Government Polytechnic Nanakpur

DEPARTMENT OF MECHANICAL ENGINEERING

E - NOTES

THEORY OF MACHINES

HOD/O.I. (Mechanical) : **Sh.SHALANDER MOR**

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Semester: 5th Sem

By: Er. Amit Kumar

Designed, Mechanical Editing & Developmental Editing

LEARNING OUTCOMES

After undergoing this course, the students will be able to:

- Explain working of different types of mechanisms and draw their inversion.
- Solve problems on power transmission.
- Determine ratio of driving tension for flat and V-belt drive.
- Identify various types of gears and their applications.
- Construct turning moment diagram of flywheel for different types of engine.
- Explain working of different types of governors.
- Identify different types of cams and followers and construct displacement diagram
- Calculate balancing of rotating mass and its position.
- Identify different type of vibrations, their causes, harmful effect and remedies.

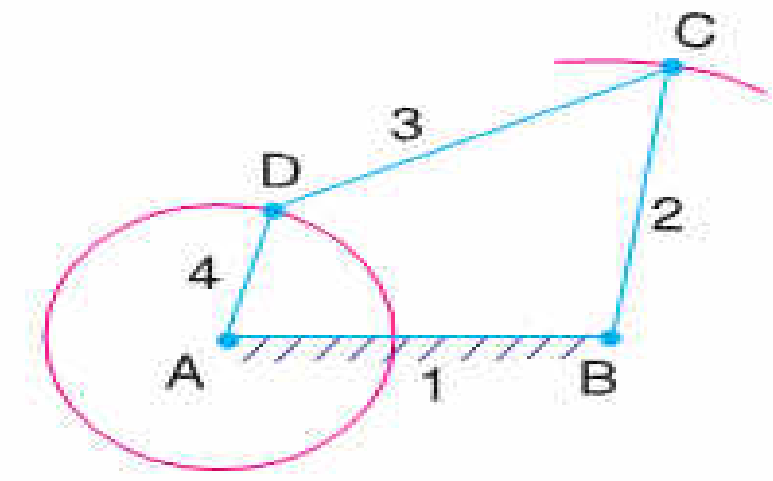
Kinematics inversions of 4 bar and slide crank chain & Kinematics analysis in simple mechanisms

The most important kinematic chains are those which consist of four lower pairs, each pair being a sliding pair or a turning pair

1. Four bar chain or quadric cyclic chain,
2. Single slider crank chain, and
3. Double slider crank chain.

Four Bar Chain or Quadric Cycle Chain

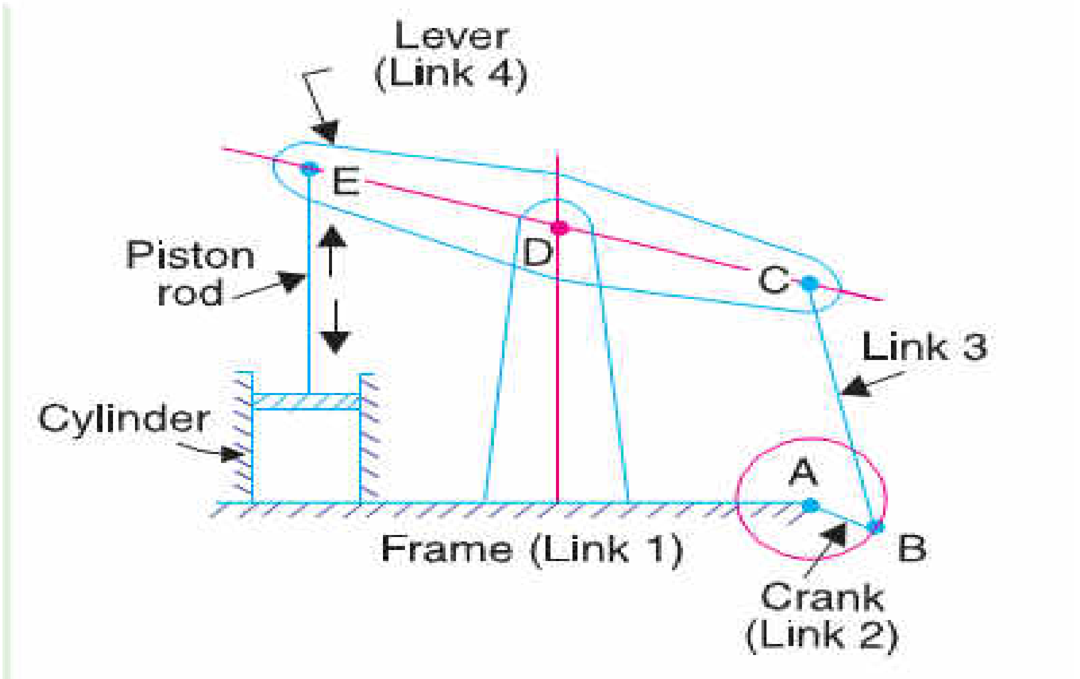
- According to Grashof 's law for a four bar mechanism, the sum of the shortest and longest link lengths should not be greater than the sum of the remaining two link lengths if there is to be continuous relative motion between the two links.



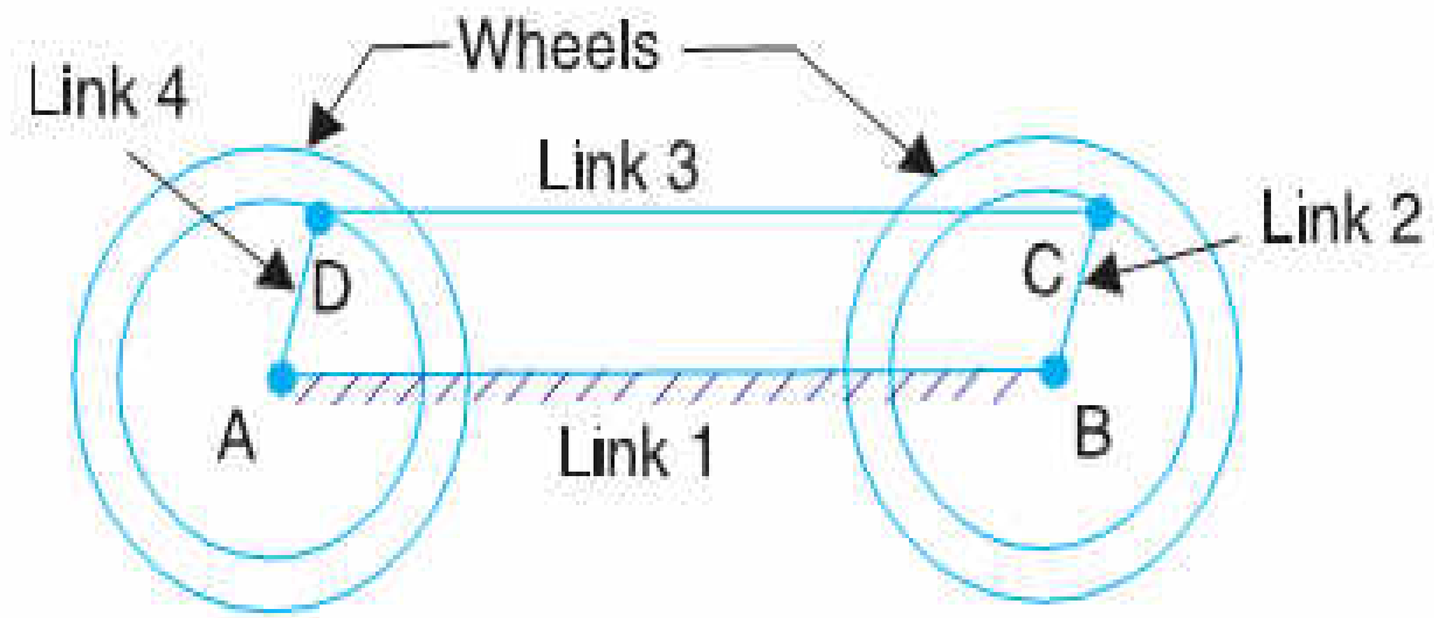
Inversions of Four Bar Chain

1. Beam engine (crank and lever mechanism)
2. Coupling rod of a locomotive (Double crank mechanism)
3. Watt's indicator mechanism (Double lever mechanism)

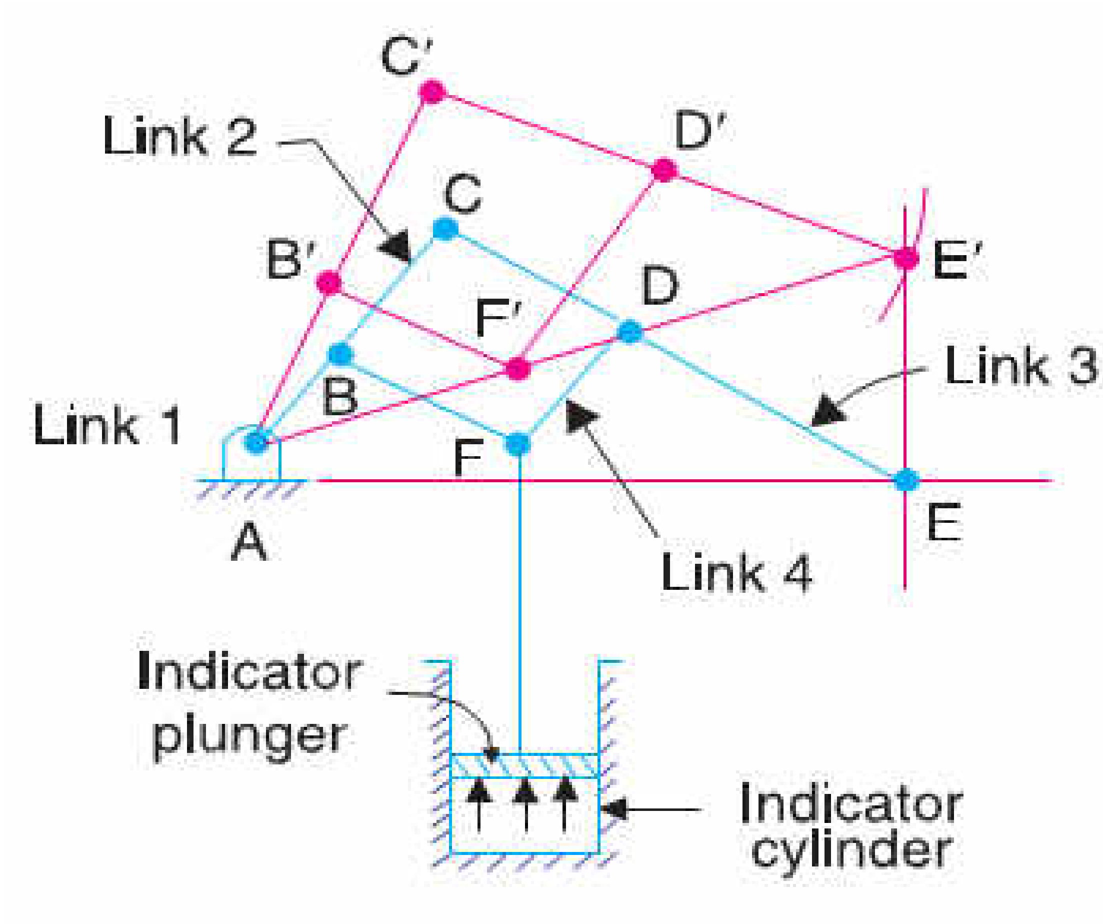
Beam engine (crank and lever mechanism)



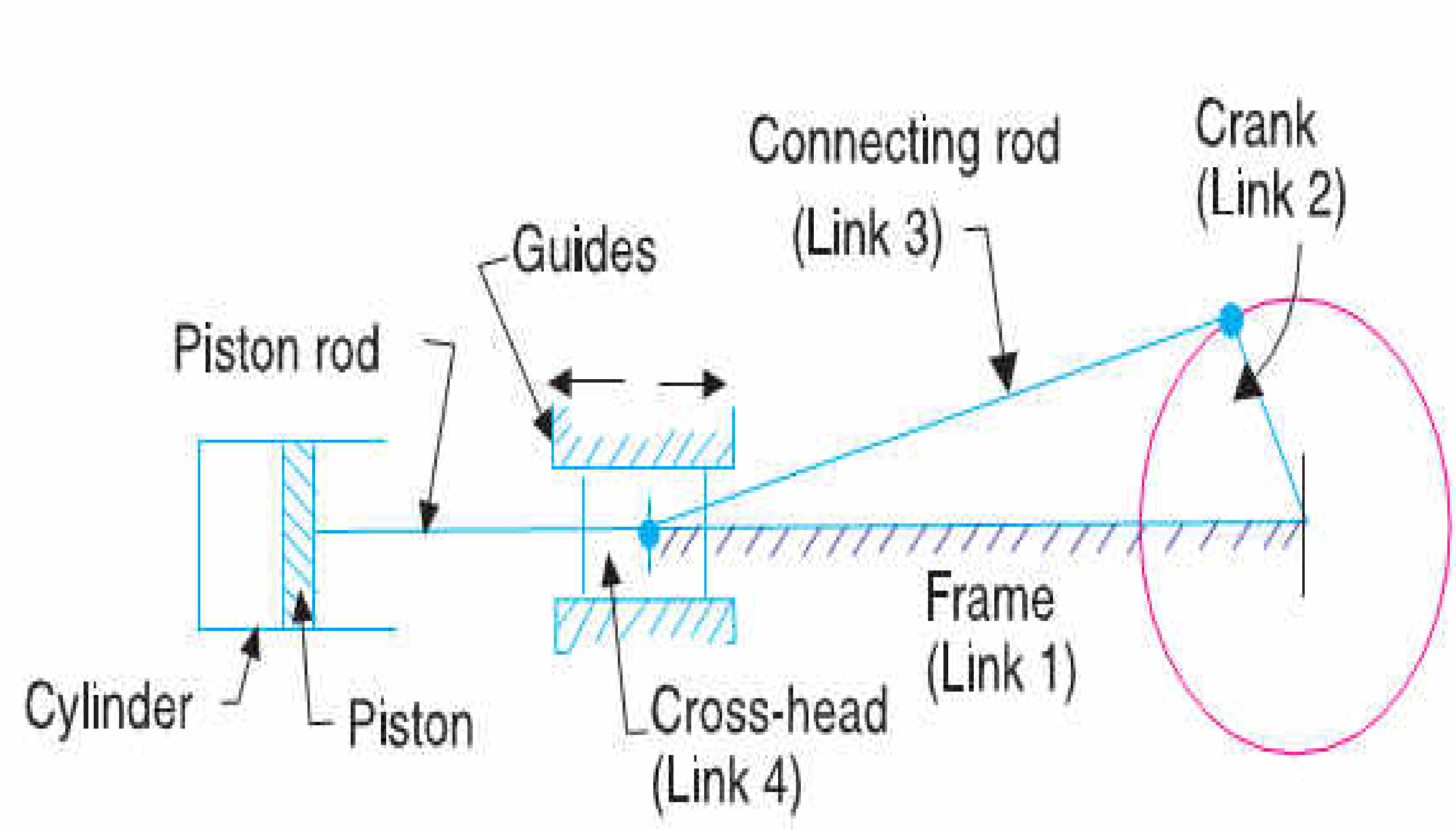
Coupling rod of a locomotive (Double crank mechanism)



Watt's indicator mechanism (Double lever mechanism)



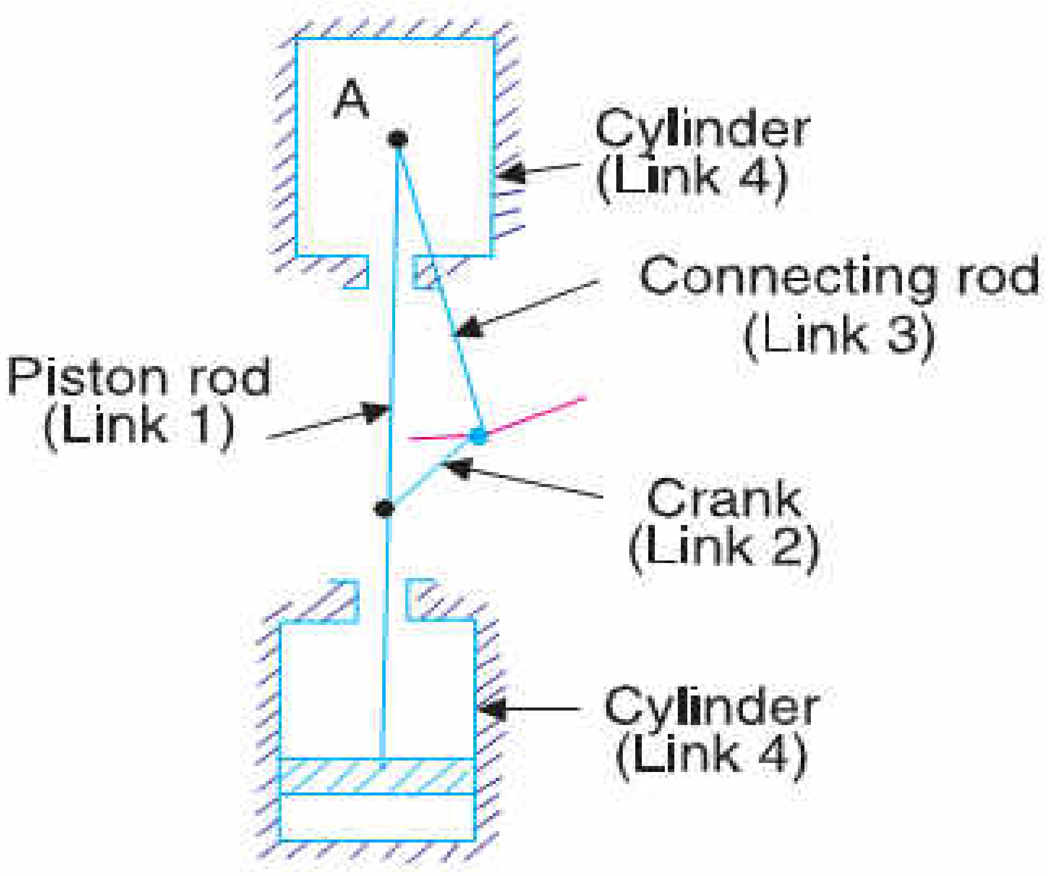
Single Slider Crank Chain



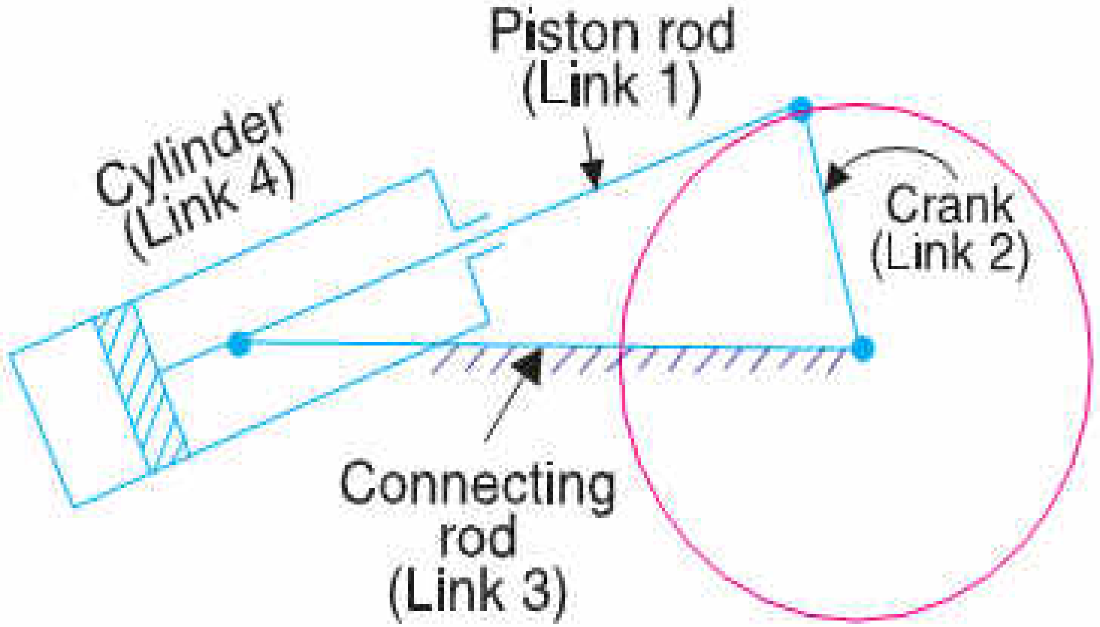
Inversions of Single Slider Crank Chain

1. Pendulum pump or Bull engine
2. Oscillating cylinder engine
3. Rotary internal combustion engine or Gnome engine
4. Crank and slotted lever quick return motion mechanism.
5. Whitworth quick return motion mechanism.

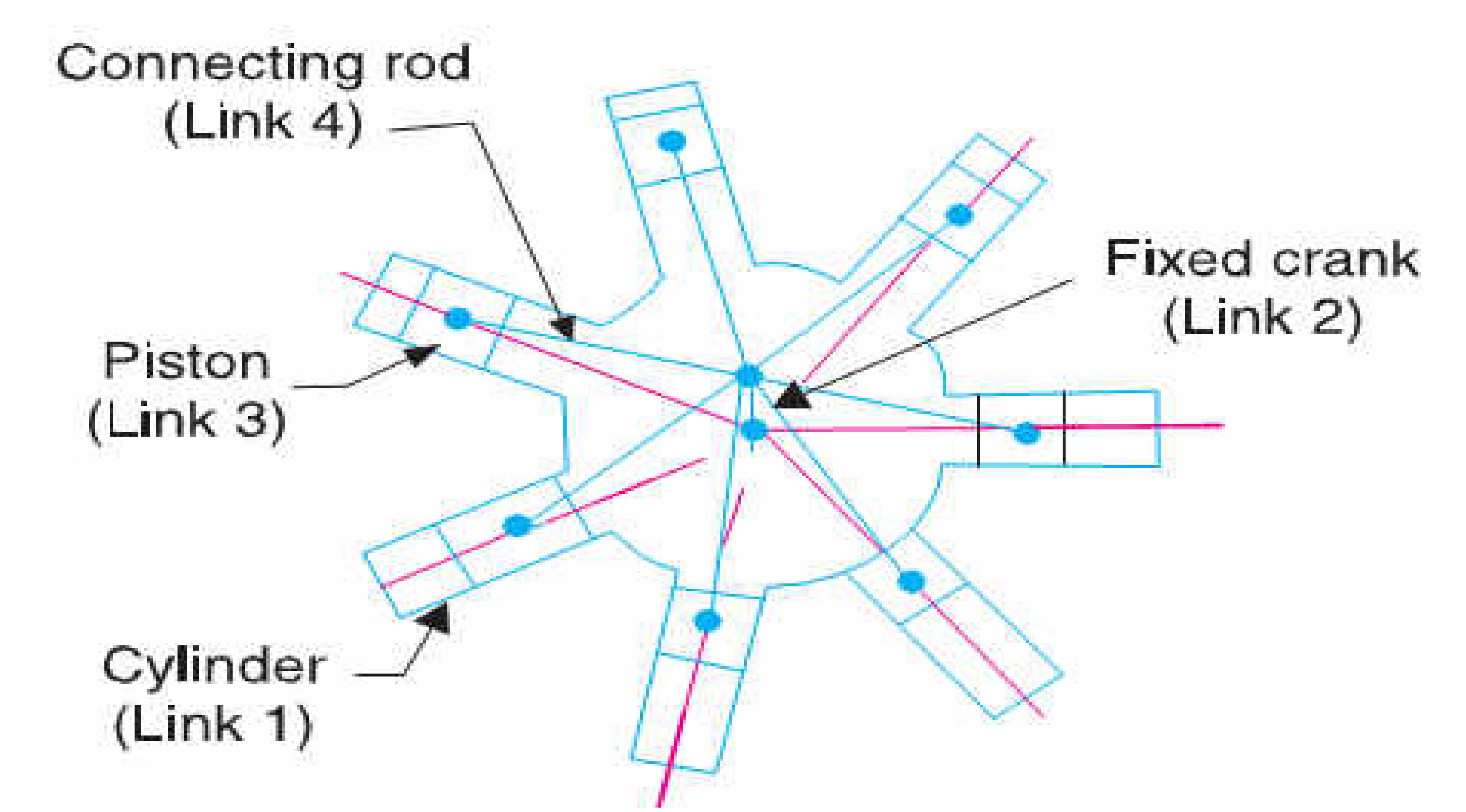
Pendulum pump or Bull engine



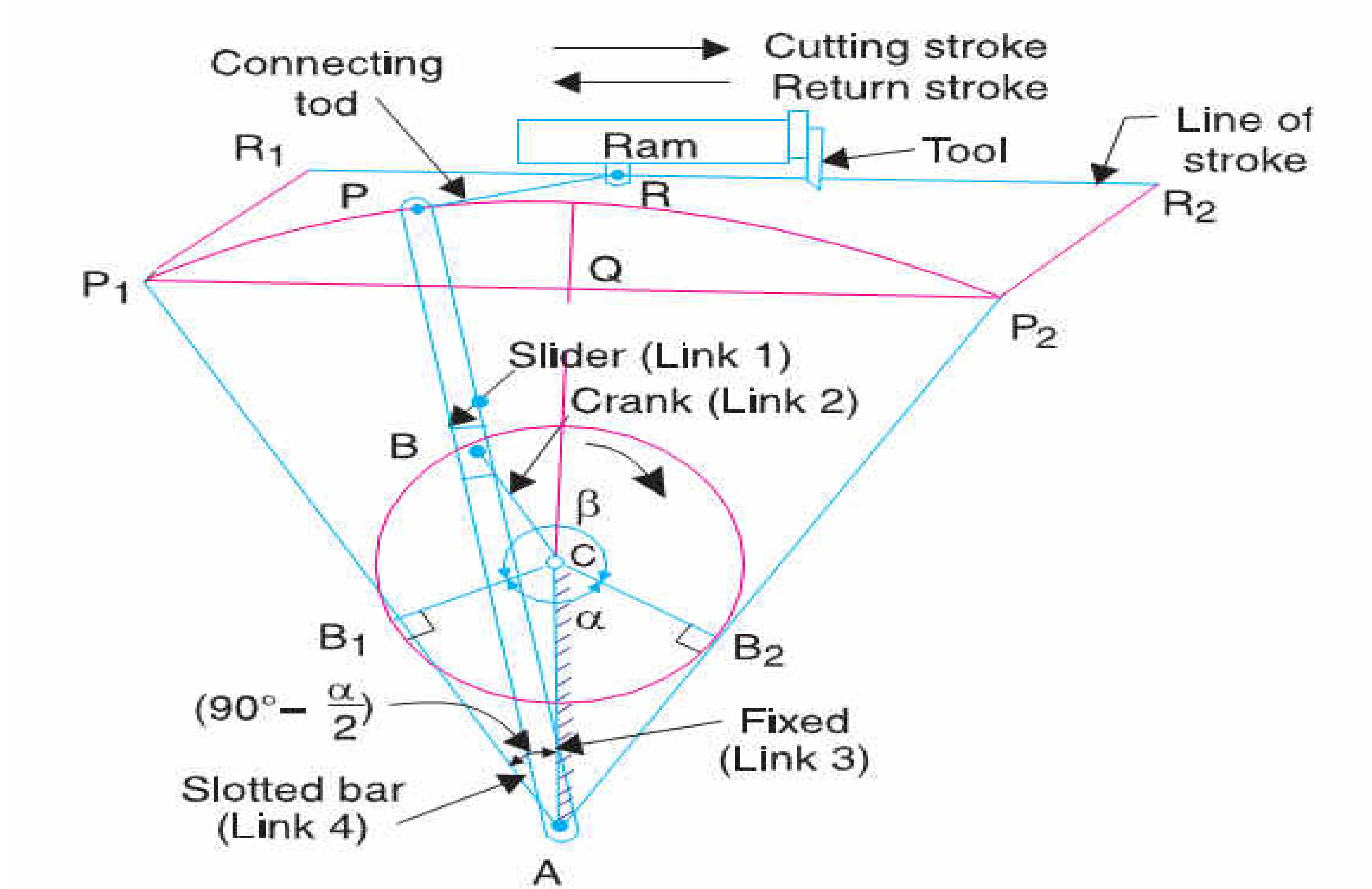
Oscillating cylinder engine



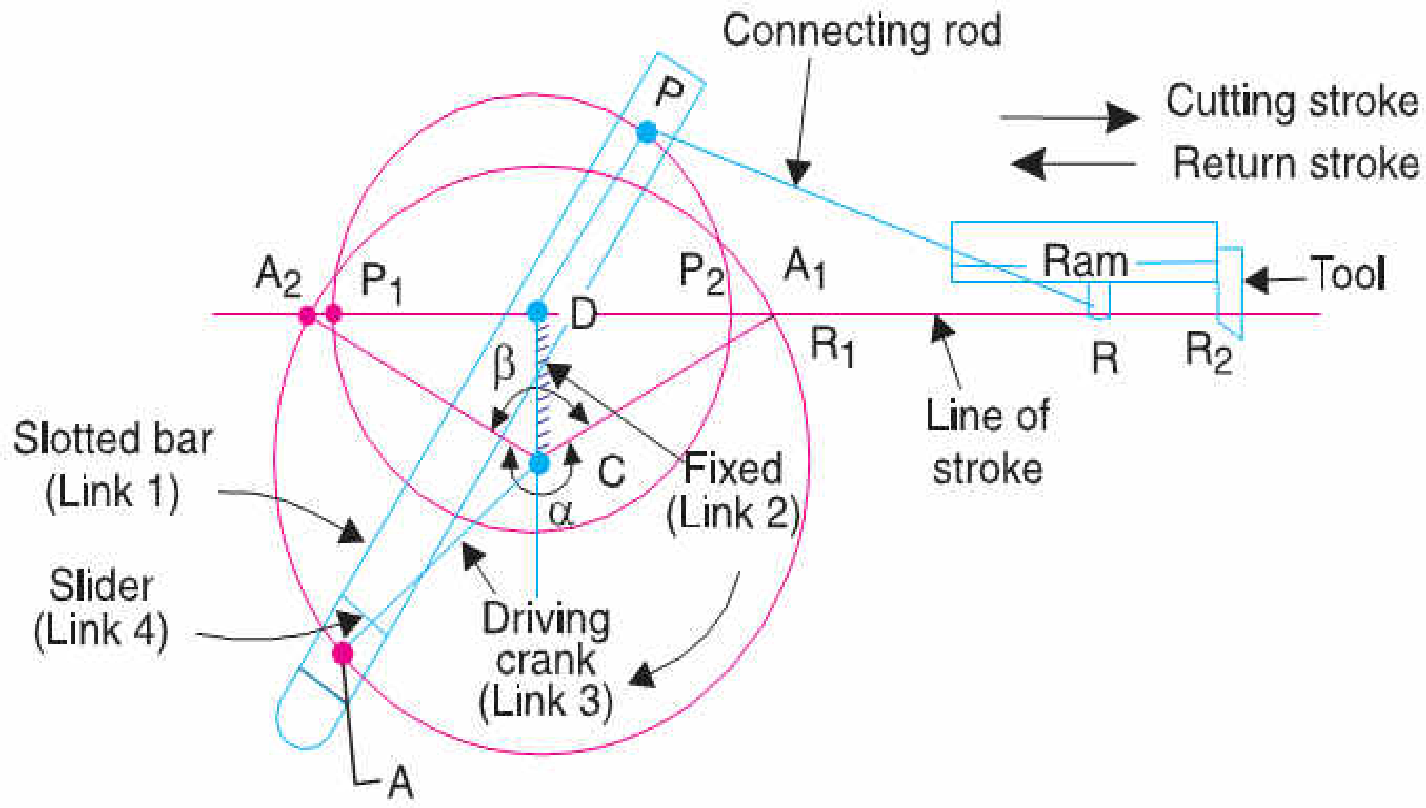
Rotary internal combustion engine or Gnome engine



Crank and slotted lever quick return motion mechanism



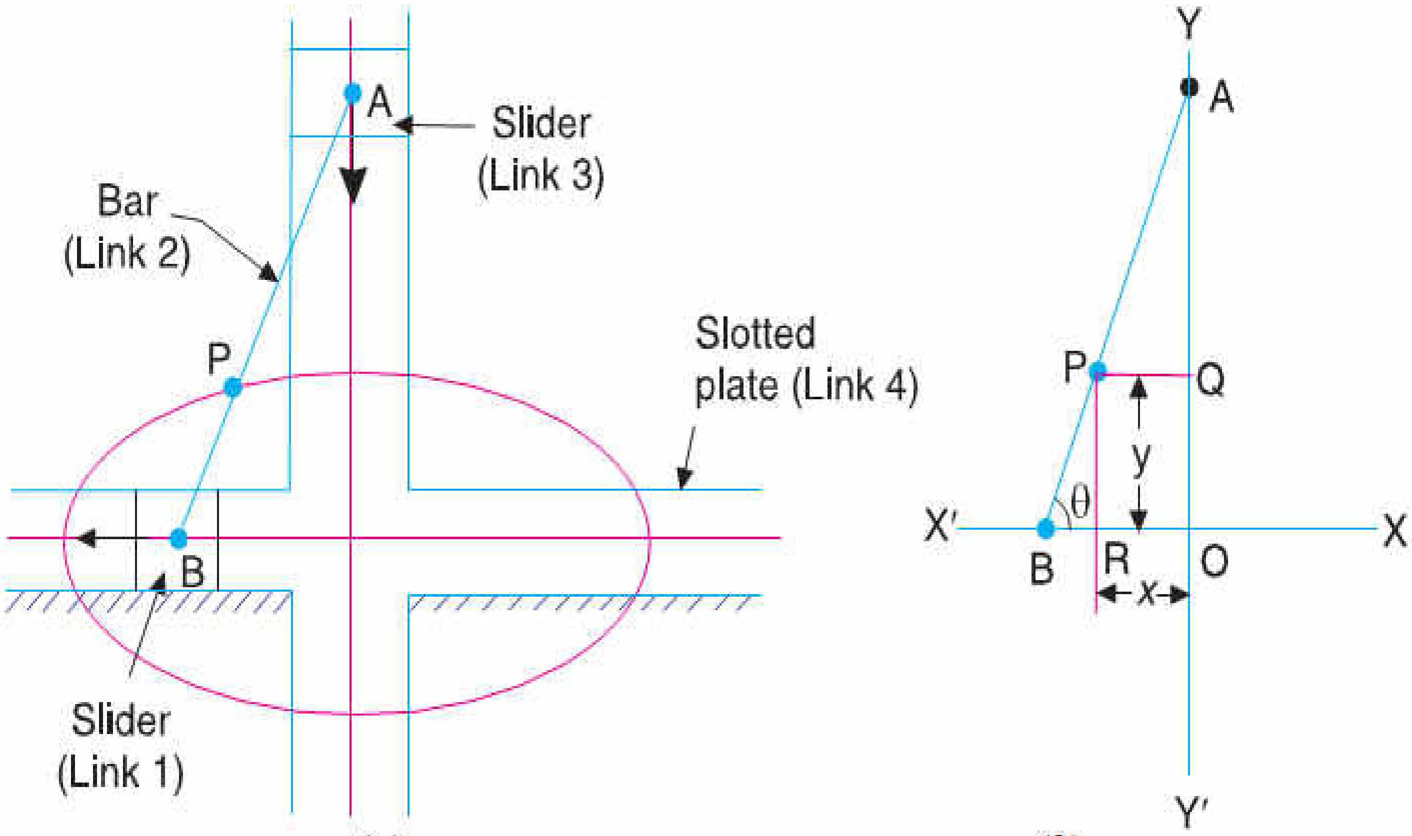
Whitworth quick return motion mechanism



Double Slider Crank Chain

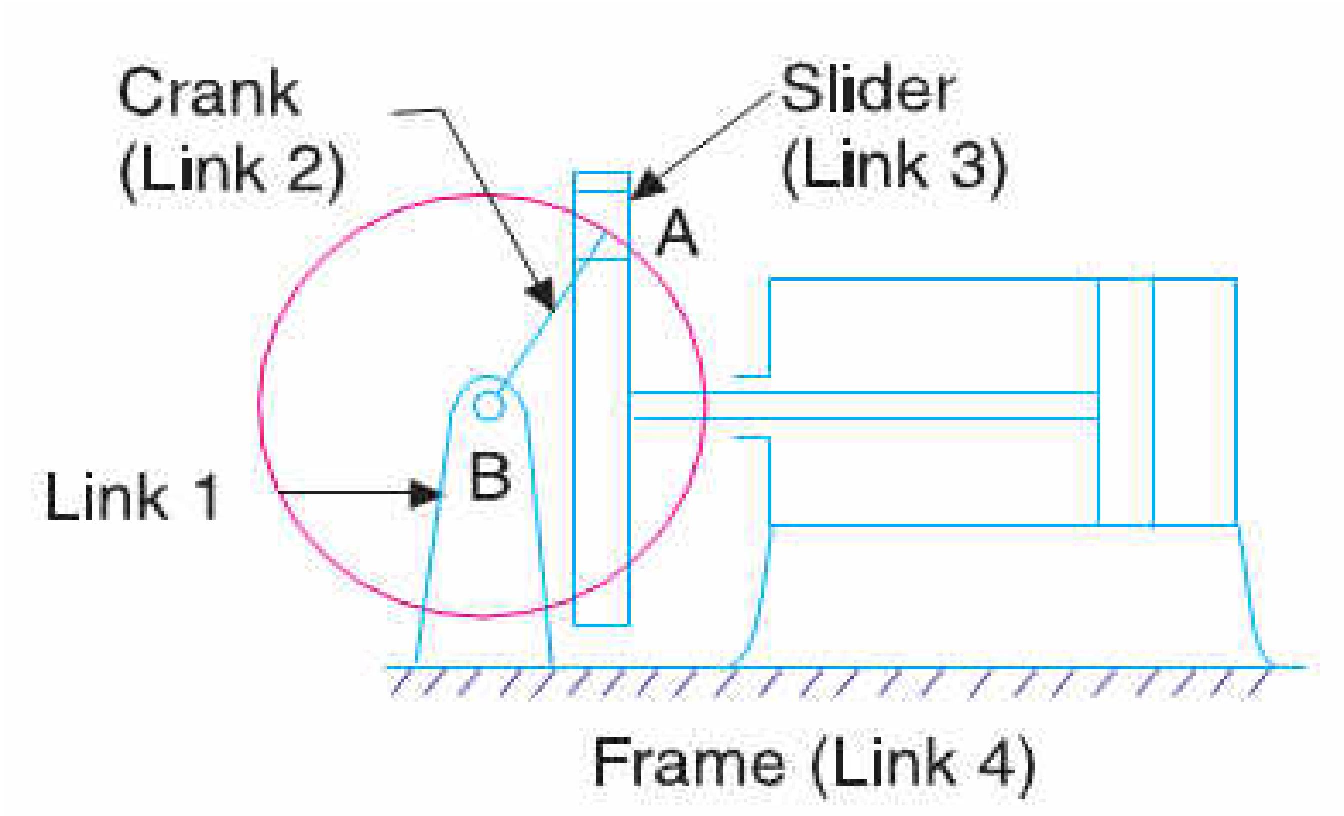
1. Elliptical trammels
2. Scotch yoke mechanism
3. Oldham's coupling

Elliptical trammels

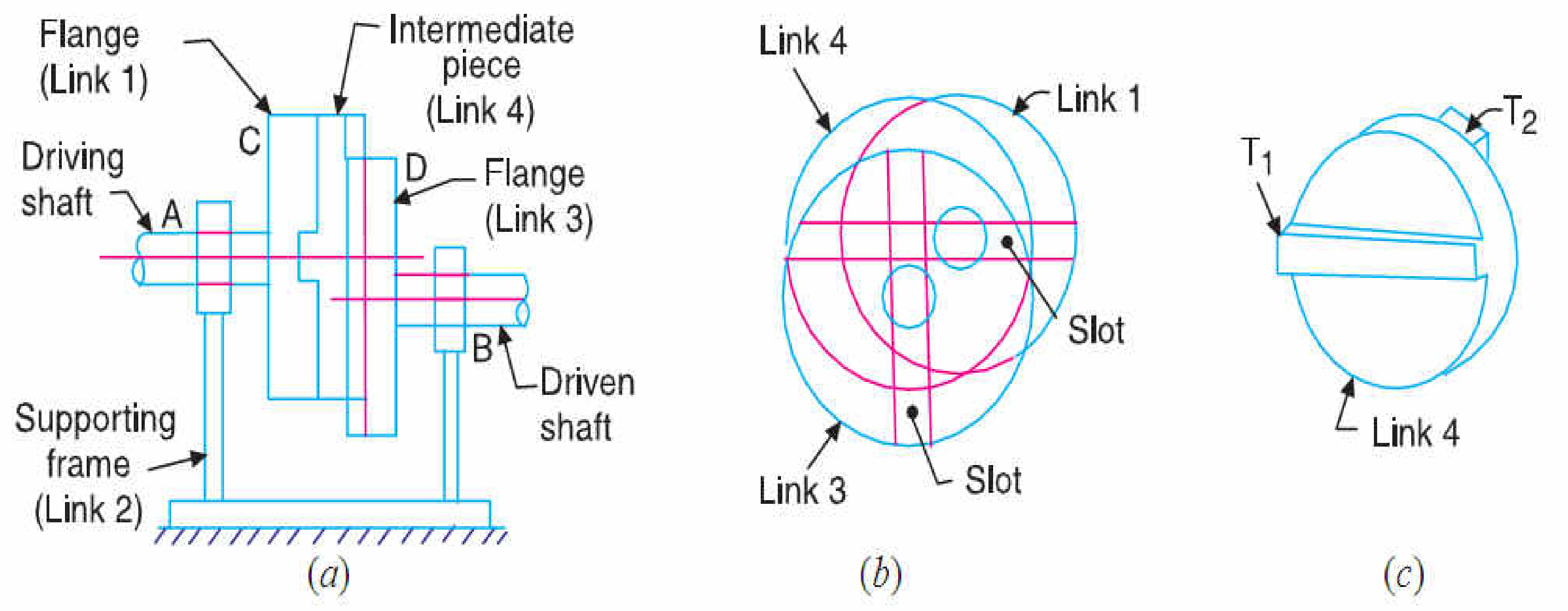


(a) (b)

Scotch yoke mechanism



Oldham's coupling

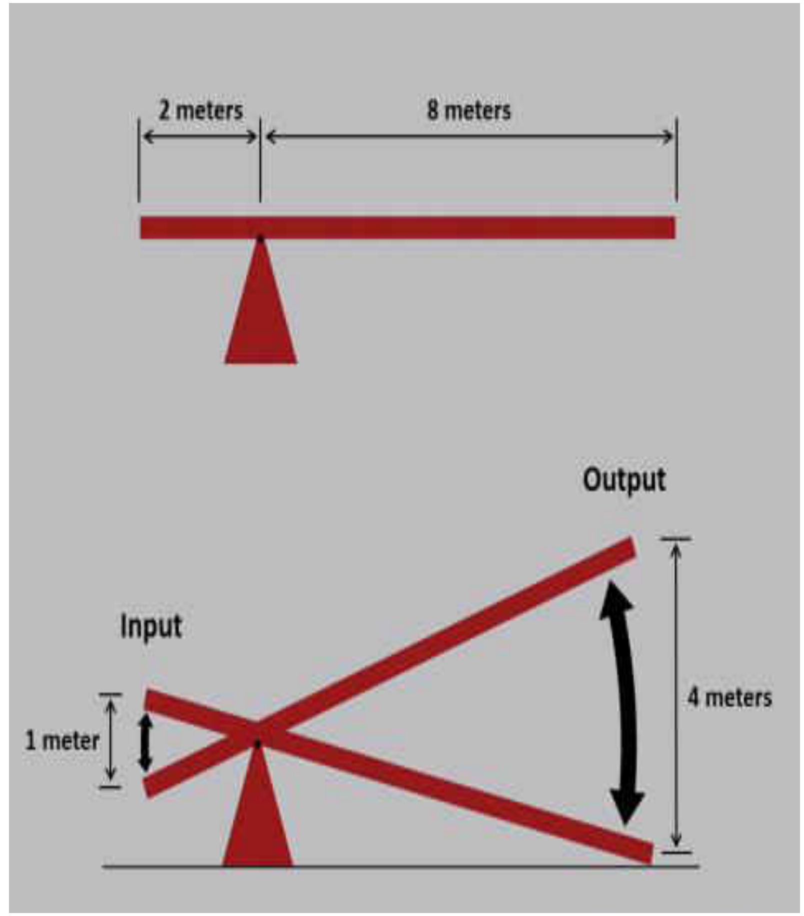


Mechanical Power Transmissions II

Gear Ratios

- Gears are not just used to transfer power, they also provide an opportunity to adjust the mechanical advantage of a mechanism. As discussed in the introduction to this unit, there are cases where a motor itself is powerful enough for an application but the motor's output characteristics are not well suited to the application. A motor that is VERY fast but has only a little bit of torque would not be suitable to lift a heavy load; in these cases it is necessary to use gear ratios to change the outputs to a more appropriate balance of torque and speed.
- Think of a bicycle: the rider has limited power, and wants to ensure the power gets harnessed as much as possible at all times.

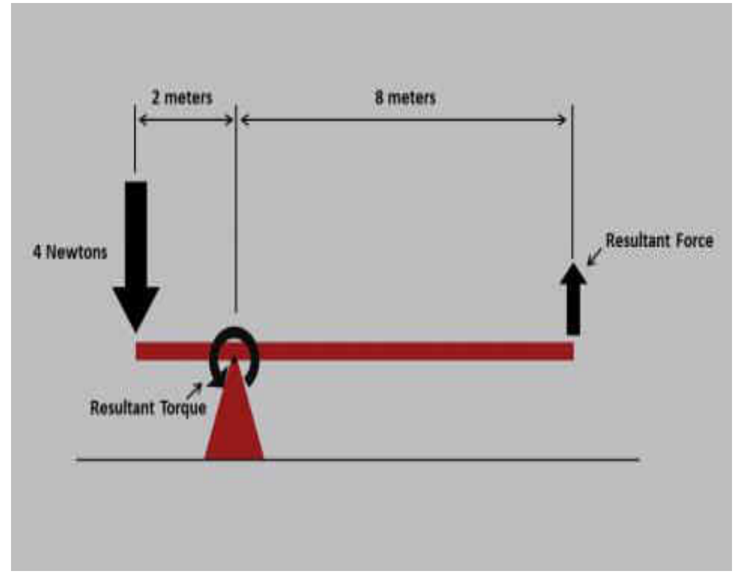
- As the mechanical advantage changes, the speed of motion also changes. Power is the rate at which work is done. If the amount of work increases, the speed at which it gets done decreases.



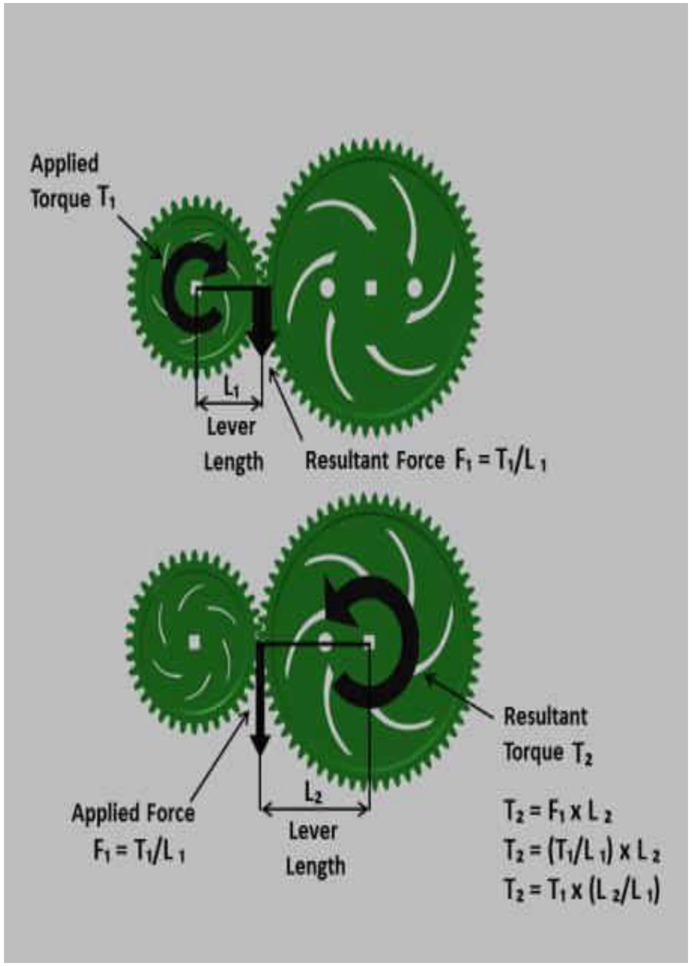
In this example, one can see that if the input side of the lever moves 1 meter then the output moves 4 meters. This difference is proportional to the ratio between the lengths of the levers. Thus, output length / input length = 8 / 2 = 4.

The interesting thing about this is that it moves these distances at the same time. Let's say that it takes one second to move the input one meter, and the input is moving at one meter per second. At the same

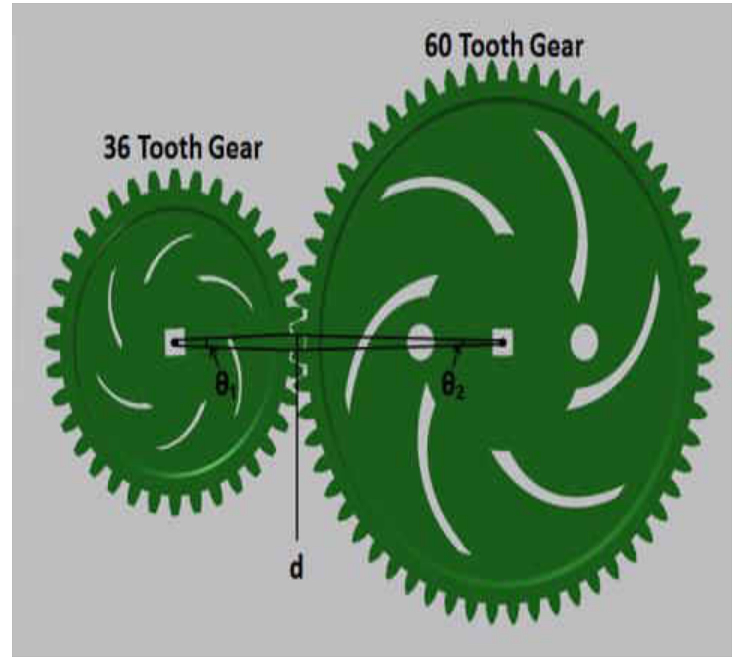
- In this example, the same system shown in the previous example, now has a 4 Newton force applied to the input. How much force then results at the output?
- The first step is to calculate the applied torque on the center of rotation caused by the input force. Using the formulas from Unit 7:
- Torque = Force x Distance from Center of Rotation = 4 N x 2 meter = 8 N-m
- The second step is to calculate the resultant force that this torque now has on the output:
- Force = Torque / Distance = 8 N-m / 8 meter = 1 Newton
- So looking at the above two examples, if the lever system above has an input Force of 4 Newtons and moves 1 meter, the output will have a force of 1 Newton and moves 4 meters – it moves faster, with less force!
- One can see how mechanical advantage (in the form of levers) can be used harness a fixed input force to accomplish a desired output. Gears work in the same manner.
- A spur gear is basically a series of levers; the larger diameter the gear, the longer the levers.



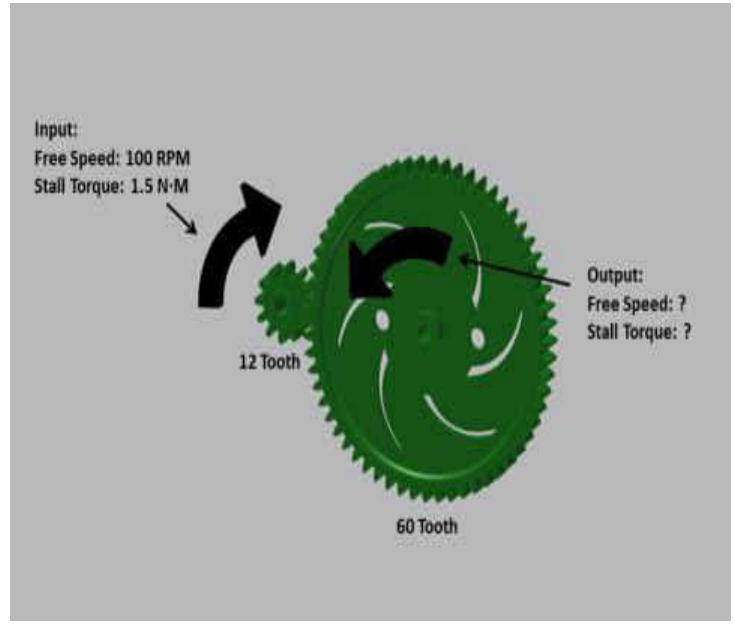
- As seen in this example , torque applied to the first gear results in a linear force at the tip of the gear teeth. That same force is applied onto the tip of the tooth of the gear it is mated with, which in turn results in a torque rotating this gear. The diameters of the gears become the lengths of the levers, and the resulting change of torque is equivalent to the ratio of the diameters. Small gears driving large gears result in a torque increase. Large gears driving small gears result in a torque decrease.



