofing,
(3) communication and interaction,
(4) synthesis and integration and
(5) scheduling and markers.

RAPID PROTOTYPING



Rapid Prototyping

Rapid Prototype

⇕

Finishing Process

- Machining: milling, lathe, boring, grinding, etc.
- Sand blasting
- Polishing
- Coating
- Painting (varnishing)

⇓ ⇓ ⇓

Applications

Design	*Engineering, Analysis and Planning*	*Manufacturing and Tooling*
• CAD-model verification (design specification) • Visualizing objects • Proof of concept • Marketing and presentation model	• Form and fit-models • Flow analysis • Analysis of stress distribution • Pre-series parts • Diagnostic and pre-surgical operation planning • Design and fabrication of custom protheses and implants	• Tooling mold parts - direct soft tools - indirect soft tools - direct hard tools - indirect hard tools • Casting - sand-casting - investment casting - evaporative pattern casting - die casting • EDM electrodes • Master models

Industries

• Aerospace	• Automotive	• Biomedical
• Jewelry	• Coin	• Tableware
• Consumer electronics	• Home appliances	• Others

Thank You

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