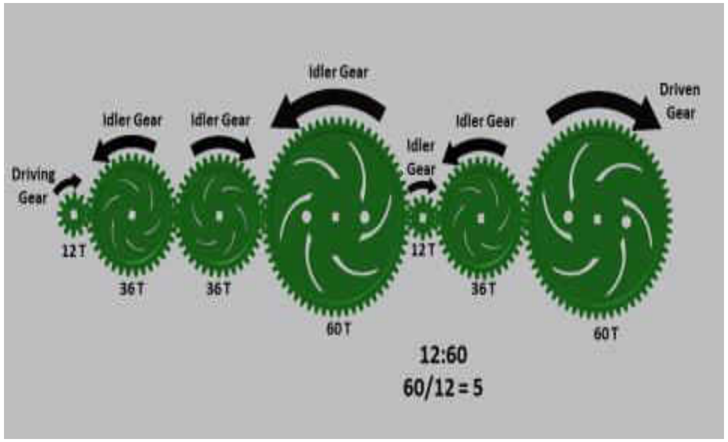
- In example, if the input 36-tooth gear is rotated 1 tooth (d = 1 tooth width) then the gear is rotating 1/36th of a revolution (a1 = 360 / 36 = 10 degrees). As it advances it moves the 60-tooth gear 1 tooth also. However, on the 60 tooth gear this is only 1/60th of a revolution (a2 = 360 / 60 = 6 degrees).
- As the small gear turns a certain amount in a given time the larger gear turns a smaller amount. This means the larger gear is spinning slower than the small gear. This concept works both ways. Small gears driving big gears result in a speed decrease. Large gears driving small gears result in a speed increase.
- Combining the lessons of examples 8.1 through 8.4, one can see that the ratio between the sizes of two gears meshing is proportional to the resulting torque change and speed change between them. This is known as the Gear Reduction.
- As discussed previously, the number of teeth a gear has is proportional to its diameter, so instead of using diameters to calculate Gear Reduction, one can just use tooth counts.
- The Gear Ratio is denoted as (Driving Gear Teeth):(Driven Gear Teeth), so the above pair of gears could be described as 36:60 (or 36 to 60).
- The Gear Reduction is calculated as Driven Gear Teeth / Driving Gear Teeth
- So Gear Reduction = Driven Gear Teeth / Driving Gear Teeth = 60 / 36 = 1.67



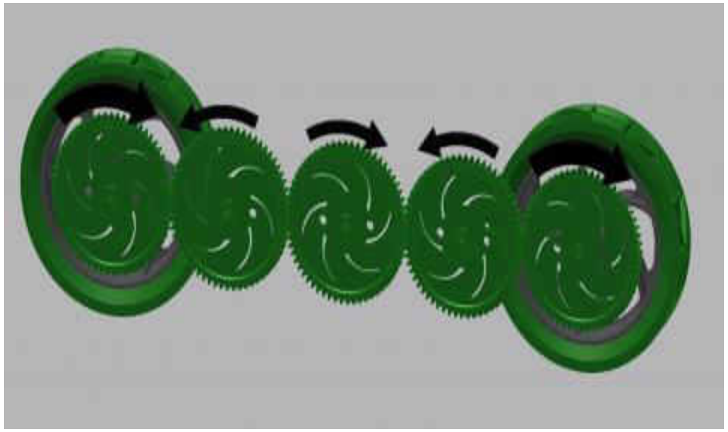
- As discussed above, the Gear Ratio is denoted as (Driving Gear Teeth):(Driven Gear Teeth), so the above pair of gears could be described as 12:60 (or 12 to 60).
- The Gear Reduction is calculated as Driven Gear Teeth / Driving Gear Teeth
- So Gear Reduction = Driven Gear Teeth / Driving Gear Teeth = 60 / 12 = 5
- Looking at the above example…
- The stall-torque of the second shaft can be calculated using the following formula:
- Output Torque = Input Torque x Gear Reduction
- Output Torque = 1.5 N-m x 5 = 7.5 N-m
- The free-speed of the second shaft can be calculated using the following formula:
- Output Speed = Input Speed / Gear Reduction = 100 RPM / 5 = 20 RPM
- So the secondary shaft spins with a free speed of 20 RPM and the stall torque is 7.5 N-m. The speed decreased, but the torque increased.

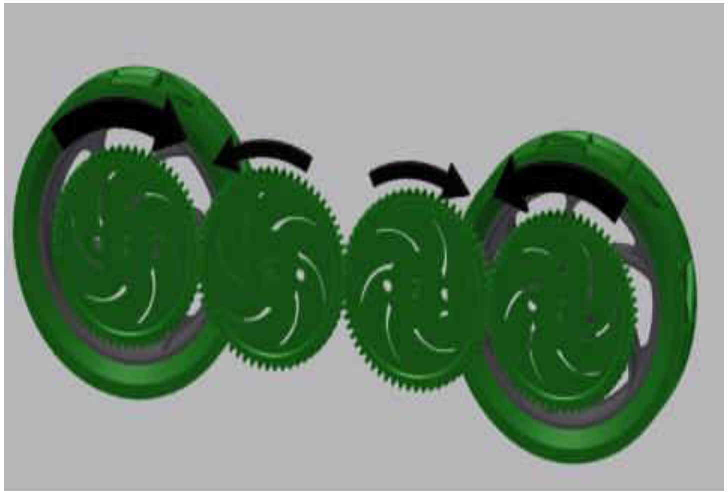


- The idler gear has no effect on the overall reduction. In a previous example it was shown that a 12:60 ratio results in a gear reduction of 5. One can similarly calculate the gear reduction on the idler gear set in two stages.
- Gear Reduction 1 = 36 / 12 = 3
- Gear Reduction 2 = 60 / 36 = 1.667
- Overall Gear Reduction = Gear Reduction 1 x Gear Reduction 2 = 3 x 1.667 = 5
- The only gears that matter to reduction in a system like this are the first gear and the last gear.



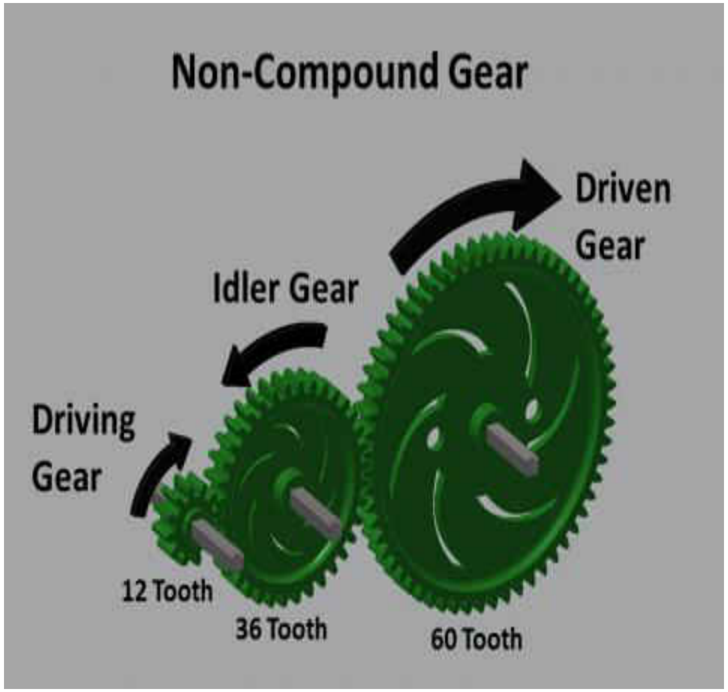
- Idler gears can be very useful, especially for spanning long distances; the below example shows how they can be used in a competition robot drivetrain.



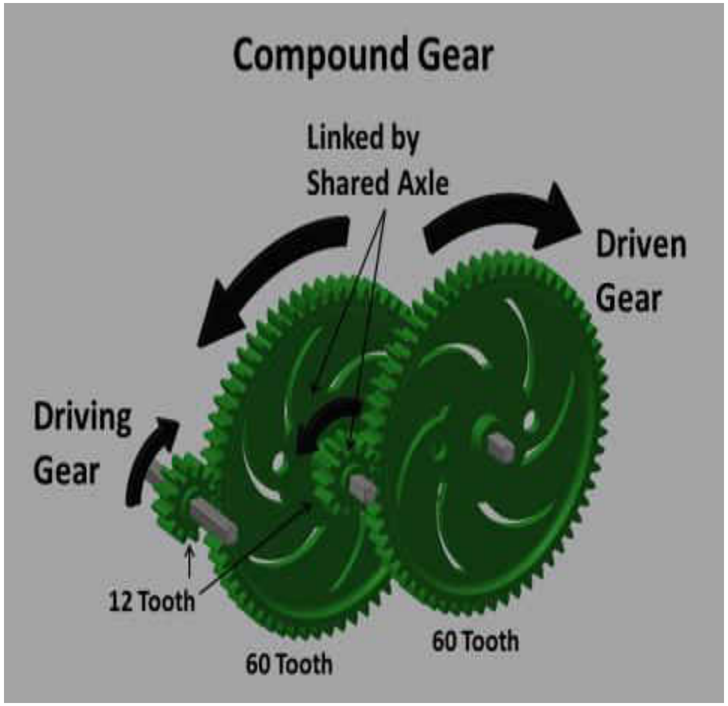


Compound Gear Reduction

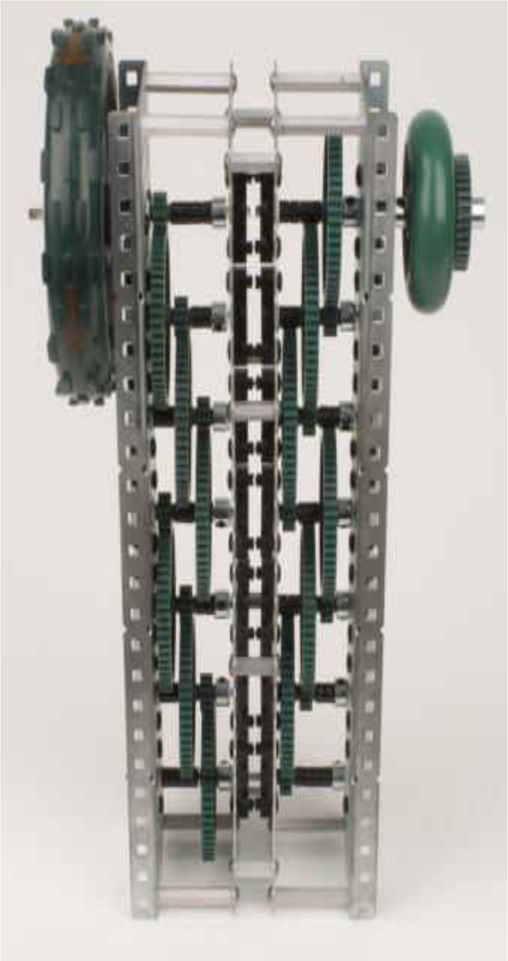
- In certain situations, a design may require more mechanical advantage than a single gear ratio can provide or is otherwise impractical. For example, if a VEX Robot Design requires a 12:500 gear ratio it is a problem because there is no 500-tooth gear available. In this situation, a designer can use multiple gear reductions in the same mechanism. This is called a compound gear reduction.



- n a compound gear system, there are multiple gear pairs. Each pair has its own gear ratio, and a shared axle connects the pairs to each other. The resulting compound gear system still has a driving gear and a driven gear, and still has a gear reduction (now called a "compound gear reduction"). The compound gear ratio is calculated by multiplying the gear reductions of each of the individual gear pairs.
- For the above example the overall gear reduction is calculated as follows:
- Compound Gear Reduction = Reduction 1 x Reduction 2 = (60 / 12) x (60 / 12) = (5) x (5) = 25
- That means the output shaft is 25 times slower than the input shaft with 25 times as much torque. Compound gear ratios add up quickly!

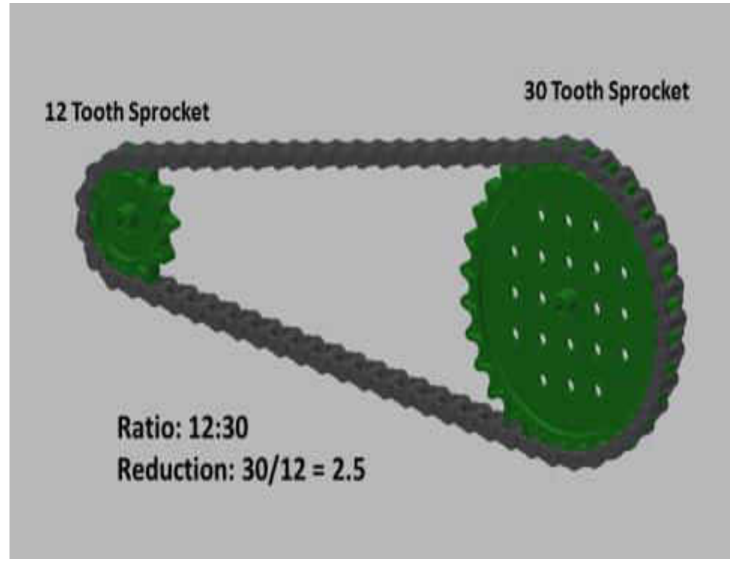


- The example is a gearbox with twelve 12:60 reductions as part of one compound reduction. This produces an overall reduction of 244,140,625, almost a quarter of a billion to 1. This means someone would need to spin the input 244,140,625 times just to get the output to spin once! Fun Fact: spinning the input once per second, it would take approximately 7 years and 9 months before the output spun once.

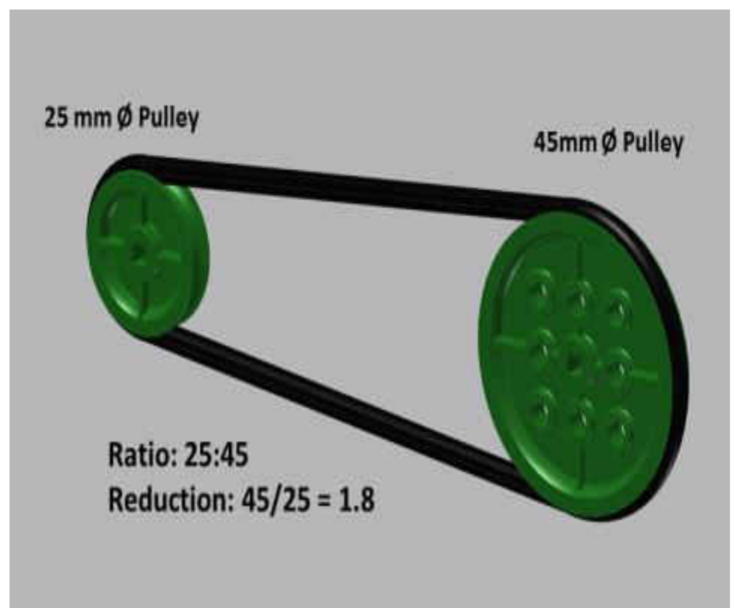


Types of Reductions

- Gears aren't the only mechanisms in competition robotics that provide gear reduction. The same principles apply to sprockets & chains and pulleys & belts.



Similar to gears, sprocket ratios can be calculated by counting their teeth.

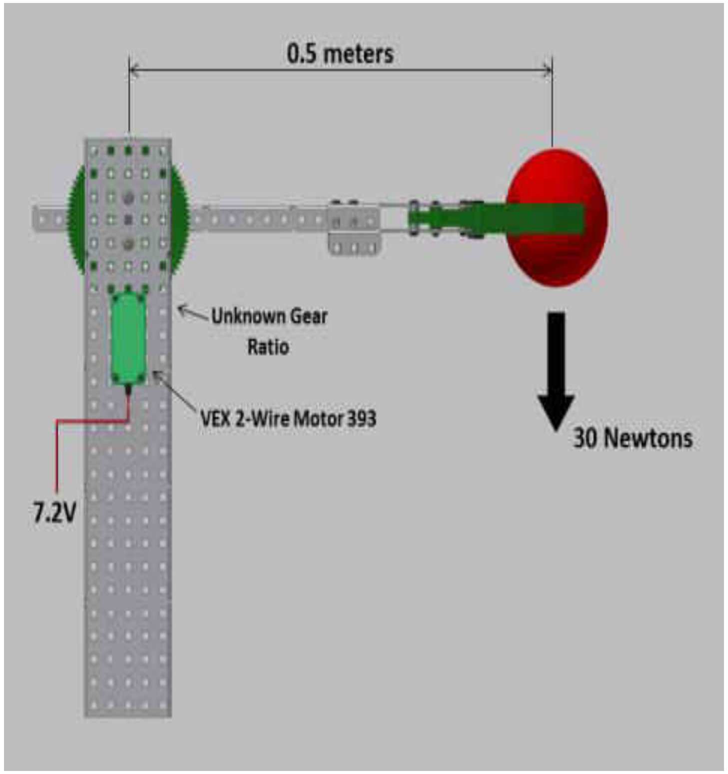


Pulleys and belts don't have teeth, but their ratio can be calculated by comparing their diameters, as shown above.

Both of these mechanisms provide more options to designers working with mechanical power transmission. These two options work great in situations where torque needs to be transferred over long distances. Unlike gears,

Applying Gear Ratios to DC Motor Systems

- Based on the lessons learned before, adjustments to mechanical advantage are important to the design of DC motor systems. DC motors sometimes have current limits they must stay under or other load limits. Designs sometimes require certain speeds, which motors must be geared up or down to achieve.
- The first step in these types of design problems is to calculate the load the motor must be under to meet the design criteria. This is done using the motor characteristics, the design criteria, and the formulas and lessons used in Unit 7. After this, it is a matter of taking the output requirements and the input limits and calculating the ratio required.



FLYWHEEL

Flywheel

- A rotating mechanical device that is used to store rotational energy.

- A flywheel is used in machines , serves as a reservoir which stores energy during the period where the supply of energy is more than the requirement.

- Conversely, a flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing the flywheel's rotational speed.

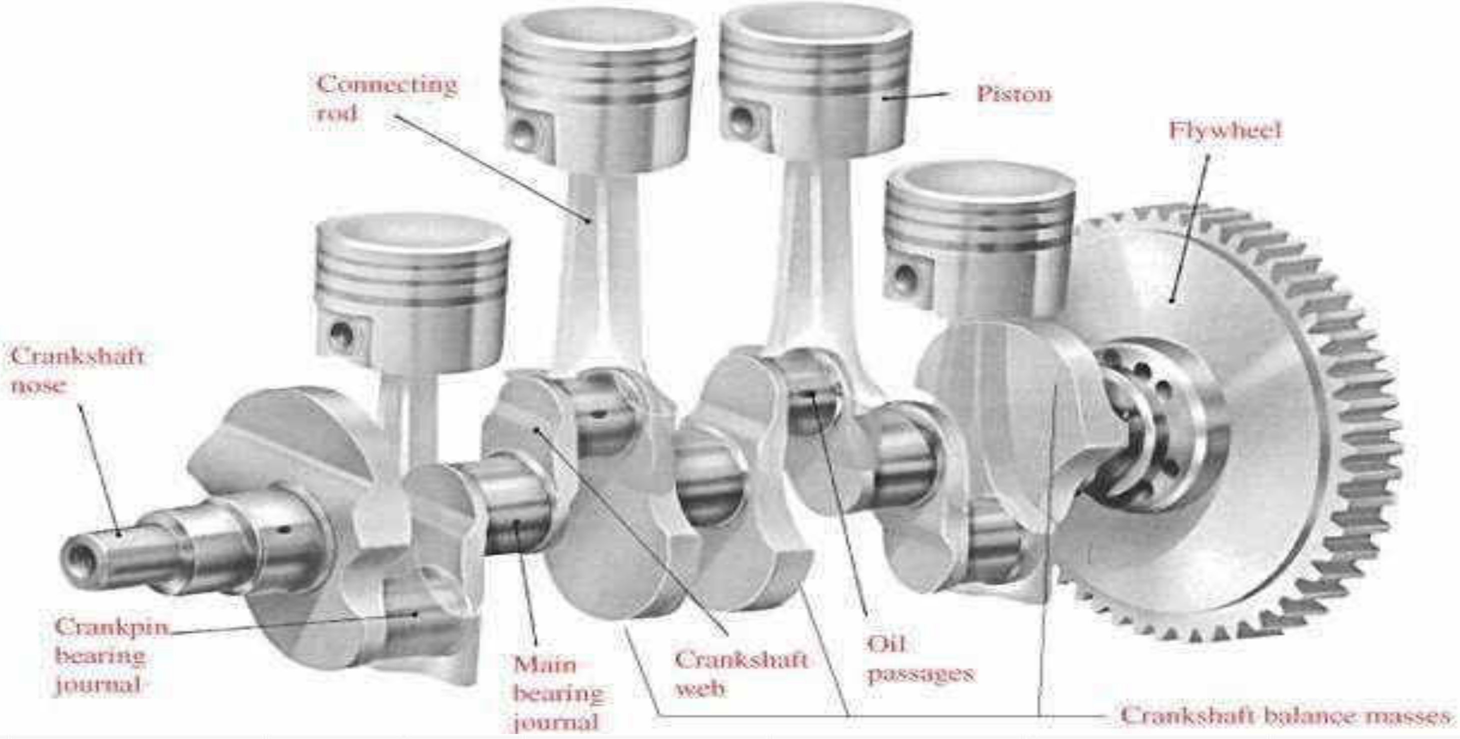
Flywheel

- In other words it can be defined as “it stores energy during power stroke and delivers during idle strokes”.

- A little considerations will show that when the flywheel absorbs energy, its speed increases and when it releases, the speed decreases. Hence a flywheel does not maintain a constant speed, it simply reduces the fluctuation of speed.

- The flywheel’s position is between the engine and clutch patch to the starter.

Flywheel position



- A Flywheel is used to maintain constant angular velocity of the crankshaft in a reciprocating engine. In this case, the flywheel—which is mounted on the crankshaft—stores energy when torque is exerted on it by a firing piston and it releases energy to its mechanical loads when no piston is exerting torque on it.

Energy stored in a flywheel

Rotational Kinetic Energy, $\mathbf{E = \frac{1}{2} I\omega^2}$

where,

I - moment of inertia of the flywheel (ability of an object to resist changes in its rotational velocity)

ω - rotational velocity (Rad / sec)

The moment of inertia, $\mathbf{I = kMr^2}$

where,

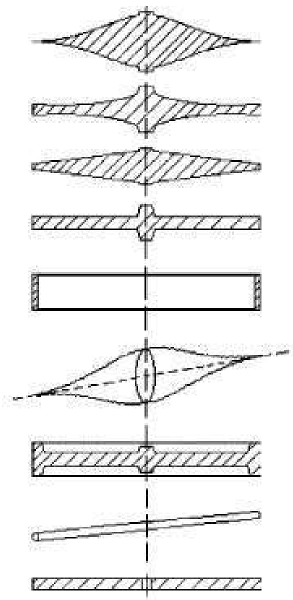
M - mass of the flywheel

r - radius of flywheel

k - inertial constant.

k depends on the shape of the rotating object. Shape-factor K for different planar stress geometries

Fly wheel geometry	Cross section	Shape factor K
Disc		1.000
Modified constant stress disc		0.931
Conical disc		0.806
Flat unpierced disc		0.606
Thin firm		0.500
Shaped bar		0.500
Rim with web		0.400
Single bar		0.333
Flat pierced bar		0.305



So for a solid disk ; $\mathbf{I = Mr^2/2}$

Co efficient of fluctuation of speed (Cs)

The difference between the max and min speeds during a cycle is called the **max fluctuation** of speed.

The ratio of the max fluctuation of speed to the mean speed is called **coefficient of fluctuation** of speed.

$Cs = (N_1 - N_2)/N$

$= 2(N_1 - N_2) / N_1 + N_2$

where N_1 = max speed in r.p.m.

N_2 = min speed in r.p.m.

N = mean speed in r.p.m.

$= (N_1 + N_2) / 2$

Permissible values for C_S

S.NO	Types of machines	Coefficient of fluctuation of speed (C_S)
1	Engines with belt transmission	0.030
2	Gear wheel transmission	0.020
3	Crushing machines	0.200
4	Electrical machines	0.003
5	Hammering machines	0.200
6	Pumping machines	0.03-0.05
7	Machine tools	0.030

Stresses in a flywheel rim

A flywheel consists of a rim at which the major portion of the mass or weight of flywheel is concentrated, a boss or hub for fixing the flywheel on to shaft and a number of arms for supporting the rim on the hub.

The following stresses are induced in the rim.

- Tensile stress due to centrifugal force.
- Tensile bending stress caused by the restraint of the arms.

1. Tensile stress due to the centrifugal force.

The tensile stress in the rim due to the centrifugal force, assuming that the rim is unstrained by the arms, is determined in the similar way as the thin cylinder subjected to internal pressure.

$\mathbf{f_t = \rho . R^2 . \omega^2 = \rho . v^2}$ ($v = R.\omega$) When ρ is in kg/m^3, v is in

m/sec, f_t will be in N/m^2 where ρ = density of the flywheel

material

ω = angular speed of the flywheel R = mean radius of the flywheel

v = linear velocity of the flywheel

2.Tensile bending stress caused by restraint of arms.

The tensile bending stress in the rim due to the restraint of arms is based on the assumption that each portion of the rim between a pair of arms behaves like a beam fixed at both ends and uniformly loaded, such that length between fixed ends,

$L = \pi.D/n = 2.\pi.R / n$ where n - number of arms

The max bending moment,

$M = w.l^2/12 = b.t.\rho.\omega^2.R/12(2.\pi.R/n)$

Section modulus, $Z = 1/6\ (b.t^2)$

So bending stress $f_b = M/Z = b.t.\rho.\omega^2.R/12\ (2.\pi.R/n) * 6\ /\ (b.t^2)$

Total stress in the rim

$$f = f_t + f_b$$

Stresses in flywheel arms

The following stresses are induced in the arms of the flywheel.

- Tensile stresses due to centrifugal force acting on the rim

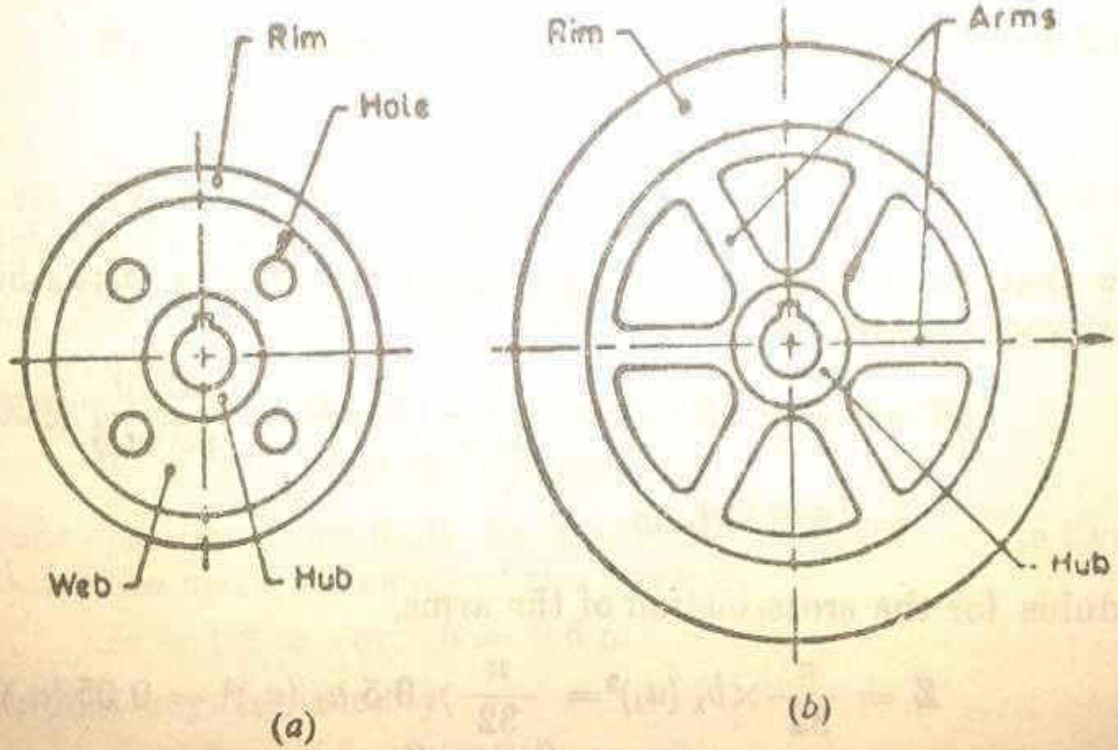
- Bending stress due to the torque transmitted from the rim to the shaft or from the shaft to the rim.

Construction of Flywheel

- Flywheels are typically made of steel and rotate on conventional bearings; these are generally limited to a revolution rate of a few thousand RPM

- The flywheel of smaller size(upto 600 mm dia)are casted in one piece. The rim and the hub are joined together by means of web.

Construction of Flywheels



(a) Flywheel with web. (b) Flywheel with arms.

Fig. 21·16

Construction

- If flywheel is of larger size (upto 2-5 meters diameter), then it is made of arms.

- The number of arms depends upon the size of the flywheel and its speed of rotation. But the flywheels above 2-5 meters are usually casted in two pieces. Such a flywheel is known as " split flywheel ".

- A split flywheel has the advantage of relieving the shrinkage stresses in the arms due to unequal rates of cooling of casting.

Applications

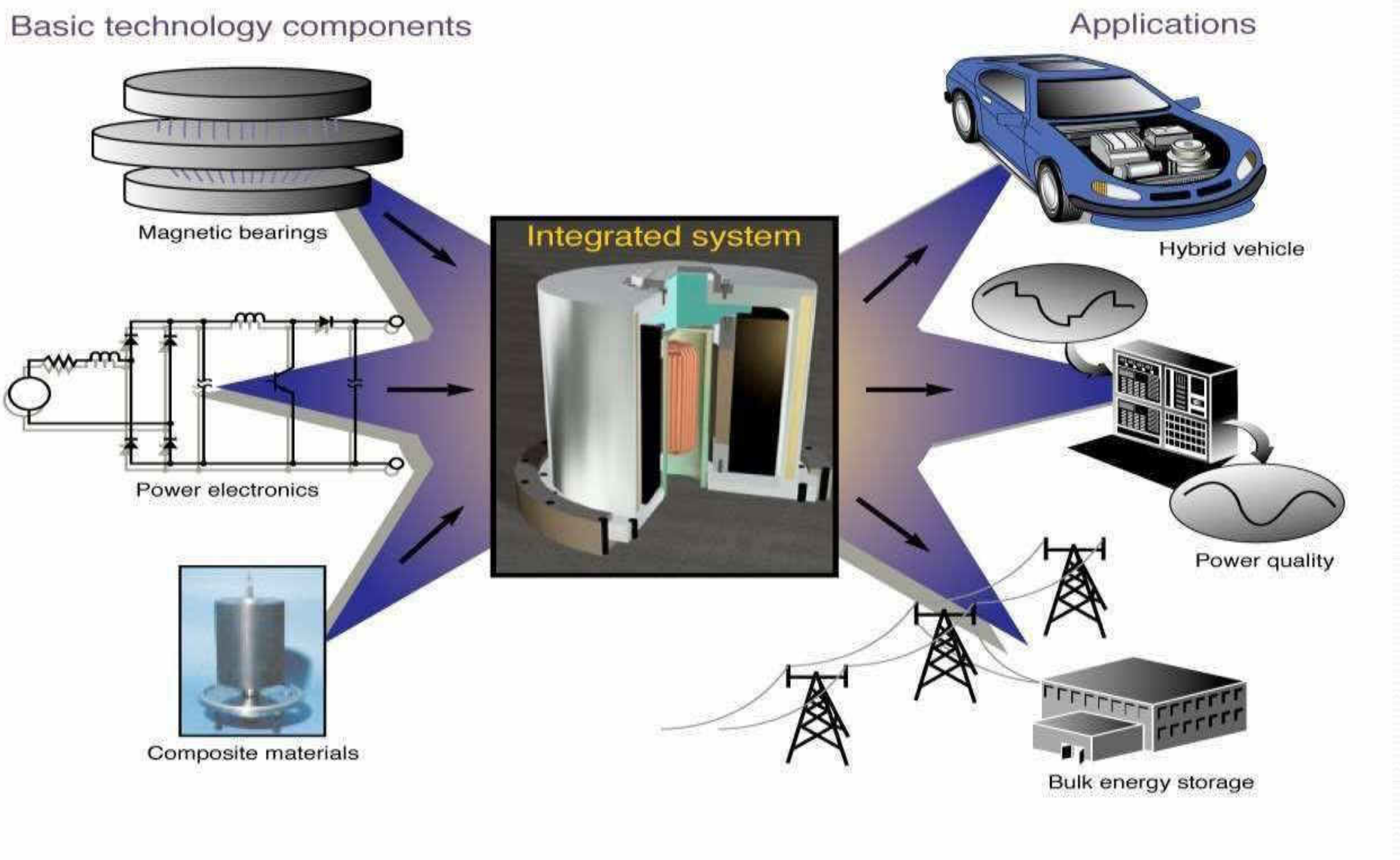
- Providing continuous energy when the energy source is discontinuous. For example, flywheels are used in reciprocating engines because the energy source, torque from the engine, is intermittent.

- Delivering energy at rates beyond the ability of a continuous energy source. This is achieved by collecting energy in the flywheel over time and then releasing the energy quickly, at rates that exceed the abilities of the energy source.

- Dynamic balancing of rotating elements.

- Energy storage in small scale electricity generator sets

Other Applications



Advance and Modern Flywheel

- Flywheels have also been proposed as a power booster for electric vehicles. Speeds of 100,000 rpm have been used to achieve very high power densities.

- Modern high energy flywheels use composite rotors made with carbon-fibre materials. The rotors have a very high strength-to-density ratio, and rotate at speeds up to 100,000 rpm. in a vacuum chamber to minimize aerodynamic losses.

Benefits in Aerospace

Flywheels are preferred over conventional batteries in many aerospace applications because of the following benefits:

- 5 to 10+ times greater specific energy
- Lower mass / kW output
- Long life. Unaffected by number of charge / discharge cycles
- 85-95% round trip efficiency
- Fewer regulators / controls needed
- Greater peak load capability
- Reduced maintenance / life cycle costs

Disadvantages

- There are safety concerns associated with flywheels due to their high speed rotor and the possibility of it breaking loose & releasing all of it's energy in an uncontrolled manner.

- Its Bulkier, adds more weight to the vehicle.

Conclusion

- Recent advances in the mechanical properties of composites has regained the interest in using the inertia of a spinning wheel to store energy.

- Carbon-composite flywheel batteries have recently been manufactured and are proving to be viable in real-world tests on mainstream cars. Additionally, their disposal is more eco-friendly.

STUDY
OF
GOVERNOR

INTRODUCTION

The function of governor is to regulate the speed of an engine when there are variation in the load

Eg. When the load on an engine increases, its speed decreases, therefore it is necessary to increase the supply of working fluid & vice-versa. Thus, Governor automatically controls the speed under varying load.

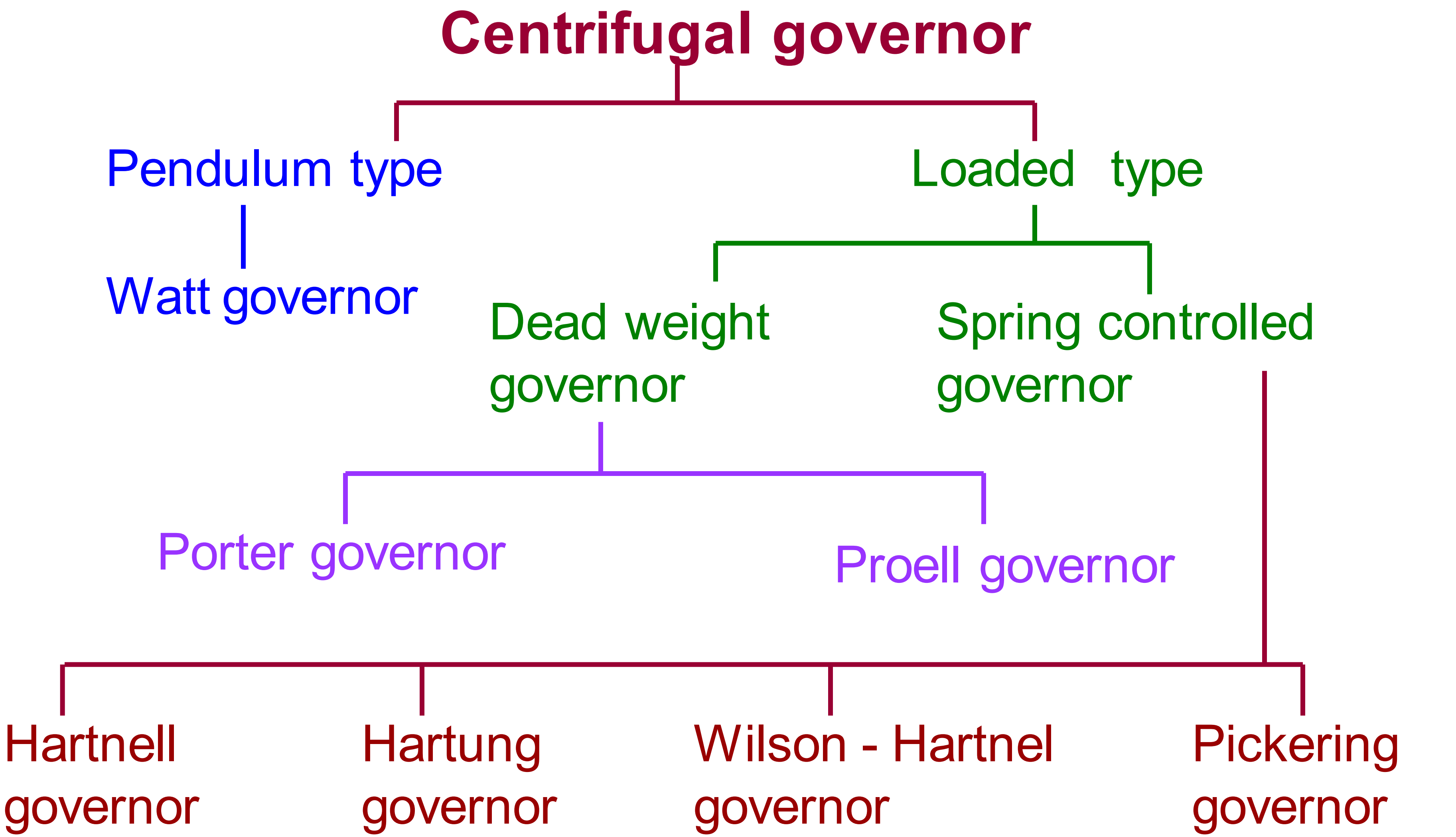
Types of Governors:

The governors may broadly be classified as

1)Centrifugal governors

2)Inertia governors

The centrifugal governors may further be classified as follows:



CENTRIFUGAL GOVERNORS

The centrifugal governors are based on the balancing of centrifugal force on the rotating balls for an equal and opposite radial force, known as the controlling force. It consist of two balls of equal mass, which are attached to the arms as shown in fig. These balls are known as governor balls or fly balls.

when the load on the engine increases, the engine and the governor speed decreases. This results in the decrease of centrifugal force on the balls. Hence the ball moves inward & sleeve moves downwards. The downward movement of sleeve operates a throttle valve at the other end of the bell rank lever to increase the supply of working fluid and thus the speed of engine is increased. In this case the extra power output is provided to balance the increased load.

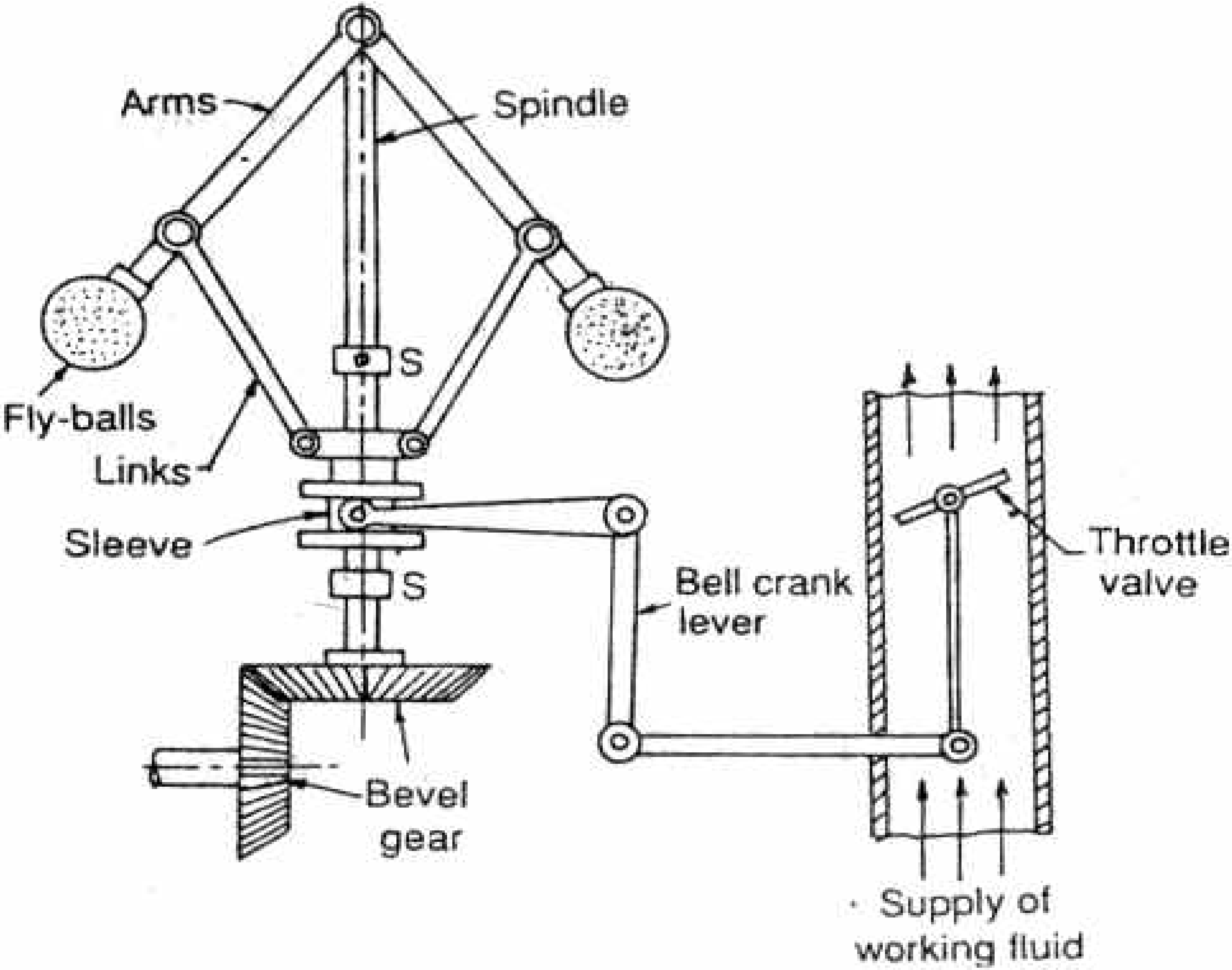


Fig. 18.1. Centrifugal governor.

When the load on the engine decreases, the engine and governor speed increased, which results in the increase of centrifugal force on the balls. Thus the ball move outwards and sleeve rises upwards. This upward movement of sleeve reduces the supply of the working fluid and hence the speed is decreased. In this case power output is reduced.

Watt Governor

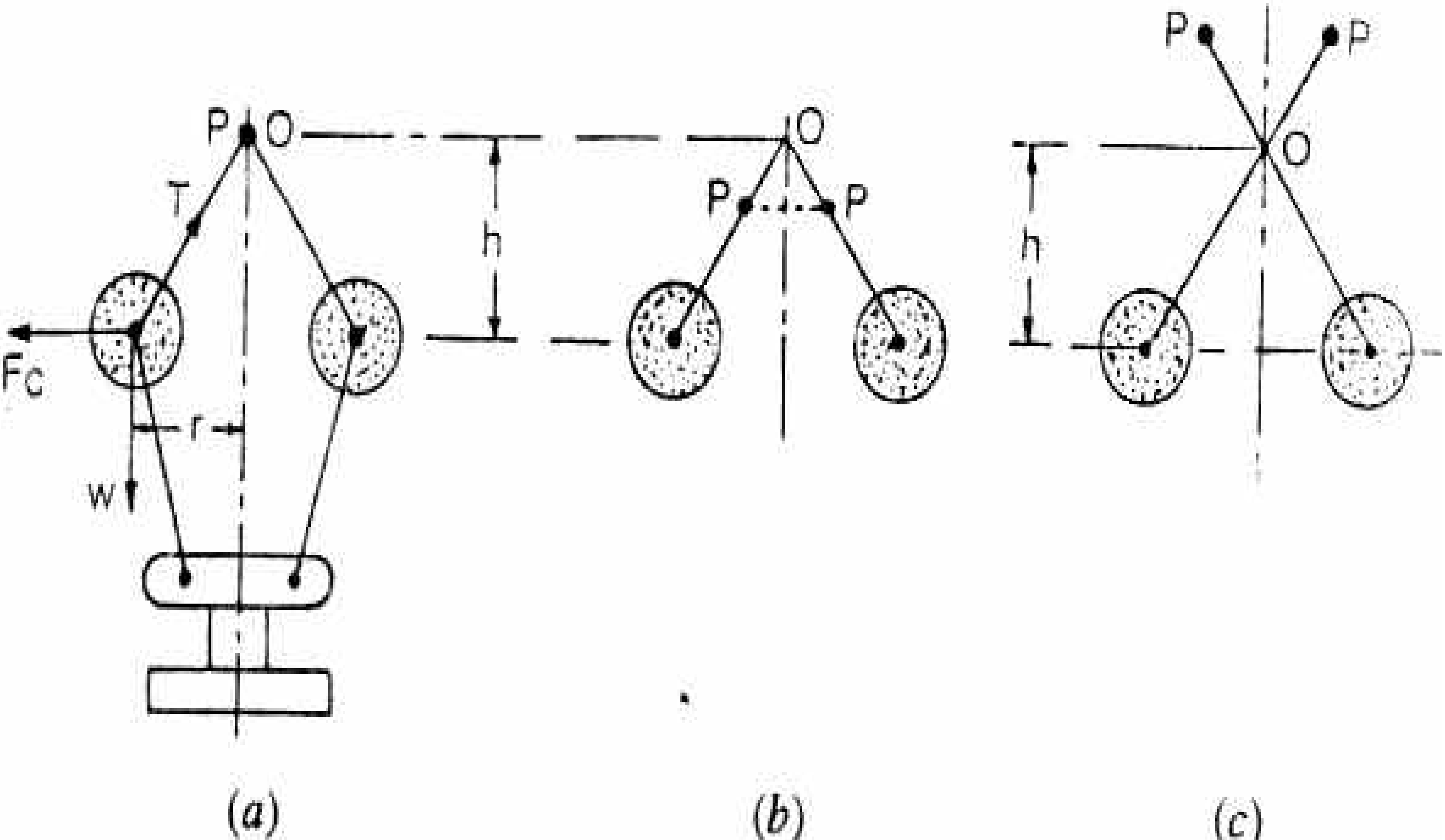


Fig. 18.2. Watt governor.

It is the simplest form of centrifugal governor. It is basically a conical pendulum with links attached to a sleeve of negligible mass. The arms of governors may be connected to the spindle in following three ways;

1. The pivot P, may be on the spindle axis
2. The pivot P, may be offset from spindle axis & the arms when produced intersect at O.
3. The pivot P, may be offset, at the arms crosses the axis at O.

Let,

m = Mass of the Ball in Kg

w = Weight of the ball in Newton (= m.g)

T = Tension in the arm in N

ω = Angular velocity of arm and ball about the spindle axis in rad/sec.

r = Radius of path of rotation of ball in mtrs.

Fc = Centrifugal force acting on the balls in Newtons ($m \omega^2 r$)

h = Height of governor in mtrs.

Final Equations:

Fc x h = W x r

$$m r \omega^2 \times h = m.g.r$$

$$h = g / \omega^2$$

When g is in m/s2 and ω is in rad/sec, then h is in mtrs. If N is the speed in r.p.m. then

$$\omega = 2\Pi N / 60$$

$$H = 9.81 / (2\Pi N / 60)$$

$$= 895 / N^2 \text{ mtrs.}$$

Porter governor

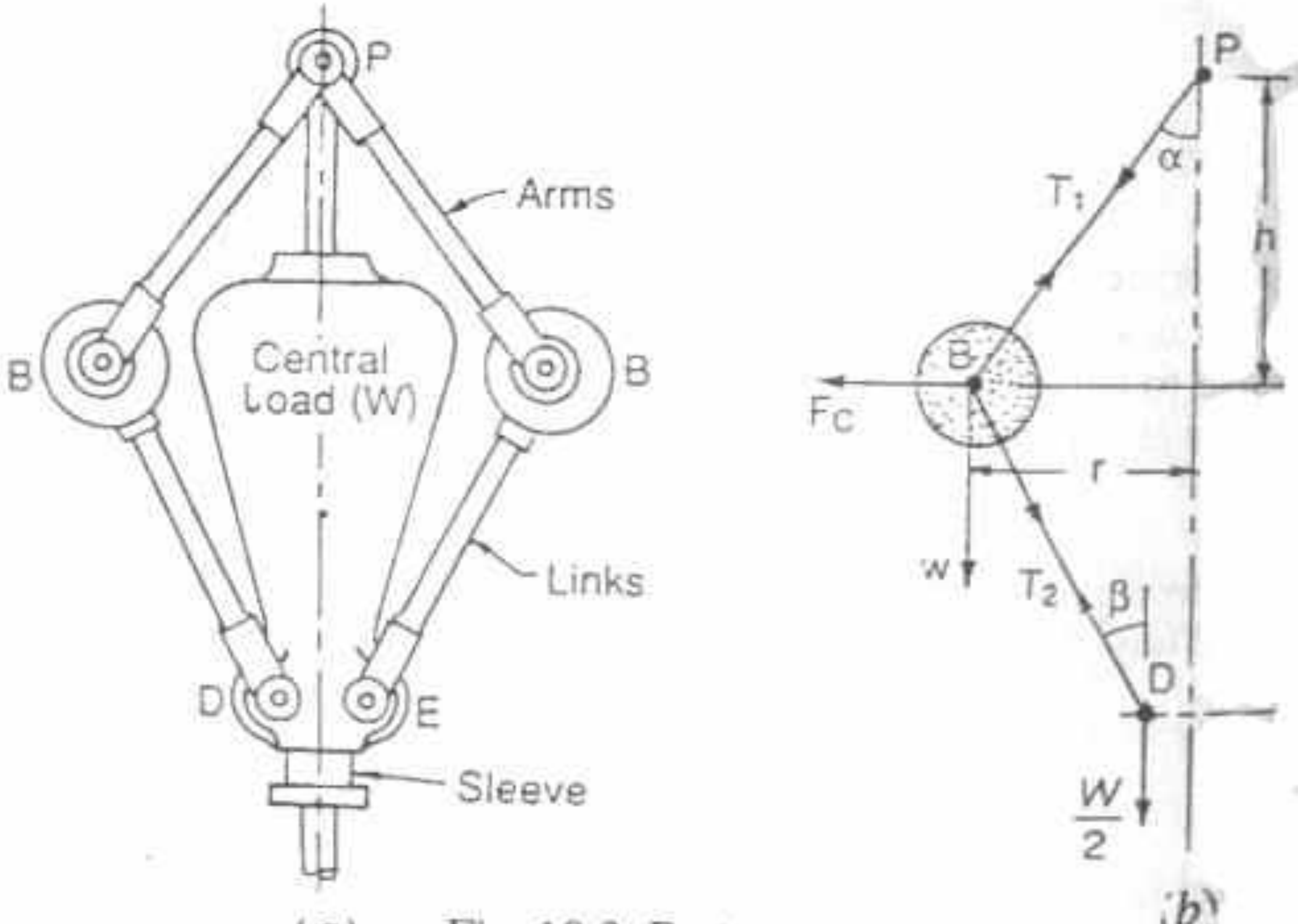


Fig. 18.3. Porter governor.

The porter governor is a modification of a Watt's governor, with central load attached to the sleeve. The load moves up and down the central spindle. This additional downward force increases the speed of revolution required to enable the balls to rise to any predetermined level.

Let,

m = mass of each ball

w = Wt. of each ball

M = mass of central load

W = Wt. of central load

r = Radius o rotation

h = Height of governor

N = Speed o ball in r.p.m.

ω = Angular speed o balls

Fc = centrifugal force

Let,

T1 = Force on the arm

T2 = Force in the links

α = Angle of inclination of arm to vertical

β = Angle of inclination of link to vertical

Final Equations:

1) $$N^2 = \frac{(m + M)}{m} \times \frac{895}{h} \longrightarrow \text{Without Friction}$$

2) $$N^2 = \frac{mg + (M.g \pm F)/2}{m.g} \times (1+q) \times \frac{895}{h} \longrightarrow \text{With Friction}$$

3) $$h = \frac{(m + M)}{m} \times \frac{g}{\omega^2}$$

Proell Governor

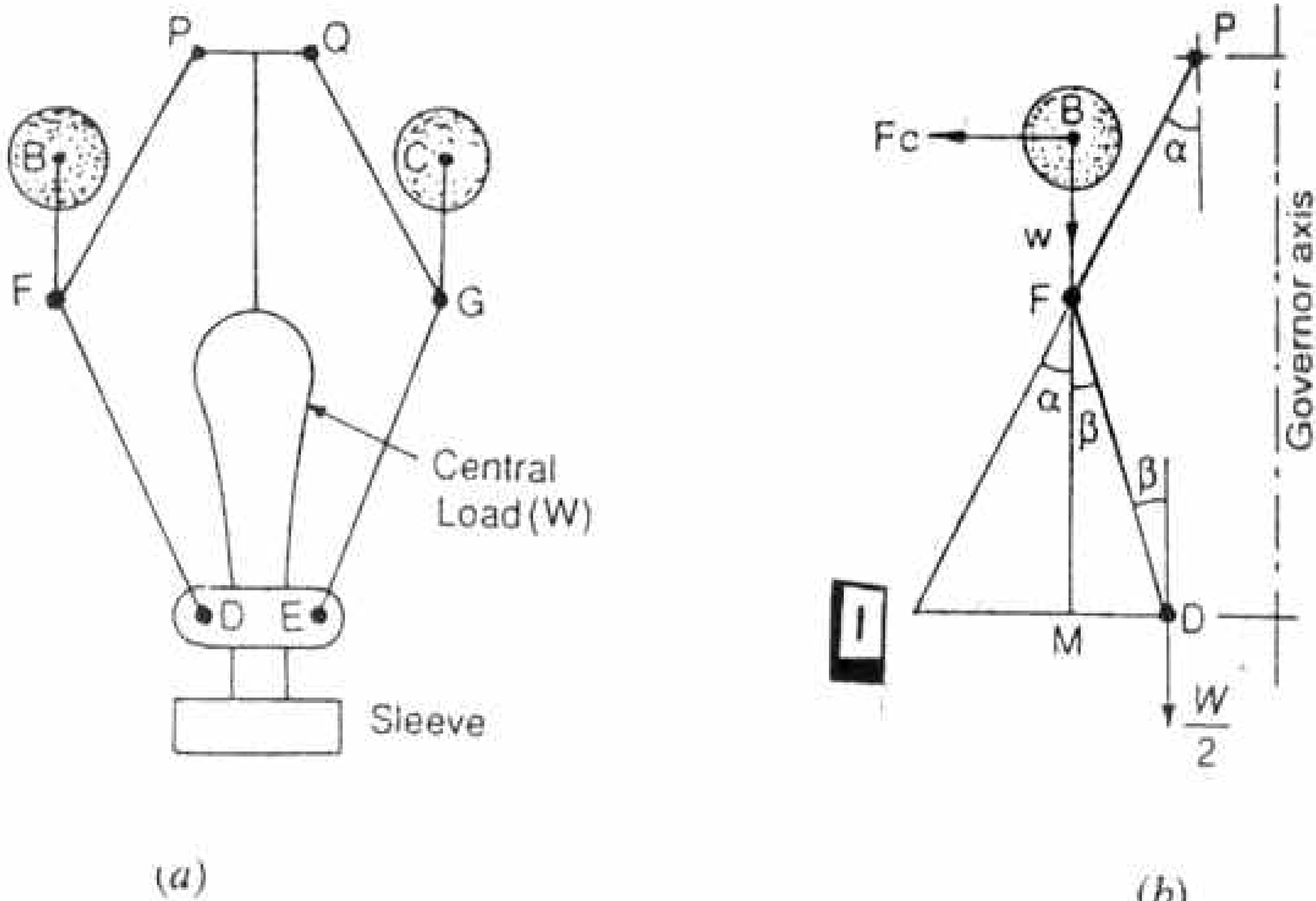


Fig. 18.12. Proell governor.

The Proell governor has the balls fixed at B & C to the extension of the links DF & EG, as shown. The arms FP & GQ are pivoted at p & Q respectively.

Consider the equilibrium of the forces on one half of the governor. The instantaneous centre (I) lies on the intersection of the line PF produced and the line from the D drawn perpendicular to the spindle axis. The perpendicular BM is drawn on ID

Final Equations:

1) $$N^2 = \frac{FM}{BM}\left[\frac{(m + M)}{m}\right] \times \frac{895}{h}$$ → Since h is in mtrs.

Hartnell Governor

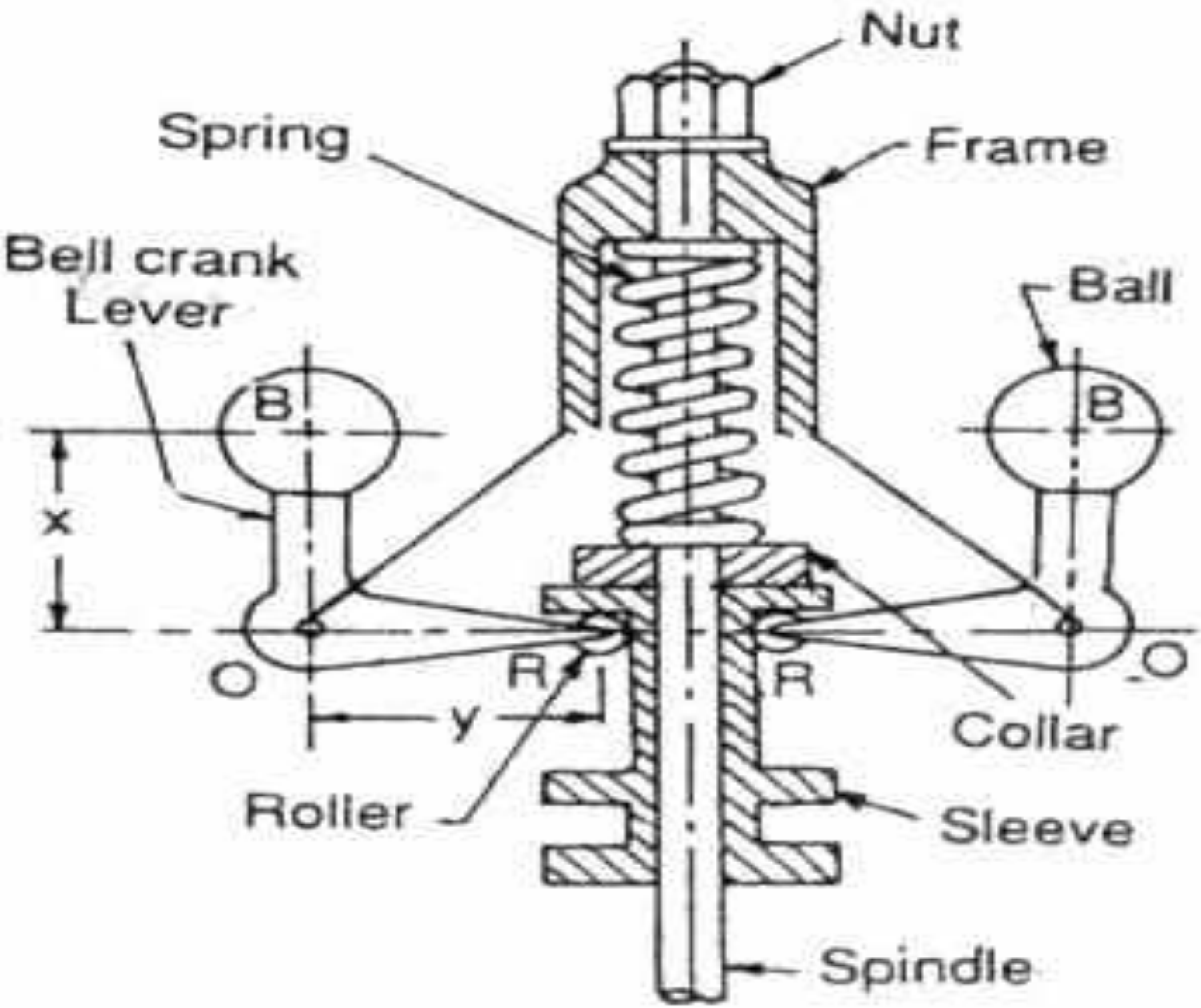


Fig. 18.18. Hartnell governor.

It is a spring loaded governor, consists of two bell crank levers pivoted at the pts. O, O to the frame. Frame is attached to the governor spindle and therefore rotates with it. Each lever carries a ball at the end of the vertical arm OB & a roller at the end of horizontal arm OR. A helical spring in compression provides equal downward forces on two rollers through collar on the sleeve. The spring force may be adjusted by screwing a nut up or down on the sleeve.

Let,

m = mass of each ball

M = Mass of sleeve in kg.

r_1 = Minimum radius of rotation

r_2 = maximum radius of rotation

r = Distance of fulcrum O from gov. axis.

ω_1 = Angular speed of governor at r_1

ω_2 = Angular speed of governor at r_2

S1 = Spring force exerted on the sleeve at ω_1

S_2 = Spring force exerted on the sleeve at ω_2

Fc_1 = centrifugal force at ω_1

Fc_2 = centrifugal force at ω_2

S = Stiffness of the spring

X = Length of vertical or ball arm

Y = length of horizontal or sleeve arm

Final Equations:

$$S = \frac{S_2 - S_1}{h} = 2\left[\frac{Fc_2 - Fc_1}{r_2 - r_1}\right]\left[\frac{x}{y}\right]^2$$

$$Fc = Fc_1 + (Fc_2 - Fc_1)\left(\frac{r - r_1}{r_2 - r_1}\right) = Fc_2 -- (Fc_2 - Fc_1)\left(\frac{r_2 - r}{r_2 - r_1}\right)$$

Hartung Governor

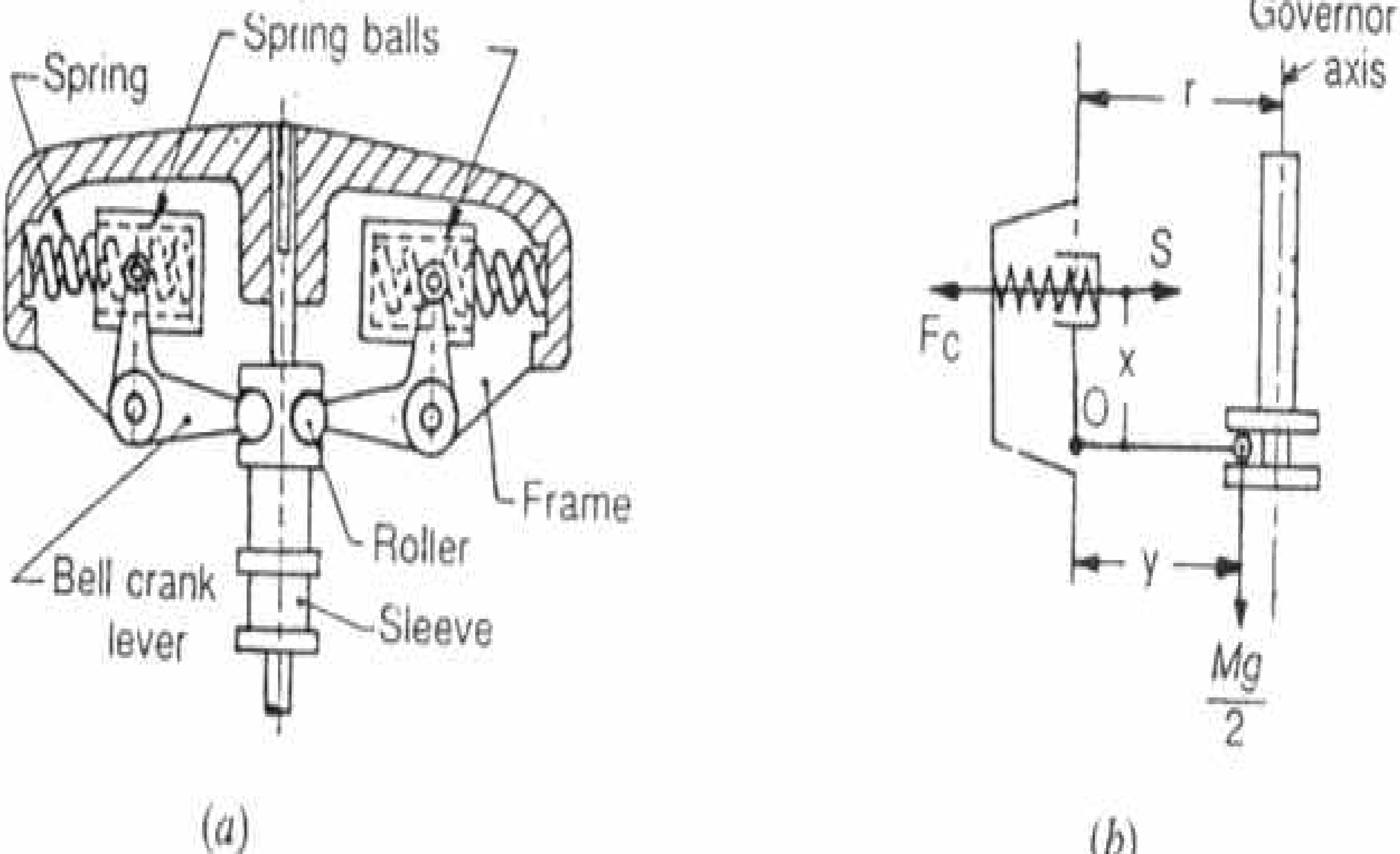


Fig. 18.26. Hartung governor.

A spring controlled governor of Hartung type is shown in fig. In this type of governor, the vertical arms of the bell crank levers are fitted with spring balls which compress against the frame of the governor when the rollers at the horizontal arm press against the sleeve.

Let,

S = Spring force

Fc = Centrifugal force

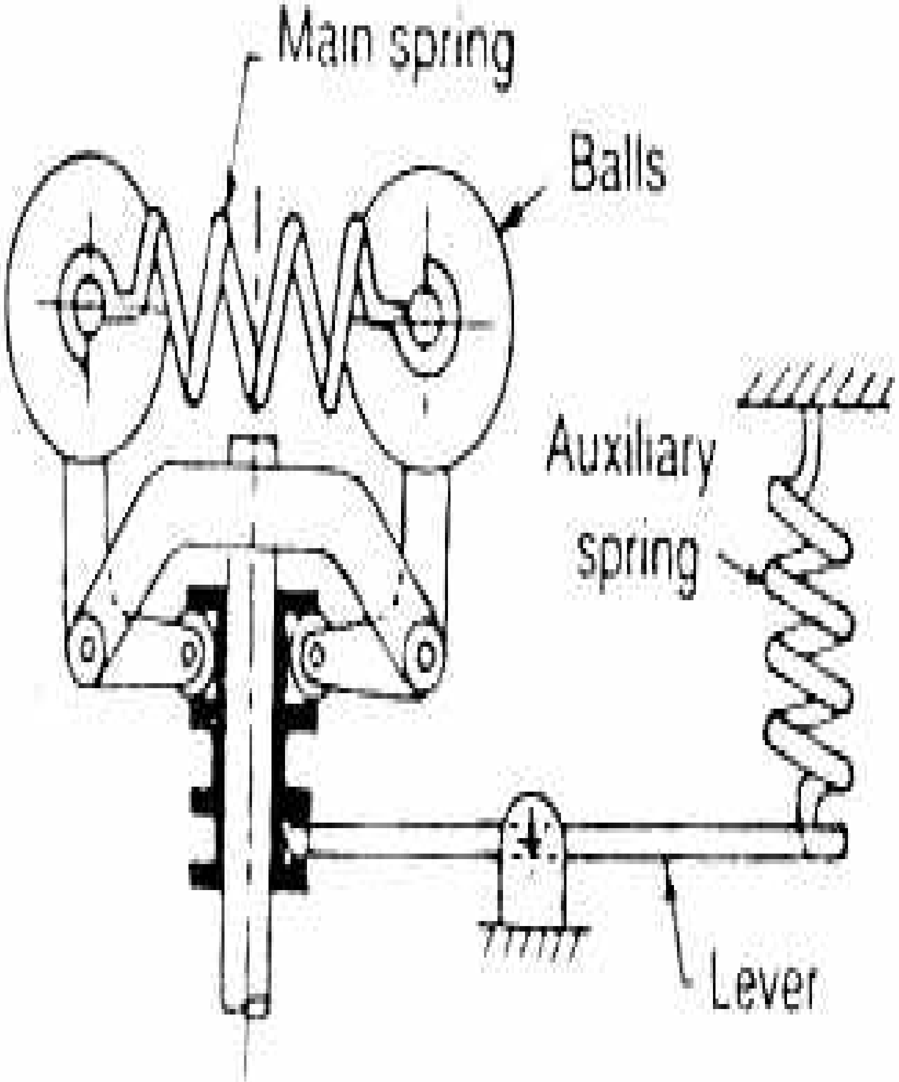
M = Mass of sleeve in kg.

x & y = length of vertical and horizontal arm of the bell crank lever

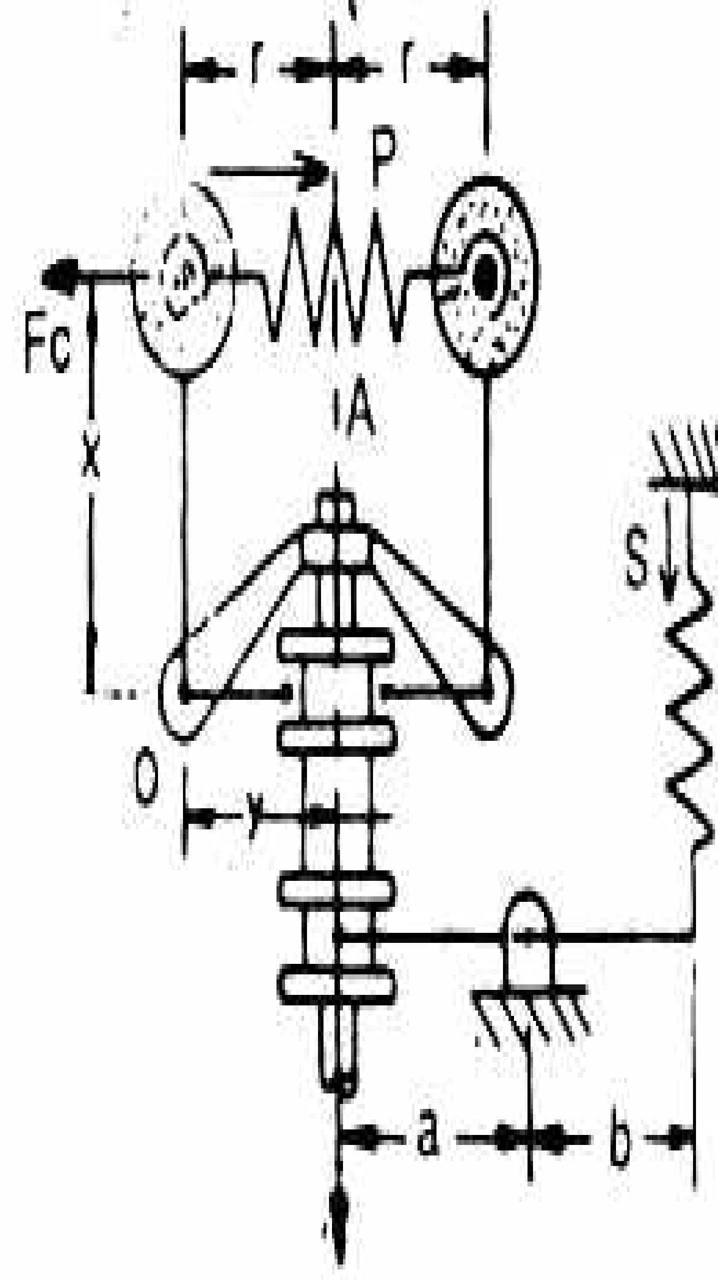
Final Equations:

$$Fc \times x = S \times x + \frac{M.g}{2} \times y$$

Wilson - Hartnell
Governor



Wilson-Hartnell governor.



Line diagram of Wilson-Hartnell gov

It is a governor in which the balls are connected by a spring in tension as shown. An auxiliary spring is attached to the sleeve mechanism, through lever by means of which equilibrium speed for a given radius may e adjusted. The main spring may e considered of two equal parts each belonging to both the balls.

Let,

P = Tension in the main spring or ball spring A

S = Tension in the auxiliary spring B

m = mass of each ball

M = Mass of sleeve in kg.

r = Radius of rotation of each ball

S_a = Stiffness of auxiliary spring

S_b = Stiffness of each ball

Final Equations:

$$4S_b = \frac{Fc_2 - Fc_1}{r_2 - r_1}$$

$$S_b = \frac{Fc_2 - Fc_1}{4\,(r_2 - r_1)}$$

Pickering Governor

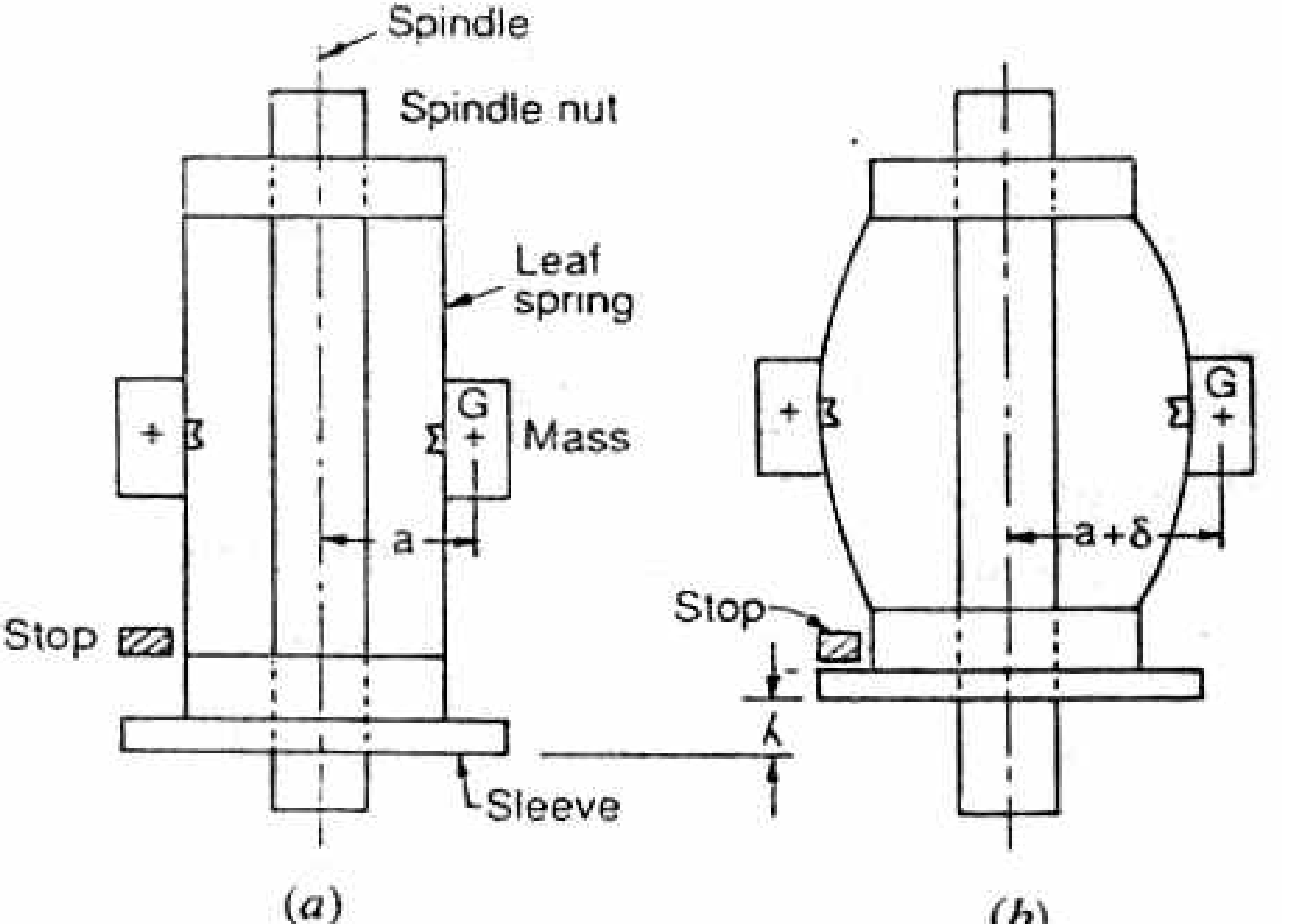


Fig. 18.32. Pickering governor.

It is mostly used for driving gramophone. It consists of three straight leaf springs arranged at equal angular intervals round the spindle. Each spring carries a weight at the centre. The weights move outwards and the springs bend as they rotate about the spindle axis with increasing speed.

Let,

m = Mass attached at the centre of the leaf spring

a = Dist. From the spindle axis to the centre of gravity of the mass, when governor is at rest

ω = Angular speed of the governor spindle

δ = Deflection of centre of leaf spring at angular speed w1

A + δ = Dist. from the spindle axis to the centre of gravity of the mass, when governor is rotating

λ = Lift of the sleeve corresponding to the deflection δ

Final Equations:

$$\delta = \frac{m\,\omega^2\,(a + \delta)\,L^3}{192\,E.I.}$$

CONCLUSION :-

In this way we have studied aout the various types and working of different governors.

Cams

- Cams are used to convert rotary motion to oscillatory motion (almost always) or oscillatory motion to rotary motion (rarely)
- For high speed applications – example, internal combustion engines
- Objectives of this chapter:
  - Learn fundamental concepts and terminology
  - Learn how to design a cam and follower set to achieve a desired output motion.

Cam types

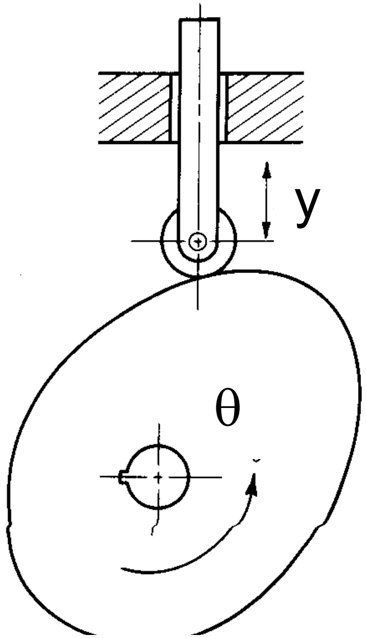
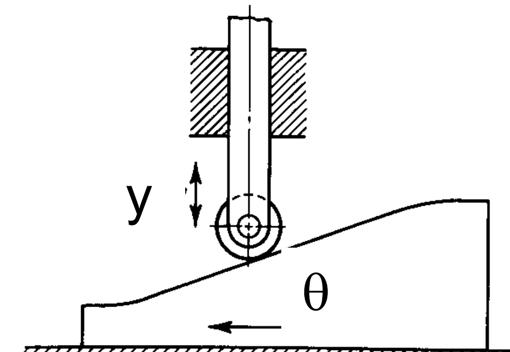
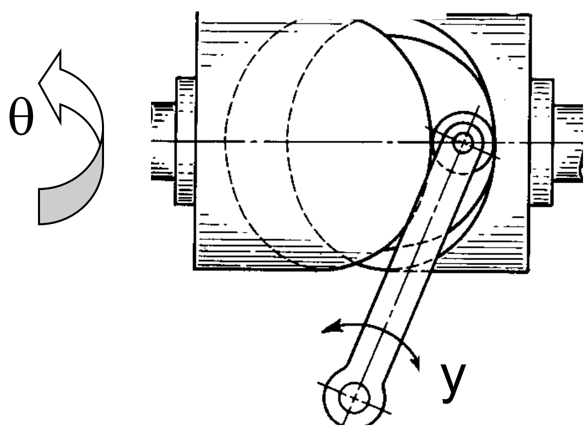


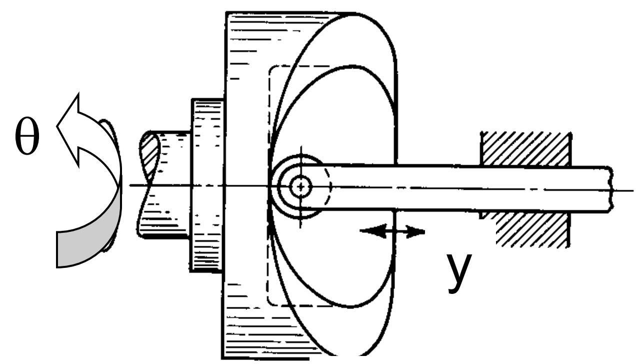
Plate cam



Wedge cam



Barrel cam



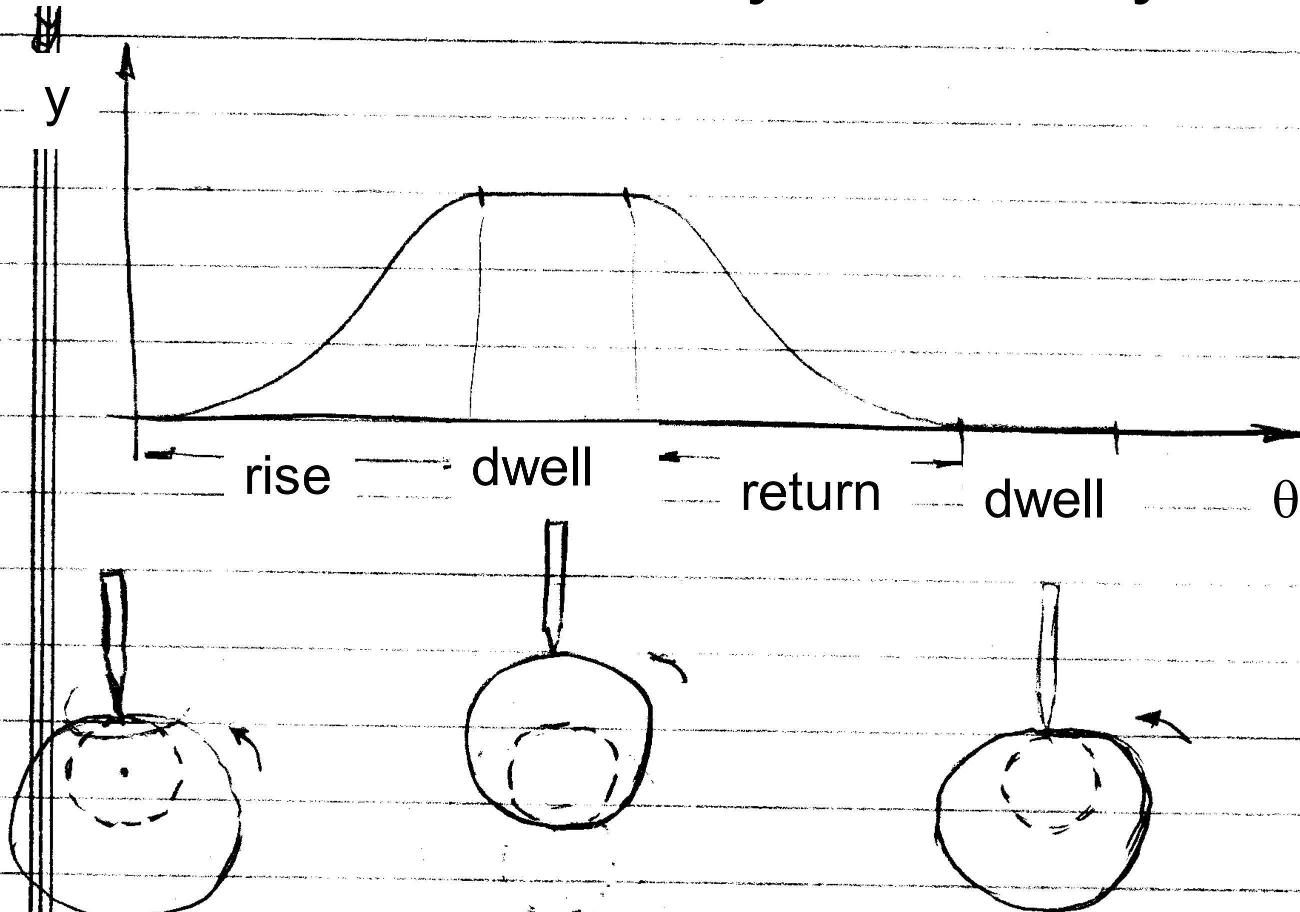
Face cam

Followers

- Knife-edge
- Flat-face
- Roller
- Sperical-face

Displacement diagrams

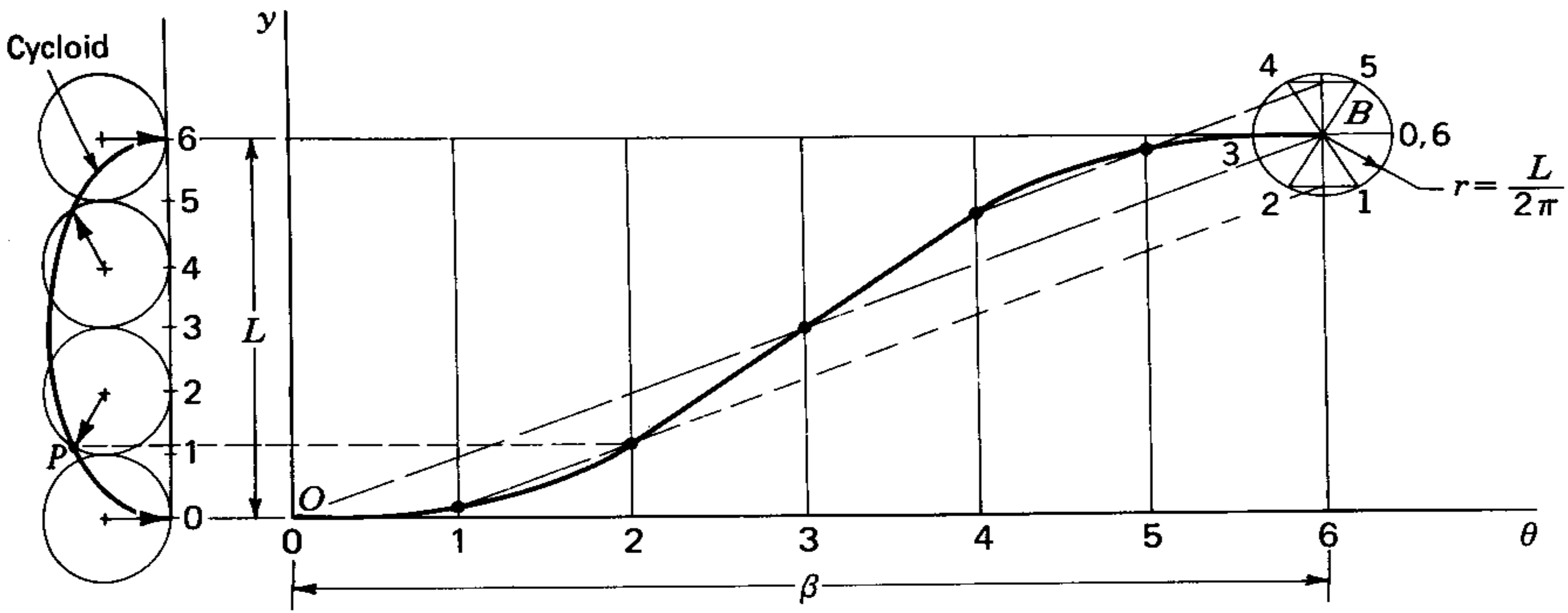
- Cam-follower: usually 1-DOF system



Displacement diagram types

- Uniform motion,
  - Constant velocity
  - Problem: infinity acceleration at point where dwell portion starts
- Parabolic-uniform
  - Can be shown that acceleration is constant
- Sinusoidal (simple harmonic motion)
- Cycloidal

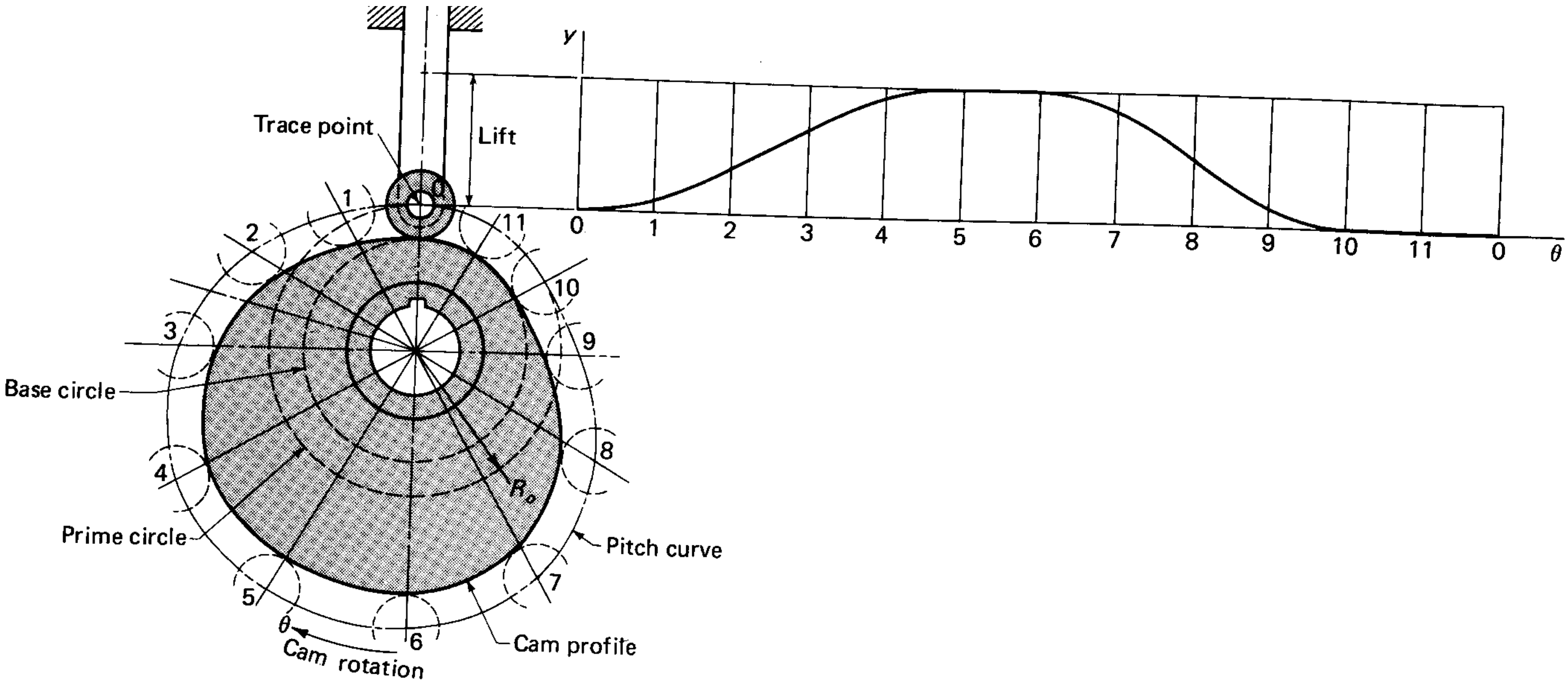
Cycloidal displacement diagram



Graphical layout of cam profiles

- Terminology
  - Trace point: on follower; point of fictitious knife-edge follower. Center of roller, surface of flat-faced follower.
- Pitch curve
  - Locus generated by trace point as follower moves relative to cam
- Prime circle
  - Smallest circle that can be drawn with center at the cam rotation axis and is tangent to the pitch circle
- Base circle
  - Smallest circle centered on cam rotation axis and is tangent to the cam surface

Layout of cam profile: roller follower

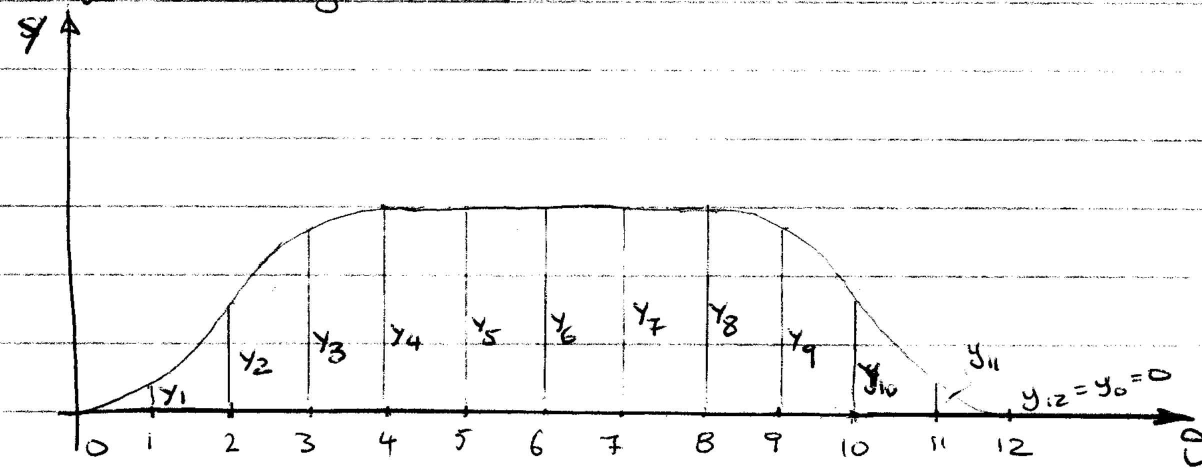


Constructing cam profile: kinematic inversion principle

- Consider that cam is stationary and that follower rotates in the opposite direction than the cam does in reality

Finding cam shape given the displacement diagram:

knife-edge translating follower



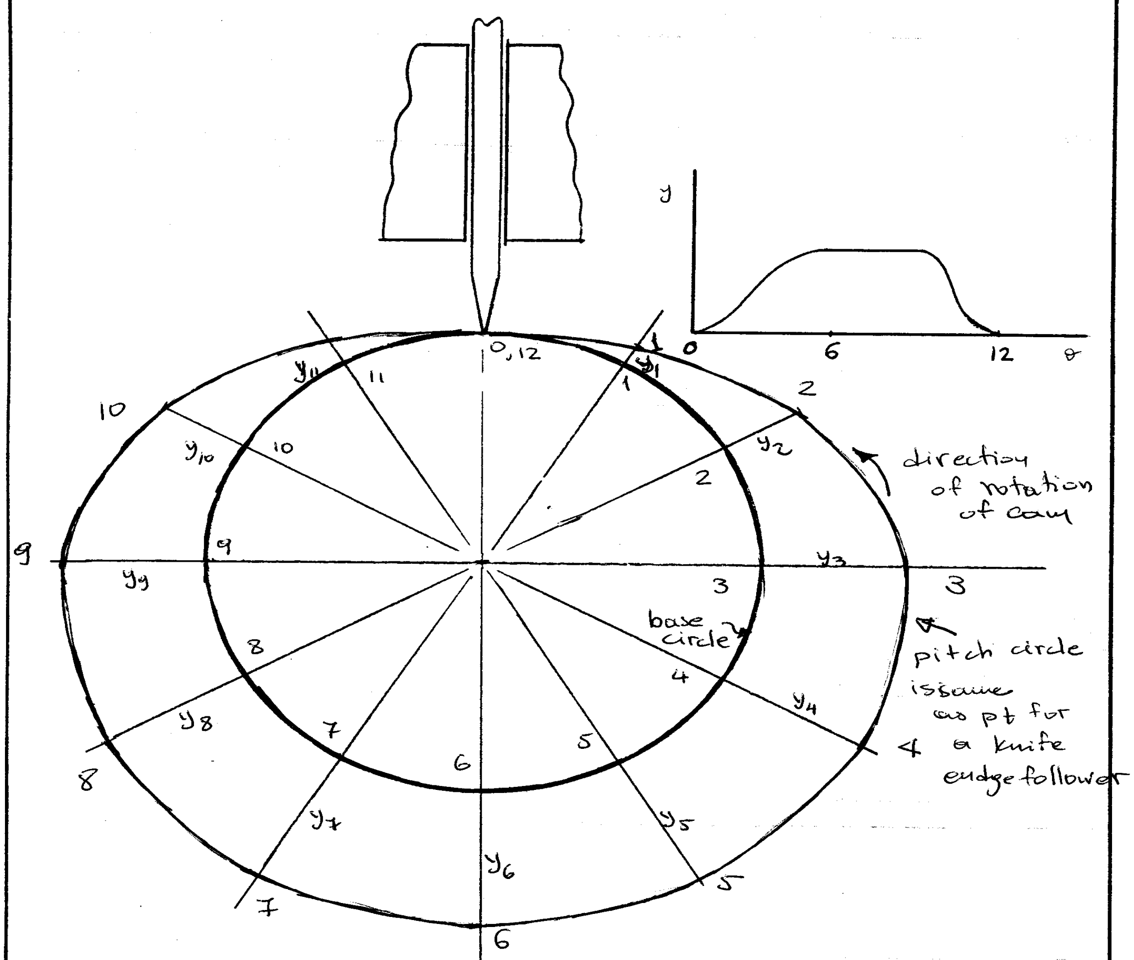
Steps

1) Break range of θ in 12 portions
2) Measure displacement of follower at each point, $y_1, \ldots y_{12}$
3) Define base circle of cam
4) Devide base circle to 12 equal sectors
5) Mark 12 radials in opposite direction of cam rotation
6) Mark follower displacements on radials
7) sketch cam.

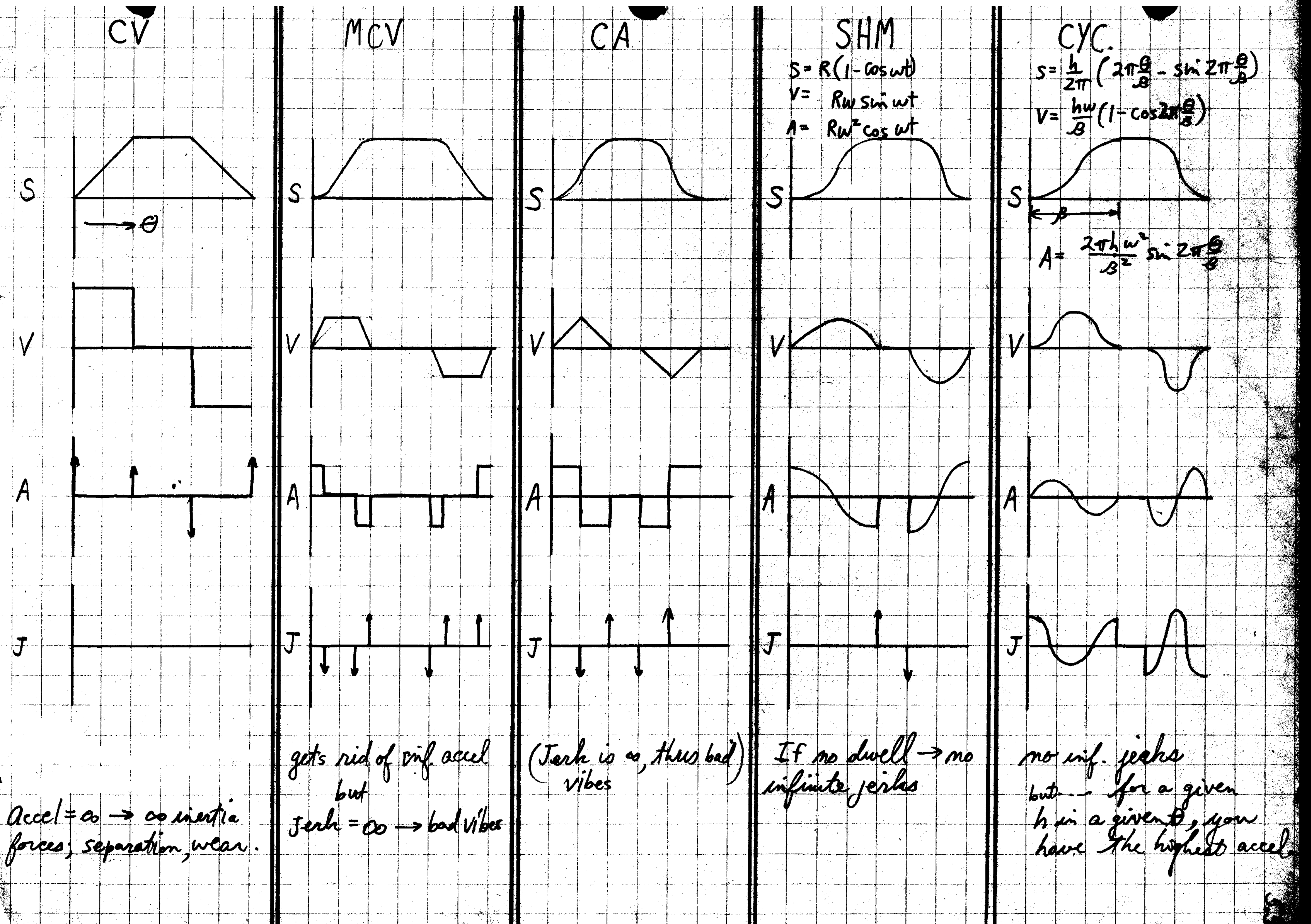
PROBLEM | The University of Toledo COLLEGE OF ENGINEERING | NAME | DATE

Knife-edge translating follower

Extracted from Dr. Kramer's notes



SVAJ diagrams: show displacement, velocity, acceleration versus θ



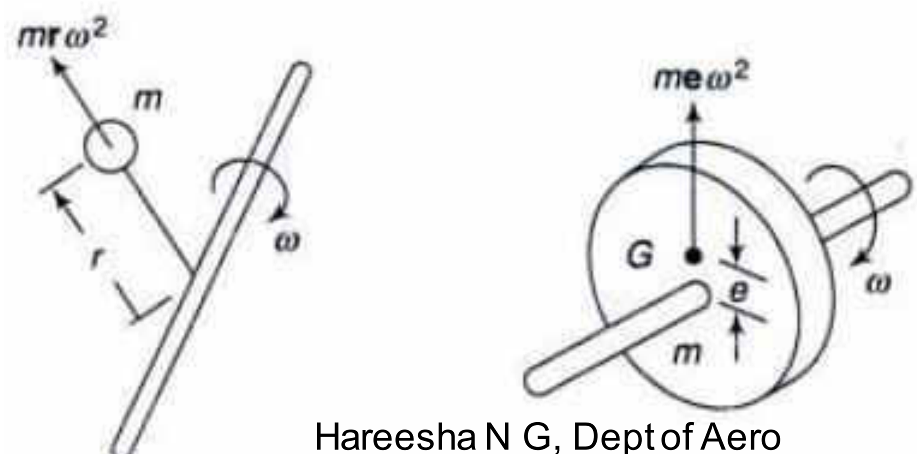
Unit Balancing of Rotating Masses

- **Static and dynamic balancing**
- **Balancing of** single rotating mass by balancing masses in same plane and in different planes.
- Balancing of several rotating masses by balancing masses in same plane and in different planes.

What is Balancing ?

- Often an unbalance of forces is produced in rotary or reciprocating machinery due to the inertia forces associated with the moving masses.
- Balancing is the process of designing or modifying machinery so that the unbalance is reduced to an acceptable level and if possible is eliminated entirely.

- A particle or mass moving in a circular path experiences a centripetal acceleration and a force is required to produce it.
- An equal and opposite force acting radially outwards acts on the axis of rotation and is known as centrifugal force .
- This is a disturbing force on the axis of rotation, the magnitude of which is constant but the direction changes with the rotation of the mass.
- In a revolving rotor, the centrifugal force remains balanced as long as the centre of the mass of the rotor lies on the axis of the shaft.
- When the centre of mass does not lie on the axis or there is an eccentricity, an unbalanced force is produced



(a) (b)

Why Balancing is necessary?

- The high speed of engines and other machines is a common phenomenon now-a-days.
- It is, therefore, very essential that all the rotating and reciprocating parts should be completely balanced as far as possible.
- If these parts are not properly balanced, the dynamic forces are set up.
- These forces not only increase the loads on bearings and stresses in the various members, but also produce unpleasant and even dangerous vibrations.

Balancing of Rotating Masses

- Whenever a certain mass is attached to a rotating shaft, it exerts some centrifugal force, whose effect is to bend the shaft and to produce vibrations in it.
- In order to prevent the effect of centrifugal force, another mass is attached to the opposite side of the shaft, at such a position so as to balance the effect of the centrifugal force of the first mass.
- This is done in such a way that the centrifugal force of both the masses are made to be equal and opposite.
- The process of providing the second mass in order to counteract the effect of the centrifugal force of the first mass, is called ***balancing of rotating masses*****.**

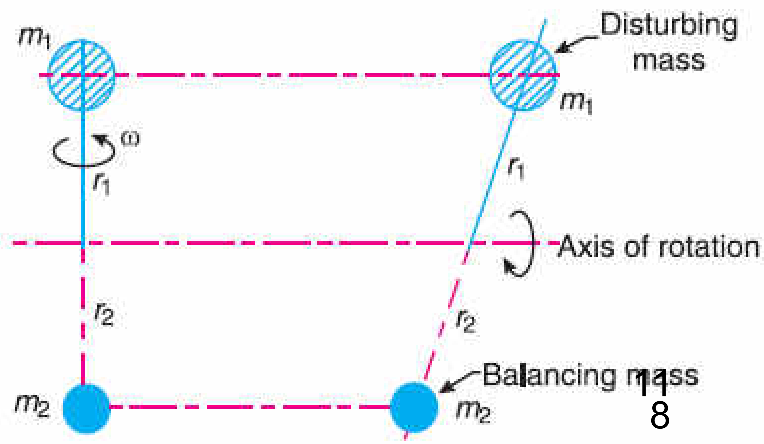
- The following cases are important from the subject point of view:
  1. Balancing of a single rotating mass by a single mass rotating in the same plane.
  2. Balancing of a single rotating mass by two masses rotating in different planes.
  3. Balancing of different masses rotating in the same plane.
  4. Balancing of different masses rotating in different planes.

Balancing of a Single Rotating Mass By a Single Mass Rotating in the Same Plane

- Consider a disturbing mass *m*1 attached to a shaft rotating at ω rad/s as shown in Fig.
- Let *r*1 be the radius of rotation of the mass *m*1 (*i.e. distance between the axis of rotation of the shaft* and the centre of gravity of the mass *m*1).
- We know that the centrifugal force exerted by the mass *m*1 on the shaft,

$$F_{C1} = m_1 \cdot \omega^2 \cdot r_1$$

- This centrifugal force acts radially outwards and thus produces bending moment on the shaft.
- In order to counteract the effect of this force, a balancing mass (*m*2) may be attached in the same plane of rotation as that of disturbing mass (*m*1) such that the centrifugal forces due to the two masses ar



Balancing of a Single Rotating Mass By a Single Mass Rotating in the Same Plane

Let r_2 = Radius of rotation of the balancing mass m_2 (*i.e.* distance between the axis of rotation of the shaft and the centre of gravity of mass m_2).

$\therefore$ Centrifugal force due to mass m_2,

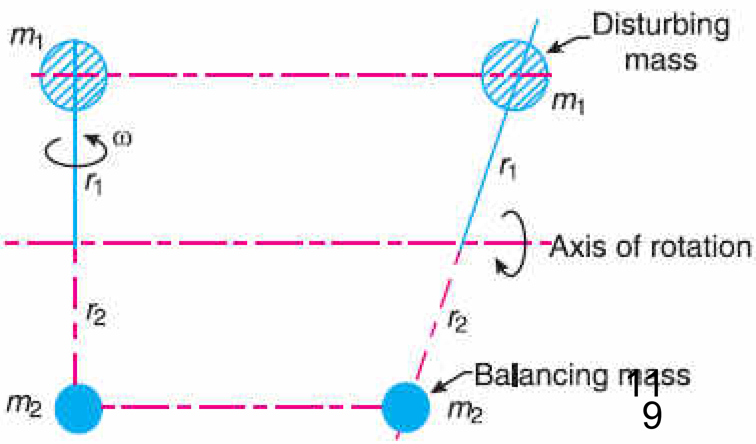
$$F_{C2} = m_2 \cdot \omega^2 \cdot r_2 \quad \ldots (ii)$$

Equating equations (*i*) and (*ii*),

$$m_1.\omega^2 \cdot r_1 = m_2 \cdot \omega^2 \cdot r_2 \quad \text{or} \quad m_1 \cdot r_1 = m_2 \cdot r_2$$

Notes : 1. The product $m_2.r_2$ may be split up in any convenient way. But the radius of rotation of the balancing mass (m_2) is generally made large in order to reduce the balancing mass m_2.

2. The centrifugal forces are proportional to the product of the mass and radius of rotation of respective masses, because ω^2 is same for each mass.



- In the previous arrangement for balancing gives rise to a couple which tends to rock the shaft in its bearings.
- Therefore in order to put the system in complete balance, two balancing masses are placed in two different planes, parallel to the plane of rotation of the disturbing mass, in such a way that they satisfy the following two conditions of equilibrium.

1. The net dynamic force acting on the shaft is equal to zero. This requires that the line of action of three centrifugal forces must be the same. In other words, the centre of the masses of the system must lie on the axis of rotation. This is the condition for ***static balancing***.
2. The net couple due to the dynamic forces acting on the shaft is equal to zero. In other words, the algebraic sum of the moments about any point in the plane must be zero.

The conditions **(1) and (2) together give *dynamic balancing*.**

Balancing of a Single Rotating Mass By Two Masses Rotating in Different Planes

- The following two possibilities may arise while attaching the two balancing masses :

1. The plane of the disturbing mass may be in between the planes of the two balancing masses, and
2. The plane of the disturbing mass may lie on the left or right of the two planes containing the balancing masses.

Fundamentals of Vibration

-

Outline

- Why vibration is important?
- Definition; mass, spring (or stiffness) dashpot
- Newton's laws of motion, 2nd order ODE
- Three types of vibration for SDOF sys.
- Alternative way to find eqn of motion: energy methods
- Examples

Why to study vibration

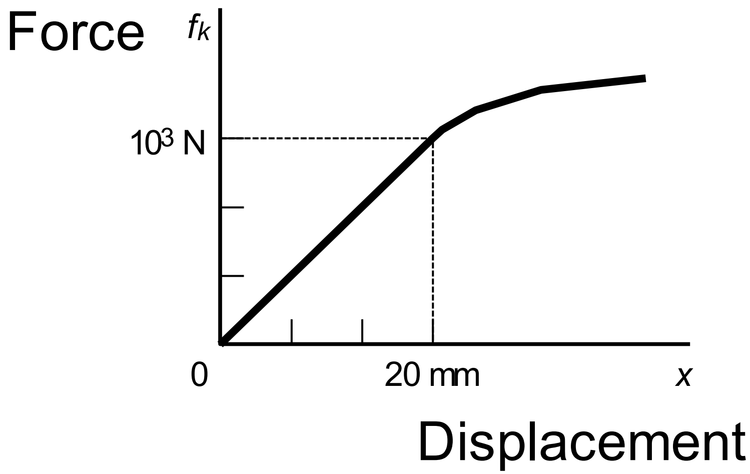
- Vibrations can lead to excessive deflections and failure on the machines and structures
- To reduce vibration through proper design of machines and their mountings
- To utilize profitably in several consumer and industrial applications
- To improve the efficiency of certain machining, casting, forging & welding processes
- To stimulate earthquakes for geological research and conduct studies in design of nuclear reactors

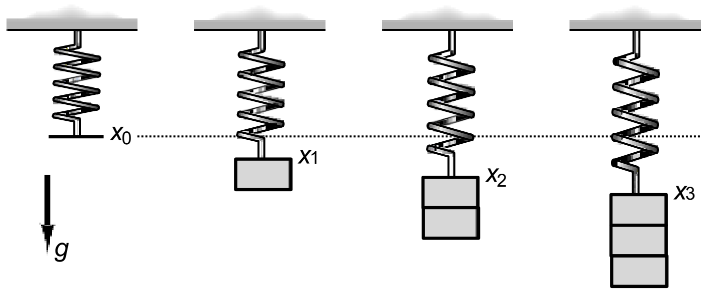
Why to study vibration

- Imbalance in the gas or diesel engines
- Blade and disk vibrations in turbines
- Noise and vibration of the hard-disks in your computers
- Cooling fan in the power supply
- Vibration testing for electronic packaging to conform Internatioal standard for quality control (QC)
- Safety eng.: machine vibration causes parts loose from the body

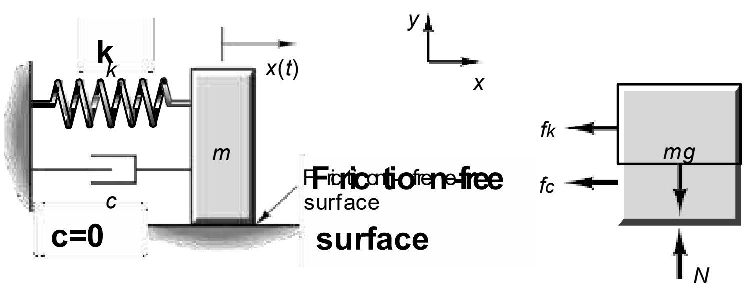
Stiffness

- From strength of materials (Solid Mech) recall:





Free-body diagram and equations of motion



- Newton's Law:

$$m\ddot{x}(t) = -kx(t)$$

$$m\ddot{x}(t) + kx(t) = 0$$

$$x(0) = x_0 \, , \; \dot{x}(0) = v_0$$

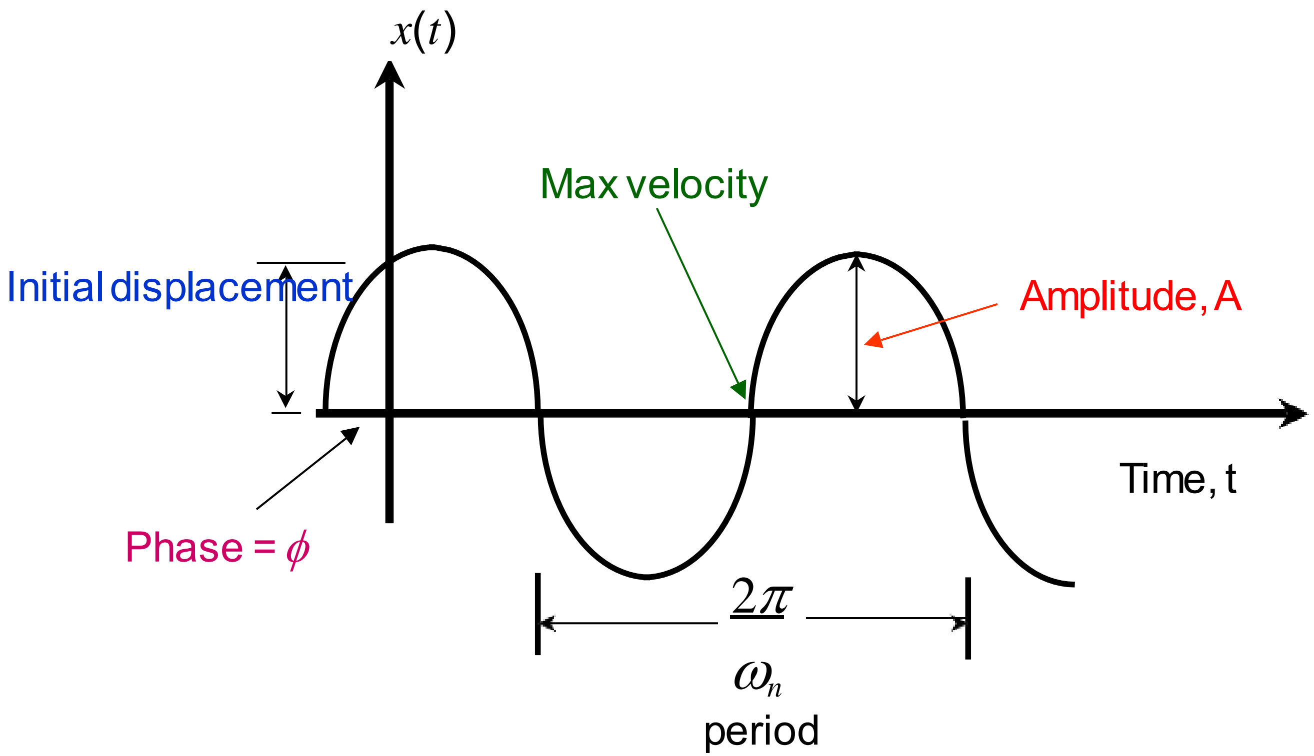
2nd Order Ordinary Differential Equation with Constant Coefficients

$$\text{Divide by } m: \ddot{x}(t) + \omega_n^2 x(t) = 0$$

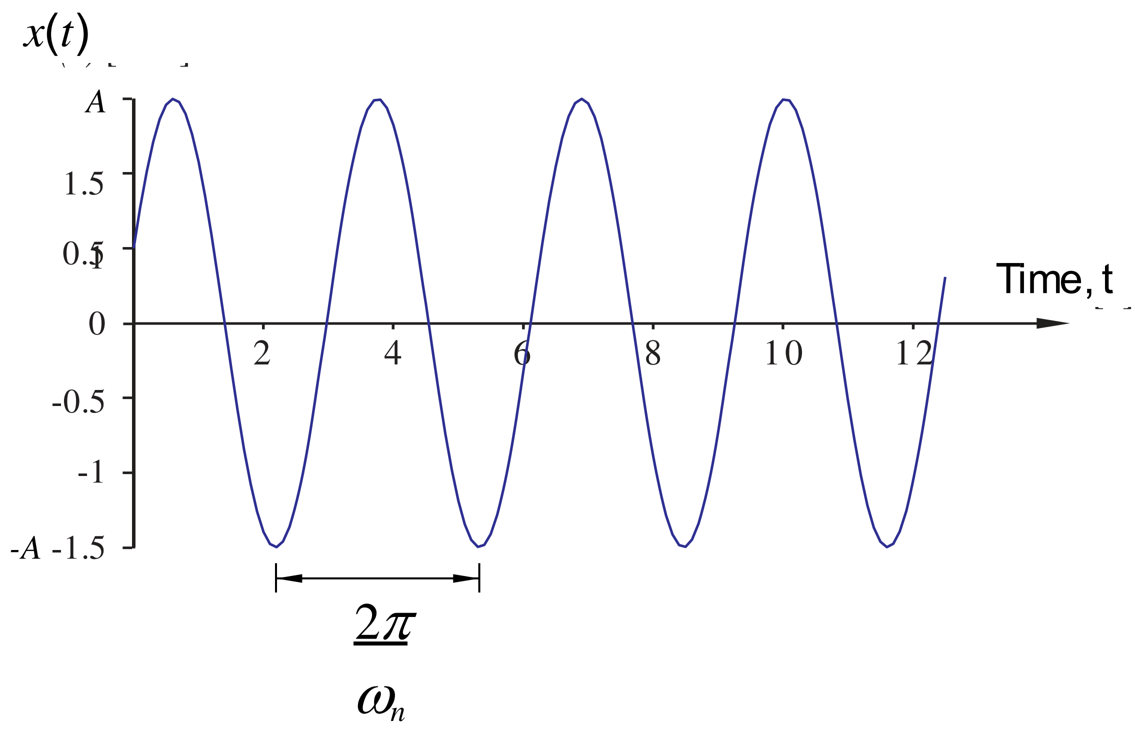
$$\omega_n = \sqrt{\frac{k}{m}} \;:\; \text{natural frequency in rad/s}$$

$$x(t) = A\sin(\omega_n t + \phi)$$

Periodic Motion



Periodic Motion



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Frequency

ω_n is in rad/s is the natural frequency

$$f_n = \frac{\omega_n \text{ rad/s}}{2\pi \text{ rad/cycle}} = \frac{\omega_n}{2\pi} \frac{\text{cycles}}{\text{s}} = \frac{\omega_n}{2\pi} \text{ Hz}$$

$$T = \frac{2\pi}{\omega_n} \text{ s} \quad \text{is the period}$$

We often speak of frequency in Hertz, but we need rad/s in the arguments of the trigonometric functions (sin and cos function).

Damping Elements

- Viscous Damping:

Damping force is proportional to the velocity of the vibrating body in a fluid medium such as air, water, gas, and oil.

- Coulomb or Dry Friction Damping: Damping force is constant in magnitude but opposite in direction to that of the motion of the vibrating body between dry surfaces

- Material or Solid or Hysteretic Damping: Energy is absorbed or dissipated by material during deformation due to friction between internal planes

Viscous Damping

- *Shear Stress (τ)* developed in the fluid layer at a distance y from the fixed plate is:

$$\tau = \mu \frac{du}{dy} \qquad (1.26)$$

where $du/dy = v/h$ is the velocity gradient.

• *Shear* or *Resisting Force (F)* developed at the bottom surface of the moving plate is:

$$F = \tau A = \mu \frac{Av}{h} = cv \qquad (1.27)$$

where A is the surface area of the moving plate.

$c = \frac{\mu A}{h}$ is the damping constant

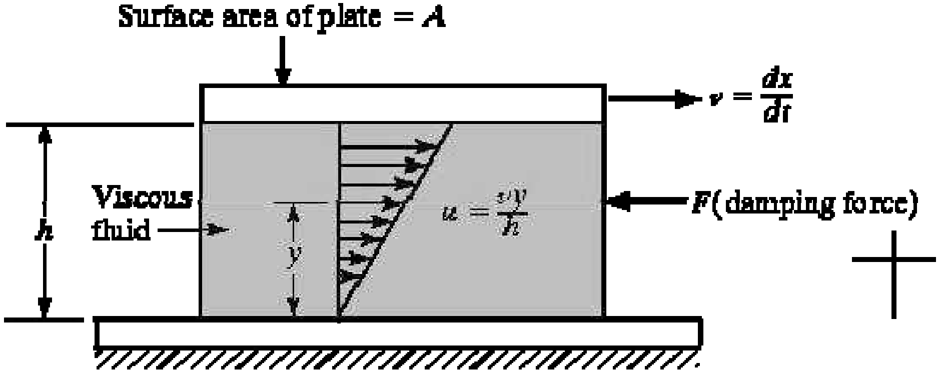
Viscous Damping

and $c = \frac{\mu A}{h}$ (1.28)

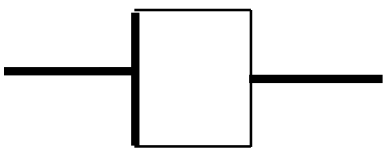
is called the damping constant.

- If a damper is nonlinear, a linearization process is used about the operating velocity (v^*) and the equivalent damping constant is:

$$c = \left.\frac{dF}{dv}\right|_{v^*} \quad (1.29)$$



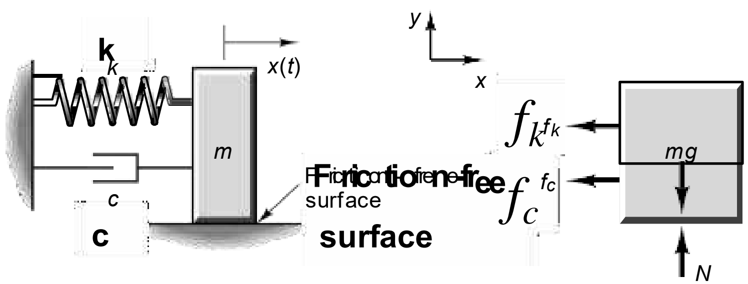
Linear Viscous Damping



- A mathematical form
- Called a dashpot or viscous damper
- Somewhat like a shock absorber
- The constant c has units: Ns/m or kg/s

$$f_c = c\dot{x}(t)$$

Spring-mass-damper systems



- From Newton's law:

$$m\ddot{x}(t) = -f_c - f_k$$

$$= -c\dot{x}(t) - kx(t)$$

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t)$$

$$= 0$$

$$x(0) = x_0, \qquad \dot{x}(0) =$$

$$v_0$$

Derivation of the solution

Substitute $x(t) = ae^{\lambda t}$ into $m\ddot{x} + c\dot{x} + kx = 0 \Rightarrow$

$$m\lambda^2 ae^{\lambda t} + c\lambda ae^{\lambda t} + kae^{\lambda t} = 0 \Rightarrow$$

$$m\lambda^2 + c\lambda + k = 0 \Rightarrow$$

$$\lambda_{1,2} = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1} \Rightarrow$$

$$x(t) = a_1 e^{\lambda_1 t} \text{ and } x(t) = a_2 e^{\lambda_2 t} \Rightarrow$$

$$x(t) = a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t}$$

Solution (dates to 1743 by Euler)

Divide equation of motion by m

$$\ddot{x}(t) + 2\zeta\omega_n \dot{x}(t) + \omega_n^2 x(t) = 0$$

where $\omega_n = \sqrt{k/m}$ and

$$\zeta = \frac{c}{2\sqrt{km}} = \text{damping ratio(dimensionless)}$$

-

Let $x(t) = ae^{\lambda t}$ & subsitute into eq. of motion

$$\lambda^2 ae^{\lambda t} + 2\zeta\omega_n \lambda ae^{\lambda t} + \omega_n^2 ae^{\lambda t} = 0$$

which is now an algebraic equation in λ:

$$\lambda_{1,2} = -\zeta\omega_n \pm \omega_n \sqrt{\zeta^2 - 1}$$

from the roots of a quadratic equation

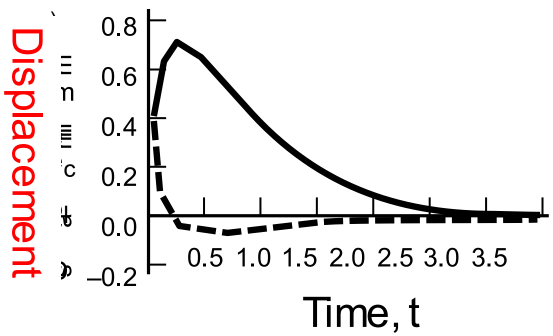
Here the discriminant $\zeta^2 - 1$,determines

the nature of the roots λ

Critical damping continued

- No oscillation occurs
- Useful in door mechanisms, analog gauges

$$x(t) = [x_0 + (v_0 + \omega_n x_0)t]e^{-\omega_n t}$$



2) $\zeta > 1$, called overdamping - two distinct real roots :

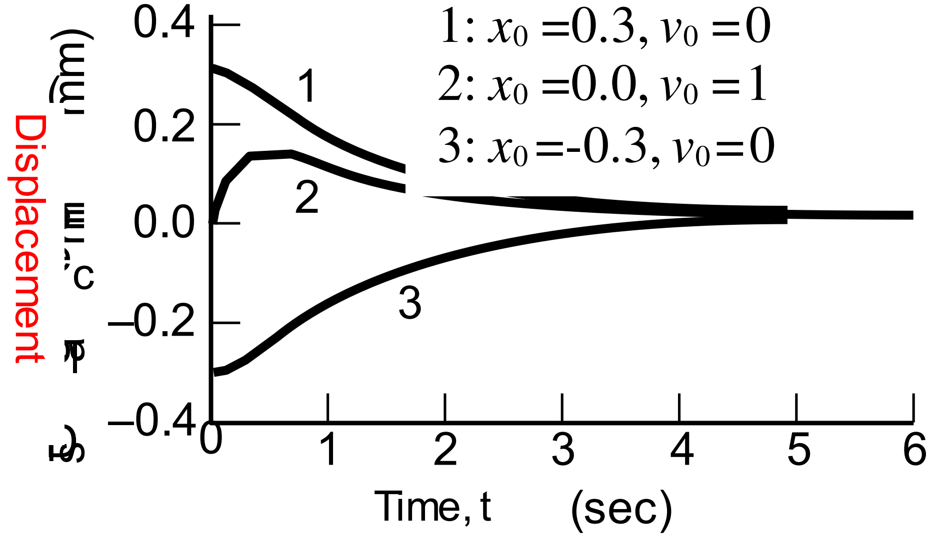
$$\lambda_{1,2} = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1}$$

$$x(t) = e^{-\zeta\omega_n t}\left(a_1 e^{-\omega_n t\sqrt{\zeta^2-1}} + a_2 e^{\omega_n t\sqrt{\zeta^2-1}}\right)$$

where $a_1 = \dfrac{-v_{0n} + (-\zeta + \sqrt{\zeta^2 - 1})\,\omega_0 x}{2\omega_n\sqrt{\zeta^2 - 1}}$

$$a_2 = \frac{v_0 + (\zeta + \sqrt{\zeta^2 - 1})\,\omega_n x_0}{2\omega_n\sqrt{\zeta^2 - 1}}$$

The overdamped response



-

3) $\zeta < 1$, called underdamped motion - most common

Two complex roots as conjugate pairs

write roots in complex form as:

$$\lambda_{1,2} = -\zeta\omega_n \pm \omega_n j\sqrt{1-\zeta^2}$$

where $j = \sqrt{-1}$

Underdamping

$$x(t) = e^{-\zeta\omega_n t}\left(a_1 e^{j\omega_n t\sqrt{1-\zeta^2}} + a_2 e^{-j\omega_n t\sqrt{1-\zeta^2}}\right)$$

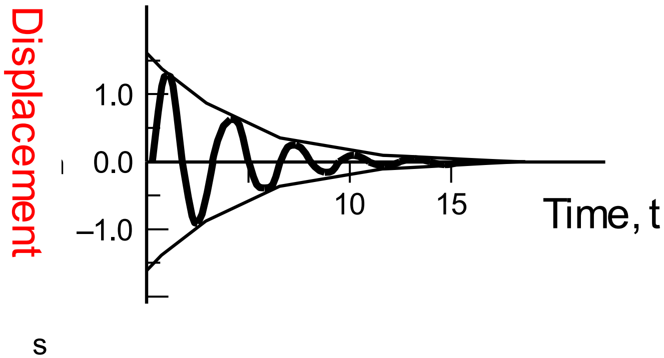
$$= Ae^{-\zeta\omega_n t}\sin(\omega_d t + \phi)$$

$\omega_d = \omega_n\sqrt{1-\zeta^2}$, damped natural frequency

$$A = \frac{1}{\omega_d}\sqrt{(v_0 + \zeta\omega_n x_0)^2 + (x_0\omega_d)^2}$$

$$\phi = \tan^{-1}\left(\frac{x_0\omega_d}{v_0 + \zeta\omega_n x_0}\right)$$

Underdamped-oscillation



- Gives an oscillating response with exponential decay
- Most natural systems vibrate with and underdamped response
- See textbook for details and other representations

Example consider the spring in Ex., if c = 0.11 kg/s,

determine the damping ratio of the spring-bolt system.

$$m = 49.2 \times 10^{-3} \text{ kg}, \quad k = 857.8 \text{ N/m}$$

$$c_{cr} = 2\sqrt{km} = 2\sqrt{49.2 \times 10^{-3} \times 857.8}$$

$$= 12.993 \text{ kg/s}$$

$$\zeta = \frac{c}{c_{cr}} = \frac{0.11 \text{ kg/s}}{12.993 \text{ kg/s}} = 0.0085 \Rightarrow$$

the motion is *underdamped*

and the bolt will oscillate

-

Example

The human leg has a measured natural frequency of around 20 Hz when in its rigid (knee locked) position, in the longitudinal direction (i.e., along the length of the bone) with a damping ratio of ζ = 0.224.

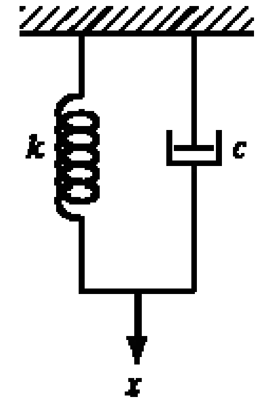
Calculate the response of the tip if the leg bone to v_0 (t=0)= 0.6 m/s and x_0(t=0)=0

This correspond to the vibration induced while landing on your feet, with your knees locked from a height of 18 mm) and plot the response. What is the maximum acceleration experienced by the leg assuming no damping?

Energy dissipation

Consider the system shown in the figure below.
The total force resisting the motion is:

$$F = -kx - cv = -kx - c\dot{x} \qquad (2.95)$$



If we assume simple harmonic motion:

$$x(t) = X \sin \omega_d t \qquad (2.96)$$

Thus, Eq.(2.95) becomes

$$F = -kX \sin \omega_d t - c\omega_d X \cos \omega_d t \qquad (2.97)$$

The energy dissipated in a complete cycle will be

$$\Delta W = \int_{t=0}^{2\pi/\omega_d} Fv\,dt$$

$$= \int_{t=0}^{2\pi/\omega_d} kX^2 \omega_d \sin \omega_d t \cdot \cos \omega_d t \cdot d(\omega_d t)$$

$$+ \int_{t=0}^{2\pi/\omega_d} c\omega_d X^2 \cos^2 \omega_d t \cdot d(\omega_d t) = \pi c \omega_d X^2 \qquad (2.98)$$

Energy dissipation and Loss Coefficient

Computing the fraction of the total energy of the vibrating system that is dissipated in each cycle of motion, Specific Damping Capacity

$$\frac{\otimes W}{W} = \frac{\pi c \omega_d X^2}{\frac{1}{2} m \omega_d^2 X^2} = 2\pi \left(\frac{2\pi}{\omega_d}\right)\left(\frac{c}{2m}\right) = 2\delta \approx 4\pi\zeta = \text{constant} \qquad (2.99)$$

where W is either the max potential energy or the max kinetic energy.

The loss coefficient, defined as the ratio of the energy dissipated per radian and the total strain energy:

$$\text{loss coefficient} = \frac{(\otimes W / 2\pi)}{W} = \frac{\otimes W}{2\pi W} \qquad (2.100)$$

References

- [PDF] Theory of Machines Book By RS Khurmi Free Download

- https://easyengineering.net/theory-machines-book-r-s-khurmi-nw-1/

- Theory of Machines - PDF Drive

- https://www.pdfdrive.com/theory-of-machines-e12587091.html

Thank You

Government Polytechnic Nanakpur

DEPARTMENT OF MECHANICAL ENGINEERING

E - NOTES

WORKSHOP TECHNOLOGY - III

HOD/O.I. (Mechanical) : **Sh.SHALANDER MOR**

Faculty Name: **Sh.Sanjay Kumar/Arvind**

Semester: 5^{th} Sem

By: Er. Amit Kumar
Designed, Mechanical Editing & Developmental Editing

LEARNING OUTCOMES

After undergoing this course, the students will be able to:

- Develop communication skills.
- Learn how to speak without fear and get rid of hesitation
-
- Use effective presentation techniques
- Understand entrepreneurial traits
- Exhibit attitudinal changes

Milling Machines
& Operations

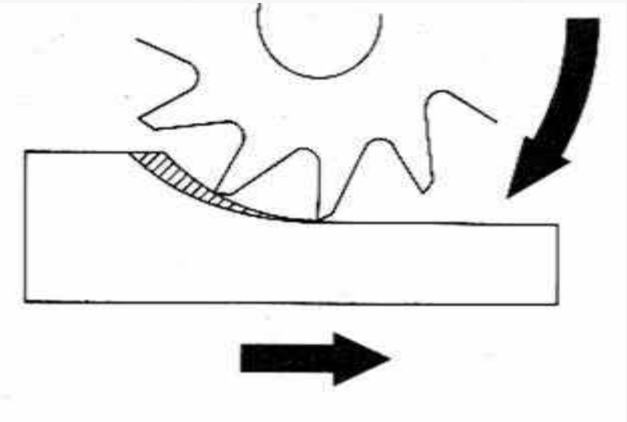
WHAT IS MILLING?

- Milling is the machining process of using rotary cutters to remove material from a workpiece advancing (or feeding) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

MILLING MACHINES

PRINCIPLE OF MILLING MACHINE

Milling operates on the principle of rotary motion. A milling cutter is spun about an axis while a workpiece is advanced through it in such a way that the blades of the cutter are able to shave chips of material with each pass.



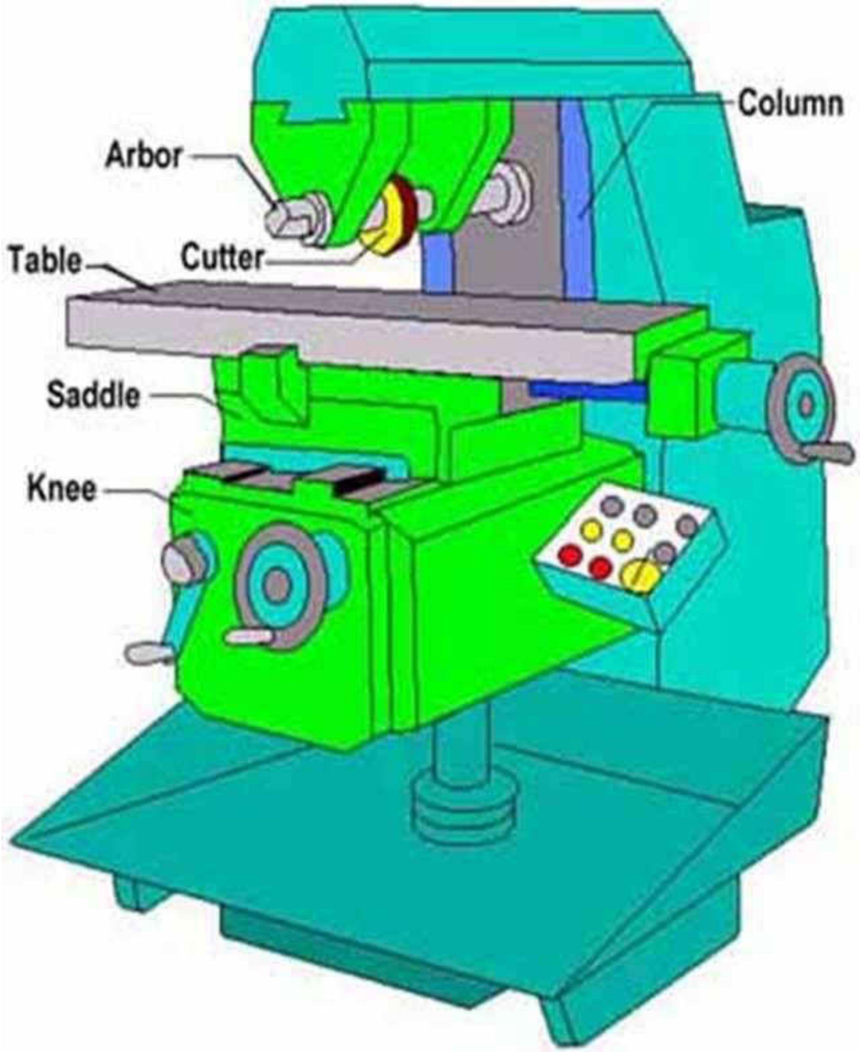
Variety of Operations

- Gear cutting
- Drilling
- Boring
- Jig boring

- Face milling
- End milling
- Keyway cutting
- Dovetail cutting
- T-slot and
- circular slot cutting

HORIZONTAL MILLING MACHINE

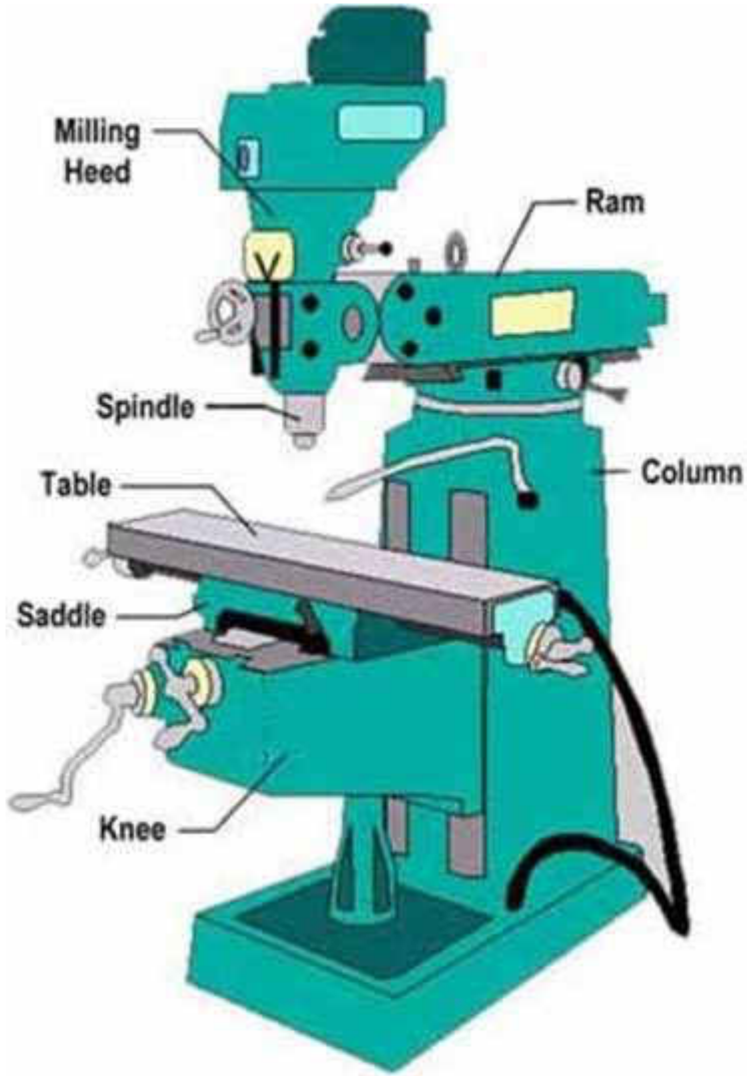
Horizontal milling machine. 1: base 2: column 3: knee 4 & 5: table (x-axis slide is integral) 6: overarm 7: arbor (attached to spindle)
A horizontal mill has the same sort of x–y table, but the cutters are mounted on a horizontal arboracross the table. Many horizontal mills also feature a built-in rotary table that allows milling at various angles; this feature is called a universal table.


Column
Arbor
Table
Cutter
Saddle
Knee

VERTICAL MILLING MACHINE

Vertical milling machine. 1: milling cutter 2: spindle 3: top slide or overarm 4: column 5: table 6: Y-axis slide 7: knee 8: base

In the vertical mill the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be extended (or the table can be raised/lowered, giving the same effect), allowing plunge cuts and drilling. There are two subcategories of vertical mills: the bed mill and the turret mill.

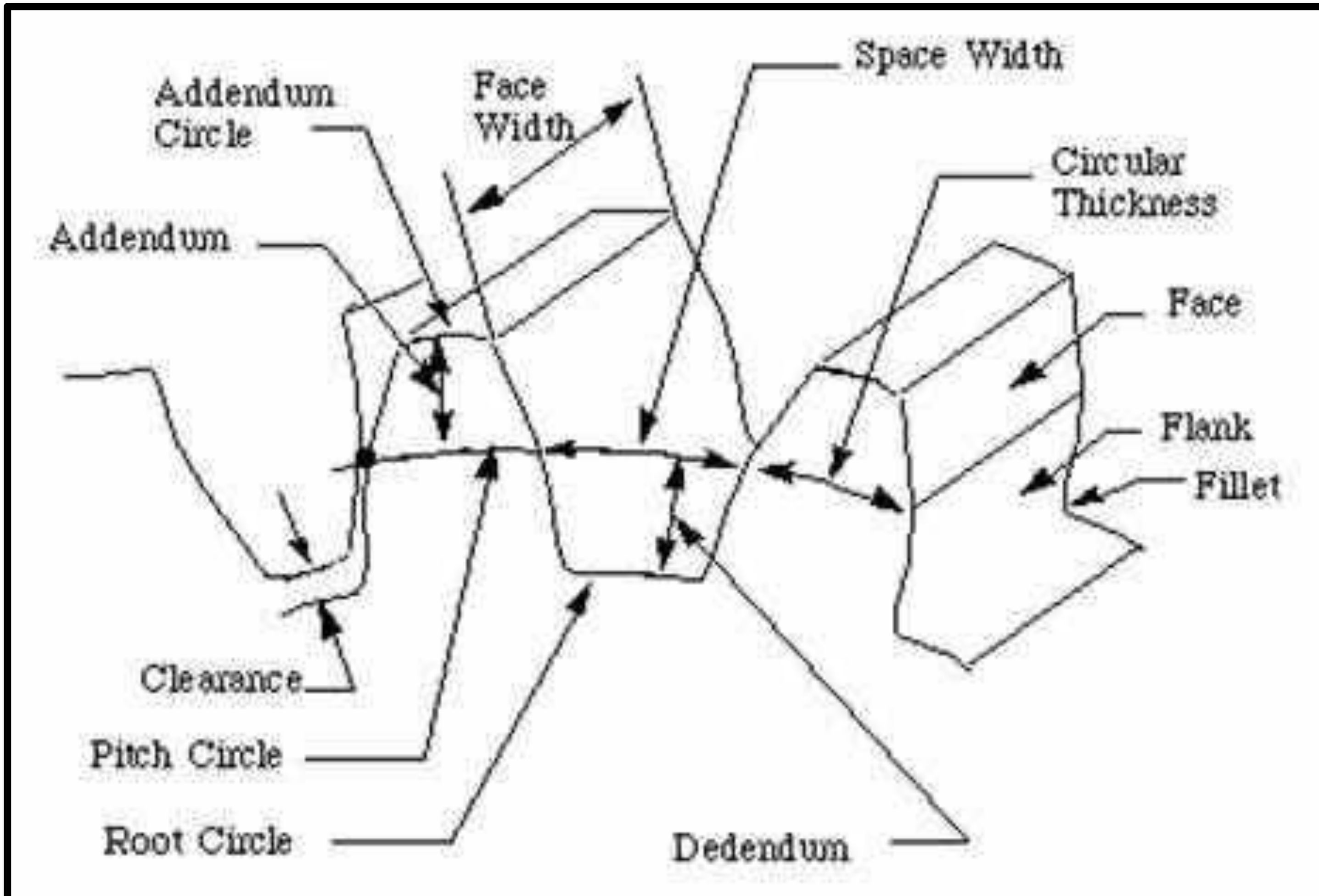

Milling
Heed
Ram
Spindle
Column
Table
Saddle
Knee

COMPARISON:

The choice between vertical and horizontal spindle orientation in milling machine design usually hinges on the shape and size of a workpiece and the number of sides of the workpiece that require machining. Work in which the spindle's axial movement is normal to one plane, with an endmill as the cutter, lends itself to a vertical mill, where the operator can stand before the machine and have easy access to the cutting action by looking down upon it. Thus vertical mills are most favored for diesinking work (machining a mould into a block of metal). Heavier and longer workpieces lend themselves to placement on the table of a horizontal mill.

Gear Manufacturing Processes

Gear Terminology



Materials
:

- Gray cast iron
- Nodular and ductile cast iron(Good casting property)
- Carburizing steel
- Nitride steel
- Bronze
- Non-metals as plastics, reinforced laminates (noiseless operation , cheaper)

Gear Manufacturing Processes:

1. Machining
2. Casting
3. Stamping
4. Coining
5. Cold Drawing
6. Rolling
7. Extrusion
8. Powder metallurgy
9. Plastic Moulding

1. Machining

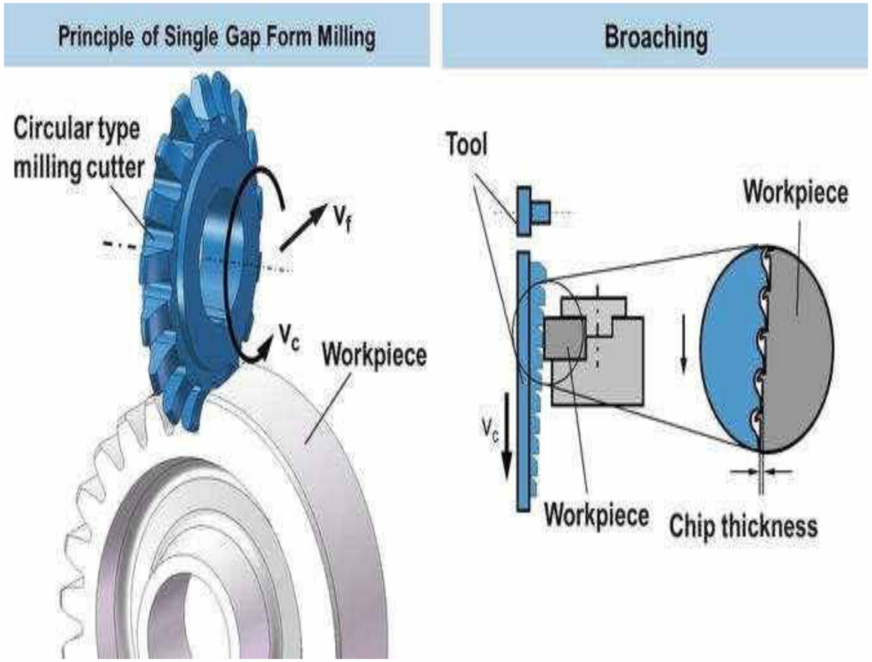
There are three machining processes for gear manufacturing ,

- Form Cutting (Same profile cutters are used)
- Template process (Cutting by single point cutting tool)
- Generating Process (Combination of straight movement of tool and rotation of work piece by spindle.

Form Cutting
:

- In Form cutting tool or cutter having profile corresponding to the tooth space.
- Accuracy depends on accuracy of cutter.
- Example : Spur ,helical and Bevel gear
- Here unique form cutter for each no. of teeth as given module.

Gear manufacturing with form Cutters.



Set of cutters for cutting different numbers of teeth :

Cutter No.	Number of teeth cut
1	135 to rack
2	55 To 134
3	35 To 54
4	26 To 34
5	21 To 25
6	17 to 20
7	14 To 16
8	12 To 13

Milling of spur gear using Disc type form cutter

Steps :

1. Determination of important dimensions.
2. Selection of suitable indexing method to space the gear teeth accurately.
3. Selection of correct cutter for required number of teeth.
4. Selection of suitable speed, feed and depth of cut.
5. Setting the cutter.

Determinaton of spur gear dimension :

- Major dimensions like outside diameter.
- Depth of tool is set.
- From the module and no. of teeth on gear , pitch circle diameter is found.
- " The standard proportions adopted by the INDIAN STANDARD SYSTEM for the elements of an involute spur grear are as following.
- Recommended series : 1, 1.25, 1.50, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, and 20

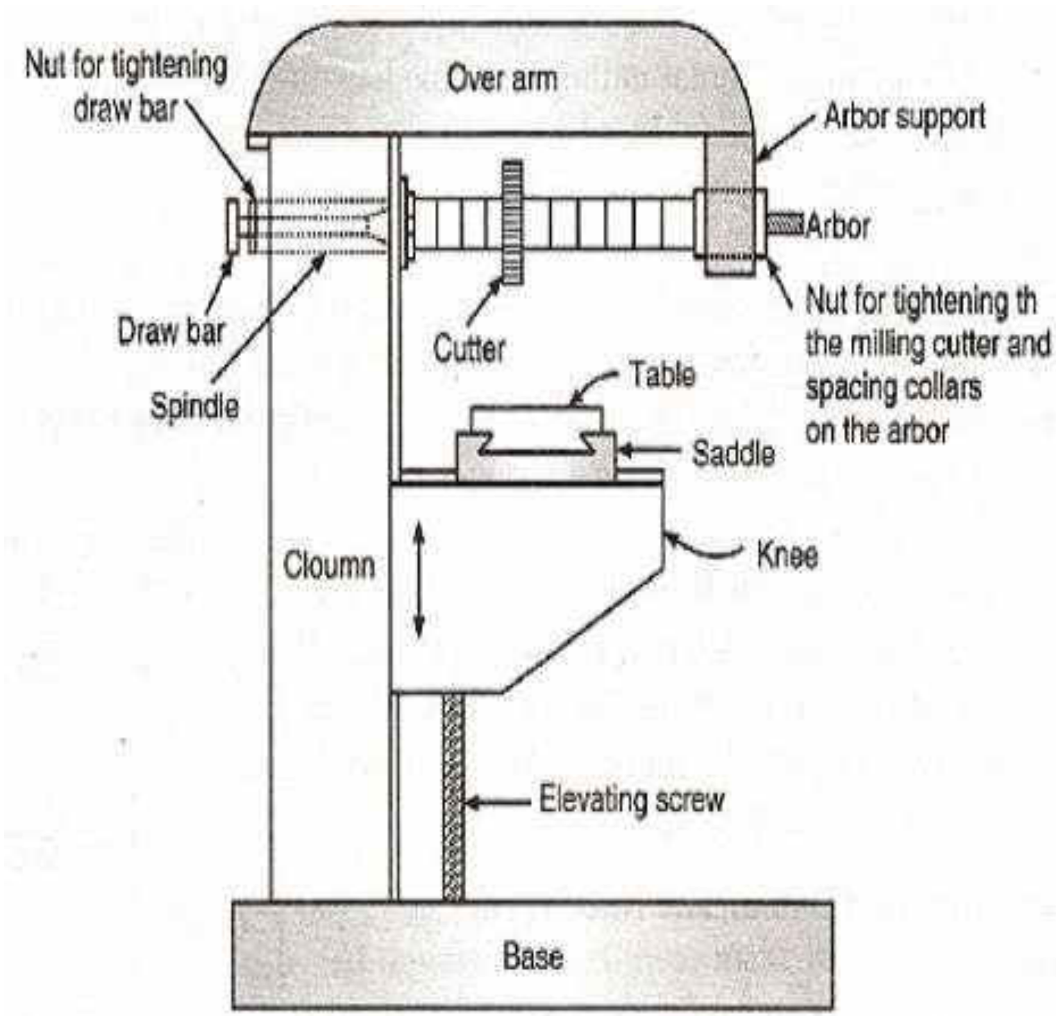
Dimension	Symbol	Gear tooth proportions
Pitch Diameter	p.d.	zm
Addendum	ha	m
Dedendum	hf	1.25m
Working depth	2ha	2m
Tooth depth	h	2.25ha
Outside diameter	p.D + 2ha	m(z+2)
Tooth thickness	s	1.5708m
Clearance	Hf-ha	0.25m
Radius of fillet	r	0.4m to 0.45m

Selection of Cutter , speed , feed and Depth of cut

- Selection of cutter used for any operation depends upon module of gear and number of teeth to be cut.
- If module and no. of teeth are know then cutter is selected from previous table.
- The speed , feed and depth of cut is chosen based on machining condition like material to be cut, material of cutter and condition of machine. (Full depth of cut - 2.25m)

Machine setting and cutting of Teeth :

- Machine setting involves setting of speed and feed on machine, mounting of cutter, bolting of dividing head and tail stock , alignment of cutter with spindle axis.
- Alignment that center line of cutter touch the center point of tail stock.


Nut for tightening
draw bar
Over arm
Arbor support
Arbor
Draw bar
Spindle
Cutter
Nut for tightening th
the milling cutter and
spacing collars
on the arbor
Table
Saddle
Knee
Cloumn
Elevating screw
Base

Milling of helical gear using Disc type form cutter

Helical gears are made on universal milling machine by use of helical milling operation.

Steps :

- Determination of important dimension.
- Selection of indexing.
- Determination and setting of table gear train.
- Table setting
- Set speed, feed and depth of cut.

Gear tooth dimension :

- Helix angle :

$$\tan\beta = \frac{\pi D}{l}$$

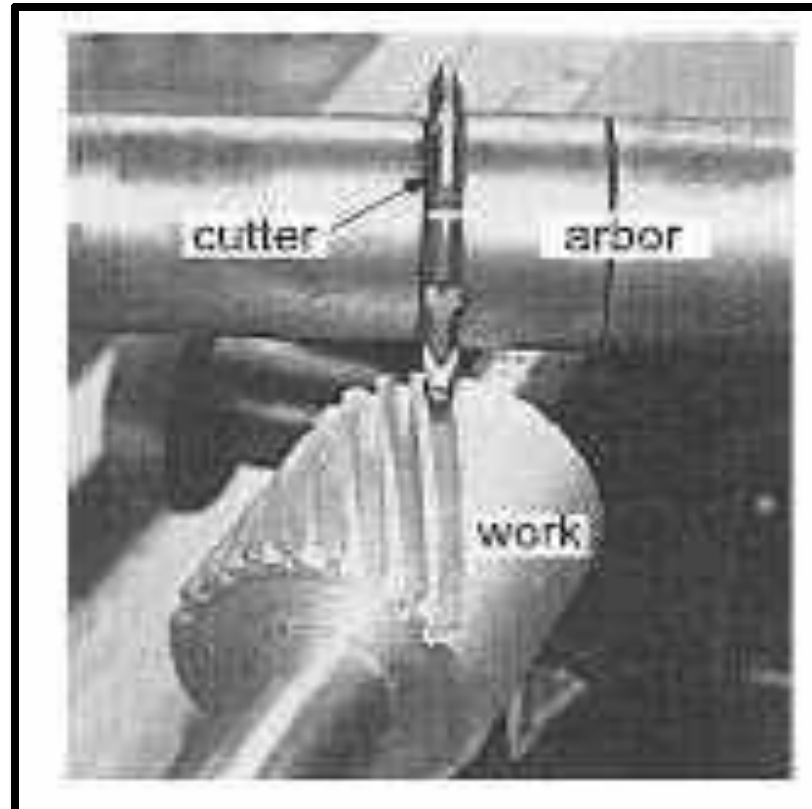
- Normal Module :

$$m_n = \frac{Cp_n}{\pi} = \frac{Cp\ cos\beta}{\pi} = mcos\beta$$

Dimension of helical gear in terns of normal module :

Gear Element	Dimension in terms of mn
Addendum	m_n
Dedendum	$1.25m_n$
Tooth depth	$2.25m_n$
Normal tooth thickness	$1.5708m_n$
Circular pitch	πmn cosβ
Diametral Pitch	cosβ mn
Pitch Diameter	zm
Outside diameter	$Zm + 2m_n$

Helical milling operation



Cont.

- After Dimension calculation , blank of required size is prepared.
- Machine (Universal milling machine) is set by mounting dividing head and tail stock.
- Blank is mounted on mandrel and support between dividing head and tail stock.
- Cutter no. is determined and it is mounted on Arbor.
- The table is swivel through helix angle .
- Arrangement for indexing by mounting required indexing plate on dividing head , set crank pin in required hole circle.
- Feed and speed are selected according to gear material, tool material and machine condition.
- Begin milling operation.
- Cutter touch the periphery of blank and desired depth of cut given by using vertical feed screw micrometer.

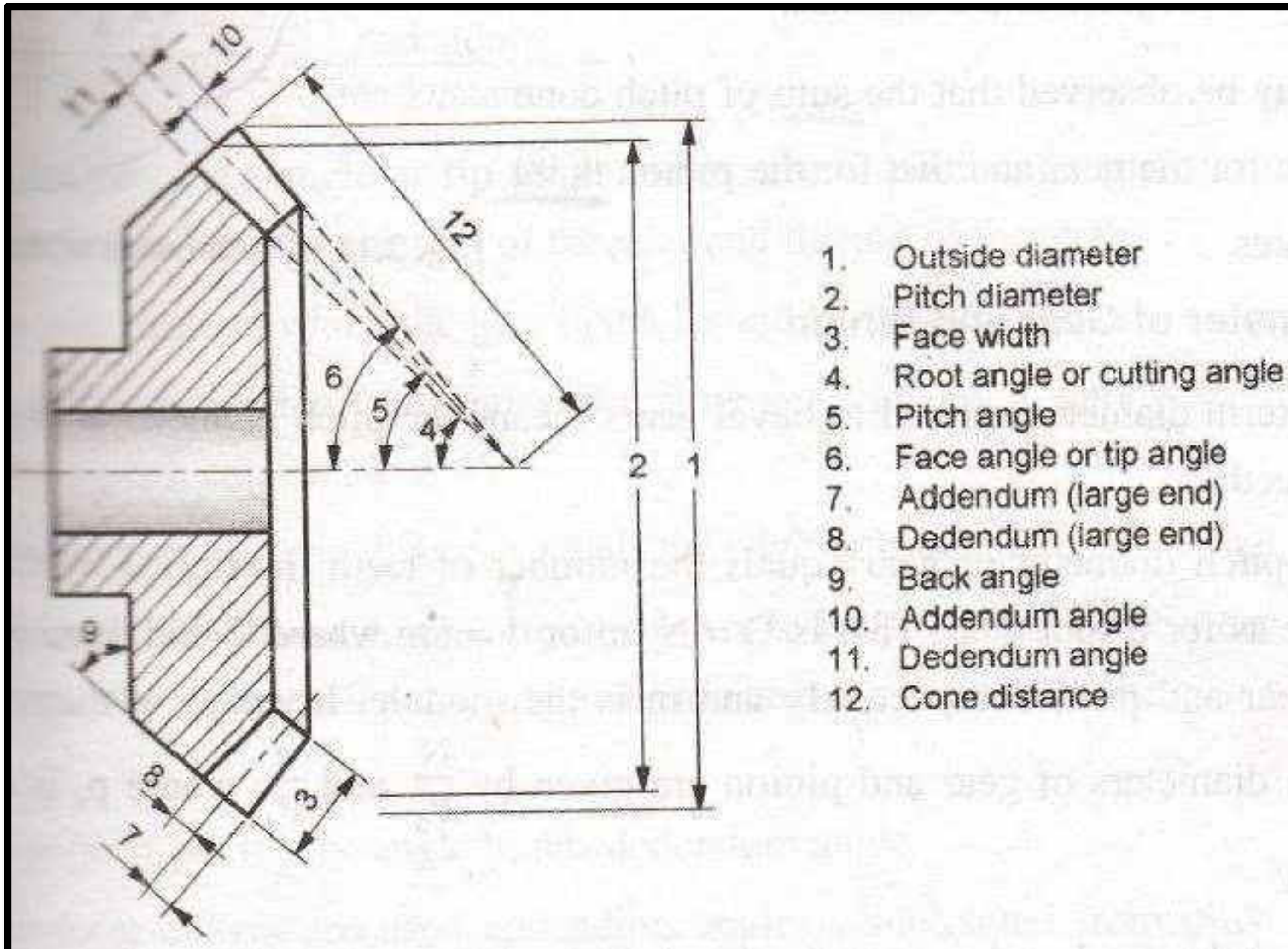
cont……

- At the end of each cut , table brought back to the initial position.
- Operation is repeated till all the teeth are machined.

Bevel gear Milling using Disc type form Cutters :

- It is not possible to cut bevel teeth of correct form by form milling with disc cutter as the cross section of bevel gear is not uniform.
- The cross section is reduced from large end to small end.
- Thus a cutter chose for producing tooth space on one side of gear will not be correct for other side.
- Steps :
  1. Determination of gear tooth proportion.
  2. Proper indexing
  3. Cutter section.
  4. Machine set-up.
  5. Calculation of offset.

Bevel Gear Parameters



Pitch cone angle of **gear** :

$$\tan A = \frac{N}{n}$$

- If gear ratio is 1:1 , pitch cone angle is 45 degree.

Pitch cone angle of **pinion** :

$$\tan a = \frac{n}{N}$$

- It may be observed that sum of pitch cone angle of gear and pinion is 90 degree.

Pitch Diameter for pinion and gear :

Module of Gear : m =D/N Module of Pinion : m =d/n

Diameteral Pitch of gear = N/D

Diameteral Pitch of pinion =n/d

Cone Distance :

$$E = \frac{D}{2 \sin A}$$

- Following table include bevel gear parameters in terms of module for 20 degree pressure angle.

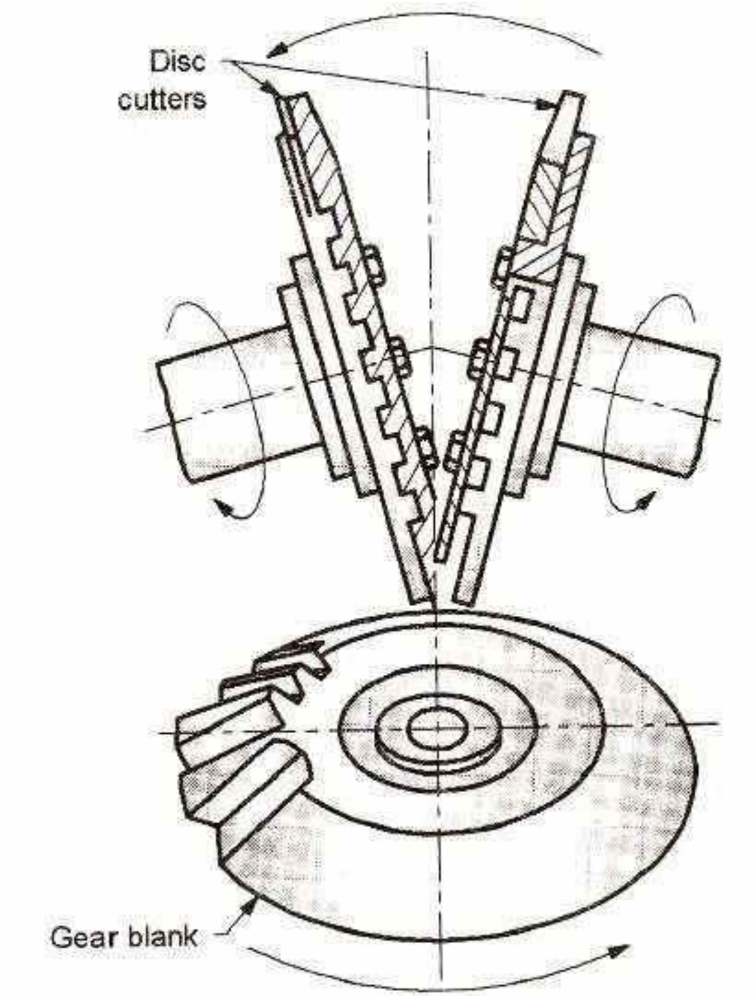
Name of element	Symbol	Dimension on terms of module
Addendum (large end)	h_a	m
Dedendum (large end)	h_f	1.25m
Tooth depth	h	2.25m
Tooth thickness	s	1.5708m
Circular pitch	p	πm
Pitch diameter	d	zm
Number of teeth	z	$\frac{d}{m}$
Angular dimensions		
Cone distance	R	$\frac{D}{2 \sin A}$
Addendum (small end)	-	$\frac{R-b}{R} \times h_a$
Tooth thickness (Small end)	-	$\frac{R-b}{R} \times s$
Face width	b	0.15R to 0.33R
Addendum angle	θ_a	$\tan \theta_a = \frac{h_a}{R}$
Dedendum angle	θ_f	$\tan \theta_f = \frac{h_f}{R}$
Tip angle	δ_a	$\delta_a = \delta' + \theta_a$
Pitch cone angle	δ'	$\sin \delta' = \frac{D}{2R}$
Root angle	δ_f	$\delta_f = \delta' - \theta_f$

Gleason Method of Generating Bevel gear tooth using Disc type form Cutter :

- The revolution of cutter about their own axis provides cutting velocity during rotation .

- After one tooth space is cut the cutters are withdrawn and blank is indexed through the required angle.

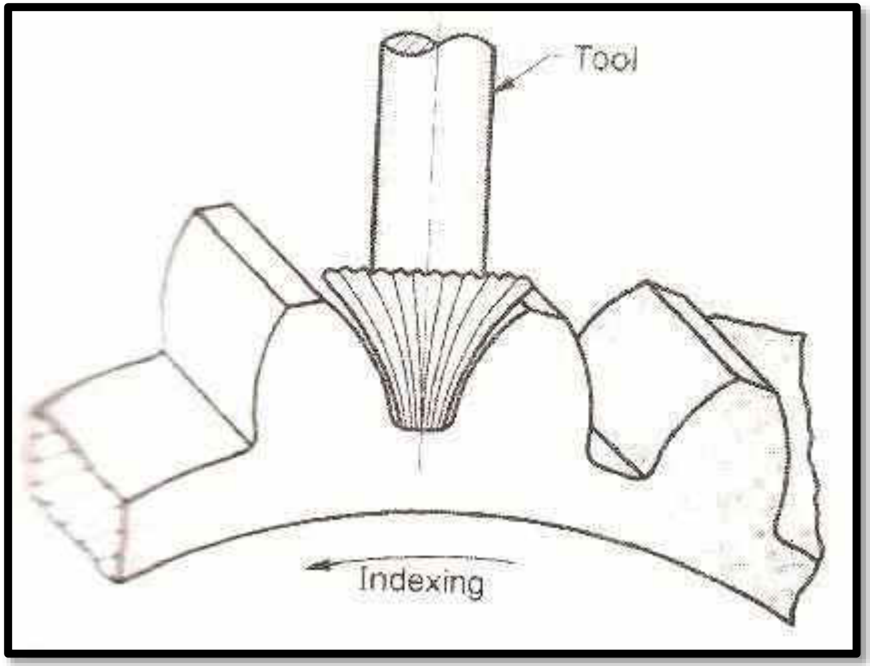
- This processes is comparatively faster than the milling process.



Form milling with End Mill type Cutter :

- Cutter is a **Shank** type cutter which is mounted directly on spindle of Vertical Milling Machine.

- Cutter axis is set radial with respect to gear blank.



- The blank is then indexed to the next tooth position as in case of milling with disc type cutters . It is suitable for producing pinions of large pitch.

Advantage and Limitations of Gear Milling Process :

Advantage :

- Spur, Helical and bevel gears are cut on commonly available machines.
- Low tooling cost
- Method is economical for one off type of gear production.
- Tooth that can not be produced by generation can be produced by this method.
- Both roughing and finishing operation can be carried out.

Limitations :

- Internal teeth can not be produced.
- Pitch accuracy depends on accuracy of Indexing mechanism.
- Processes is slow.
- Mass production not applicable.

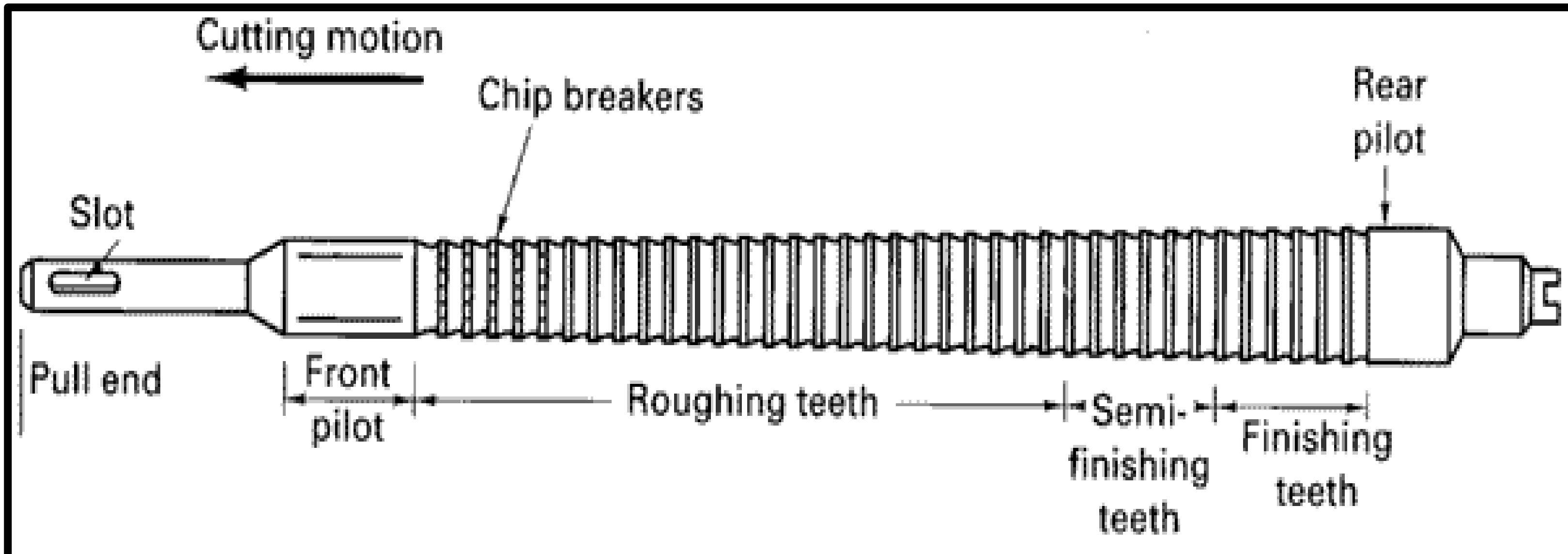
Gear Cutting with Single point Form Tool on Shaper:

- This operation is carried out on shaper (or Planner) machine.
- Dividing head is bolted on table of shaper and gear blank mounted on spindle of dividing head.
- The stroke of shaper is adjusted according to width of gear.
- Gear teeth are cut one by one with indexing.
- The process is even slower than gear milling and not suitable for mass production.

Broaching :

- A broach is multi – toothed

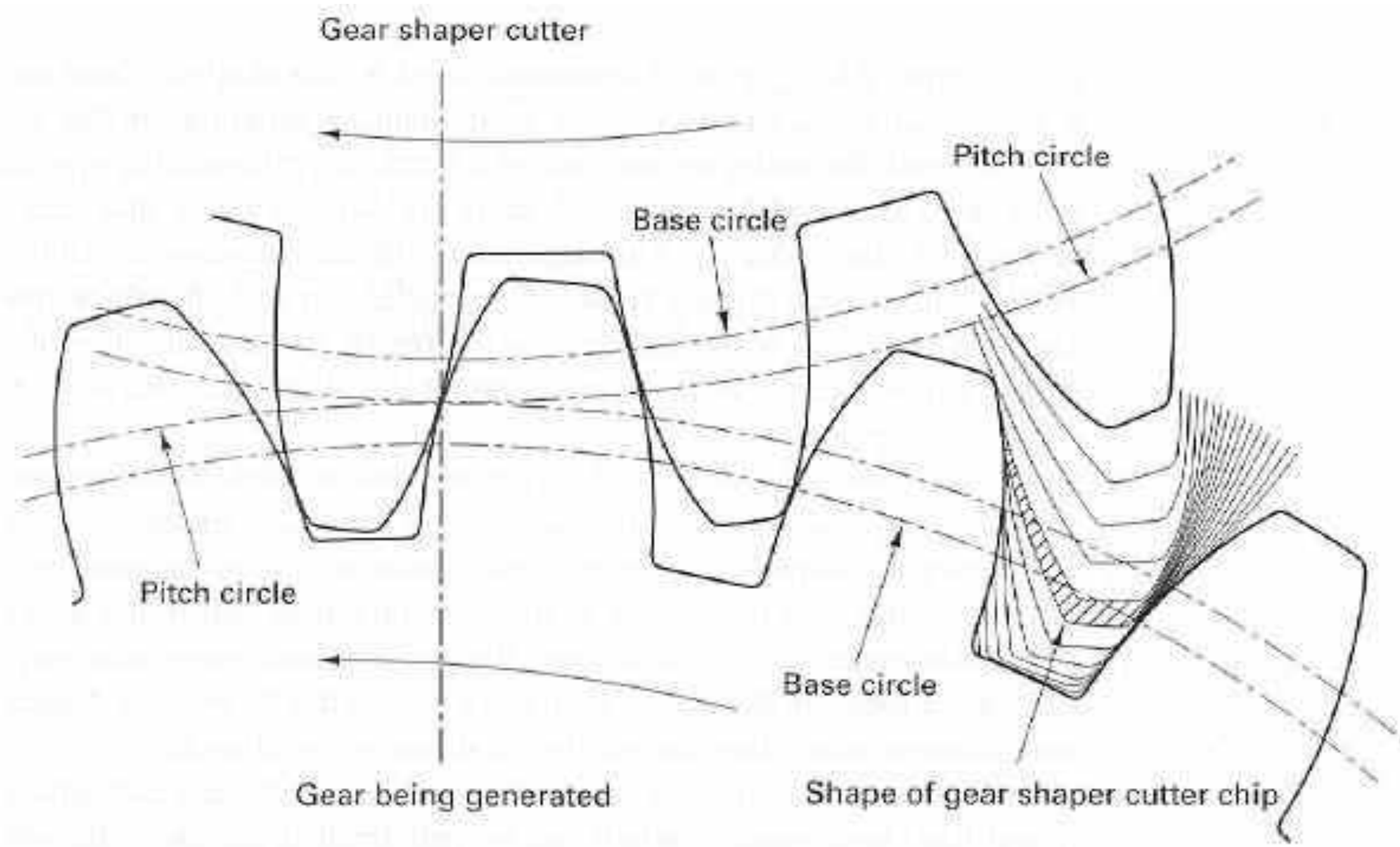
- tool in which each succe s a small cut but when ve passed over the surfa ed the required amount o en removed and surfac ith desired size and accura
- The form of the spa eth correspond to form of b
- This method leads to hi nd quality but cost of ma is very high.



Cutting motion
Chip breakers
Rear pilot
Slot
Pull end
Front pilot
Roughing teeth
Semi-finishing teeth
Finishing teeth

Gear Shaping

Principle of gear Shaping :

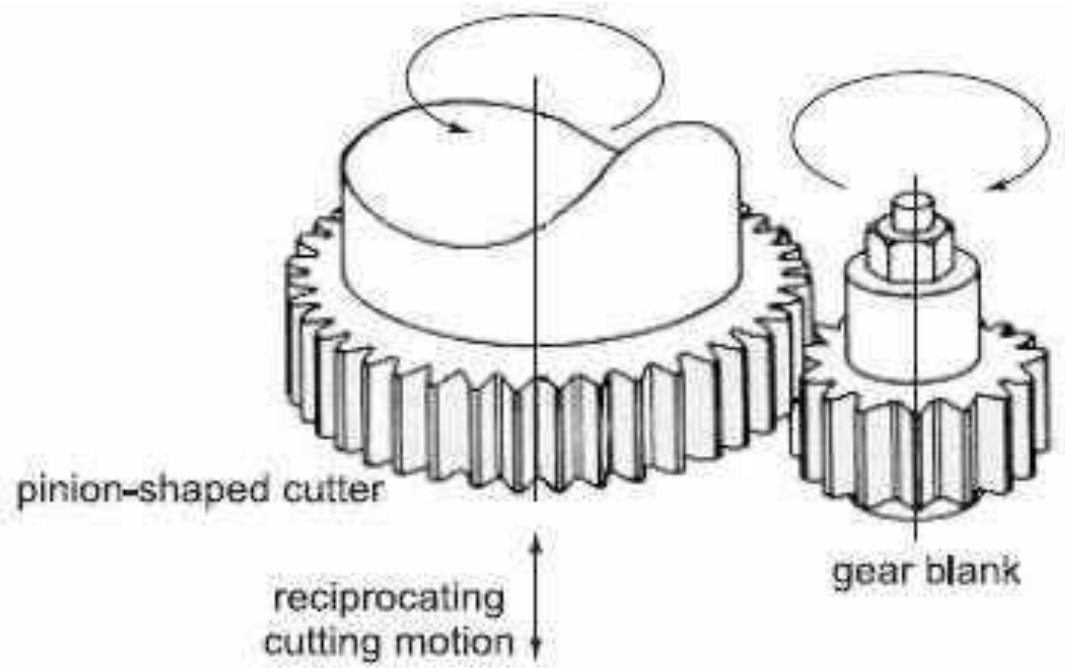


- The cutter used is provided with cutting edges.
- The tool and gear blank are rotated as they would in actual meshing.
- Each tooth space on gear is generated by series of incremental cuts.
- The cutter mounted on spindle provides motion on it’s own axis and cutting may take place either in upward or downward stroke of the cutter.
- Two types of gear shaping machines are commonly used base on shape of the cutter.

1. Machine using Pinion type cutter.
2. Machine using rack type cutter.

1. Gear Shaping using pinion type Cutters :

- The cutting cycle is commenced after the cutter is fed radically into the gear blank Equal to the depth of tooth required.
- The cutter is then given reciprocating cutting motion parallel to its axis and the cutter & the blank are made to rotate slowly about their axis at speeds which are equal at the matching pitch surfaces.



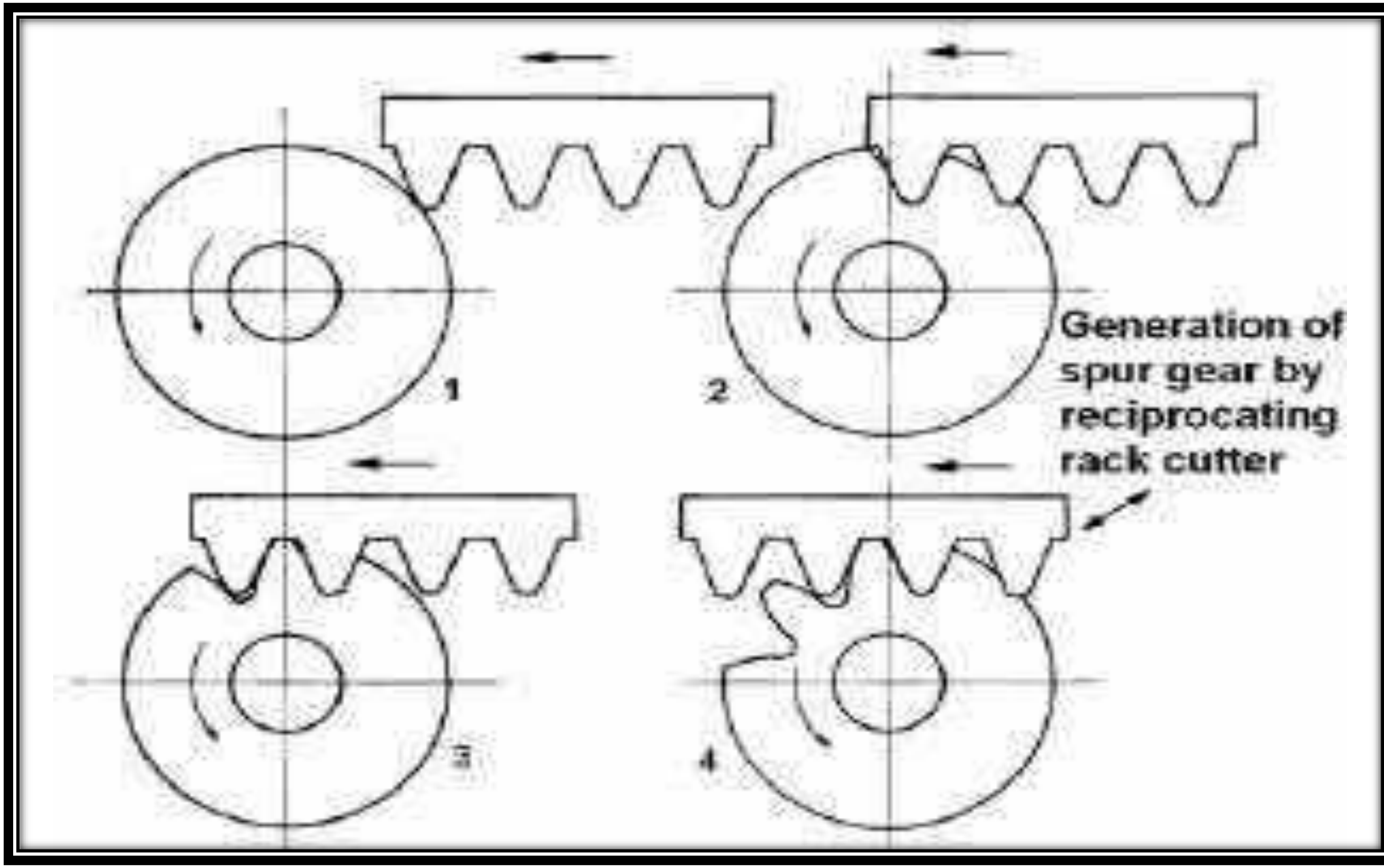
Setup of gear shaping opeartion with a pinion-shaped cutter.

In short,

- Combined rotating & reciprocating cutter
- Axes are parallel
- Relative motion is achieved by train of gears
- Cutting: either at upstroke or at down stroke
- Internal or external gears can be obtained
- High dimensional accuracy, low cost

2. Gear Shaping using rack type cutter

- The rack cutter generating process is also called gear shaping or rack planning process. In this method, the generating cutter has the form of a basic rack for a gear to be generated.
- The cutting action is similar to a shaping machine. The cutter reciprocates rapidly & removes metal only during the cutting stroke.
- The blank is rotated slowly but uniformly about its axis and between each cutting stroke of the cutter, the cutter advances along its length at a speed Equal to the rolling speed of the matching pitch lines.
- When the cutter & the blank have rolled a distance Equal to one pitch of the blank, the motion of the blank is arrested, the cutter is with drawn from the blank to give relief to the cutting Edges & the cutter is returned to its starting position. The blank is next indexed & the next cut is started following the same procedure.


1
2
3
4
Generation of spur gear by reciprocating rack cutter

Process modifications :

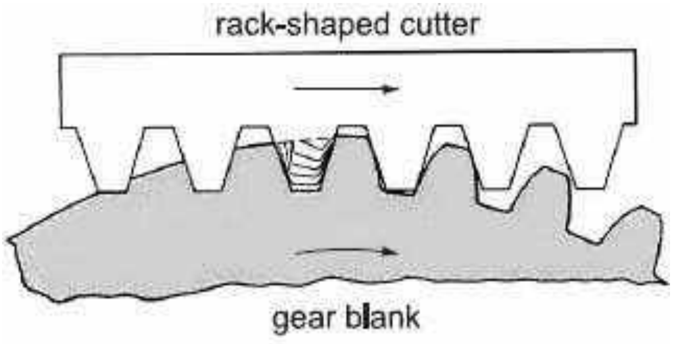
1) Double cutting Method :

➢Two blanks are mounted side by side and two cutters are mounted in a duplex cutter holder.

2) Double action Method :

➢Special cutter box carries two cutters back to back .One cutter is set for side finishing and other for bottom.

SUNDERLAND Method :



➢Rack shaped cutter

➢Reciprocates parallel to the gear axis

➢6 – 12 teeth on the rack cutter

➢Cutter gets disengaged at suitable intervals & returns

➢High dim. accuracy, low cost, low & large production rate.

Advantage and Limitations of Gear Shaping :

ADVANTAGES :

- One cutter is used to produce all gears of same module.
- Profile of tooth is more accurate.
- The rate of production is faster.
- The method is versatile and used for producing all types of gears.

LIMITATIONS :

- Cutting takes place only during one stroke. Therefore process is slower than hobbing.
- Special helical guides are required for cutting helical gears.

GEAR HOBBING :

- Hobbing process is carried out on gear hobbing machine using hob as tool.
- Hob is a cylinder on the surface of which a continuous thread has been cut having the cross section of involutes gear teeth. Length wise gashes or flutes are cut across the spiral to form cutting edges

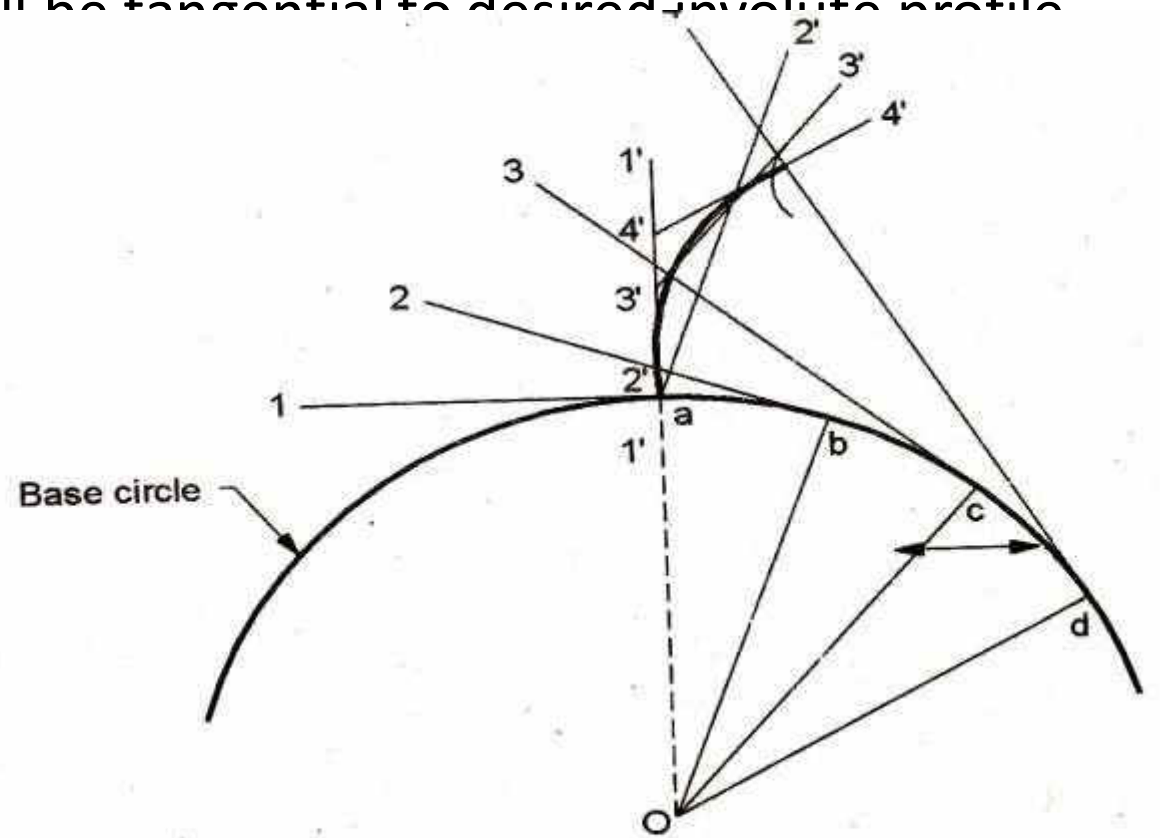
- Hobs are generally made of **High speed steel or Cemented carbide**. Hob are also used with carbide tipped teeth.
- A hob may have one, two or more **starts**. A single start hob Cuts a gear having T teeth so that in the time in which gear blank makes one rotation, Hob makes T rotation.
- Similarly double start hob makes T/2 rotation and triple start hob makes T/3 rotation for each rotation of gear blank.
- So multi start hob cut faster than single start hob
- Hobbing machines

  1. Horizontal work spindle

  2. Vertical work spindle
- Machine with vertical work spindle are more popular but it is not suitable for **shaft work or Long work-piece**.
- The rotating hob is given longitudinal feed parallel to gear axis.
- Single pass up to 8 mm module.
- In two passes 1st remove 60 % material and module more than 8.

Principle of gear Hobbing

- From a, b, c, d, draw tangents to base circle marked a1, b2, c3.
- When equally spaced teeth of hob contacts the w/p they cut small flats 1'1',2'2'...at right angle to tangents.
- All the flats will be tangential to desired involute profile



Hob setting for Spur and Helical Gear :

- The thread on hob should be located along the axis of gear blank for cutting spur gears and along the helix of gear for cutting helical gear.
- If λ is lead angle of hob and β is helix angle of gear the angle (90-S) set between axis of hob and axis of gear as following

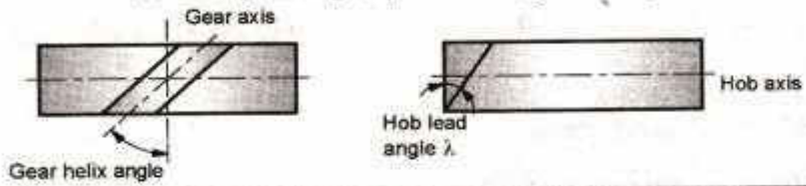
For spur gear : 90- λ

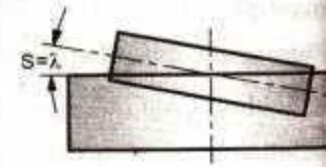
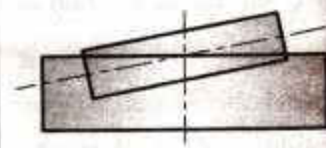
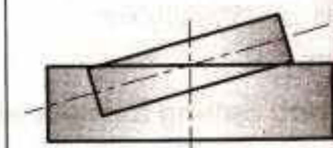
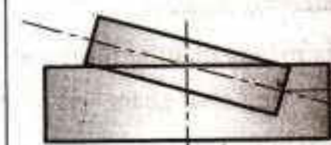
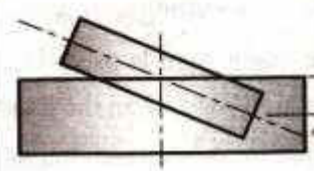
For helical gear : 90-(β+ λ) (when hands are different)

90-(β- λ) (when hands are same)

- It is preferable to use hob and gear of same hand.
- If the hands of hob and workpiece are opposite, the feed rate has to be slightly reduced and this may affect the surface finish.

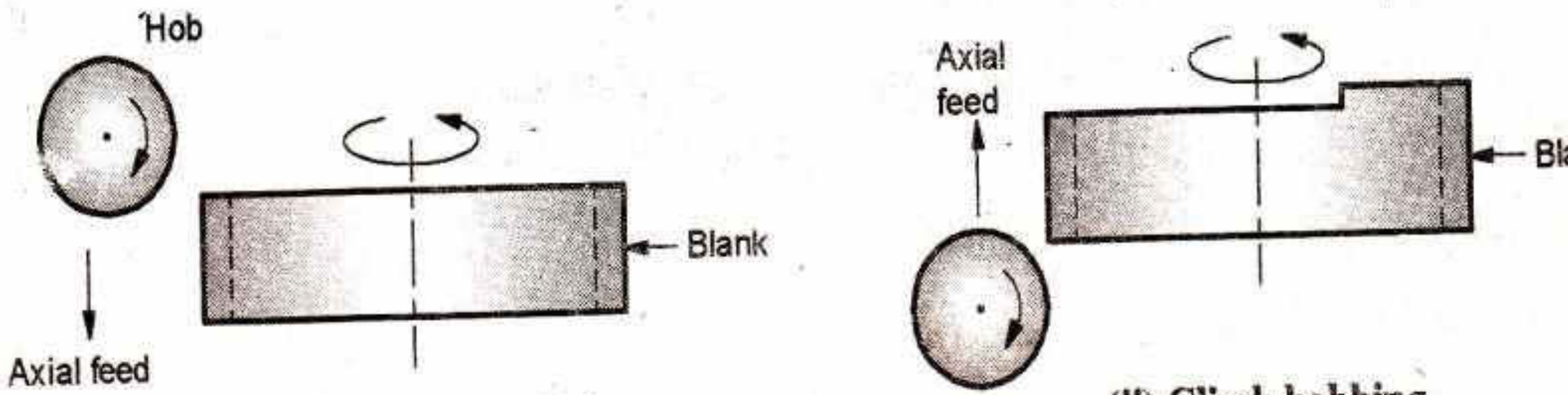
λ = Hob lead angle, β = Helix angle of the gear



Sr. No	Gear	Hob	Setting angles degree	Position
a	SPUR	LH OR RH	λ	
b	RH HELICAL	RH	$\beta - \lambda$	
c	RH HELICAL	LH	$\beta + \lambda$	
d	LH HELICAL	LH	$\beta - \lambda$	
e	LH HELICAL	RH	$\beta + \lambda$	

Feed directions in Hobbing :

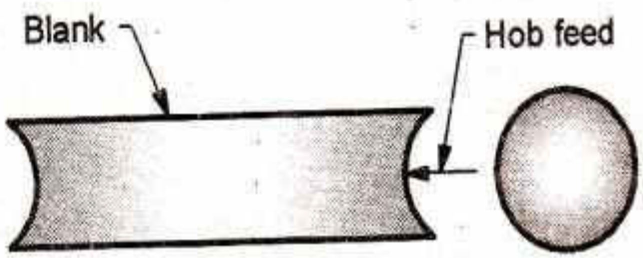
- The direction of feed during hobbing operation depends, upon the type of gear to be cut.
- Following directions are commonly used in gear cutting.
    1. Axial feeding
    2. Radial Feeding
    3. Tangential feeding
    4. Combined radial and axial feeding
    5. Diagonal Feeding



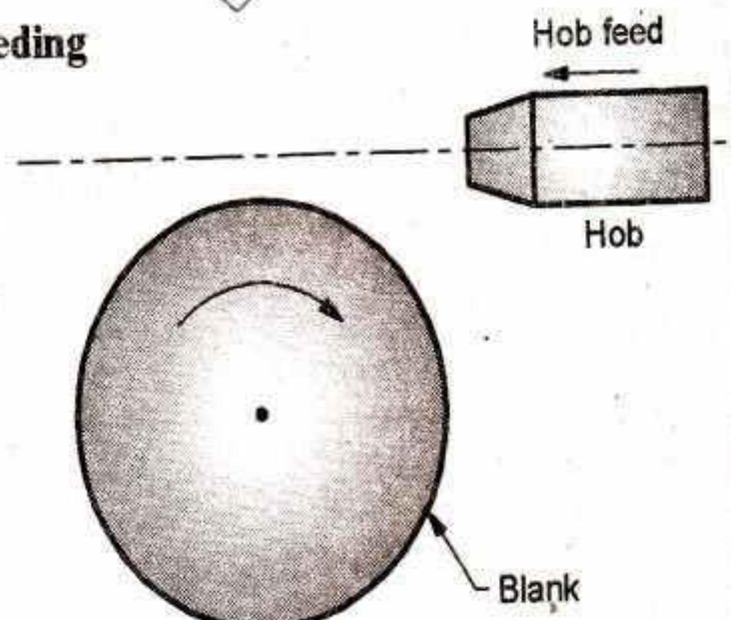
(i) Conventional hobbing

(ii) Climb hobbing

(a) Axial feeding



(b) Radial feeding



(b) Tangential feeding

1. Axial Feeding :

- The gear blank is first brought radialy towards the hob to get desired depth of the tooth to be cut.
- The blank movement is then stopped and the hob is given an axial feeding motion along the face of blank to complete the gear.

2. Radial Feeding :

- In radial feeding the hob is feed radialy towards the centre of the blank.
- The feeding stops when the full depth of cut is reached.
- This type of feeding is used for cutting worm wheel having helix angle less than 6-7 degrees.
- Disadvantage of this type of feeding is that small portion of hob involve in cutting at given time and thus, hob wear is non-uniform and may affect the accuracy of profile.

3. Tangential Feeding :

- In this method the hob is first set to the full depth of cut and then fed in a direction tangential to gear blank.

4. Combined Axial and Radial Feeding :

- This type of feeding become necessary when enough space is not available for providing axial feeding .

5. Diagonal Feeding :

- Diagonal Feeding is combination of radial and tangential feeding and it gives excellent rolling characteristics.
- In this feeding wear of hob is uniform along the length of hob, resulting in longer hob life.

Advantage and Limitations of Gear Hobbing :

Advantage:

- Higher rate of production.
- The method is versatile and used for producing variety of jobs.
- Teeth produced with more accurate profile.
- Same cutter is used to cut gears having same module.
- Process is also suitable for non-metallic materials.

Limitations:

- Gear hobbing cannot be used for producing internal gears without use of special tooling.
- Hobbing cannot be used for cutting Herringbone gears.

Gear Finishing :

- For effective and noiseless operation at high speed , it is important that profile of teeth is accurate , smooth and without irregularities.
- In Milling , it may not have accurate profile because of use of limited cutters.
- In Shaping and Hobbing, it composed to tiny flats. This difficulty achieved by reducing feed rate but it increases cutting time.
- In many cases gears are hardened after cutting teeth to improve life but it introduce slightly distortion or surface roughness.
- Finishing operation intended to perform following function :
  1) Eliminate after effect of heat treatment.
  2) Correct error of profile and pitch.
  3) Ensure proper concentricity of Pitch circle and Centre hole.

Gear Finishing Operation :

- **Gear Shaving**
- **Gear Burnishing**
- **Gear Grinding**
- **Gear lapping**
- **Honing**

Gear Shaving:

- Gear teeth finished by rotate it at high speed in mesh and pressed against a hardened gear shaving cutter.
- Two Types of cutters commonly used
  1) Rotary type
  2) Rack Type
- The shaving operation is carried out on rotary shaving machines.
- Cutter is mounted on mandrel and rotate at surface speed around 2 m/s.
- In Machine.....
- Rack type shaving operation is carried ving machine but process has limitations in c
- Fast and rapid production process for un

Gear Burnishing:

- Gear Burnishing is a cold working process in which high spots on unhardened gears are plastically deformed to produce smooth and accurate surface.
- During burnishing operation, burnishing gears are fed inward toward workpiece and made to turn few rotation in each direction.
- The surface irregularity of gear teeth squeezed and good surface finish obtained.
- Gear teeth also get slightly hardness due to cold working.
- Process improves only surface finish of teeth and does not correct the tooth profile or pitch of teeth.
- This process is suitable only for gears which do not require high accuracy.

Gear grinding:

- It is suitable for finishing of hardened gears which cannot be finished by shaving or Burnishing.
- Gear teeth grinding processes:

1) Form Wheel grinding
2) Threaded wheel grinding
3) Generation grinding

Form Wheel grinding:

- Grinding wheel shaped to the exact profile of gear tooth space like disc type form milling cutter.
- The teeth are finished one by one and after one tooth finished, the blank is indexed to the next tooth space as in the form milling operation.

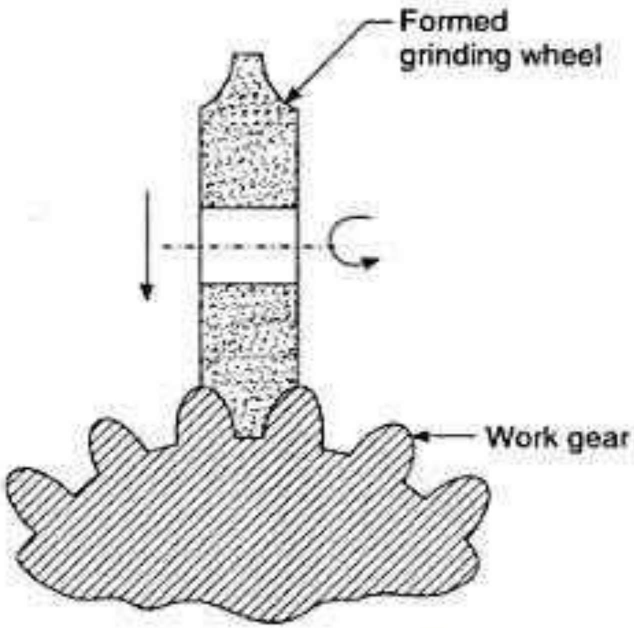


Fig. 15.24 Grinding a gear with formed wheel grinding method.

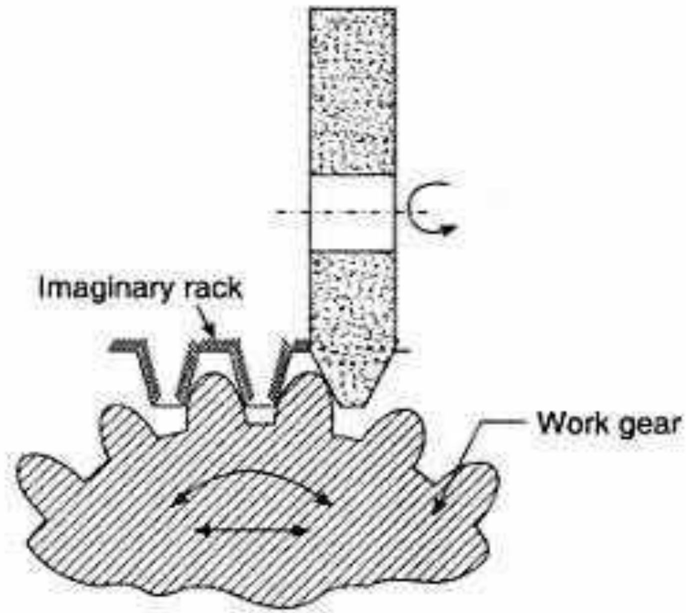


Fig. 15.25 Showing the principle of generation gear grinding. The grinding wheel shown forms one tooth of the imaginary rack.

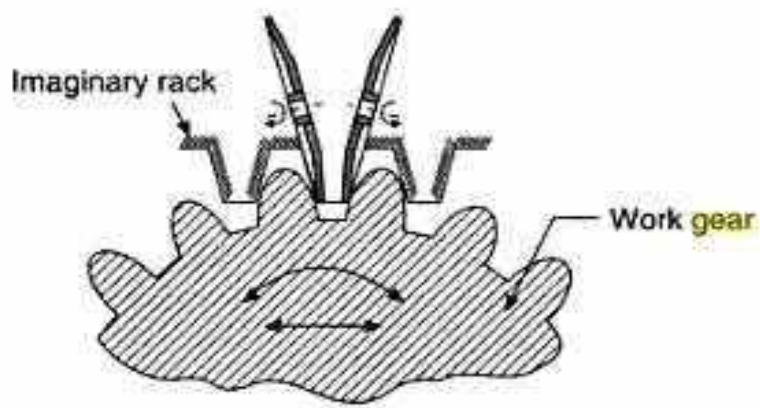


Fig. 15.26 Generation gear grinding with two saucer-shaped grinding wheels.

Threaded wheel grinding:

- Threaded wheel is rotated about it’s own axis and workpiece is also given a rotational movement in mesh with the wheel and periodic in feed given towards the wheel.
- This method is fast but lot of time is required to prepare the grinding wheel.

Generation Grinding:

- It uses one or two saucer shaped grinding wheels.
- The work mounted on mandrel between centers and given rotary motion as well as reciprocating motion in lateral direction.
- The accuracy of gear tooth depends on accuracy of wheel.
- Gear grinding process need cares and skilled operator to avoid overheating of teeth.
- Hardened gears may crack due to overheating unless sufficient care is taken during operation.

Gear Lapping:

- Lapping is done on generally gears having hardness more than 45 RC to remove burrs, abrasions from the surface and to remove small errors caused by heat treatment.
- In lapping process work gear is mesh with one or more small cast iron toothed laps under flow of fine abrasives in oil. This creates sliding action between the teeth all over the contact surface.
- In lapping process very small amount of material is removed.

Honing:

- Honing is suitable for finishing of heat treated gears.
- It is carried out with steel tools having abrasive or cemented carbide particles embedded in their surface.
- The machine for honing process is similar to gear shaving machines.
- The tool and w/p mounted in relation such that the honing tool rotates w/p at high speed.
- The honing tool are costlier than lapping tools but the honing process is much faster. Honing is preferred only for large quantity operations.

Grinding

Overview

- **Introduction to Grinding**-Need and different methods of grinding, Abrasives; natural and synthetic, manufacturing and selection of grinding wheels, Wheel specifications, mounting and dressing
- **Surface finishing:** Honing, lapping, super-finishing, polishing and buffing

Introduction to Grinding

- Most common form of abrasive machining.
- Process of removing material by abrasive action of a revolving wheel on the surface of a work-piece in order to bring it to required shape and size
- Cutting by abrasive tool whose cutting elements are grains of abrasive material known as grit.
- Grits have sharp cutting points, high hot hardness, and chemical stability and wear resistance.
- The grits are held together by a suitable bonding material to give shape of an abrasive tool.
- Abrasive machining is advanced version of conventional grinding with better performance

Cutting action of abrasive grains

Similarities & Dissimilarities between Grinding & Milling/Advantages/Applications

SIMILARITIES	**DISSIMILARITIES**
Cutting occurs on either the periphery the face of the grinding wheel, cutting to peripheral and face milling. with hig average, Self-sharpening nature, ne edges wear & pulled out.	Smaller grains with more teeth, high or speeds, randomly oriented grits similar h negative rake angle on w grains are exposed as old cutting

ADVANTAGES

A grinding wheel need only two types of specification , Dimensional accuracy, Good surface finish, Good form and locational accuracy , applicable to both hardened and unhardened material

APPLICATIONS

Surface finishing, slitting and parting, descaling, deburring, stock removal (abrasive milling), finishing of flat as well as cylindrical surface, Grinding of tools and cutters and resharpening of the same.

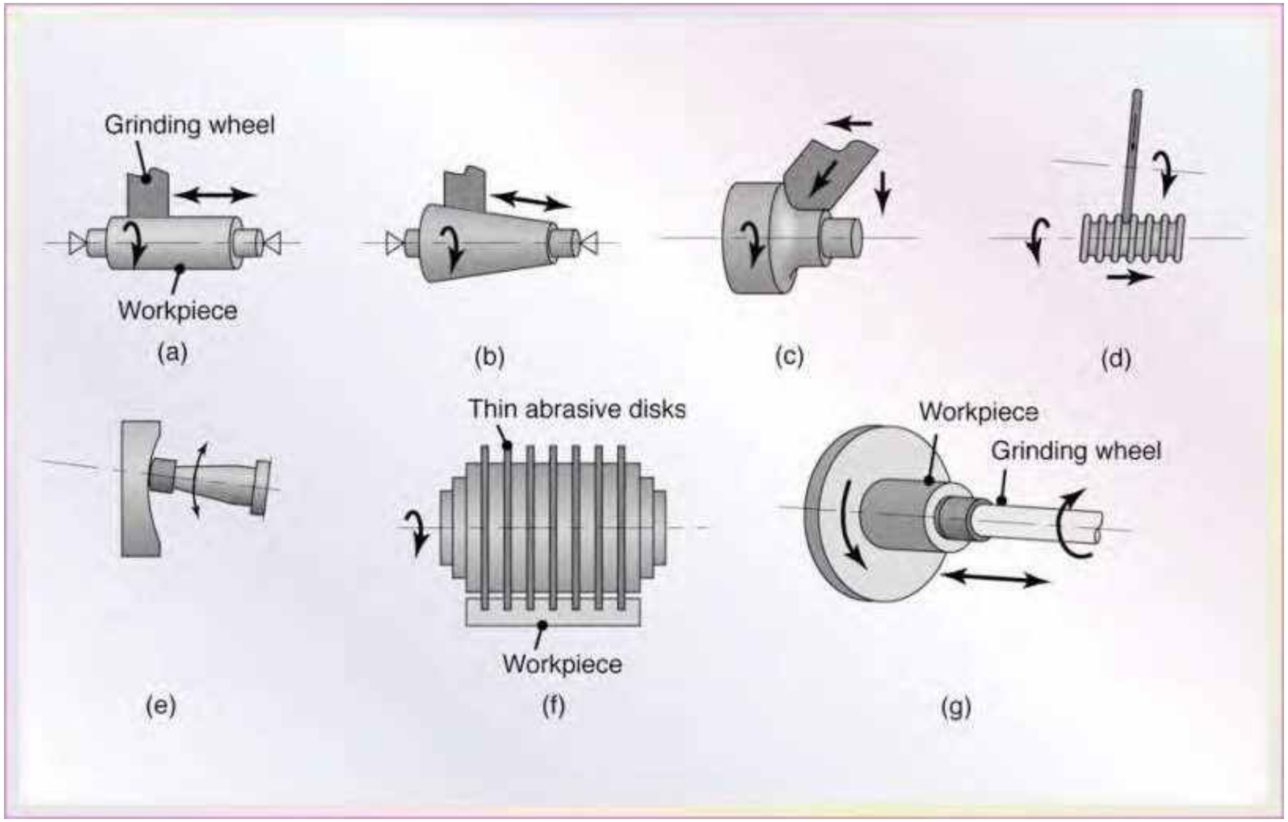
Grinding Wheel

- Consists of abrasive particles and bonding material. The bonding material holds the particles in place and establishes the shape and structure of the wheel. These two ingredients and the way they are fabricated determine the five basic parameters of a grinding wheel:
  - **Abrasive material**
  - **Grain size**
  - **Bonding material**
  - **Wheel structure**
  - **Wheel grade**
- To achieve the desired performance in a given application, each of the parameters must be carefully selected.

Abrasive Material

- Abrasives are extreme hard, sharp edged, irregular shaped particles used to shape other materials by a grinding or abrading action in the form of tiny chips.
- Used as loose grains as in grinding wheels, or as coatings on cloth or paper or forming into ceramic cutting tools for machining.
- Because of their superior hardness and refractory properties, they have advantages in speed of operation, depth of cut, and smoothness of finish.
- Abrasives also are used to hone, lap, buff, and polish workpieces.
- By computer-controlled machines a wide variety of workpiece geometries with very fine dimensional accuracy and surface finishes can be achieved. Dimensional tolerances can be less than 1 *µm,* and surface roughness can be as fine as 0.025 */µm*.
- Used for cleaning and machining all types of metal, for grinding and polishing glass, for grinding logs to paper pulp, for cutting metals, glass, and cement, removing unwanted weld beads and spatter, cleaning surfaces with jets of air or water containing abrasive particles and for manufacturing many miscellaneous products such as brake linings and nonslip floor tile.

Abrasive Material



The types of workpieces and operations typical of grinding: (a) cylindrical surfaces, (b) conical surfaces. (c) fillets on a shaft, (d) helical profiles, (e) concave shape, (f) cutting off or slotting with thin wheels, and (g) internal grinding (b) A variety of bonded abrasives used in abrasive machining processes

Abrasive Material

- General properties of an abrasive material used in grinding wheels include high hardness, wear resistance, toughness (common properties of any cutting tool) and friability.

Friability

- Refers to the capacity of the abrasive material to fracture when the cutting edge of the grain becomes dull, thereby exposing a new sharp edge.
- High friability indicates low strength or low fracture resistance of the abrasive. Aluminum oxide has lower friability than silicon carbide and, correspondingly, a lower tendency to fragment.
- Blocky grains (which are analogous to a negative rake angle in single-point cutting tools are less friable than less blocky or plate-like grains.
- Probability of defects diminishes as the grain size becomes smaller (due to the size effect), smaller grains are stronger and less friable than larger ones.

Abrasive Material

Ranges of Knoop Hardness for Various Materials and Abrasives			
Common glass	350–500	Titanium nitride	2000
Flint, quartz	800–1100	Titanium carbide	1800–3200
Zirconium oxide	1000	Silicon carbide	2100–3000
Hardened steels	700–1300	Boron carbide	2800
Tungsten carbide	1800–2400	Cubic boron nitride	4000–5000
Aluminum oxide	2000–3000	Diamond	7000–8000

Table : hardness of various materials & Abrasives

Classification of Abrasives

Natural Abrasive

- ❖The common natural abrasives are sand stone, emery (50-60% crystalline Al_2O_3 + iron oxide) corundum (75-90% crystalline aluminium oxide + iron oxide), and diamond.
- ❖The sand stone is used only for sharpening some wood-working tool .
- ❖Diamond is used for dressing the grinding wheel and acts as an abrasive material for hard material.
- ❖Other natural abrasives are garnet, an aluminosilicate mineral; feldspar, used in household cleansers; calcined clay; lime; chalk; and silica, SiO_2, in its many forms — sandstone, sand (for grinding plate glass), flint, and diatomite.
- ❖Generally contain impurities and possess non uniform properties, their performance is inconsistent and unreliable.

Classification of Abrasives

Artificial abrasive

- These are manufactured under controlled conditions in closed electric furnaces in order to avoid the introduction of impurities and to achieve the necessary temperature for chemical reactions to take place

Advantages and use of artificial Abrasive

- The controlled conditions in the electric furnace enable uniformly in the product
- The quality of production and supply can easily be varied according to the demands
- Fulfill growing demand of more abrasive material in the modern manufacturing process
- Aluminum oxide, silicon carbide, cubic boron nitride, and diamond are mostly used.

Classification of Abrasives

Aluminum oxide (Al_2O_3)

- Aluminum oxide was first made in 1893 and is produced by fusing bauxite, iron filings, and coke.
- Dark (less friable), white (very friable), and single crystal.
- Seeded gel (1987) is purest form of unfused aluminum oxide known as ceramic aluminum oxide. Very small grain size on the order of 0.2 μm. These grains are sintered to form larger sizes. Relatively high friability hence sharp, used for difficult-to-grind materials.
- Used to grind steel and other ferrous, high-strength alloys

Silicon carbide (SiC)

- 1891, made with silica sand and petroleum coke.
- black (less friable) and green (more friable)
- higher friability than aluminum oxides. Hence, they have a greater tendency to fracture and remain sharp.
- Used on ductile metals such as aluminum, brass, and stainless steel, as well as brittle materials such as some cast irons and certain ceramics. Nonferrous metals, cast irons, carbides, ceramics, glass, and marble.
- Cannot be used effectively for grinding steel because of the strong chemical affinity between the carbon in SiC and the iron in steel

Classification of Abrasives

Cubic boron nitride (cBN)

- Developed in 1970, second hardest material, cubic boron nitride is made by bonding a 0.5 to 1 mm layer of polycrystalline cubic boron nitride to a carbide substrate by sintering under high pressure and high temperature. While the carbide provides shock resistance, the cBN layer provides very high wear resistance and cutting-edge strength . Cubic-boron- nitride tools also are made in small sizes without a substrate.
- At elevated temperatures, cBN is chemically inert to iron and nickel. (Hence, there is no wear due to diffusion.) Its resistance to oxidation is high; thus, it is particularly suitable for cutting hardened ferrous Braze and high-temperature alloys and for high-speed machining operations
- It also is used as an abrasive. Because cBN tools are brittle, stiffness of the machine tool and the fixturing is important to avoid vibration and chatter.
- Furthermore, in order to avoid chipping and cracking due to thermal shock, machining generally should be performed dry (i.e., cutting fluids should be avoided), particularly in interrupted cutting operations (such as milling), which repeatedly subject the tool to thermal cycling.
- Used for hard materials such as hardened tool steels and aerospace alloys
- Steels and cast irons above 50 HRC hardness and high temperature alloys.

Classification of Abrasives

Diamond

- Diamond first used as an abrasive in 1955.
- Principal form of carbon with a covalently bonded structure.
- It is the hardest substance known (7000 to 8000 HK).
- However, it is brittle and begins to decompose in air at about 700°C, but it resists higher temperatures in nonoxidizing environments.
- Manufactured by putting graphite to a hydrostatic pressure of 14 GPa and a temperature of 3000°C.
- Synthetic diamond has superior properties because of its lack of impurities, available in various sizes and shapes; for abrasive machining, the most common grit size is 0.01 mm in diameter.
- Diamond-like carbon also has been developed and is used as a diamond film coating, Diamond particles also can be coated with nickel, copper, or titanium for improved performance in grinding operations.
- Used on hard, abrasive materials such as ceramics, cemented carbides, and glass and some hardened steels

diamond dissolves in iron at the high temperatures encountered in grinding.

Grain Size

- Important in determining surface finish and material removal rate.
- Large grit- big grinding capacity, rough workpiece surface
- Fine grit- small grinding capacity, smooth workpiece surface
- The selection of grit size also depends to some extent on the hardness of the work material. Harder work materials require smaller grain sizes to cut effectively, whereas softer materials require larger grit sizes.
- The grit size is measured using a screen mesh procedure. In this procedure, smaller grit sizes have larger numbers and vice versa. Grain sizes used in grinding wheels typically range between 8 and 250. Grit size 8 is very coarse and size 500 is very fine.

Bonding Material

- The bonding material holds the abrasive grains and establishes the shape and structural integrity of the grinding wheel.
- Desirable properties of the bond material include strength, toughness, hardness, and temperature resistance.
- The bonding material must be able to withstand the centrifugal forces and high temperatures experienced by the grinding wheel
- It should resist shattering in shock loading of the wheel, and hold the abrasive grains rigidly in place to accomplish the cutting action while allowing those grains that are worn to be dislodged so that new grains can be exposed.

Types of Bonding Material

- **Vitrified bond (V)**
- **Silicate bond (S)**
- **Shellac bond (E)**
- **Resinoid bond (B)**
- **Rubber bond (R)**
- **Oxychloride bond (O)**
- **Metallic bond**
- **Electroplated bond**
- **Brazed bond**
- **Reinforced Wheels**
- **Thermoplastics**

Vitrified Bond (V)

- In this process, the **abrasive and clay** are mixed with sufficient water and then poured in moulds, dried, and after cooling trimmed to more perfect size and shape and then baked at a temp **1260 degree**. When the burning proceeds, the clay vitrifies and forms a **porcelain or glass like substance** that surrounds and connects the abrasive grains.
- Also called ceramic bond and most widely used bond material
- Wheels with vitrified bonds are **strong, stiff, porous, and resistant to oils, acids, water and high temperatures**. Porosity combined with strength allow high stock removal, excellent coolant flow and chip clearance
- However, they are **brittle** and lack resistance to mechanical and thermal shock.
- Not recommended for very high speed grinding because of possible **breakage of the bond under centrifugal force**
- **Different wheel color** can be added so that wheels can be color coded for use with specific workpiece materials.

Silicate Bond (S)

- In this process, the **abrasive and silica of soda or water glass** are mixed then pressed in moulds, dried and later the shapes are baked at a temp 260 degree.
- The silicate bonded wheels are water proof.
- Consists of sodium silicate (Na_2SO_3)
- Limited to situations in which heat generation must be minimized, such as grinding cutting tools.

Shellac Bond (E)

- In this process, the **abrasive and shellac** are mixed in heated containers and then rolled or pressed in heated moulds and later the shapes are baked at a temp 150 degree.
- Shellac bond wheels are also known as elastic bonded wheels.
- Relatively greater elasticity, considerable strength but not rigid
- often used in applications requiring a good fine finish
- It is not used for heavy duty.
- Used for finishing chilled iron, cast iron and steel rolls

Resinoid Bond (B)

- In this process, the **abrasive and thermosetting resins and additives** are mixed and then pressed in shape of grinding wheel and later the shapes are cured at a temp 175 degree.
- Resin Phenol formaldehyde is generally used. Bond material is an organic compound.
- It has very high strength, tougher and more resistant to higher temperatures and is used for rough or heavy duty grinding because of their ability to withstand shock load.
- More flexible bond than vitrified (low E), also more resistant to higher temperatures.
- Vibration absorbing characteristics finds its use with diamond and cBN in grinding of cemented carbide and steel respectively.
- Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening.
- Fiberglass reinforced resin bond is used with cut off wheels which requires added strength under high speed operation

Rubber Bond (R)

- In this process, the **abrasive and pure rubber and Sulphur** are mixed and rolled into sheets then wheels are punched out of these sheets on a punch press followed by heating under pressure for vulcanization
- These are less heat resistant and more dense then the Resinoid wheels
- Flexible bond type, inexpensive, used in bonding of cutoff wheels or cutoff blades like saw.
- Its principal use is in thin wheels for wet cut-off operation.
- Rubber bond was once popular for finish grinding on bearings and cutting tools

Oxychloride Bond (O)

- this process consists of mixing abrasive grains with oxide and chloride of magnesium.
- The mixing of bond and abrasive is performed in the same way as for vitrified bond wheel.
- These wheels are used in making wheels and wheel segments for disc grinding operation.
- Denoted by "O"

Metallic Bond (M)

- The abrasive grains (usually diamond or cubic boron nitride) are bonded to the periphery of a metal wheel to depths of 6 mm or less using powder metallurgy under high pressure and temperature.
- The wheel itself (the core) may be made of aluminum, bronze, steel, ceramics, or composite materials depending on requirements such as strength, stiffness, and dimensional stability.
- Most inexpensive bond type
- Metal, usually bronze, is the common bond material for diamond and cBN grinding wheels
- Used with super abrasive wheels.
- Extremely high toughness provides form accuracy and high stock removal if desired.

Electroplated Bond

- This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing.
- This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels.
- Presently it is the only bond for making wheels for abrasive milling and ultra-high speed grinding

Brazed Bond

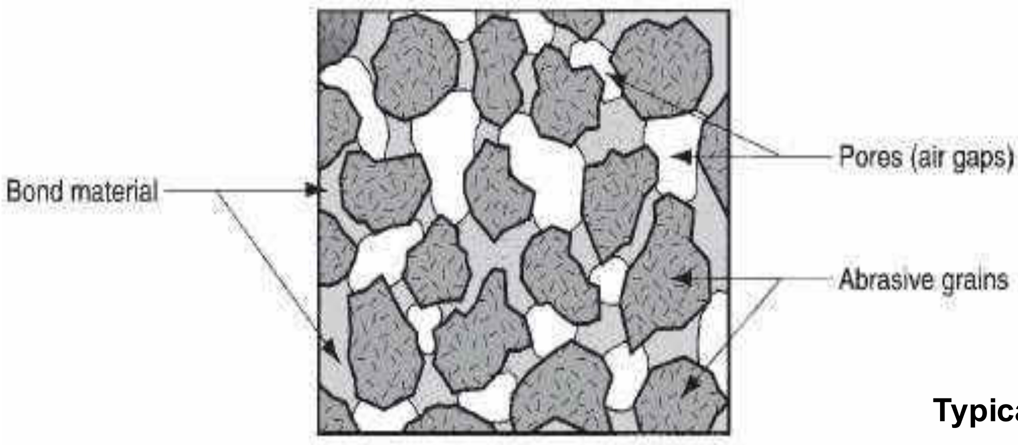
- Recent development, allows crystal exposure as high 60-80%.
- Grit spacing can be precisely controlled.
- This bond is particularly suitable for very high material removal either with diamond or cBN wheel.
- The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

Reinforced Wheels

- These wheels typically consist of one or more layers of fiberglass mats of various mesh sizes.
- The fiberglass in this laminate structure provides reinforcement in resinoid wheels by slowing the disintegration of the wheel if it breaks during use, rather than improving its strength.
- Large-diameter resinoid wheels can be supported additionally with one or more internal rings made of round steel bars inserted during the molding of the wheel.

Thermoplastic

- In addition to thermosetting resins, thermoplastic bonds are used in grinding wheels. Wheels are available with sol-gel abrasives bonded with thermoplastics.



Wheel Structure

Typical structure of a grinding wheel

- Refers to the relative spacing of the abrasive grains in the wheel.
- Abrasive grains, bond material and air gaps or pores complete the structure. The volumetric proportions of grains, bond material, and pores can be expressed as-

$$P_g + P_b + P_p = 1$$

Where

P_g =proportion of abrasive grains in the total wheel volume

P_b=proportion of bond material

P_p =proportion of pores (air gaps)

- **Type**

Open: Pp is relatively large, and Pg is relatively small. Recommended in situations in which clearance for chips must be provided. The space between the grits also serves as pocket for holding grinding fluid and cooling.

Dense: Pp is relatively small, and Pg is larger. Used to obtain better surface finish and dimensional control

Wheel Grade

- Wheel grade indicates the grinding wheel's bond strength in retaining the abrasive grits during cutting.
- This is largely dependent on the amount of bonding material present in the wheel structure P_b.

Minimum and maximum range of scale:

- **Soft:** lose grains readily, used for applications requiring low material removal rates and grinding of hard work materials. The worn out grit must pull out from the bond and make room for fresh sharp grit in order to avoid excessive rise of grinding force and temperature. Therefore, a soft grade should be chosen for grinding hard material.
- **Hard:** retain their abrasive grains, used to achieve high stock removal rates and for grinding of relative soft work materials. On the other hand, during grinding of low strength soft material grit does not wear out so quickly. Therefore, the grit can be held with strong bond so that premature grit dislodgement can be avoided.

Specification of Grinding Wheel

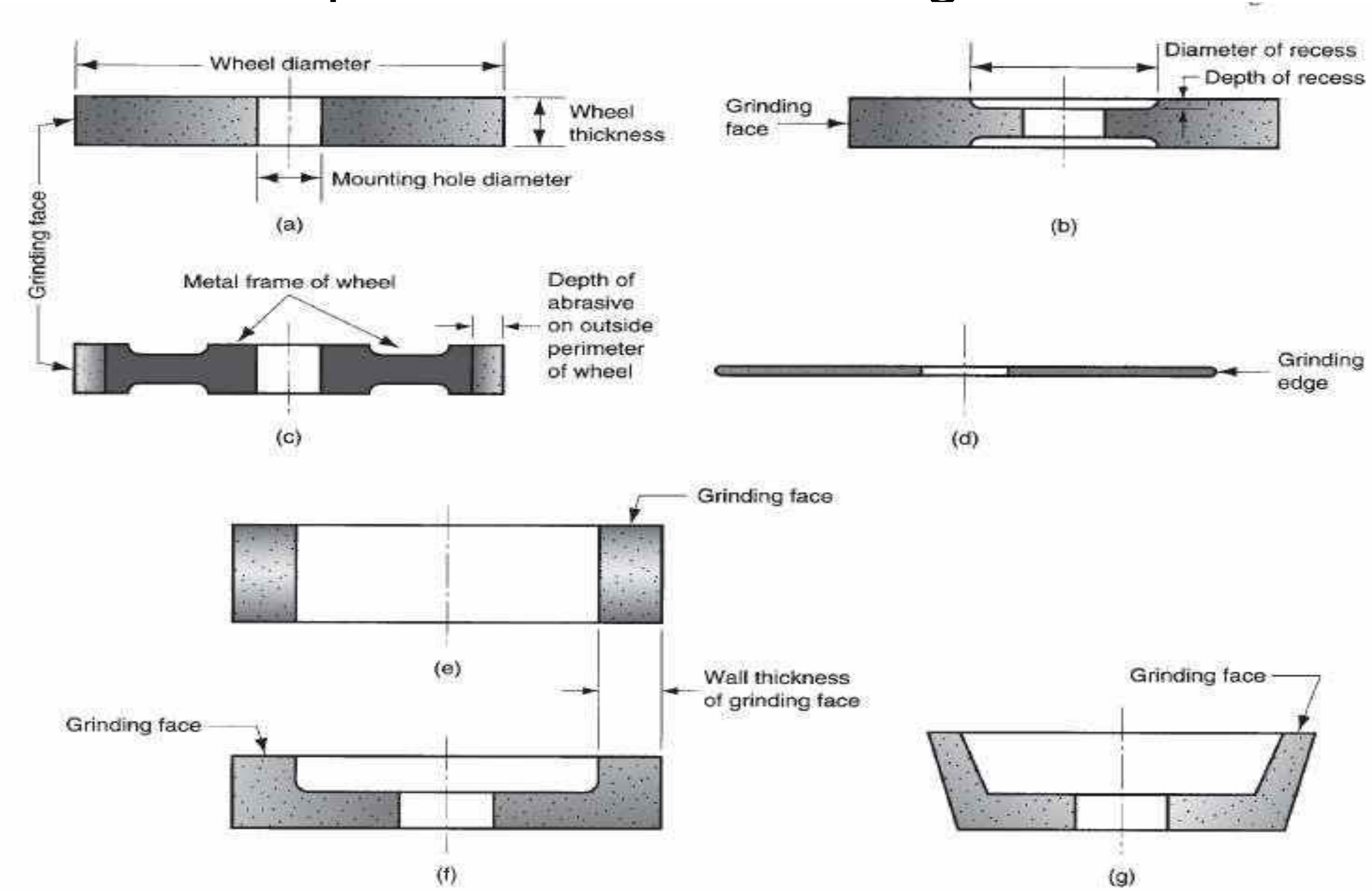
A grinding wheel requires two types of specification

- Geometrical specification
- Compositional specification

Geometrical specification

- Refers to geometry & includes wheel diameter, width and depth of rim and the bore diameter.
- Depends on operation and material
- Wide ranges : diameter (400 mm in high efficiency grinding to 1 mm in internal grinding),Width (less than an mm in dicing and slicing)

Specification of Grinding Wheel



Some of the standard grinding wheel shapes: (a) straight, (b) recessed two sides, (c) metal wheel frame with abrasive bonded to outside circumference, (d) abrasive cutoff wheel, (e) cylinder wheel, (f) straight cup wheel, and (g) flaring cup wheel

Specification of Grinding Wheel

Compositional specifications

▪Refers to composition of grinding wheel, Specification of a grinding wheel ordinarily means compositional specification.

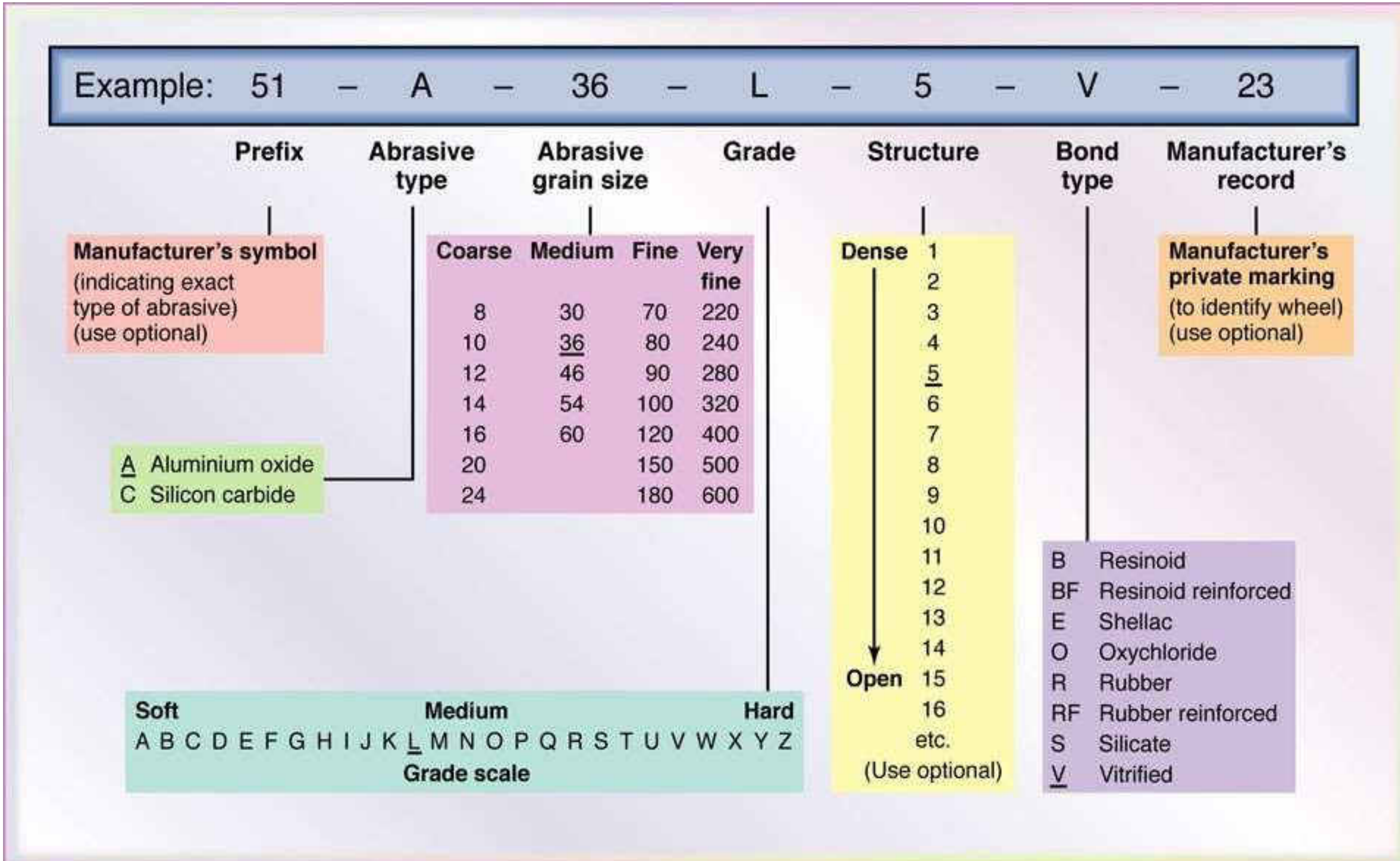
▪Conventional abrasive grinding wheels are specified by the following parameters.

- **The type of grit material (Abrasive Type)**
- **The grit size (Abrasive Grain Type)**
- **The bond strength of the wheel, commonly known as wheel hardness (Grade)**
- **The structure of the wheel denoting the porosity i.e. the amount of inter grit spacing**
- **The type of bond material**
- **Manufacturer identification code prefixing or suffixing (or both)**

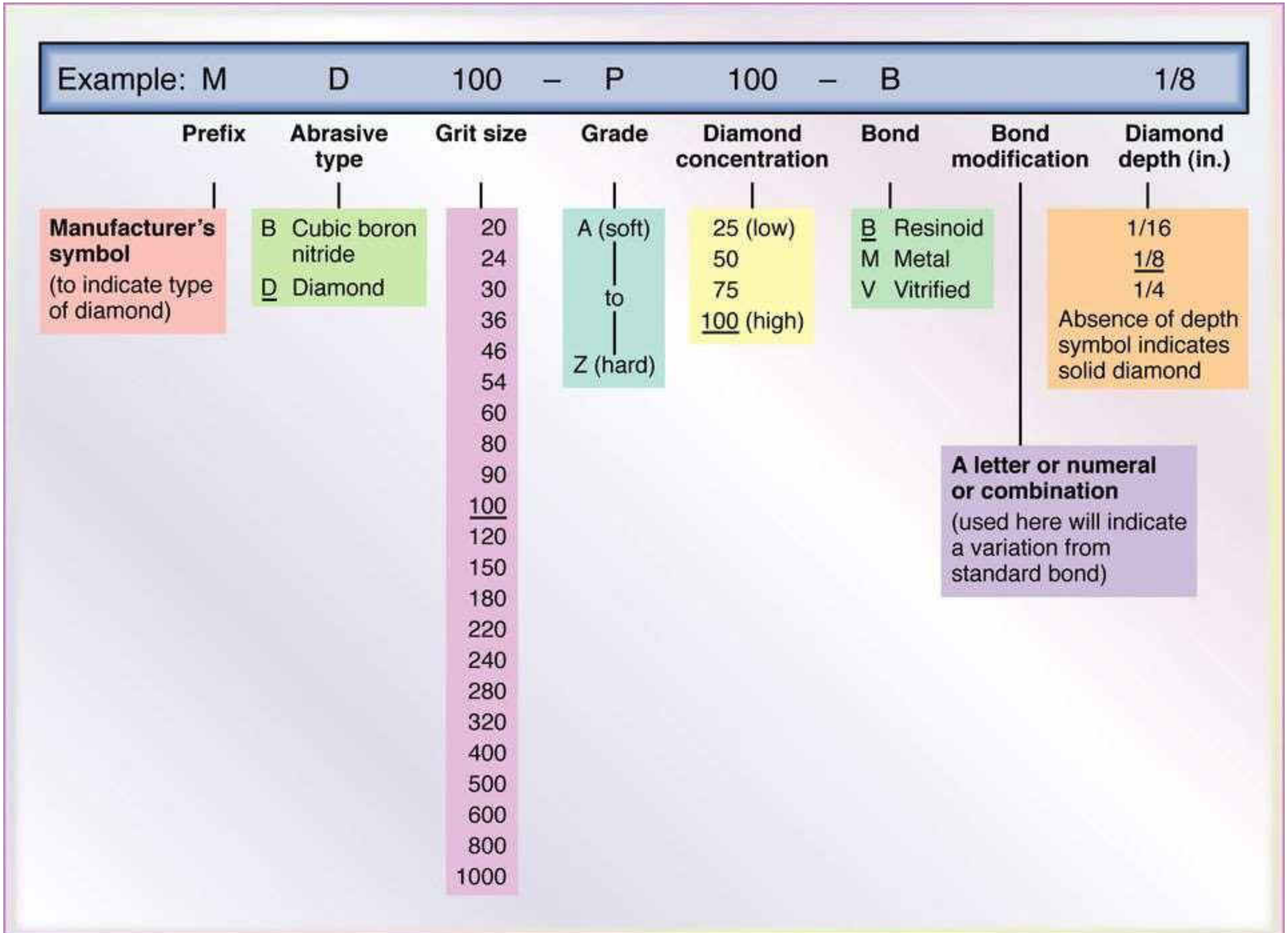
- The preceding parameters can be concisely designated in a standard grinding wheel marking system defined by the American National Standards Institute (ANSI)/BIS

  ▪This marking system uses numbers and letters to specify abrasive type, grit size, grade, structure, and bond material.

Specification of Grinding Wheel



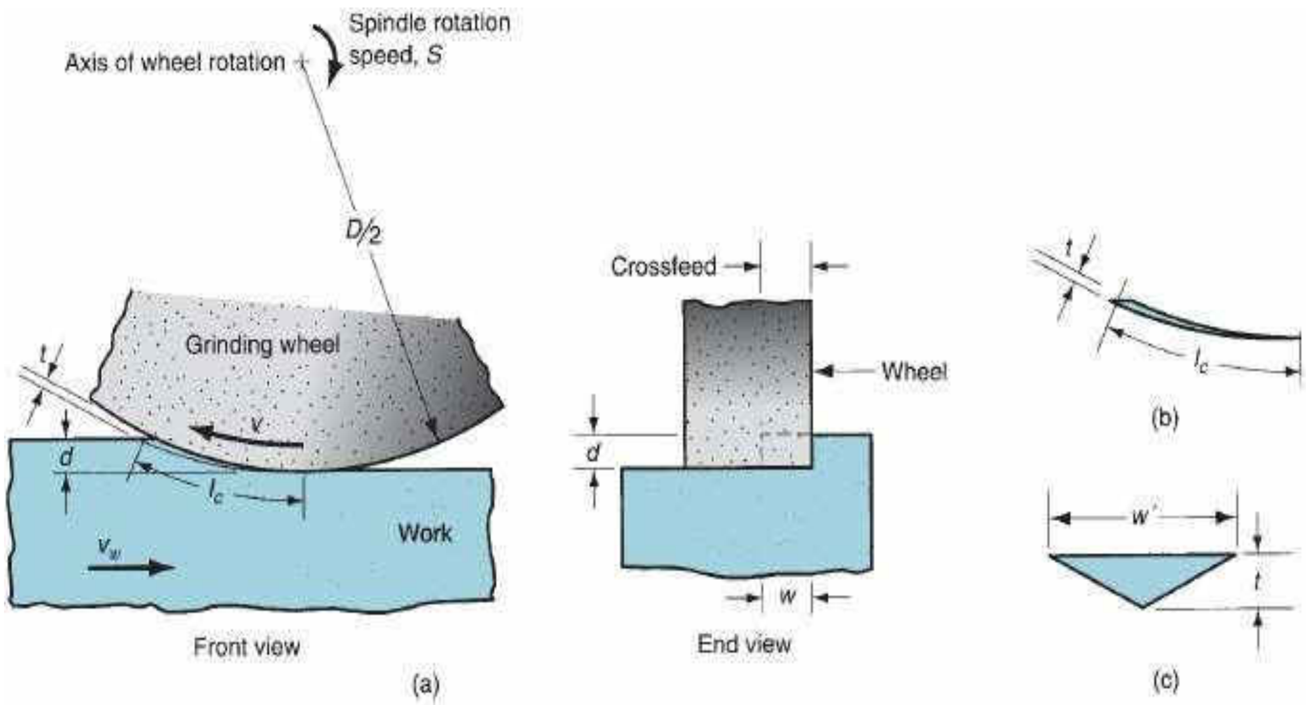
Specification of Grinding Wheel



Marking system for diamond and cubic boron nitride grinding wheels as defined by ANSI

Analysis of the Grinding Process

$$v = \pi D N$$



Where

v = surface speed of wheel, m/min

N = spindle speed, rev/min

D = wheel diameter, m

d = depth of cut, called the infeed, is the penetration of the wheel below the original work surface.

w =Crossfeed or lateral feed which determines the width of the grinding path w figure (a). This width, multiplied by depth d determines the cross-sectional area of the cut.

(a) The geometry of surface grinding, showing the cutting conditions; (b) assumed longitudinal shape and (c) cross section of a single chip

Analysis of the Grinding Process

In most grinding operations, the work moves past the wheel at a certain speed v_w, so that the material removal rate is

$$R_{MR} = v_w w d$$

Each grain in the grinding wheel cuts an individual chip whose longitudinal shape before cutting is shown in Figure (b) and whose assumed cross-sectional shape is triangular, as in Figure (c). At the exit point of the grit from the work, where the chip cross section is largest, this triangle has height t and width w'.

In a grinding operation, we are interested in how the cutting conditions combine with the grinding wheel parameters to affect

- **surface finish**
- **forces and energy**
- **temperature of the work surface**
- **wheel wear**

Surface Finish

- The surface finish of the workpart is affected by the size of the individual chips formed during grinding.
- One obvious factor in determining chip size is grit size—smaller grit sizes yield better finishes.
- Let us examine the dimensions of an individual chip. From the geometry of the grinding process, it can be shown that the average length of a chip is given by

$$l_c = \sqrt{Dd}$$

Where

l_c = length of the chip, mm D=wheel diameter, mm d=depth of cut, infeed, mm

This assumes the chip is formed by a grit that acts throughout the entire sweep arc shown in the diagram. Figure (c) shows the assumed cross section of a chip in grinding. The cross sectional shape is triangular with width w' being greater than the thickness t by a factor called the grain aspect ratio r_g

$$r_g = \frac{w'}{t}$$

Typical values of grain aspect ratio are between 10 and 20.

Surface Finish

- The number of active grits (cutting teeth) per square inch on the outside periphery of the grinding wheel is denoted by C.
- In general, smaller grain sizes give larger C values. C is also related to the wheel structure. A denser structure means more grits per area.
- Based on the value of C, the number of chips formed per time n_c is given by

$$n_c = vwC$$

Where

v = wheel speed, mm/min w = crossfeed, mm

C=grits per area on the grinding wheel surface, grits/mm^2

- It stands to reason that surface finish will be improved by increasing the number of chips formed per unit time on the work surface for a given width w. Therefore, according to Eq. , increasing v and/or C will improve finish.

Forces & Energy

If the force required to drive the work past the grinding wheel were known, the specific energy in grinding could be determined as

$$U = \frac{F_c v}{v_w w d}$$

- ✓ **Ineffective grain actions**

Reasons for High Specific Energy

Size effect

The small chip sizes in grinding cause the energy required to remove each unit volume of material to be significantly higher than in conventional machining—roughly 10 times higher.

Negative rake angles

the individual grains in a grinding wheel possess extremely negative rake angles. The average rake angle is about -30^o to -60^o .These very low rake angles result in low values of shear plane angle and high shear strains, both of which mean higher energy levels in grinding.

Ineffective grain actions

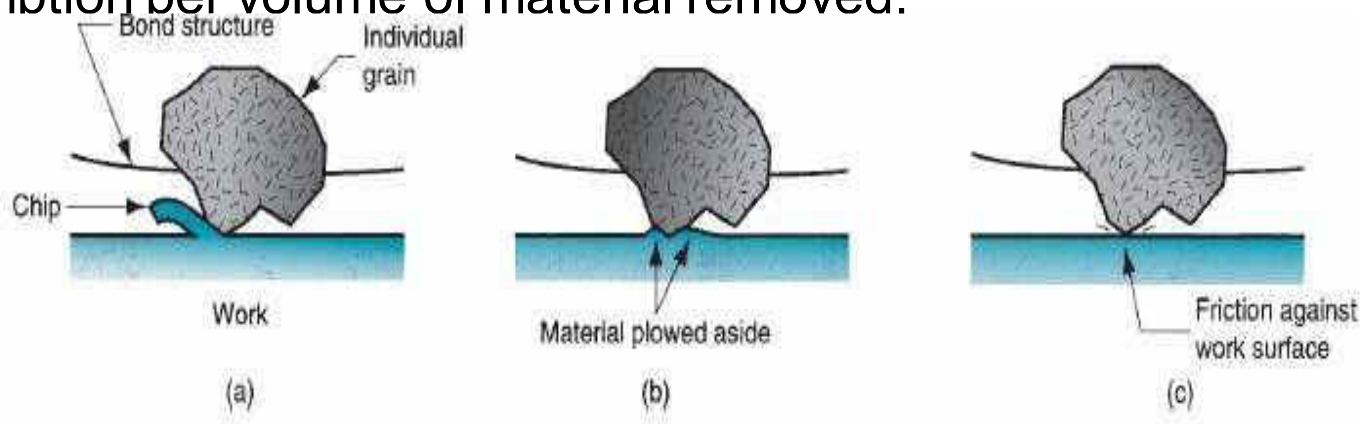
Not all of the individual grits are engaged in actual cutting. Because of the random positions and orientations of the grains in the wheel, some grains do not project far enough into the work surface to accomplish cutting.

Three Types of Grain Actions

Cutting/shearing: grit projects far enough into the work surface to form a chip and remove material

Plowing: grit projectsvery less into the work, the work surface is deformed and energy is consumed without any material removal **Rubbing:** grit rubs and only rubbing friction occurs, thus consuming energy without removing any material

The size effect, negative rake angles, and ineffective grain actions combine to make the grinding process inefficient in terms of energy consumption per volume of material removed.



Three types of grain action in grinding: (a) cutting/shearing, (b) plowing, (c) rubbing

Cutting Force On Grain

- Using the specific energy relationship, and assuming that the cutting force acting on a single grain in the grinding wheel is proportional to $r_g t$, it can be shown that-

$$F_c' = K_1 \left(\frac{r_g V_w}{vC}\right)^{0.5} \left(\frac{d}{D}\right)^{0.25}$$

- where Fc' is the cutting force acting on an individual grain, K1 is a constant of proportionality that depends on the strength of the material being cut and the sharpness of the individual grain, and the other terms have been previously defined.
- The practical significance of this relationship is that Fc' affects whether an individual grain will be pulled out of the grinding wheel, an important factor in the wheel's capacity to "resharpen" itself. Referring back to our discussion on wheel grade, a hard wheel can be made to appear softer by increasing the cutting force acting on an individual grain through appropriate adjustments in V_w, v, and d.

Temperature at the Work Surface

- Because of the size effect, high negative rake angles, and plowing and rubbing of the abrasive grits against the work surface, the grinding process is characterized by high temperatures.
- Unlike conventional machining operations in which most of the heat energy generated in the process is carried off in the chip, much of the energy in grinding remains in the ground surface resulting in high work surface temperatures. The high surface temperatures have several possible damaging effects.
- **Surface burns and cracks:** The burn marks show themselves as discolorations on the surface caused by oxidation. Grinding burns are often a sign of metallurgical damage immediately beneath the surface. The surface cracks are perpendicular to the wheel speed direction. They indicate an extreme case of thermal damage to the work surface.
- **Softening of the work surface**: High grinding temperatures reduces hot hardness of surface obtained through heat treatment.
- **Residual stresses in the work surface:** possibly decreasing the fatigue strength of the part

Temperature at the Work Surface

- it has been observed that surface temperature is dependent on energy per surface area ground (closely related to specific energy U).
- Because this varies inversely with chip thickness, it can be shown that surface temperature Ts is related to grinding parameters as follows:

$$T_s = K_2 d^{0.75} \left(\frac{r_g C v}{v_w} \right)^{0.5} D^{0.25}$$

Where K_2 = a constant of proportionality.

- The practical implication of this relationship is that surface damage owing to high work temperatures can be mitigated by decreasing depth of cut d, wheel speed v, and number of active grits per square inch on the grinding wheel C, or by increasing work speed vw. In addition, dull grinding wheels and wheels that have a hard grade and dense structure tend to cause thermal problems. Of course, using a cutting fluid can also reduce grinding temperatures.

Grinding Machines

Classification

Surface grinding machine

- horizontal spindle with reciprocating worktable
- vertical spindle with reciprocating worktable
- horizontal spindle with rotating worktable
- vertical spindle with rotating worktable
- Creep feed grinding machine

Cylindrical grinding machine (External Cylindrical grinder)

- Plain centre type cylindrical grinder
- Universal cylindrical surface grinder
- Centreless cylindrical surface grinder
- Special application of cylindrical grinder
- Tool post grinder

Classification

Internal grinding machine

- Chucking type internal grinder
- Planetary internal grinder
- Centreless internal grinder
- Tool and cutter grinding machine

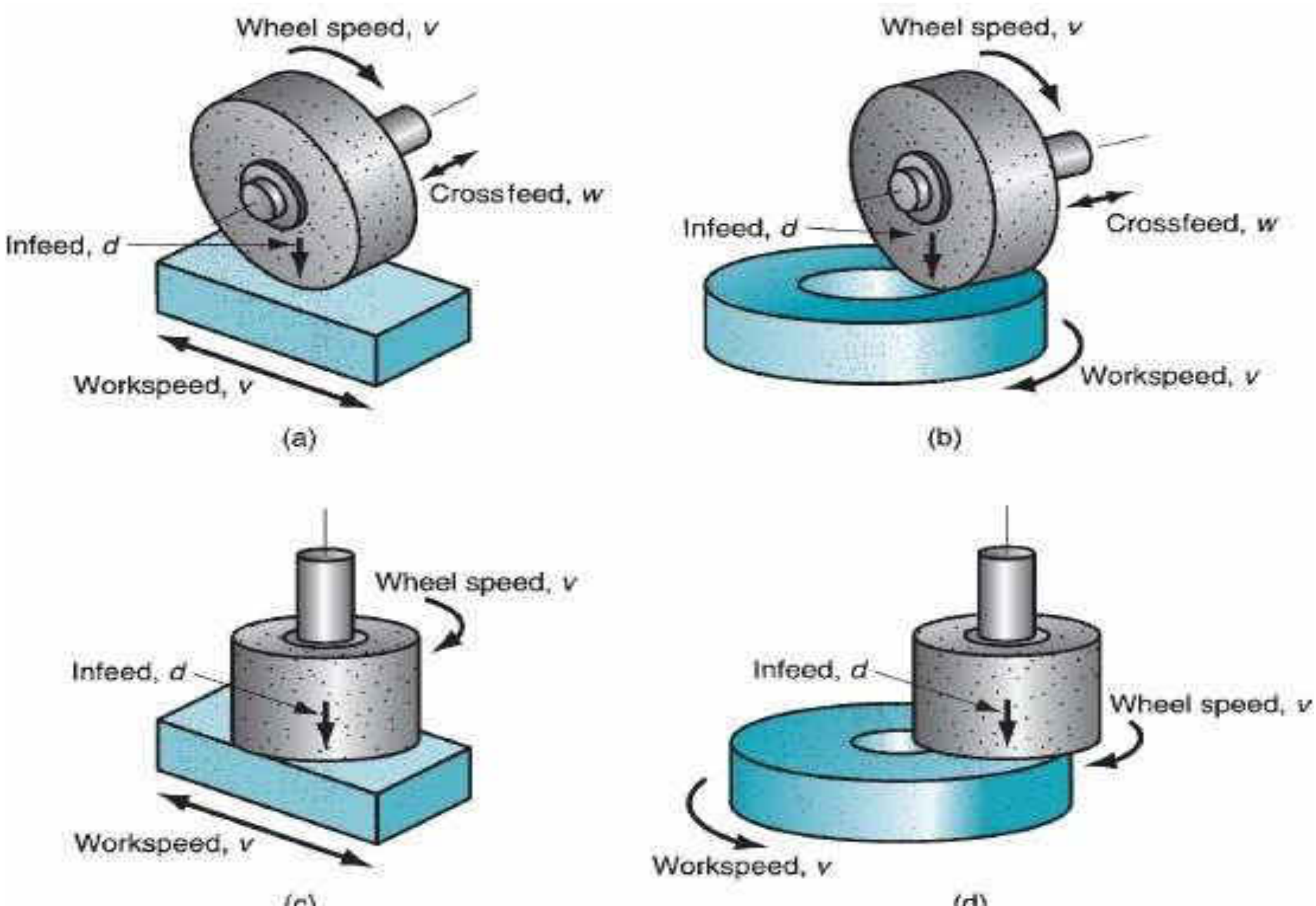
Other Grinding Operations

- Tool grinding
- Jig grinding
- Disk grinding
- Snag grinding
- Abrasive belt grinding

Surface Grinding Machine

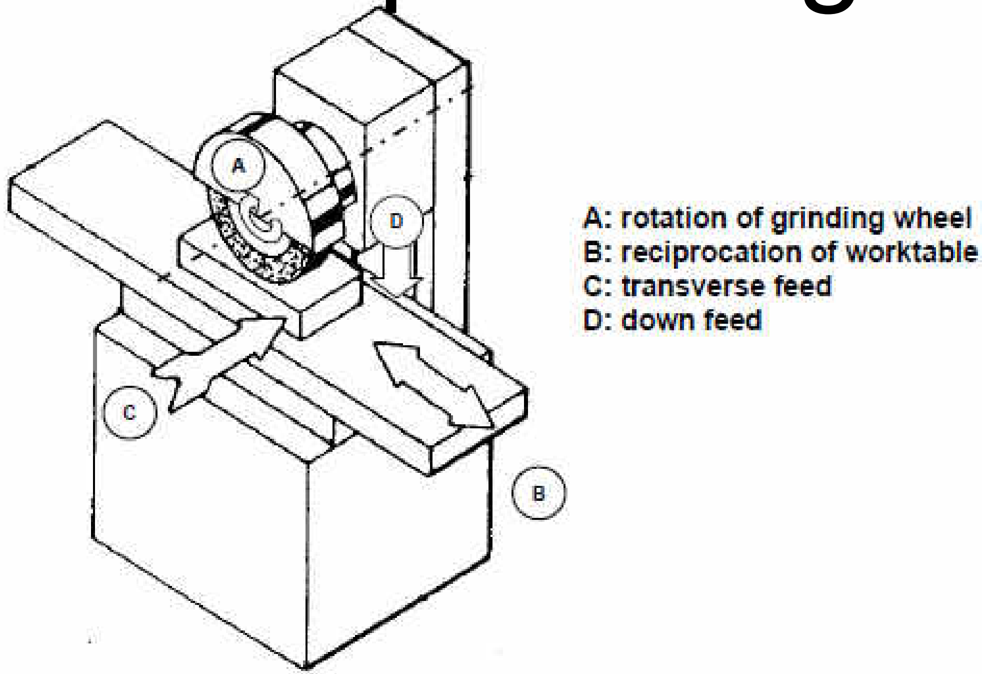
- Surface grinding is normally used to grind plain flat surfaces.
- It is performed using either the periphery of the grinding wheel or the flat face of the wheel. Because the work is normally held in a horizontal orientation, peripheral grinding is performed by rotating the wheel about a horizontal axis, and face grinding is performed by rotating the wheel about a vertical axis.
- In either case, the relative motion of the workpart is achieved by reciprocating the work past the wheel or by rotating it.
- These possible combinations of wheel orientations and workpart motions provide the four types of surface grinding machines.

Surface Grinding Machine

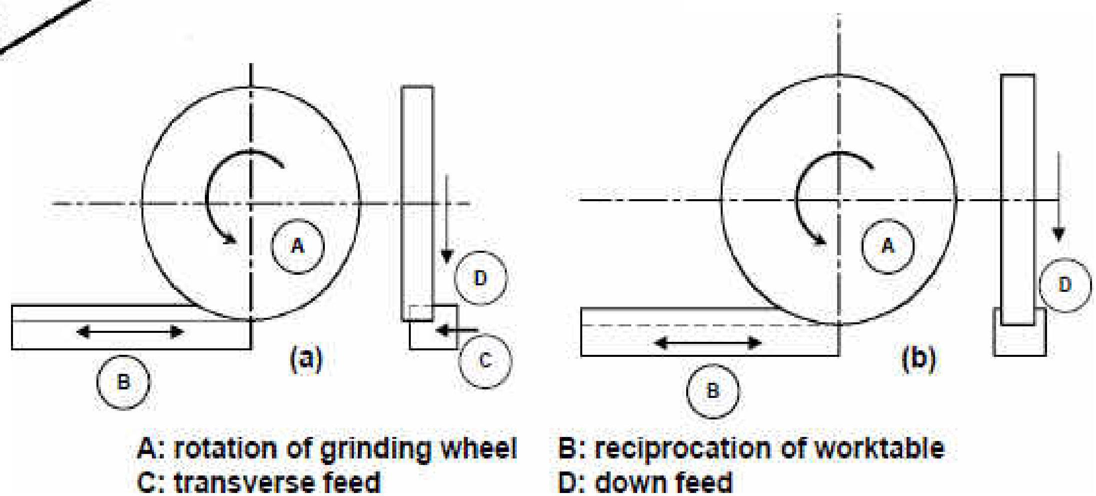


Four types of surface grinding: (a) horizontal spindle with reciprocating worktable, (b) horizontal spindle with rotating worktable, (c) vertical spindle with reciprocating worktable, and (d) vertical spindle with rotating worktable.

Horizontal spindle reciprocating table grinder

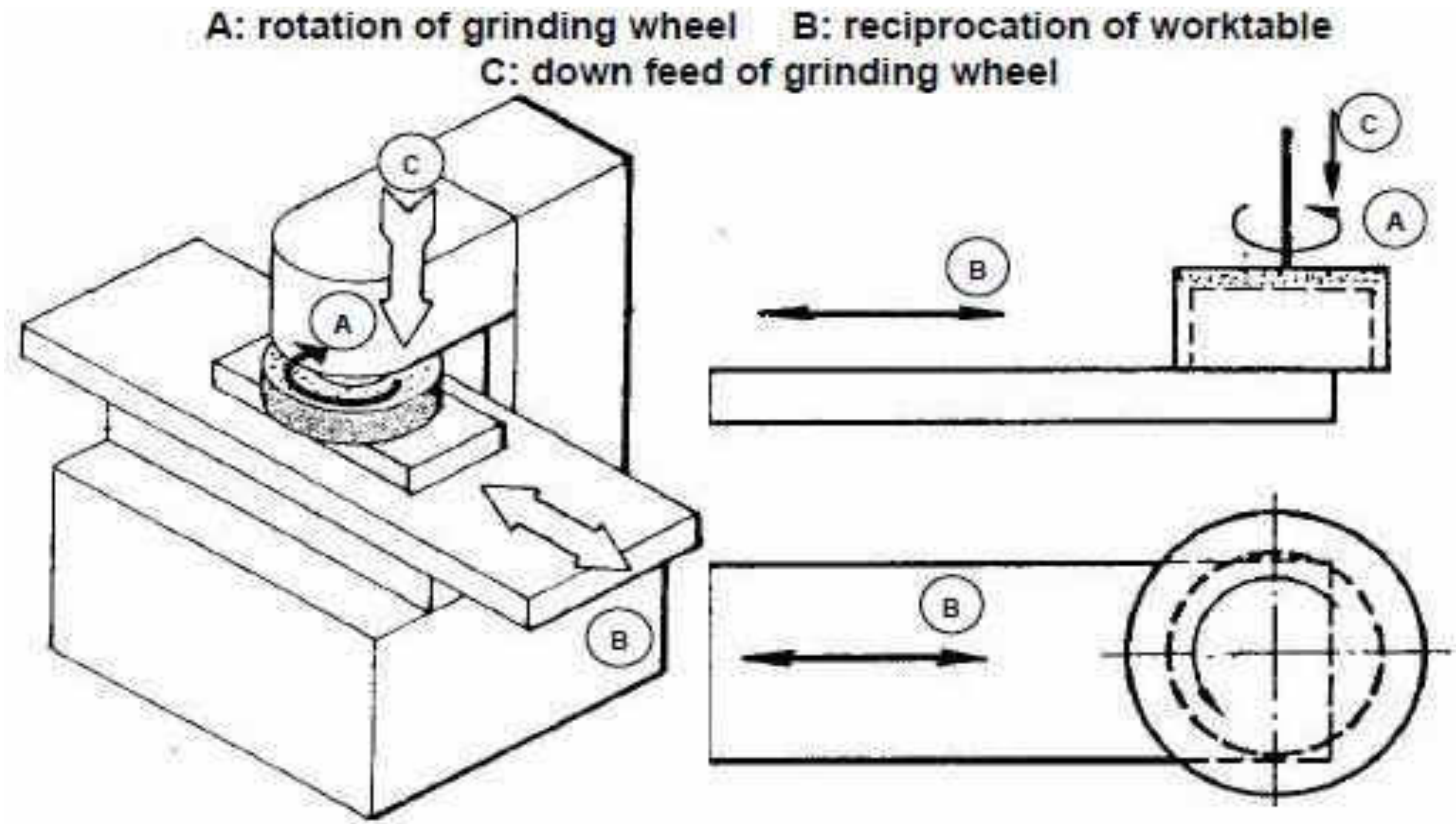


- **Working motions as in figure for grinding action**
- **A disc type grinding wheel performs the grinding action with its peripheral surface.**
- **Both traverse and plunge grinding can be carried out**



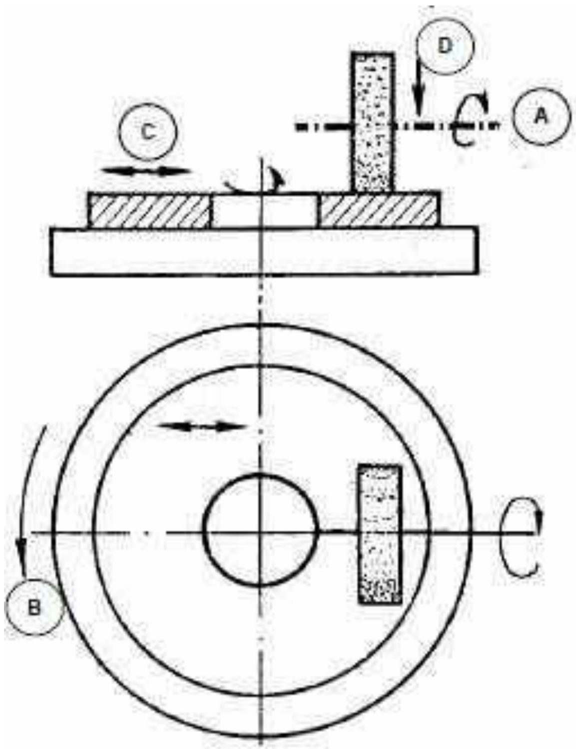
Surface grinding (a) traverse grinding (b) plunge grinding

Vertical spindle reciprocating table grinder

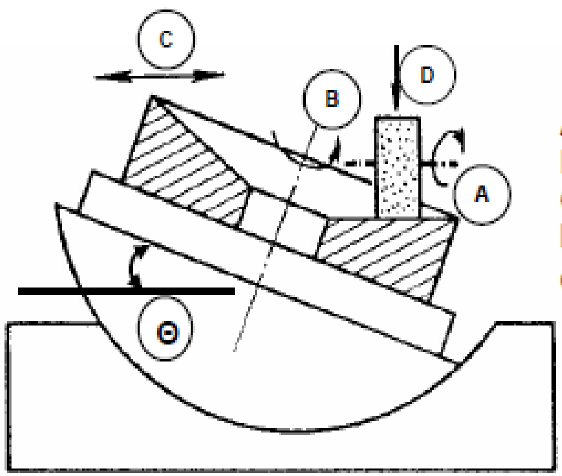


- **Working motions as in figure for grinding action**
- **similar to face milling on a vertical milling machine.**
- **a cup shaped wheel grinds the workpiece over its full width using end face of the wheel.**
- **more grits in action hence a higher material removal rate**

Horizontal spindle rotary table grinder



A: rotation of grinding wheel
B: table rotation
C: table reciprocation
D: down feed of grinding wheel

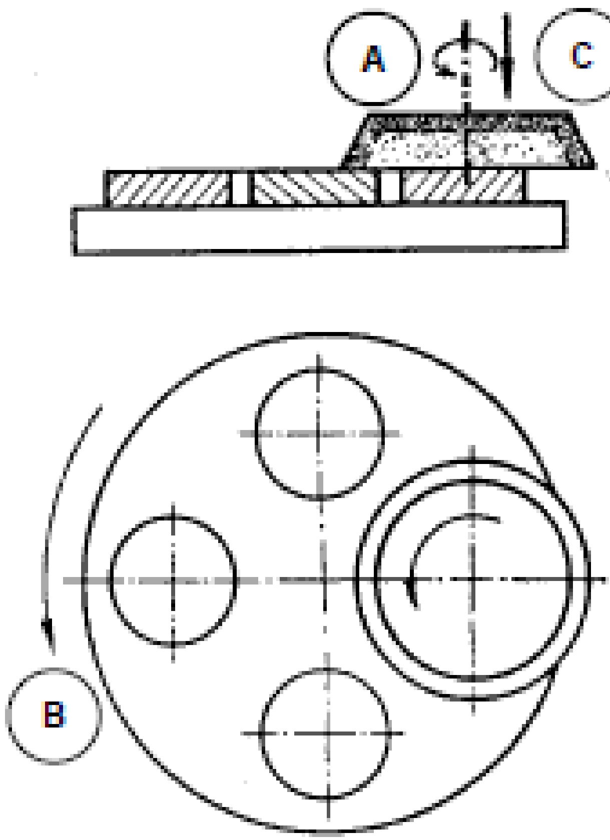


A: rotation of grinding wheel
B: table rotation
C: table reciprocation
D: down feed of grinding wheel
Θ: swivel angle

- **Working motions as in figure for grinding action**
  - **In principle the operation is same as that for facing on the lathe.**
  - **limitation in accommodation of workpiece hence less used.**
  - **However, by swiveling the worktable, concave or convex or tapered surface can be produced on individual part**

Grinding of a tapered surface in horizontal spindle rotary table surface grinder

Vertical spindle rotary table grinder



A: rotation of grinding wheel
B: work table rotation
C: down feed of grinding wheel

- **Working motions as in figure for grinding action**
- **suitable for small workpieces in large quantities.**
- **often uses two or more grinding heads thus enabling both roughing and finishing in one rotation of the work table.**

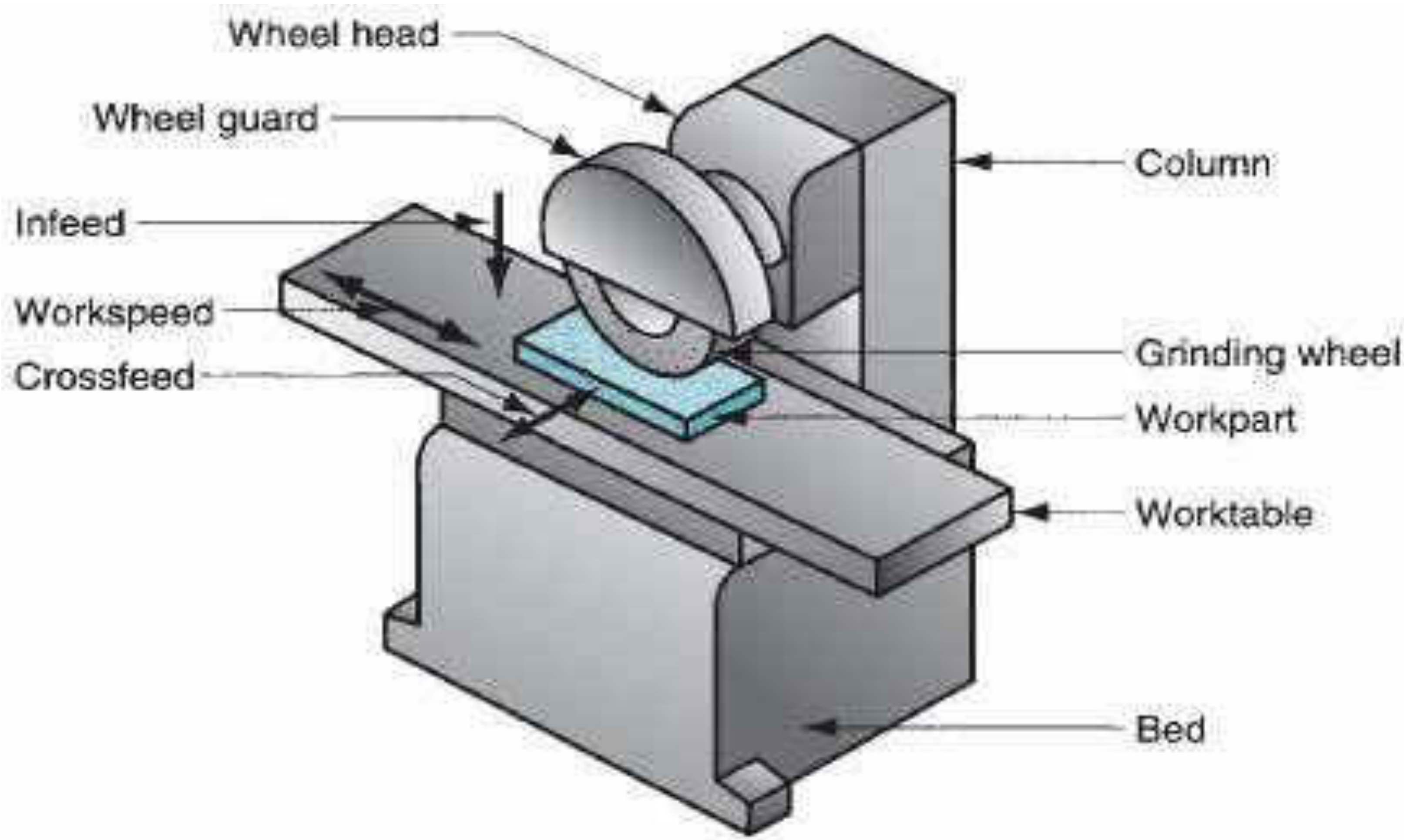

Horizontal spindle reciprocating table


Vertical spindle reciprocating table

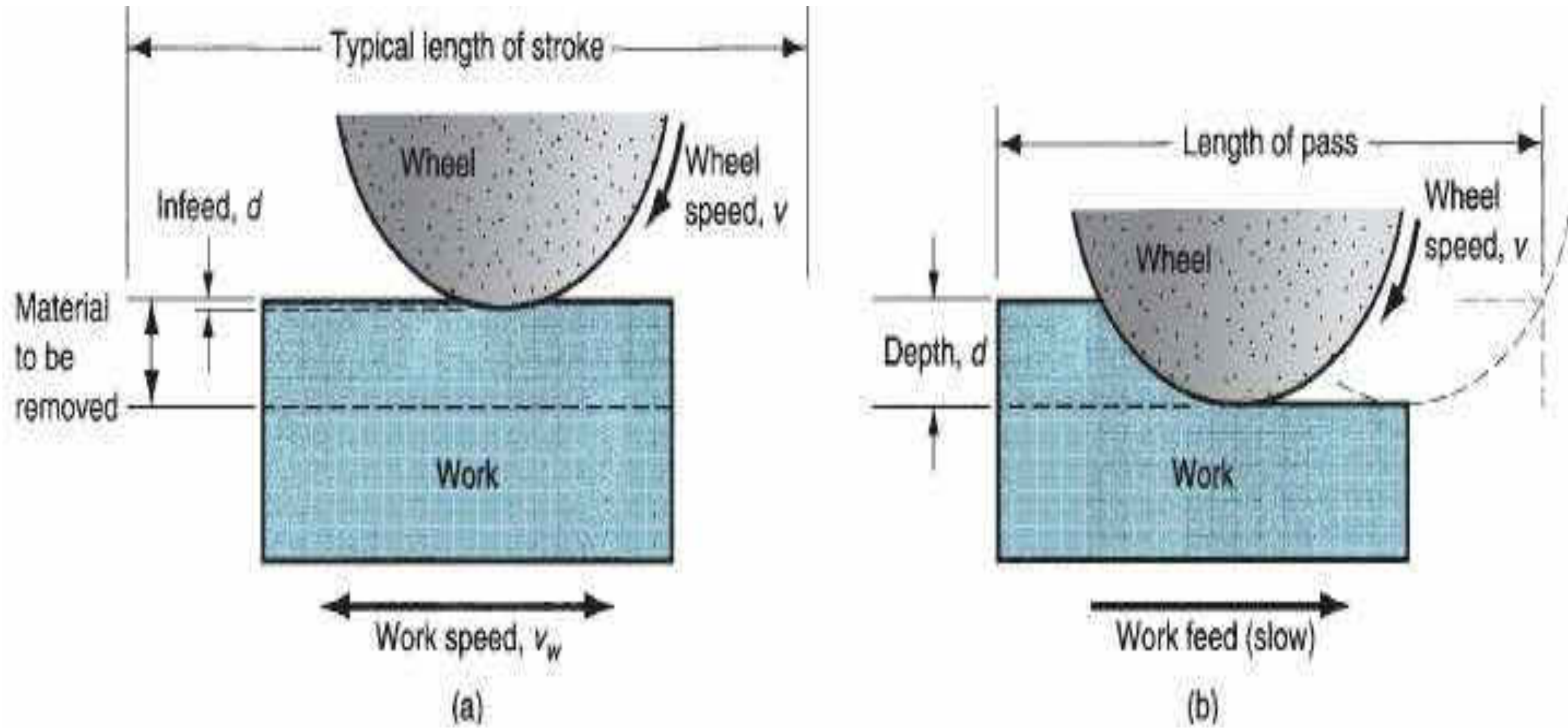

Horizontal spindle rotary table


Vertical spindle rotary table

Typical Surface Grinder



Creep Feed Grinding



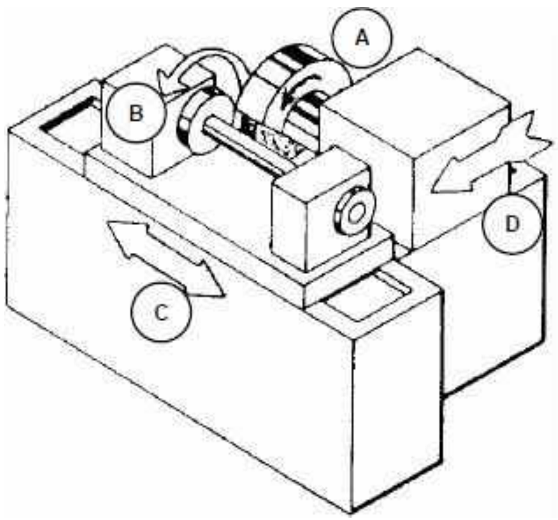
Comparison of (a) conventional surface grinding and (b) creep feed grinding.

Creep feed grinding is performed at very high depths of cut and very low feed rates; hence, the name creep feed. Single pass operation

Cylindrical Grinding (External Cylindrical Grinder)

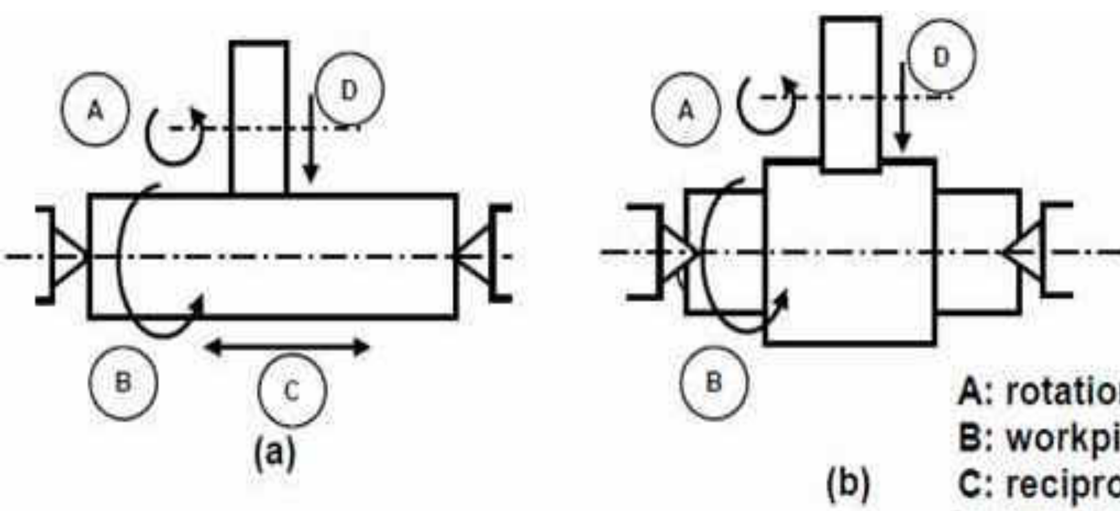
- This machine is used to produce external cylindrical surface.
- The surfaces may be straight, tapered, steps or profiled.
- Broadly there are three different types of cylindrical grinding machine as follows:
  - ✓ **Plain centre type cylindrical grinder**
  - ✓ **Universal cylindrical surface grinder**
  - ✓ **Centreless cylindrical surface grinder**

Plain centre type cylindrical grinder



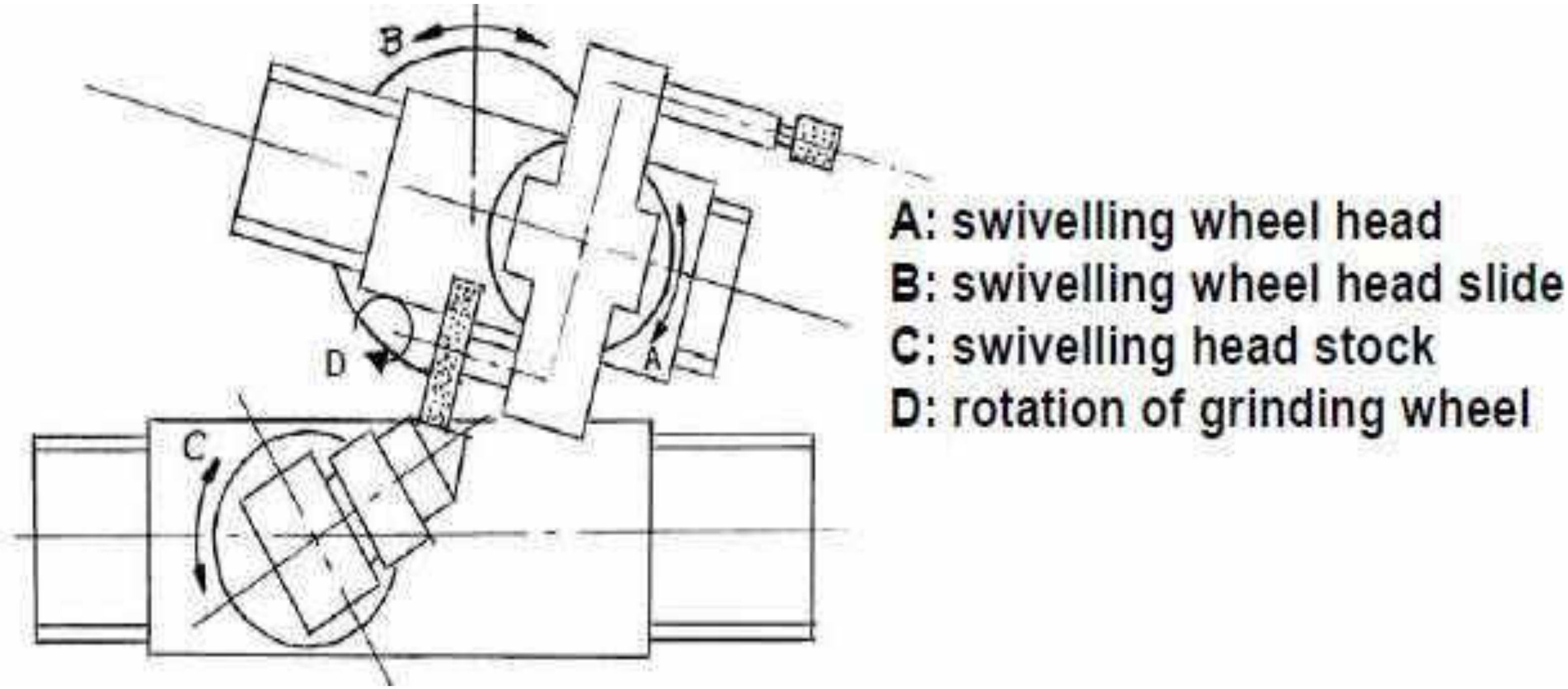
A: rotation of grinding wheel
B: work table rotation
C: reciprocation of worktable
D: infeed

- The machine is similar to a centre lathe in many respects.
- The workpiece is held between head stock and tailstock centers.
- A disc type grinding wheel performs the grinding action with its peripheral surface.
- Both traverse and plunge grinding can be carried out in this machine.



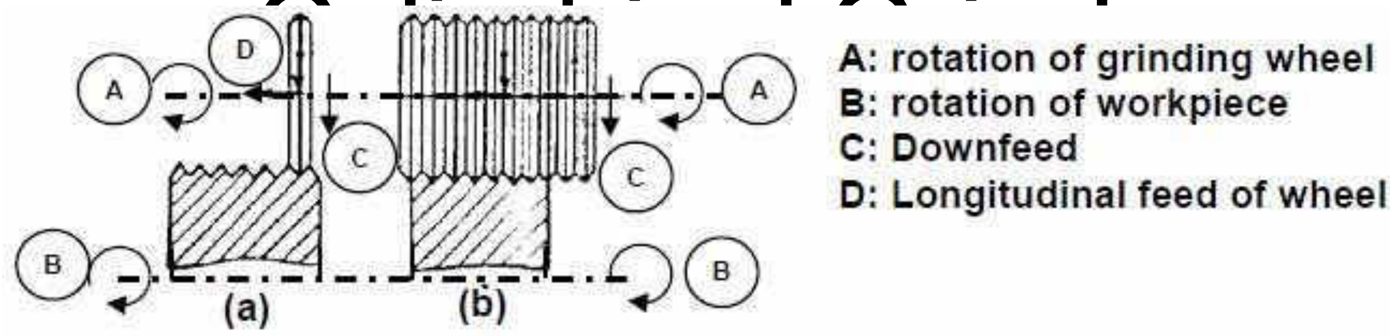
A: rotation of grinding wheel
B: workpiece rotation
C: reciprocation of worktable
D: infeed

Universal Cylindrical Surface Grinder

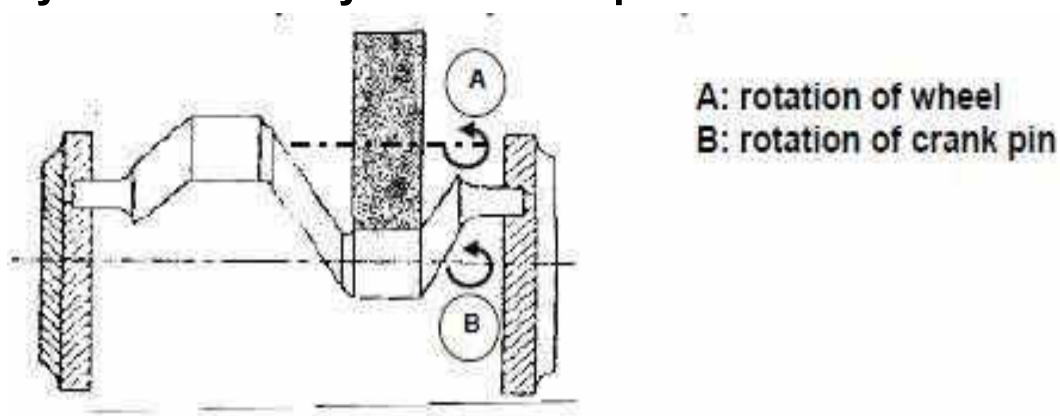


- Universal cylindrical grinder is similar to a plain cylindrical one except that it is more versatile.
- In addition to small worktable swivel, this machine provides large swivel of head stock, wheel head slide and wheel head mount on the wheel head slide.

Special Application of



- **Principle of cylindrical grinding is being used for thread grinding with specially formed wheel that matches the thread profile. A single ribbed wheel or a multi ribbed wheel can be used**
- **Roll grinding is a specific case of cylindrical grinding wherein large workpieces such as shafts, spindles and rolls are ground.**
- **Crankshaft or crank pin grinders also resemble cylindrical grinder but are engaged to grind crank pins which are eccentric from the centre line of the shaft. The eccentricity is obtained by the use of special chuck.**

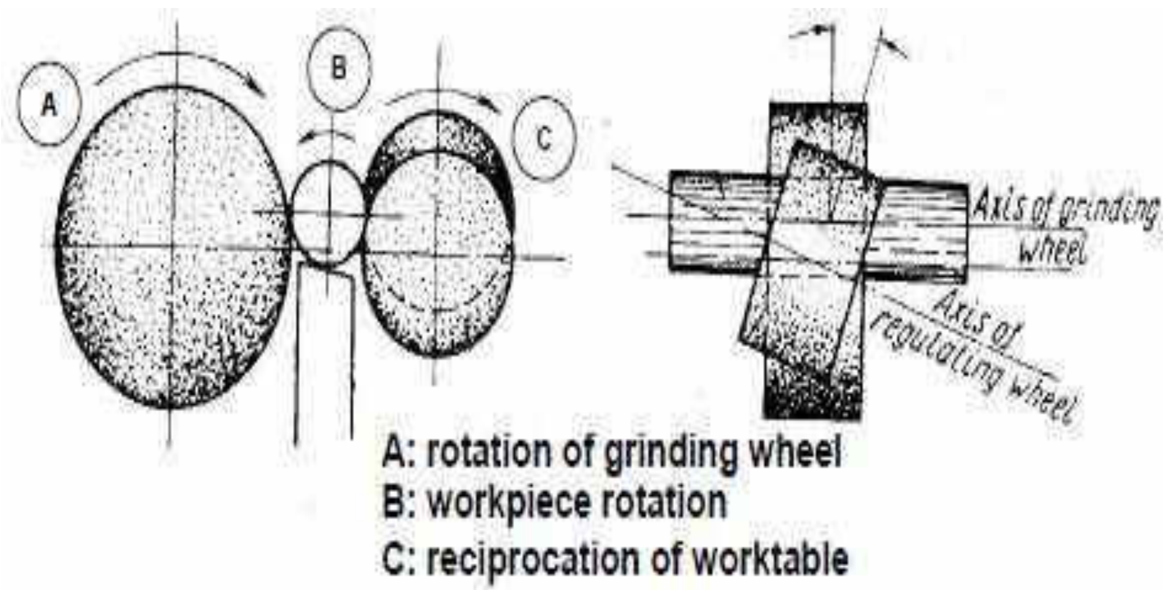


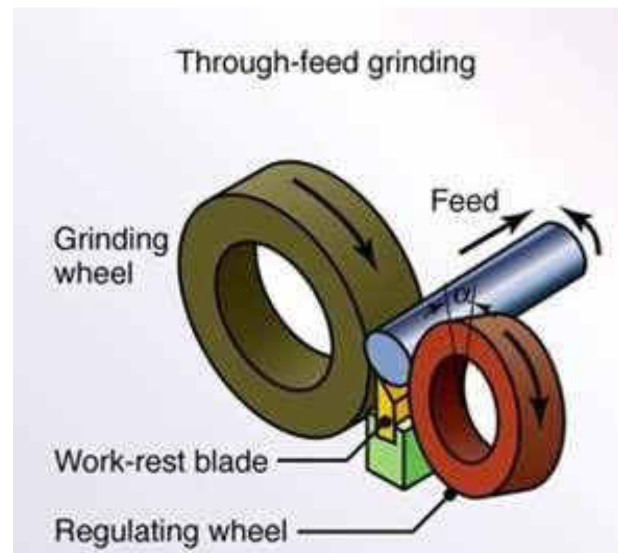
External Centreless Grinder

- A production machine in which outside diameter of the workpiece is ground.
- The workpiece is not held between centres but by a work support blade. This results in work handling time reduction; hence, used for high-production work.
- It is rotated by means of a regulating wheel and ground by the grinding wheel. Both wheels rotate in same directions
- The work parts which may be many individual short pieces or long rods (e.G., 3 to 4m long) are supported by a rest blade and fed through between the two wheels. The grinding wheel does the cutting, rotating at surface speeds of 1200 to 1800 m/min

Centreless through feed grinding

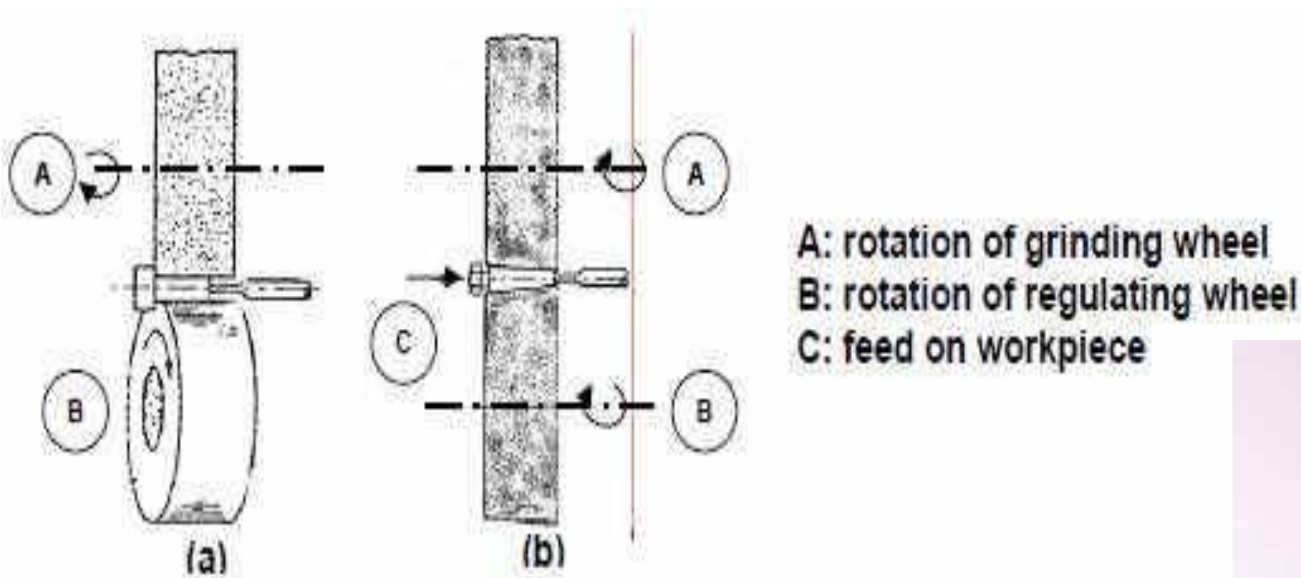
In through-feed centreless grinding, the regulating wheel revolving at a much lower surface speed than grinding wheel controls the rotation and longitudinal motion of the workpiece. The regulating wheel is kept slightly inclined to the axis of the grinding wheel and the workpiece is fed longitudinally

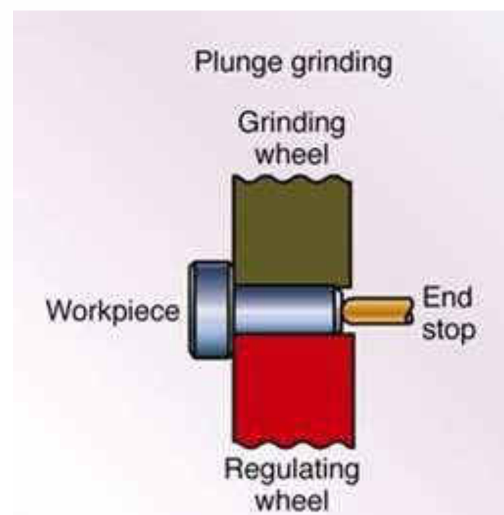




Centreless Infeed & End feed grinding

- Parts with variable diameter can be ground by Centreless in feed grinding. The operation is similar to plunge grinding with cylindrical grinder.
- End feed grinding is used for workpiece with tapered surface. The grinding wheel or the regulating wheel or both require to be correctly profiled to get the required taper on the workpiece.
-





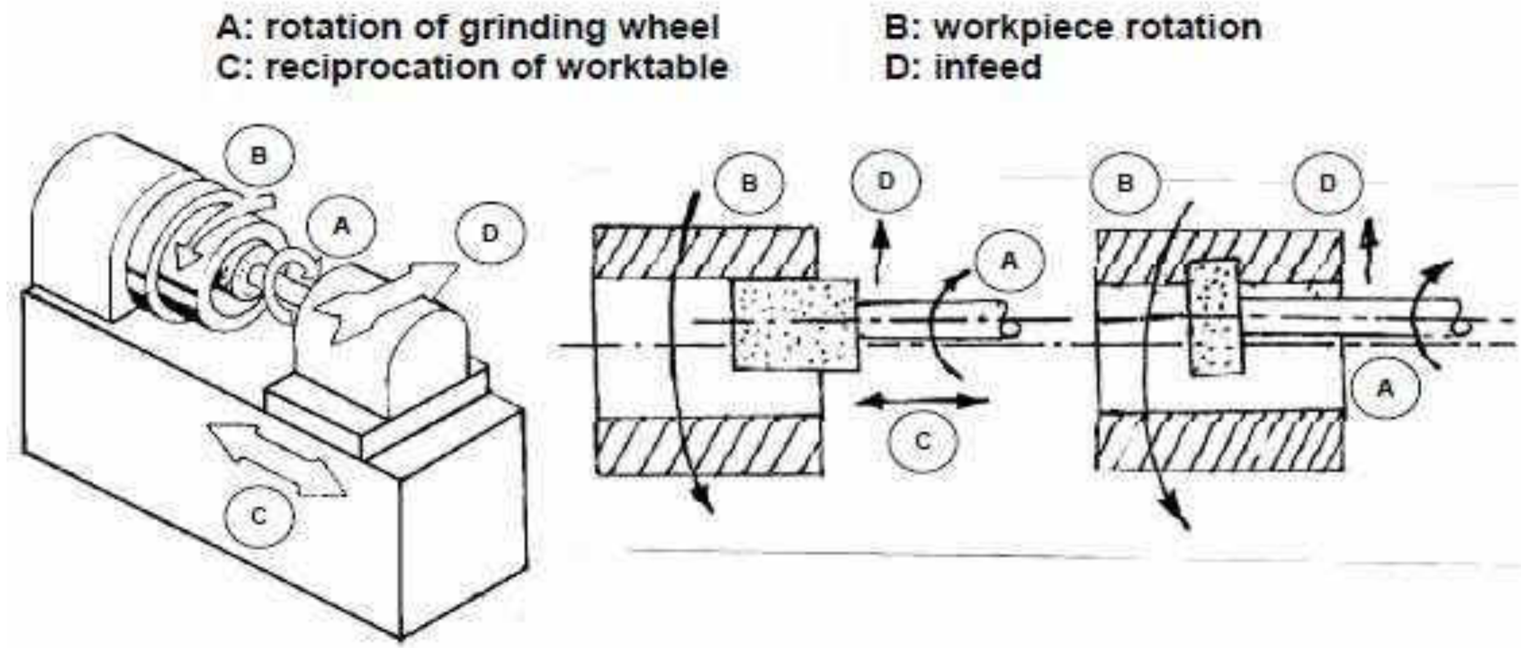
Tool Post Grinder

A self powered grinding wheel is mounted on the tool post or compound rest to provide the grinding action in a lathe. Rotation to the workpiece is provided by the lathe spindle. The lathe carriage is used to reciprocate the wheel head.

Internal Grinding Machine

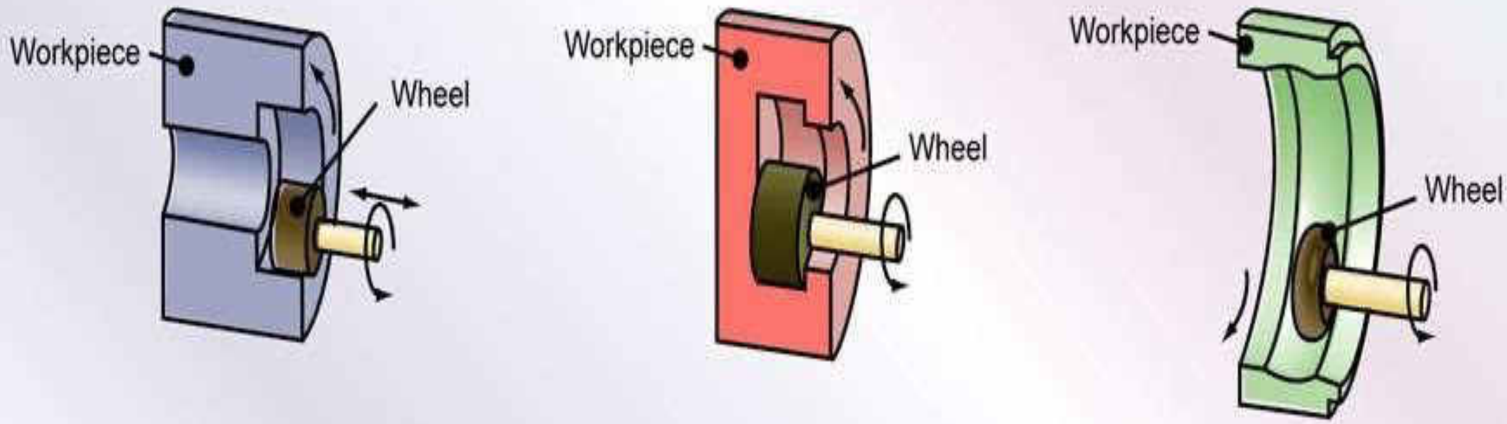
- Used to produce internal cylindrical surface.
- The surface may be straight, tapered, grooved or profiled.
- three different types
  1. **Chucking type internal grinder**
  2. **Planetary internal grinder**
  3. **Centreless internal grinder**

Chucking type internal grinder



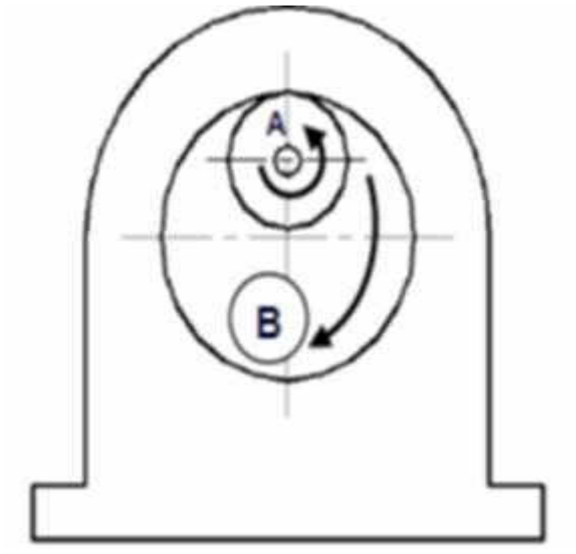
- various motions required for grinding action as per figure
- The workpiece is usually mounted in a chuck. A magnetic face plate can also be used.
- A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out

Chucking type internal grinder



(a) Traverse grinding (b) Plunge grinding (c) Profile grinding

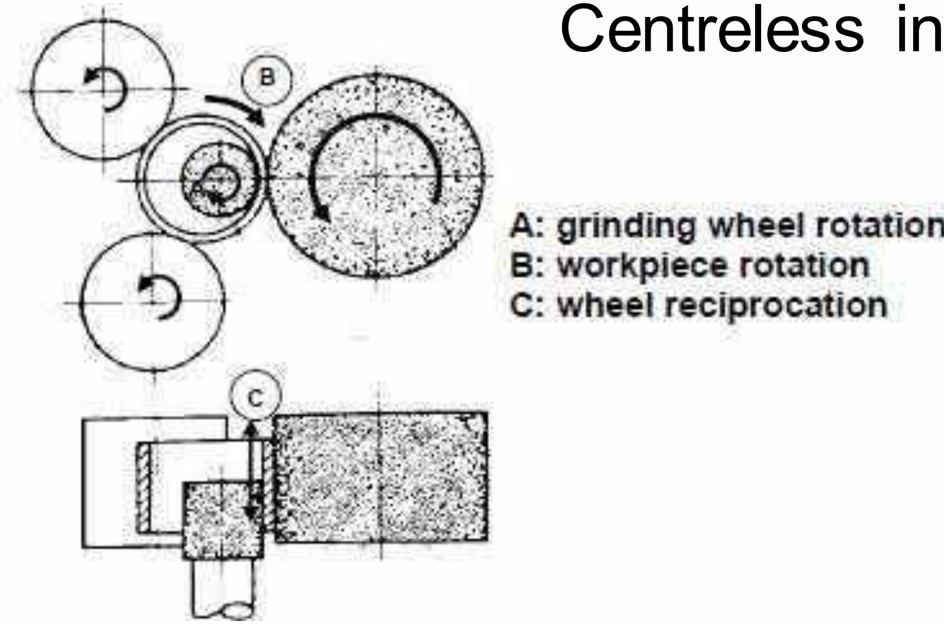
Planetary Internal grinder

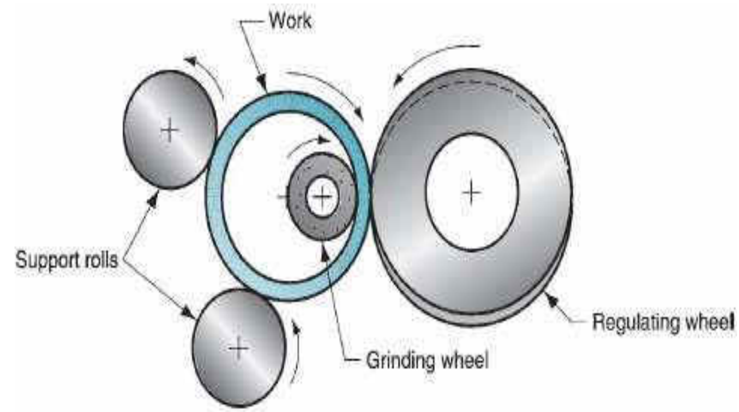


A: rotation of grinding wheel
B: orbiting motion of grinding

- Various motions required for grinding action as per figure
- Used where the workpiece is of irregular shape and cannot be rotated conveniently.
- Workpiece does not rotate. Instead, the grinding wheel orbits the axis of the hole in the workpiece.

Centreless internal grinder





- Various motions required for grinding action as per figure
- Used for grinding cylindrical and tapered holes in cylindrical parts (e.g. Cylindrical liners, various bushings etc.).
- The workpiece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel
- In place of the rest blade, two support rolls are used to maintain the position of the work.
- The regulating wheel is tilted at a small inclination angle to control the feed of the work past the grinding wheel.
- Because of the need to support the grinding wheel, throughfeed of the work as in external centerless grinding is not possible. Therefore this grinding operation cannot achieve the same high-production rates as in the external centerless process.
- Its advantage is that it is capable of providing very close concentricity between internal and external diameters on a tubular part such as a roller bearing race

Tool & Cutter Grinder Machine

- Tool grinding may be divided into two subgroups: tool manufacturing and tool resharpening.
- There are many types of tool and cutter grinding machine to meet these requirements.
- Simple single point tools are occasionally sharpened by hand on bench or pedestal grinder.
- However, tools and cutters with complex geometry like milling cutter, drills, reamers and hobs require sophisticated grinding machine commonly known as universal tool and cutter grinder.
- Present trend is to use tool and cutter grinder equipped with CNC to grind tool angles, concentricity, cutting edges and dimensional size with high precision.

Other Grinding Operations & Machine

- **Tool grinding**
- **Jig grinding**
- **Disk grinding**
- **Snag grinding**
- **Abrasive belt grinding**

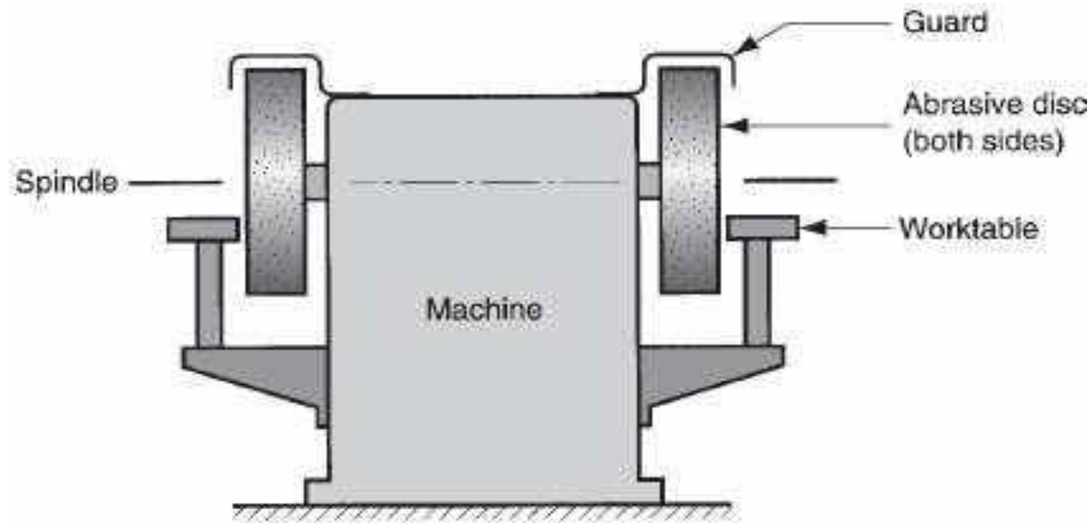
Tool Grinding

- Cutting tools are made of hardened tool steel and other hard materials.
- Tool grinders are special grinding machines of various designs to sharpen and recondition cutting tools.
- They have devices for positioning and orienting the tools to grind the desired surfaces at specified angles and radii.
- Some tool grinders are general purpose while others cut the unique geometries of specific tool types.
- General-purpose tool and cutter grinders use special attachments and adjustments to accommodate a variety of tool geometries.
- Single-purpose tool grinders include gear cutter sharpeners, milling cutter grinders of various types, broach sharpeners, and drill point grinders.

Jig Grinders

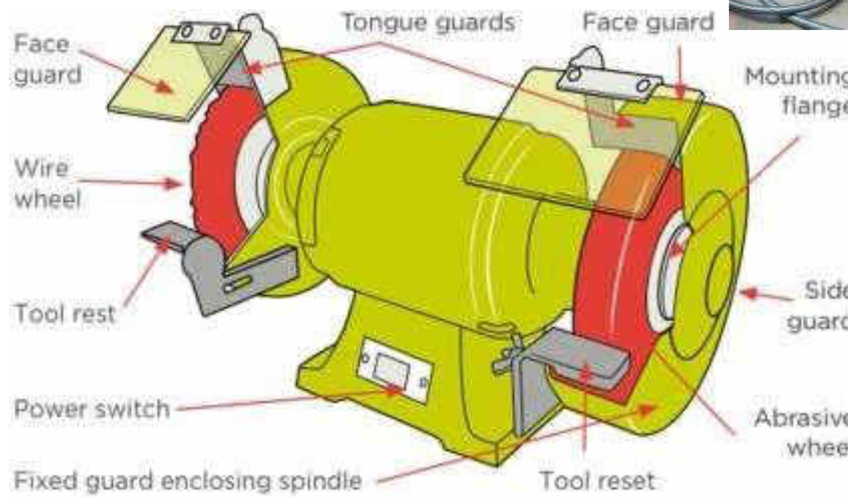
- traditionally used to grind holes in hardened steel parts to high accuracies.
- The original applications included press working dies and tools.
- today used where high accuracy and good finish are required on hardened components.
- Numerical control is available on modern jig grinders to achieve automated operation.

Disk Grinders



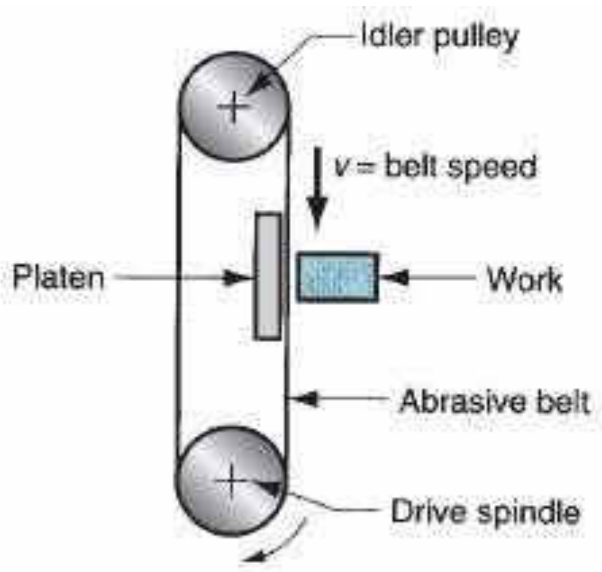
- Grinding machines with large abrasive disks mounted on either end of a horizontal spindle.
- **Single disk:** the work is held (usually manually) against the flat surface of the wheel to accomplish the grinding operation.
- **Double disk:** have double opposing spindles. By setting the disks at the desired separation, the workpart can be fed automatically between the two disks and ground simultaneously on opposite sides.
- **Advantages** good flatness and parallelism at high production rates.

Snag Grinders



- Similar in configuration to a disk grinder. Both single disc & double disc available
- Grinding is done on the outside periphery of the wheel rather than on the side flat surface.
- Different in design than those in disk grinding.
- Generally a manual operation, used for rough grinding operations such as removing the flash from castings and forgings, and smoothing weld joints.

Abrasive Belt Grinders



- Uses abrasive particles bonded to a flexible (cloth) belt.
- Support of the belt is required when the work is pressed against it, and this support is provided by a roll or platen located behind the belt. A flat platen is used for work that will have a flat surface. A soft platen can be used if it is desirable for the abrasive belt to conform to the general contour of the part during grinding.
- Belt speed depends on the material being ground; a range of 750 to 1700 m/min is typical .
- Owing to improvements in abrasives and bonding materials, abrasive belt grinding is being used increasingly for heavy stock removal rates, rather than light grinding, which was its traditional application.
- The term belt sanding refers to the light grinding applications in which the workpart is pressed against the belt to remove burrs and high spots, and produce an improved finish quickly by hand.

Related Abrasive Processes & Surface Finishing Processes in Grinding

Related Abrasive Surface Finishing Processes

- **Honing**
- **Lapping**
- **Superfinishing**
- **Polishing**
- **Buffing**

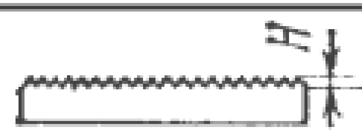
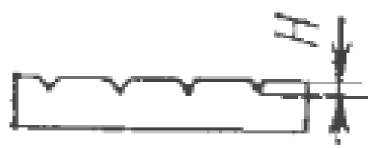
Introduction

- To ensure reliable performance and prolonged service life of modern machinery, its components require to be manufactured not only with *high dimensional and geometrical accuracy* but also with *high surface finish.*
- The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction.

  •Unfortunately, normal machining methods like turning, milling or even classical grinding cannot meet this stringent requirement.

  •Therefore, super finishing processes like lapping, honing, polishing, burnishing are being employed to achieve and improve the above-mentioned functional properties in the machine component

Introduction

Process	Diagram of resulting surface	Height of micro irregularity (μm)
Precision Turning		1.25-12.50
Grinding		0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super Finishing		0.01-0.25

gradual improvement of surface roughness produced by various processes ranging from precision turning to super finishing including lapping and honing

Finishing Operations Short Overview

Coated abrasives
have a more pointed and open structure than grinding wheels

Belt Grinding
high rate of material removal with good surface finish

Wire Brushing
produces a fine or controlled texture

Honing
improves surface after boring, drilling, or internal grinding

Superfinishing
very light pressure in a different path to the piece

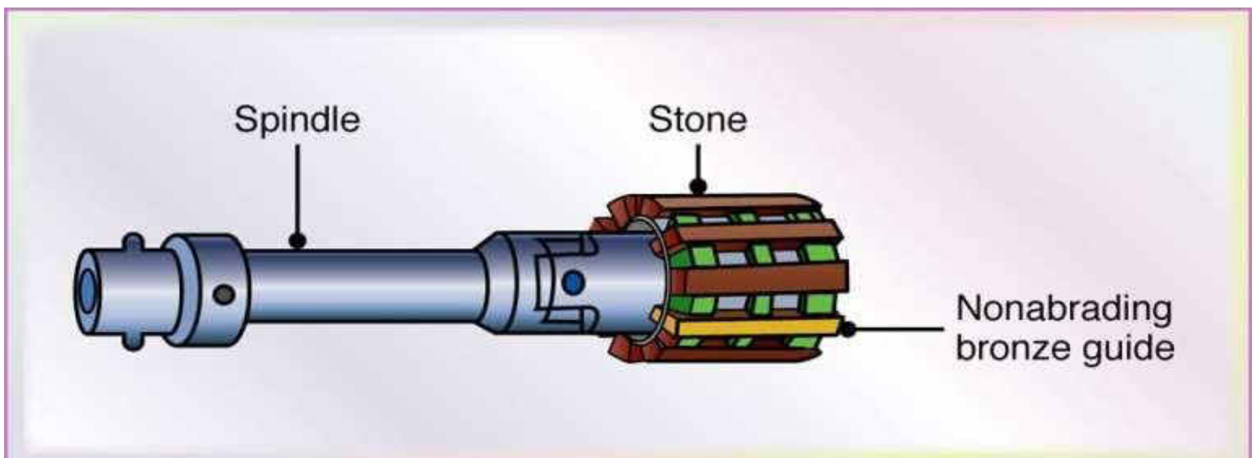
Lapping
abrasive or slurry wears the piece's ridges down softly

Chemical-Mechanical Polishing
slurry of abrasive particles and a controlled chemical corrosive

Electroplating
an unidirectional pattern by removing metal from the surface

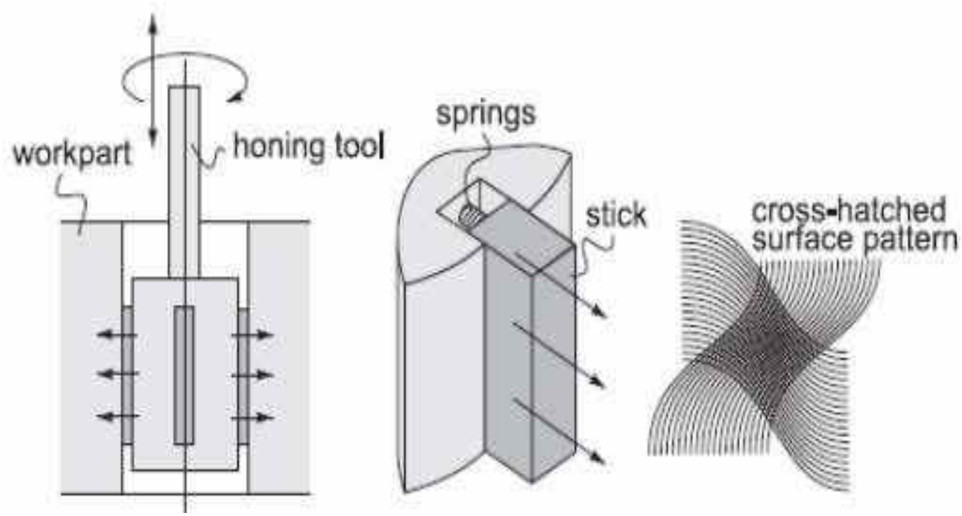
Honing

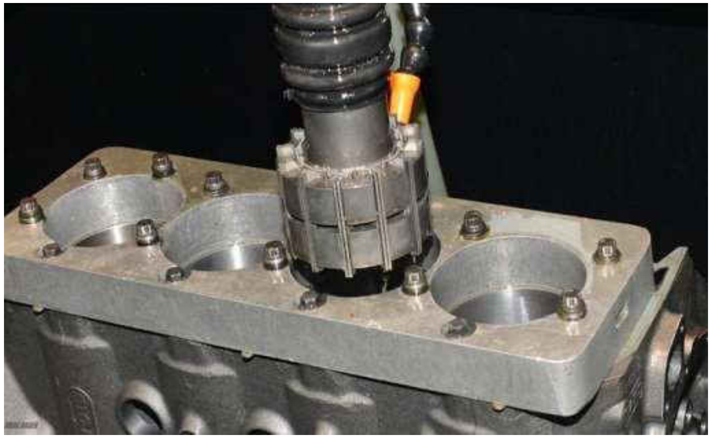
- finishing process for internal cylindrical surfaces in which a tool called hone carries out a combined rotary and reciprocating motion while workpiece is stationary.
- Main purpose to remove scratches after grinding
- Hone uses a cylindrical mandrel dressed with bonded abrasive sticks of aluminium oxide, silicon carbide, diamond etc.



Honing

- The number of sticks depends on size of hole. Two to four sticks for small holes (e.g., gun barrels), and a dozen or more for larger diameter holes.
- The honing stones are held against the workpiece with controlled light pressure. The honing head is guided by the work surface .
- Honing stones should not leave the work surface & Stroke length must cover the entire work length.





Honing

- During the process, the sticks are pressed outward against the hole surface to produce the desired abrasive cutting action.
- The honing tool is supported in the hole by two universal joints, thus causing the tool to follow the previously defined hole axis. Honing enlarges and finishes the hole but cannot change its location.
- Combined rotary and reciprocating motion is complex and produce crosshatched pattern beneficial for retaining lubrication
- Surface finish of around 0.12 mm or slightly better are typically achieved
- Honing speeds are 15 to 150 m/min. The amount of material removed from the work surface during a honing operation may be as much as 0.5 mm, but is usually much less than this.
- A cutting fluid must be used in honing to cool and lubricate the tool and to help remove the chips.

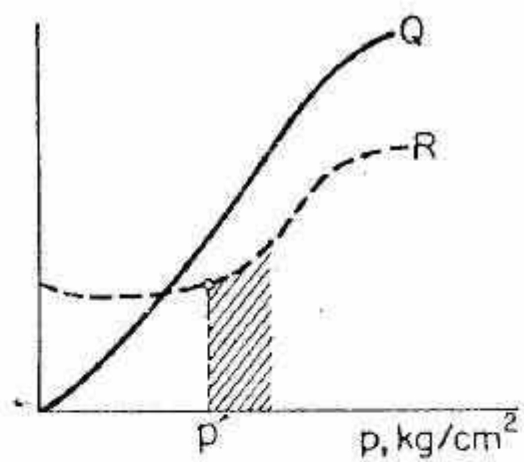
Honing

- Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. Other applications include bearings, hydraulic cylinders, and gun barrels.
  - The critical process parameters are:
    - ✓Rotation speed
    - ✓Oscillation speed
    - ✓Length and position of the stroke
    - ✓Honing stick pressure
- Diamond and carbon boron nitrite grits are used for complete the operation in just one stroke rather than several strokes needed in conventional honing stick.

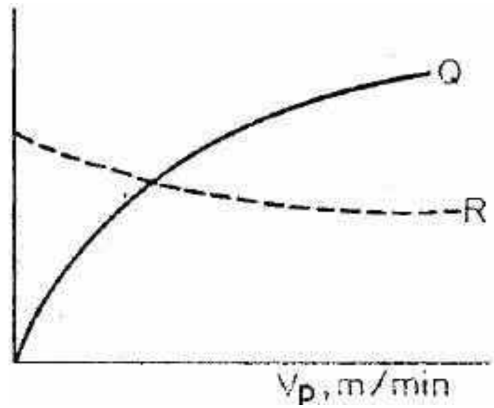
Honing

- **Parameters affecting MRR (Q) and surface roughness (R)**
- The important parameters that affect material removalrate (MRR) and surface roughness (R) are:
  - ✓ **Unit pressure, p**
  - ✓ **Peripheral honing speed, V_p**
  - ✓ **Honing time, T**

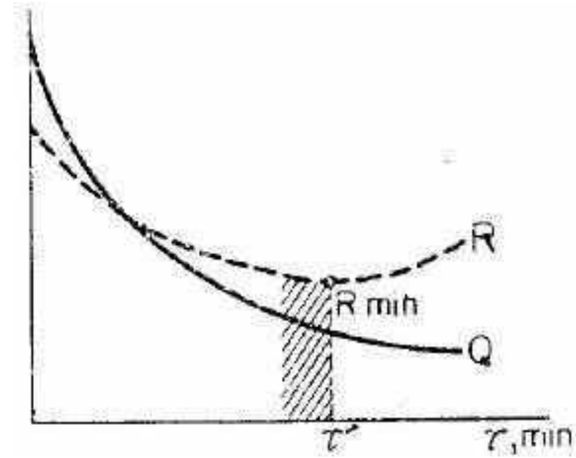
Honing



Effect of honing pressure on MRR and surface finish



Effect of peripheral honing speed



Effect of honing time on material removal rate and surface roughness

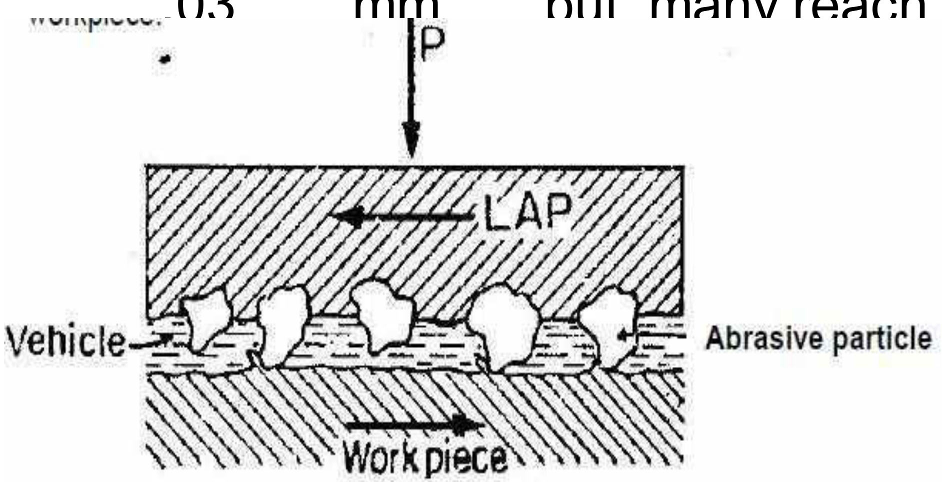
unit pressure should be selected so as to get minimum surface roughness with highest possible MRR.

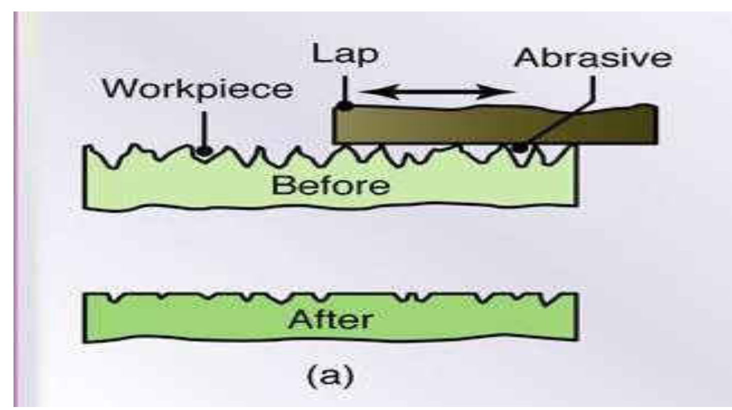
an increase of peripheral honing speed leads to enhancement of material removal rate and decrease in surface roughness.

With honing time T, MRR decreases. On the other hand, surface roughness decreases and after attaining a minimum value again rises. The selection of honing time depends very much on the permissible surface roughness.

Lapping

- The oldest method of obtaining a fine finish.
- An abrasive process in which loose abrasives function as cutting points finding momentary support from the laps.
- A processwhere two surfaces are rubbed against each other with
abrasive particles in between them
- Material removalin lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1 mm in certain cases.





Scheme of lapping Process

Lapping

- **Characteristics of lapping process:**
- Use of loose abrasive between lap and the workpiece
- Usually lap and workpiece are not positively driven but are guided in contact with each other
- Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the workpiece.

•**Materials used:**

•Cast iron is the mostly used lap material.

•However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

Vehicle materials for lapping

•Machine oil
•Rape oil
•Grease

Abrasives of lapping:

•Al_2O_3 and SiC, grain size 5~100 μm
•Cr_2O_3, grain size 1~2 μm
•B_4C_3, grain size 5-60 μm
•Diamond, grain size 0.5~5 V

Technical parameters affecting lapping processes are:

•Unit pressure
•The grain size of abrasive
•Concentration of abrasive in the vehicle
•lapping speed

Lapping

Types:

Hand Lapping: Hand lapping is done manually with abrasive powder as lapping medium

Machine Lapping: Machine lapping is done either with abrasive powder or with bonded abrasive wheel.

Flat Lapping by hand

•by rubbing the component over accurately finished flat lap usually made of a thick soft close-grained cast iron bl

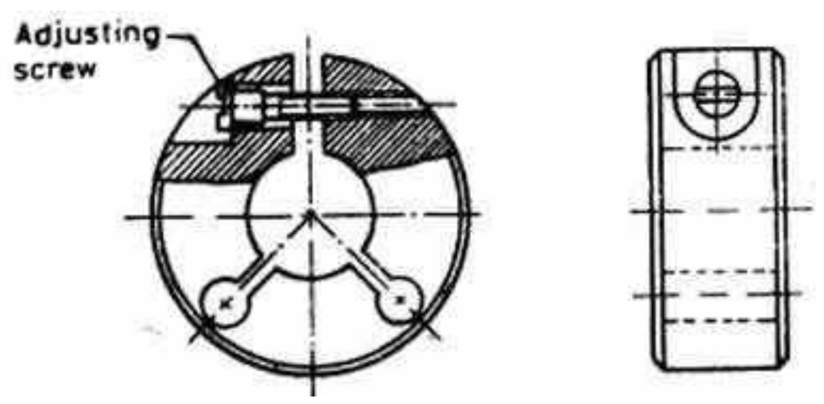
•Lapping compound is spread on CI plate and moved r like emglish letter 8.

•abrading action is accomplished by very fine abrasive powder held in a vehicle.

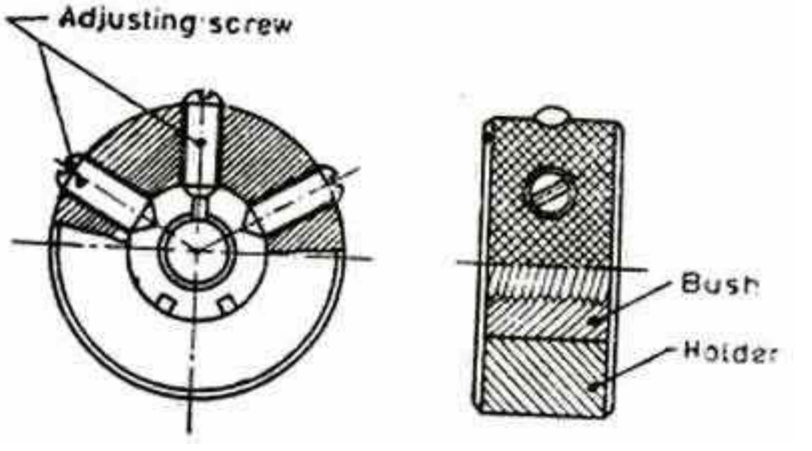
•Manual lapping requires high personal skill because the e and speed have to be controlled manually.

Ring Lapping

- Laps in the form of ring made of closed grain cast iron are used for manual lapping of external cylindrical surface.
- Workpiece held in lathe chuck and rotated. Ring lap is reciprocated over workpiece. Lap should be short than workpiece and should have adjustable slots
- Bore of ring lap and work size are very close and can be adjusted by screws.
- Ring lapping is recommended for finishing plug gauges and machine spindles requiring great roundness accuracy.
- For External threads lapping , Special laps having interchangeable threaded bush corresponding to the external thread to be lapped , with provision for precise adjustment are used.



Lapping external cylindrical surface



External threads lapping

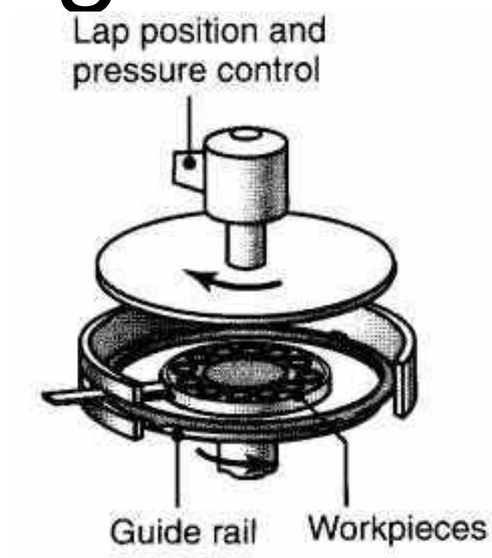
Machine Lapping

- In this method a rotating table is used in place of the plate.
- Again the work piece to be lapped is given rotary by a cage and rotated on the surface of the table. Rotating lap is used above & below the work piece to produce parallel surfaces
- Used for economic lapping with high accuracy of batch qualities.

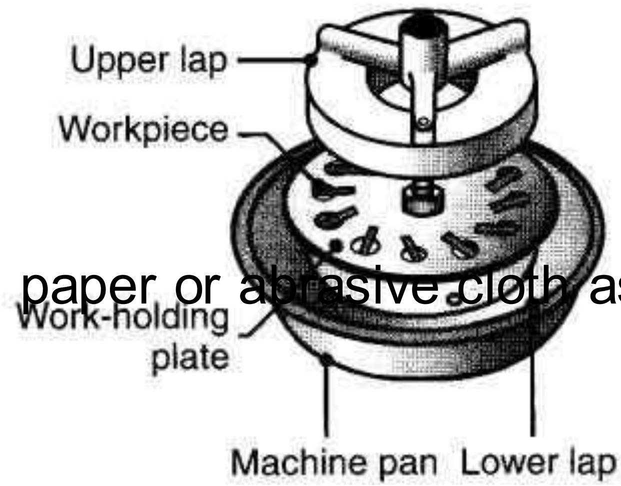
▪ Metal laps and abrasive powder held in suitable vehicles are used.

▪ Bonded abrasives in the form wheel are chosen for commercial lapping.

▪ Machine lapping can also employ abrasive paper or abrasive cloth as the lapping medium.



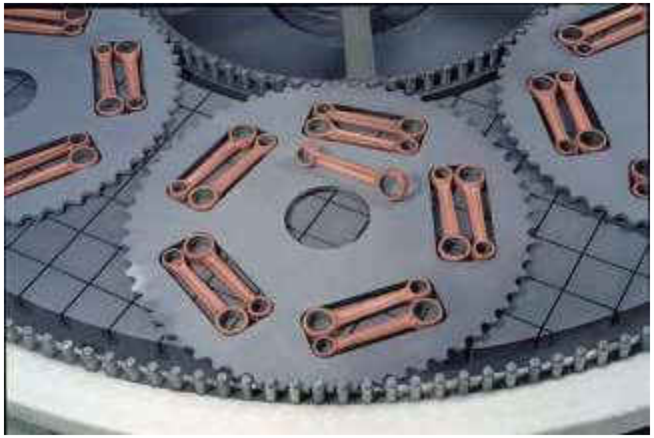
Production lapping of flat surfaces



Production lapping of cylindrical surfaces

Machine Lapping

- **Conditioning Rings or Retaining Rings**
- to prevent the components from being thrown off the plate from the action of centrifugal force.
- to evenly spread and maintain a thin film layer of slurry that contributes to process consistency by maximizing the transfer of cutting energy.
- to continuously machine (condition) the surface of the lap plate to eliminate wear caused by the abrasive action of the components and to maintain the flatness of the components by adjusting the concave or convex curvature movement of the lap plate.



Lapping Advantages

- Reduction of peaks and valleys results in **maximum bearing area**
- between mating surfaces - This ensures tight seating of seals
- Improves **service life** of the moving parts which are subject to wear
- Improves **geometrical & dimensional** accuracies
- Absolutely **no distortion** in the component after lapping since no clamping devices are used
- The lapping process **generates minimal heat** so hardened parts will not have to be hardened again
- Accessible flat surfaces of parts of **any shape & size** and **any type of material** can be lapped

Typical Applications & Industries that Make Use

ng

Valve Manufacturers

Automotive industries

Pump Manufacturers

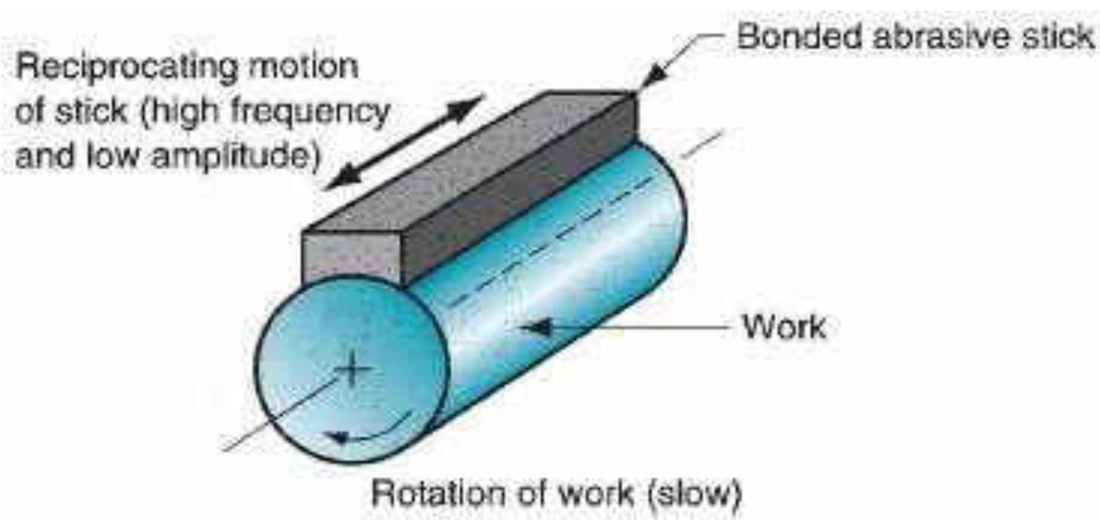
Air Compressor Industries

Electronic Industries

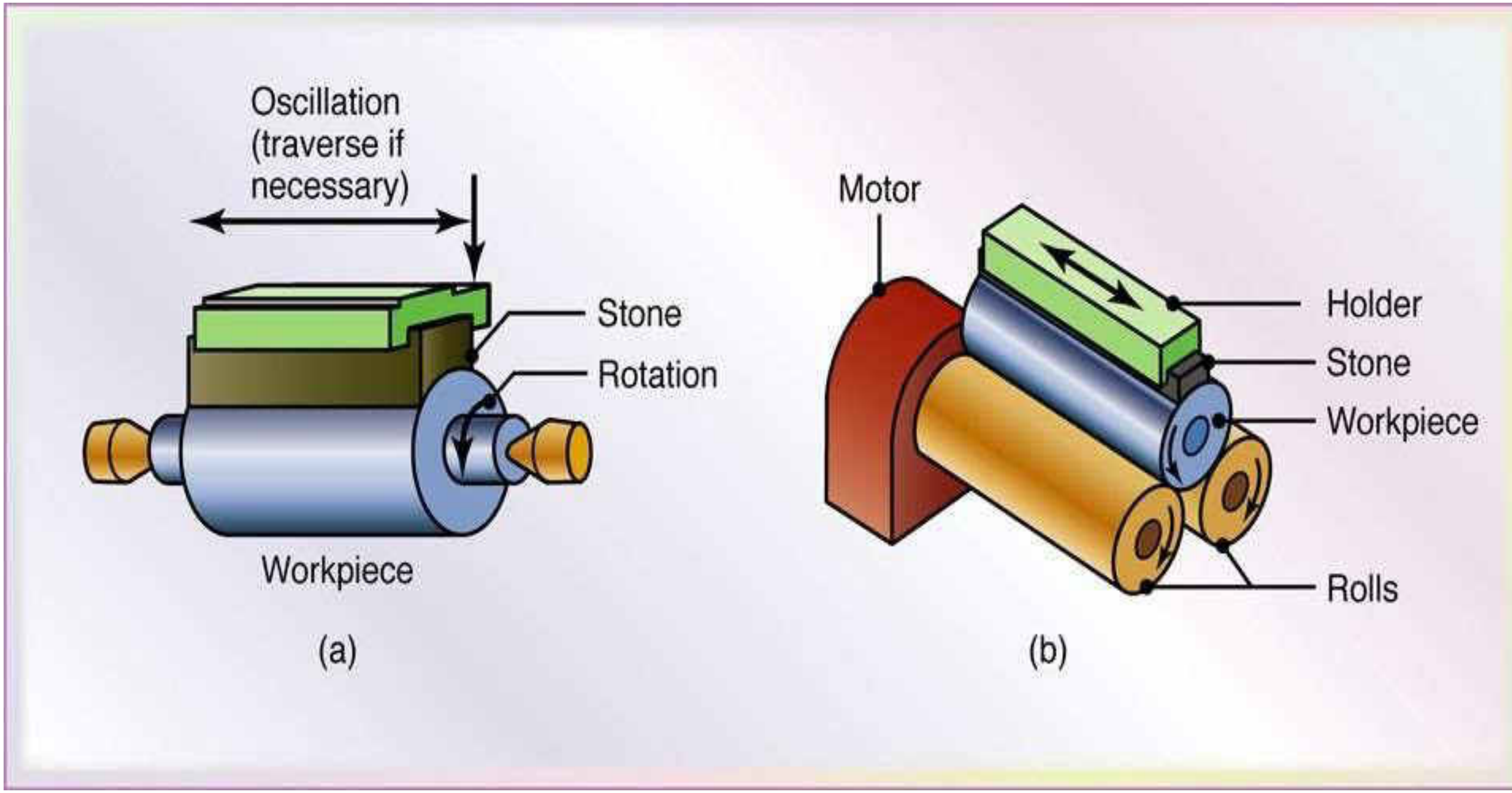
What can be lapped?

Superfinishing

- Similar to honing, but uses a single abrasive stick.
- The reciprocating motion of the stick is performed at higher frequency and smaller amplitudes.
- Also, the grit size and pressures applied on the abrasive stick are smaller.
- A cutting fluid is used to cool the work surface and wash away chips.
- Cutting action terminates by itself when a lubricant film is built up between the tool and work surface. Thus, superfinishing is capable only of improving the surface finish but not dimensional accuracy.
- Mirror like finishes with surface roughness values around 0.01 μm.
- Superfinishing can be used to finish flat and external cylindrical surfaces.

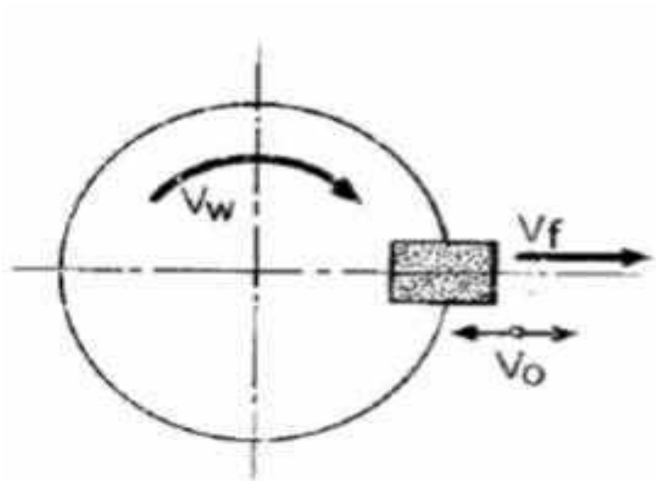


Superfinishing

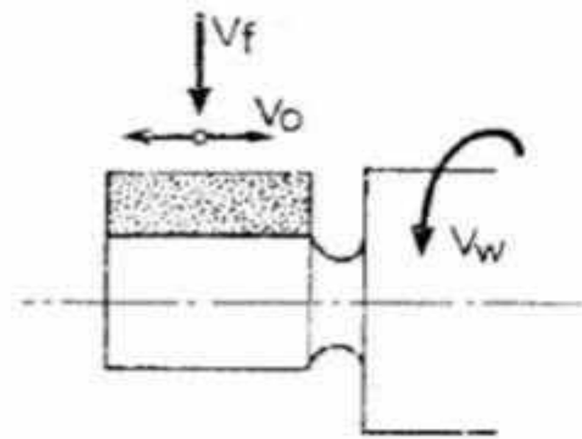


Schematic illustration of the superfinishing process for a cylindrical part. (a) Cylindrical microhoning (b) Centerless microhoning

Radial & Plunge Mode in Superfinishing



superfinishing of end face of a cylindrical work piece in radial mode



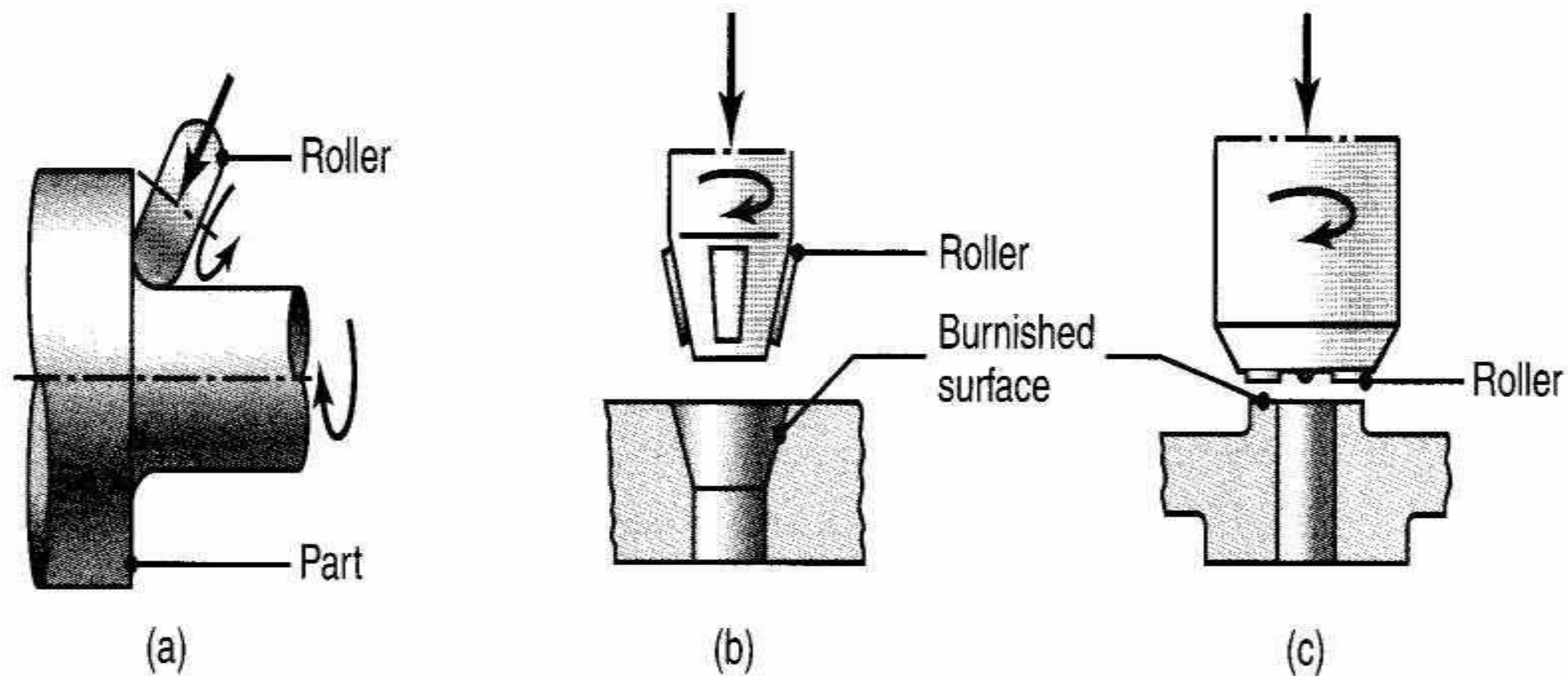
superfinishing operation in plunge mode

In **Radial Mode** both feeding and oscillation of the superfinishing stone is given in the radial direction.

In **Plunge Mode** the abrasive stone covers the section of the workpiece requiring super finish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction

Burnishing

- In this process, also called surface rolling, the surface of the component is cold worked by a hard and highly polished roller or set of rollers. The process is used on various flat, cylindrical, or conical surfaces



Burnishing tools and roller burnishing of (a) the fillet of a stepped shaft to induce compressive surface residual stresses for improved fatigue life; (b) a conical surface; and (c) a flat surface.

Burnishing

- **Roller burnishing** improves surface finish by removing scratches, tool marks, and pits and induces beneficial compressive surface residual stresses. Consequently, corrosion resistance is improved, since corrosive products and residues cannot be entrapped.
- **Low-plasticity burnishing:** the roller travels only once over the surface, inducing residual stresses and minimal plastic deformation.
- **Ball burnishing:**
- Internal cylindrical surfaces are burnished by ballizing or ball burnishing.
- In this process, a smooth ball (slightly larger than the bore diameter) is pushed through the length of the hole.
- The burnishing process consists of pressing hardened steel rolls or balls into the surface of the workpiece and imparting a feed motion to the same.

Burnishing

Use & Advantages

•Considerable residual compressive stress is induced in the surface of the workpiece and thereby fatigue strength and wear resistance of the surface layer increase.

•to improve the mechanical properties of surfaces as well as their surface finish.

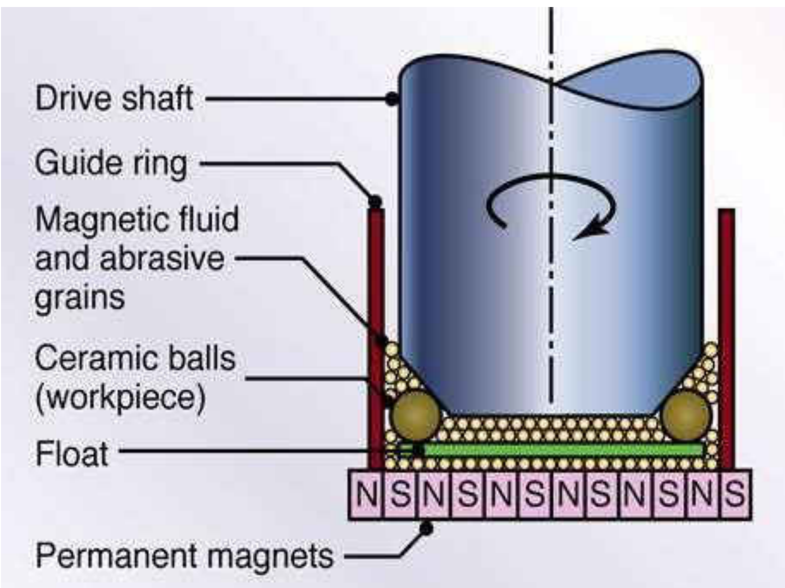
•It can be used either by itself or in combination with other finishing processes, such as grinding, honing, and lapping.

•The equipment can be mounted on various CNC machine tools for improved productivity and consistency of performance.

•All types of metals (soft or hard) can be roller burnished.

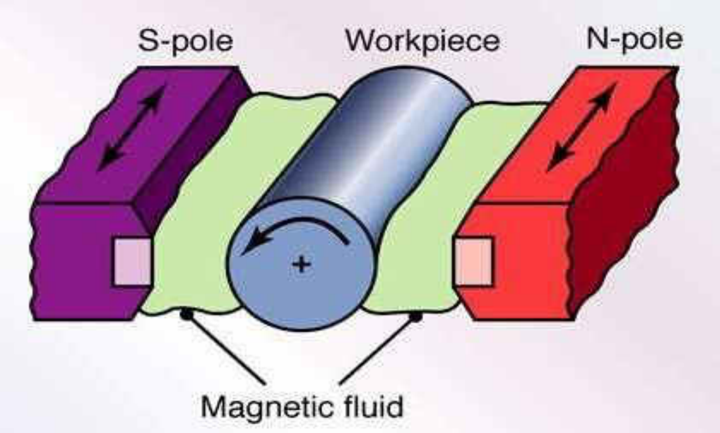
•Roller burnishing is typically used on hydraulic-system components, seals, valves, spindles, and fillets on shafts.

Magnetic Float Polishing



- Used for precision polishing of ceramic balls.
- A magnetic fluid is used for this purpose. The fluid is composed of water or kerosene carrying fine ferro-magnetic particles along with the abrasive grains.
- Ceramic balls are confined between a rotating shaft and a floating platform.
- Abrasive grains ceramic ball and the floating platform can remain in suspension under the action of magnetic force.
- The balls are pressed against the rotating shaft by the float and are polished by their abrasive action.
- Fine polishing action can be made possible through precise control of the force exerted by the abrasive particles on the ceramic ball.

Magnetic Float Polishing

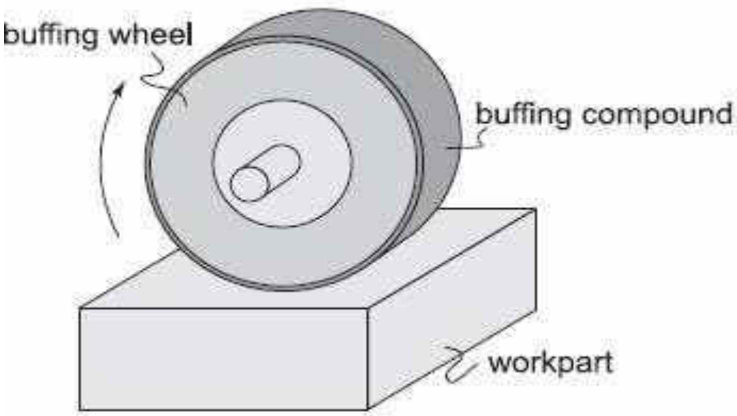


- Magnetic field assisted polishing is particularly suitable for polishing of steel or ceramic roller.
- A ceramic or a steel roller is mounted on a rotating spindle.
- Magnetic poles are subjected to oscillation, thereby, introducing a vibratory motion to the magnetic fluid containing these magnetic and abrasive particles.
- This action causes polishing of the cylindrical roller surface.
- In this technique, the material removal rate increases with the field strength, rotational speed of the shaft and mesh number of the abrasive.
- But the surface finish decreases with the increase of material removal rate.

Electropolishing

- Electropolishing is the reverse of electroplating.
- Here, the workpiece acts as anode and the material is removed from the workpiece by electrochemical dissolution.
- The process is particularly suitable for polishing irregular surface since there is no mechanical contact between workpiece and polishing medium.
- The electrolyte electrochemically etches projections on the workpiece surface at a faster rate than the rest, thus producing a smooth surface.
- This process is also suitable for deburring operation.

Buffing



Schematics of the buffing operation.

- Buffing is a surface finishing process, which is performed after polishing for providing a high bright lusture finish to the polished surface of metal & composites.
- Buffing is a rotating cloth wheel that is impregnated with liquid rouge or a greaseless compound-based matrix of specialized fine abrasive called compound. Mostly buffing wheel is made by linen, cotton, broad cloth and canvass. This wheel made by multiple layers of these cloths overlapped on each other
- The compound is sprayed or pressured into the rotating buffing wheel. The buff wheel acts as the carrier of the compound, which ultimately does the surface finishing.

Buffing

Difference between Buffing & Polishing

•Finishing processes that utilize abrasive belts are referred to as polishing, and processes that use cloth wheels with compound applied is buffing.

•Polishing generates a brushed or lined finish, where buffing removes the lines and creates a bright luster finish.

Requirements before buffing

•Surface refinement polishing prior to buffing.

•First Polishing by abrasive belts or discs is done by fine abrasives to level surfaces, remove scratches, pits, scale and polish the surface enough so the cut buff can remove the polishing lines.

•Each finer polishing step should be cross-polished 90 degrees from the previous polishing process. A 320 - 400 grit polishing line is generally the coarsest surface preparation that a cut buff process can efficiently remove.

Buffing

Stages after polishing:

•**Cut Buff:** Cut buff is the course buff process. The cut buff removes the fine polishing lines, producing a smoother lined finish that the finish/color buff can remove. The cut buff is the more difficult buff process and requires more time, effort and pressure, causing increased operator fatigue.

•**Finish Color buff:** Finish/color buff is the finest buff process for surface finishing. The finish buff removes the fine lines created by the cut buff process, while creating a bright luster finish. The finish buff is an easier, quicker, less pressure process than the cut buff.

Buffing

Finishing Compounds :

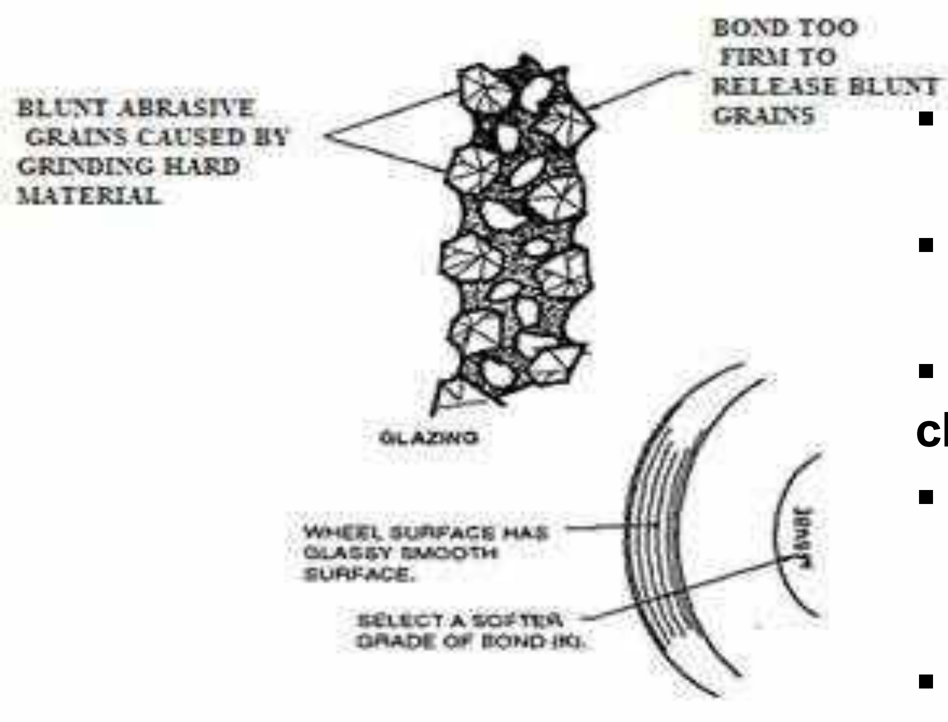
- **Green Rouge** Primarily used in final finish (coloring) buff operations on stainless steel, steel, brass, aluminum, nickel, and chrome. The green rouge is a chrome oxide, and is considered the best all around luster compound.
- **White Rouge** The white rouge is the softer, calcite alumina (unfused) type. Primarily used in the final finish (coloring) of steel, stainless steel, and zinc. This compound is also a favorite in coloring aluminum and brass.
- **Red Rouge** Primarily used in the final finish (coloring) of gold and silver, it is the finest of all rouges. The abrasive is Ferric Oxide, which is spherical in shape and gives an exceptionally high luster. It is produces an excellent finish on brass.

Wheel Conditioning

Overview

- **Loading**
- **Glazing**
- **Chattering**
- **Wheel Conditioning-Truing**
- **Wheel Conditioning-Dressing**

Glazing



GLAZED WHEEL

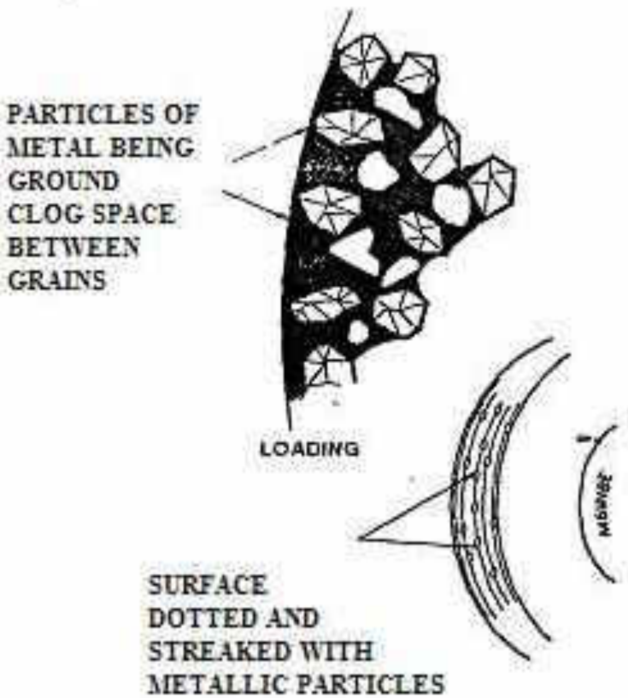
- **When the surface of a grinding wheel develops a smooth and shining appearance, it is said to be glazed.**
- **Abrasive grains due to wear become dull, flat, round and loose sharpness**
- **Hard bonds don't break and supply of fresh sharp grains is stopped.**
- **For proper cutting wheel is to be cleaned and sharpened (or dressed)**
- **Glazing takes place if the wheel is rotated at very high speeds and is made with harder bonds.**
- **Rotating the wheel at lesser speeds and using soft bonds are the remedies.**
- **The glazed wheels are dressed to have fresh, sharp cutting edges.**

1

Loading

- When soft materials like aluminium, copper, lead, etc. are ground, the **metal particles either adhere to the grits or get clogged between the void** between abrasive particles. This condition is called loading.
- Loading can occur in grinding soft materials or from improper selection of wheels or process parameters.
- The loaded grinding wheel cuts inefficiently, dull very fast, raising grinding forces and temperature thus reducing its grinding ability which results in surface damage and loss of dimensional accuracy of the workpiece.
- It is caused by grinding a softer material or by using a very hard bonded wheels and running it very slowly. It may also take place if very deep cuts are taken by not using the right type of coolant.

Fig. 2



SELECT A MORE OPEN STRUCTURE WHEEL (8)
LOADED WHEEL

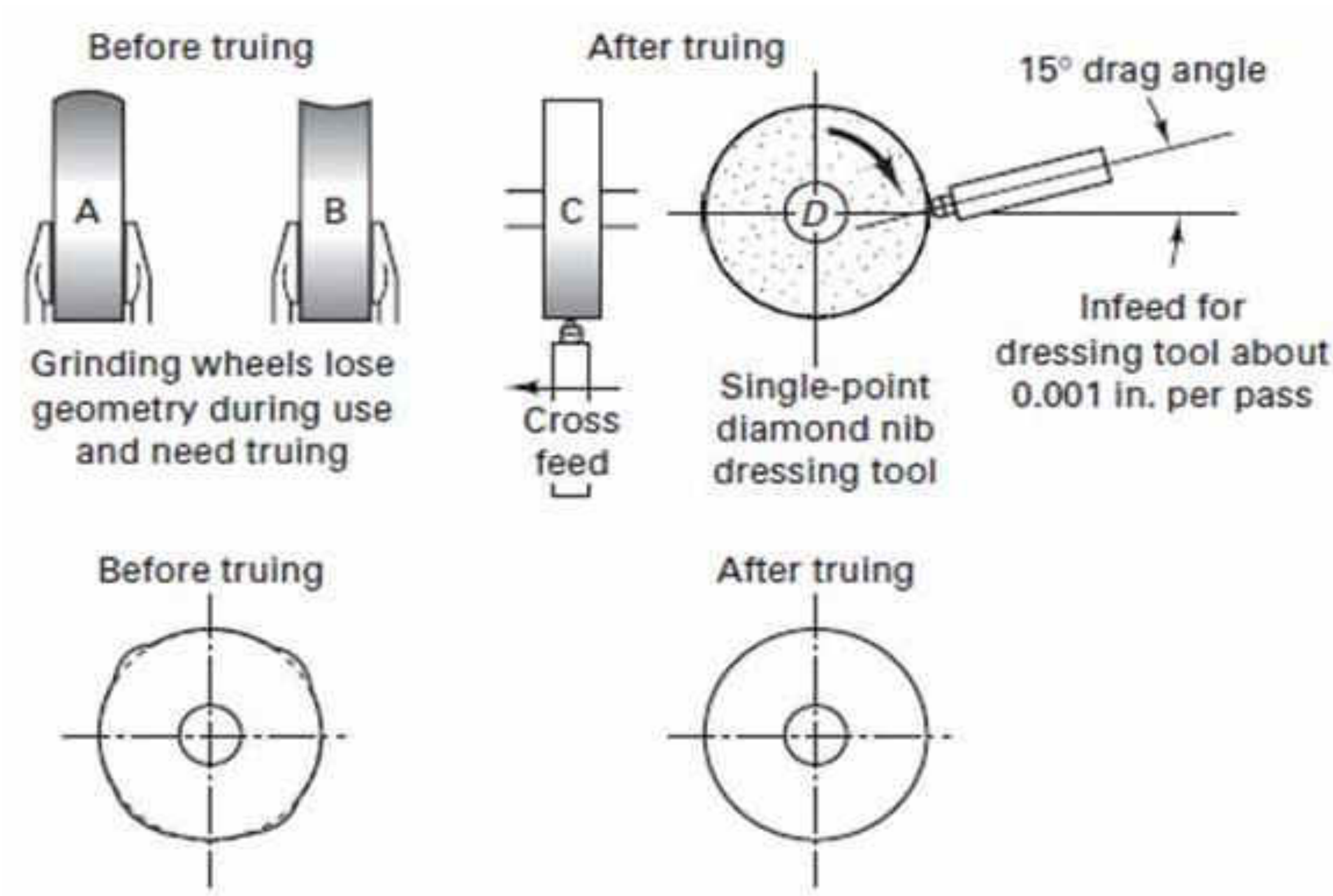
Chattering

- The wavy pattern of crisscross lines is visible on the ground surface some times. This condition is known as chattering.
- It takes place when the spindle bearings are not fitted correctly and because of the imbalance of the grinding wheel.

Wheel Conditioning-Truing

- A worn, loaded and glazed wheel ceases to cut and lose its original shape and geometry.
- Truing is the act of regenerating the required geometry on the grinding wheel. Geometry may be a special form or flat profile
- It make the wheel concentric with the bore, and its sides plane and parallel and change the face contour for form grinding.
- Produces the macro-geometry of the grinding wheel.
- Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system.
- Truing and dressing are done with the same tools, but not for the same purpose.
- The procedure uses a diamond-pointed tool that is fed slowly and precisely across the wheel as it rotates. A very light depth is taken (0.025 mm or less) against the wheel.
-

Truing Operation

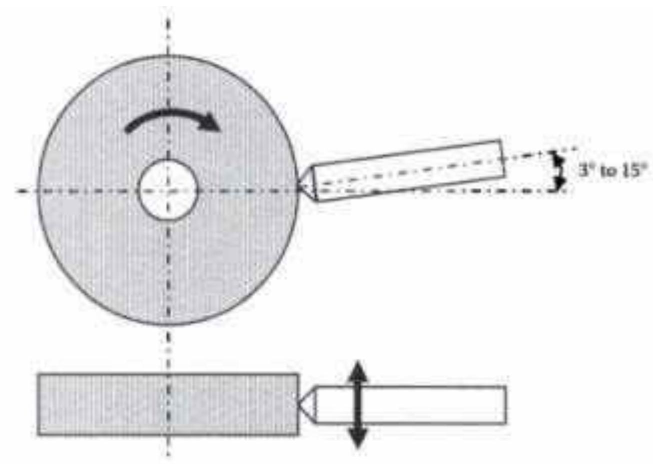


Truing Tools

- **Steel cutter:** used to roughly true coarse grit conventional abrasive wheel to ensure freeness of cut.
- **Vitrified abrasive stick and wheel:** It is used for offhand truing of conventional abrasive wheel. These are used for truing resin bonded superabrasive wheel.
- **Steel or carbide crash roll:** It is used to crush-true the profile on vitrified bond grinding wheel.
- **Diamond truing tool: Single Point/ Multipoint**
- **Impregnated diamond truing tools**
- **Rotary Powered truing wheels**
- **Diamond form truing blocks**

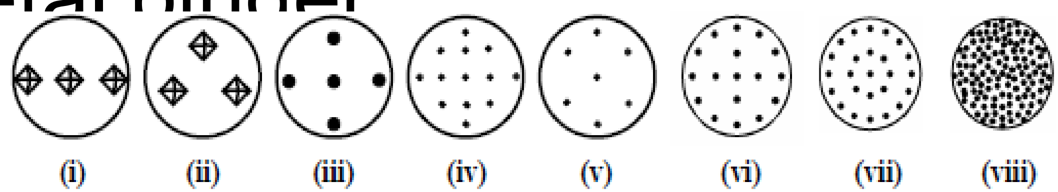
Single Point Diamond Truing Tools

- The single point diamond truing tools for straight face truing are made by setting a high quality single crystal into a usually cylindrical shank of a specific diameter and length by brazing or casting around the diamond. During solidification contraction of the bonding metal is more than diamond and latter is held mechanically as result of contraction of metal around it.



Multistone Diamond Truing Tools

- Consists of a number of small but whole diamonds which contact the abrasive wheel.
- The diamond particles are surface set with a metal binder
- Tool nf r a e as o

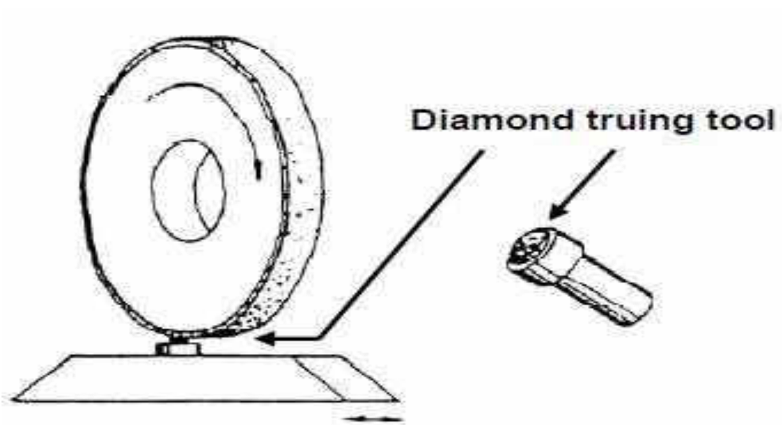


Distribution of diamond	Diamond weight	Distribution of diamond`	Diamond weight
(i) 1 layer-3stone	10	(v) 5 layer-17 stone	50
(ii) 2 layer-3 stone	10	(vi) 5 layer-7 stone	10
(iii) 3 layer-5 stone	10	(vii) 5 layer-25 stone	250
(iv) 5 layer-13 stone	25	(viii) throughout	50

- Suitable for heavy and rough truing

Impregnated diamond truing tools

- Crushed and graded diamond powder mixed with metal powder and sintered.
- Diamond particles randomly distributed in matrix
- The size of diamond particles may vary from 80-600 microns.
- By using considerably smaller diamond grit and smaller diamond section it is possible to true sharp edge and fine grit grinding wheel.
- The use of crushed diamond product ensures that there are always many sharp points in use at the same time and these tools are mainly used in fine grinding, profile grinding, thread grinding, cylindrical grinding and tool grinding.



Impregnated diamond truing tools

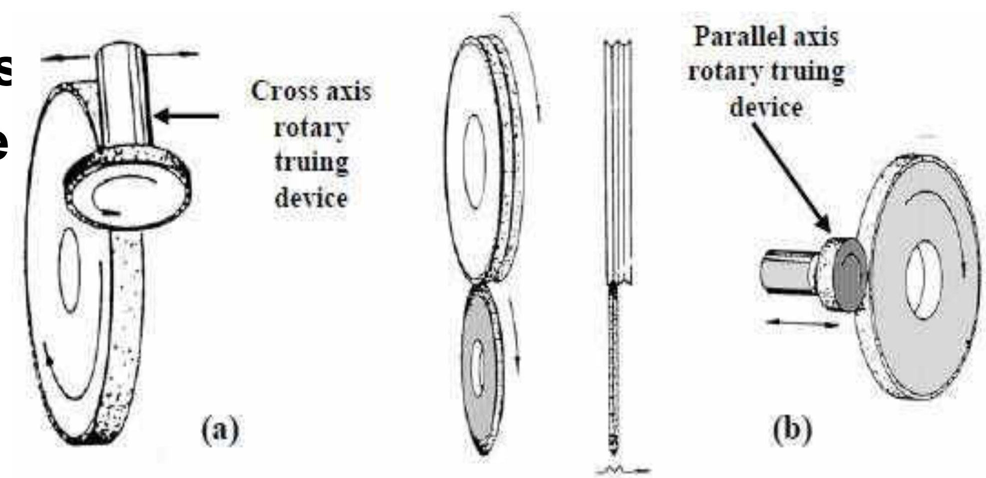
Rotary powered diamond truing tools

- Most widely recommended truing tool in long run mass production
- Not ideally suited for wheels with large diameters (greater than 200 mm).
- They can be pneumatic, hydraulic or electrically powered.
- Rotary powered truing device can be used in cross axis and parallel axis mode.
- Three types

✓ **Surface set truing wheels**

✓ **Impregnated truing wheels**

✓ **Electroplated truing tool**



Rotary powered diamond truing tools

Surface set truing wheels

- Here the diamond particles are set by hand in predetermined pattern. A sintered metal bond is used in this case. These truing wheels are designed for high production automated operations.

Impregnated truing wheels

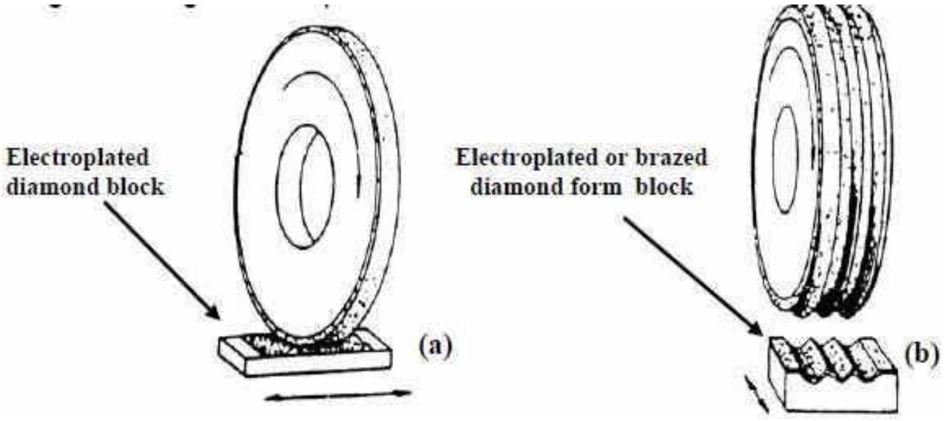
- In this case impregnated diamond particles are distributed in a random pattern to various depths in a metal matrix. This type of roll finds its best applications (i.e. groove grinding) where excess wheel surfaces must be dressed of.

Electroplated truing tool

- In this truing wheel diamond particles are bonded to the wheel surface with galvanically deposited metal layer. Main advantage of this technique is that no mould is necessary to fabricate the diamond truing wheel unlike that of surface set or impregnated truing wheels.

Diamond form truing blocks

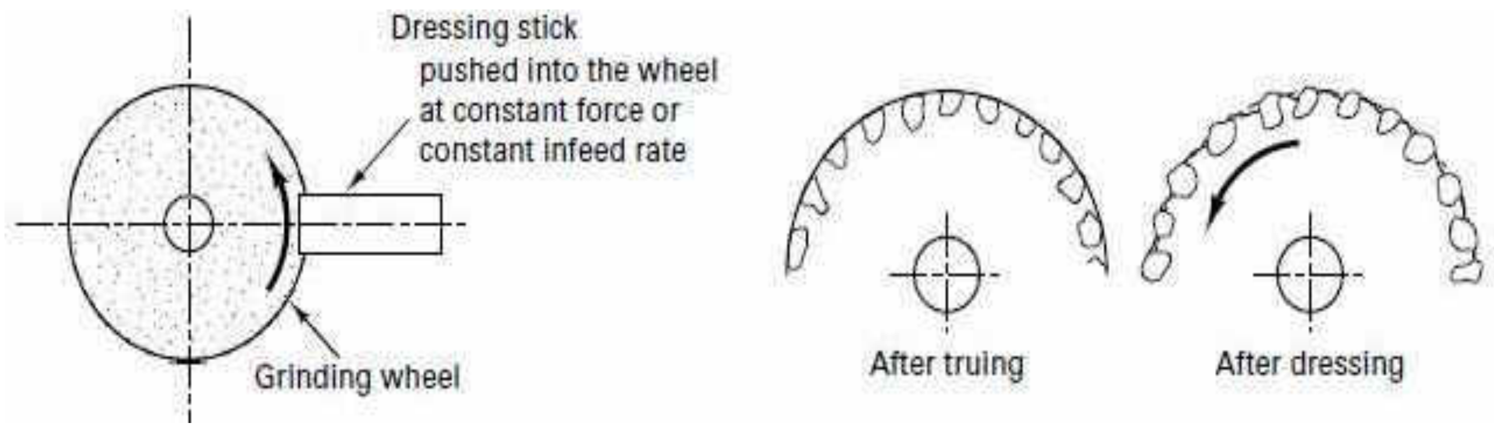
- can be either diamond impregnated metal bond or electroplated.
- Brazed type diamond truing block has also come as an alternative to electroplated one. They can be as simple as flat piece of metal plated with diamond to true a straight faced wheel or contain an intricate form to shape the grinding wheel to design profile.
- Truing block can eliminate the use of self propelled truing wheels and are used almost exclusively for horizontal spindle surface grinder to generate specific form.



Diamond form truing block to true (a) a straight faced wheel (b) a form wheel

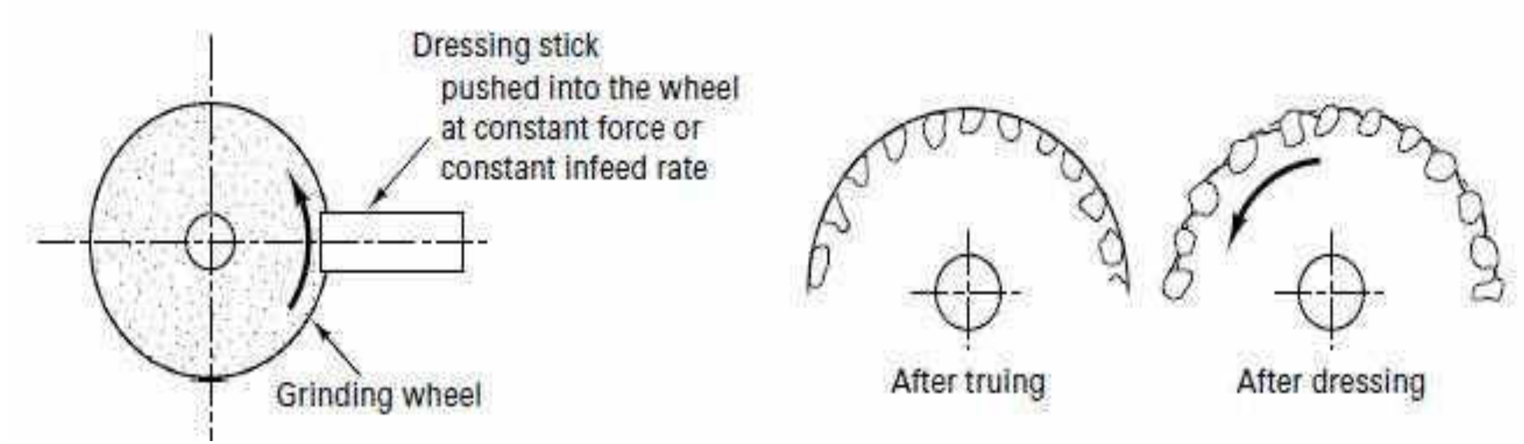
Dressing

- Dressing is the conditioning of the wheel surface to remove dull grits and to expose fresh sharp grains and removing chips that have become clogged in the wheel.
- Done by a rotating disk, an abrasive stick, or another grinding wheel operating at high speed, held against the wheel being dressed as it rotates.
- Although dressing sharpens the wheel, it does not guarantee the shape of the wheel. Dressing therefore produces micro-geometry.
- Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for superabrasive wheel.



Dressing of Super abrasive wheel

- Done with soft conventional abrasive vitrified stick, which relieves the bond without affecting the superabrasive grits.
- However, modern technique like electrochemical dressing has been successfully used in metal bonded superabrasive wheel. The wheel acts like an anode while a cathode plate is placed in front of the wheel working surface to allow electrochemical dissolution.
- Electro discharge dressing is another alternative route for dressing metal bonded superabrasive wheel. In this case a dielectric medium is used in place of an electrolyte.
- Touch-dressing, a new concept differs from conventional dressing in that bond material is not relieved. In contrast the dressing depth is precisely controlled in micron level to obtain better uniformity of grit height resulting in improvement



Selection of Grinding Wheel

Selection of Grinding Wheel

- To achieve better result in grinding operation the following factors are to be considered. The factor are classified in to two groups
- **Constant factor**

  a. Material to be ground

  b. Amount of stock to be removed

  c. Area of contact

  d. Type of grinding (nature of work)
- **Variable factor**

  a. Wheel speed

  b. work speed

  c. Condition of machine

  d. personal factor

Constant Factors

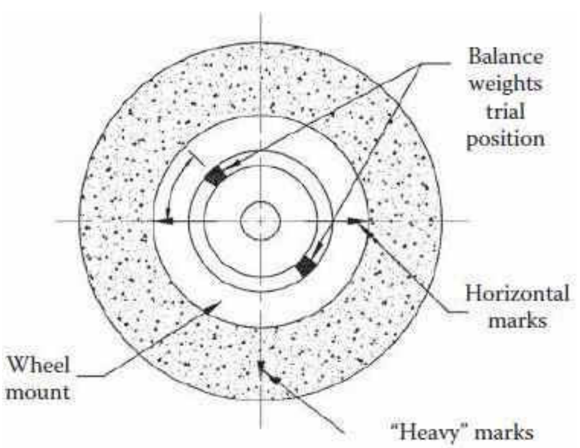
- **Material to be ground:** Its affect the selection of grinding wheel which influence the selection of
  - **Abrasive:** aluminium oxide for high tensile strength material (steel and steel alloys)
  - **Grainsize:** Medium grains are used for operationwhere the stock removal and finish both are required
  - **Grade:** Hard wheel for soft material & vice versa
- **Amount of stock to be removed:**
- Coarse grain are used for fast removal of material & fine grain for finishing
- **Area of contact:**
- For long contact area coarser grain and soft grades of grinding wheels are used and for small contact area finer and hard wheels are used.
- **Type of grinding machine:**
- Light machine is subjected to vibration. For harder grinding wheel the poor condition machine would be ok
- For soft grinding wheel the heavy rigidly constructed and well maintained machine

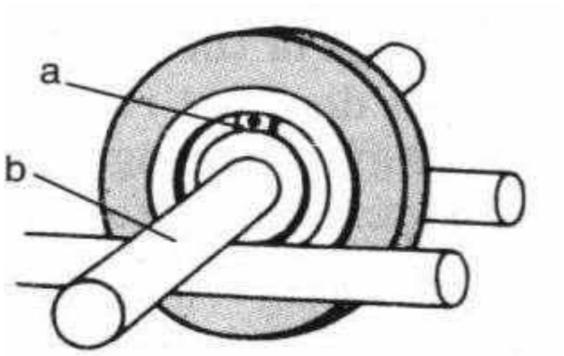
Variable Factors

- **Wheel speed:** It is influenced by Grade & Bond, High wheel speed for soft grinding wheel
- **Work Speed:** Harder wheel for high speed work in relation with wheel speed
- **Condition of grinding machine:** heavy rigid machine required softer wheel
- **Personal Factor**: Skilled operator can worked with softer wheel & achieve optimum production

Wheel Balancing

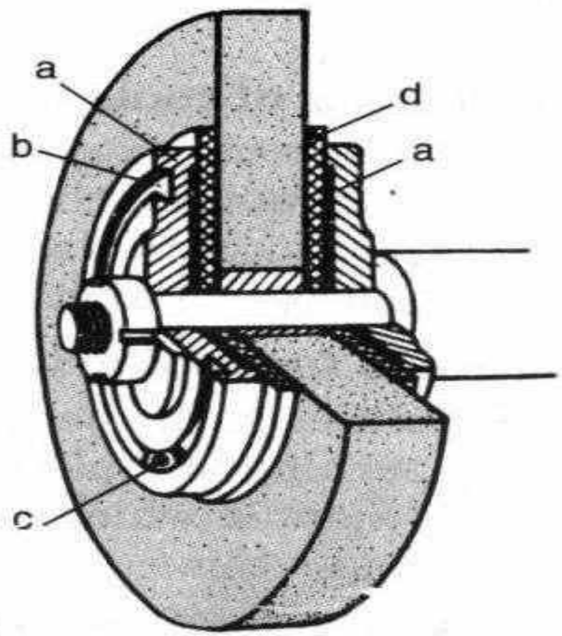
- Grinding wheels rotate at high speeds. The density and weight should be evenly distributed throughout the body of the wheel. If it is not so, the wheel will not rotate with correct balance and will produce poor surface quality.
- The grinding wheels are balanced by mounting them on test mandrels. The wheel along with the mandrel is rolled on knife edges to test the balance and corrected.
- New wheels are supplied with removable balance weights allowing for location adjustment. In static balancing, the wheel is rotated on an arbor and the balancing weights are adjusted until the wheel no longer stops its rotation at a specific position.





a. Counter balance b. Test mandrel

Wheel Mounting



Mounting of the grinding wheel. (*a*) Clamping flange, (*b*) circular groove, (*c*) counter balance, (*d*) carboard packing felt or leather.

- All wheels should be closely inspected just before mounting to make sure that they have not been damaged in transit, storage, or otherwise.

  The wheel must first be subjected to the ringing test. For this purpose, the grinding wheel is put on an arbor while it is subjected to slight hammer blows. A clear, ringing, vibrating sound must be heard. If a grinding wheel contains fine cracks, discordant sound that fail to vibrate will be emitted. This test is applicable to vitrified and silicate wheels. Shellac, resinoid or rubber loaded wheels will not ring distinctly.

Wheel Mounting

- The abrasive wheels should have an easy fit on their spindles or locating spigots. They should not be forced on.
- The hole of grinding wheels mostly is lined with lead. The lead liner bushes should not project beyond the side of wheels.
- There must be a flange on each side of the wheel. The mounting flanges must be large enough to hold the wheel properly, at least the flange diameter must be equal to the half of the grinding wheel diameter. Both the flanges should be of the same diameter, other-wise the wheel is under a bending stress which is liable to cause fracture.
- The sides of the wheel and the flanges which clamp them should be flat and bear evenly all round
- All flanges must be relieved in the center so that the flanges contact the wheel only with the annular clamping area. If they are not properly relieved, the pressure of the flanges is concentrated on the sides of the wheel near the hole, a condition which should be avoided.

Wheel Mounting

- Washers of compressible materials such as card board, leather, rubber, etc. not over 1.5 mm thick should be fitted between the wheel and its flanges. In this way any unevenness of the wheel surface is balanced and a tight joint is obtained. The diameter of washers may be normally equal to the diameter of the flanges.
- The inner fixed flange should be keyed or otherwise fastened to the spindle, whereas the outer flange should have an easy sliding fit on the spindle so that it can adjust itself slightly to give a uniform bearing on the wheel and the compressible washers.
- The nut should be tightened to hold the wheel firmly. Undue tightness is unnecessary and undesirable as excessive clamping strain is liable to damage the wheel.
- The wheel guard should be placed and tightened before the machine is started for work.

NON-CONVENTIONAL

MODERN MACHINING PROCESSES

LBM Operation

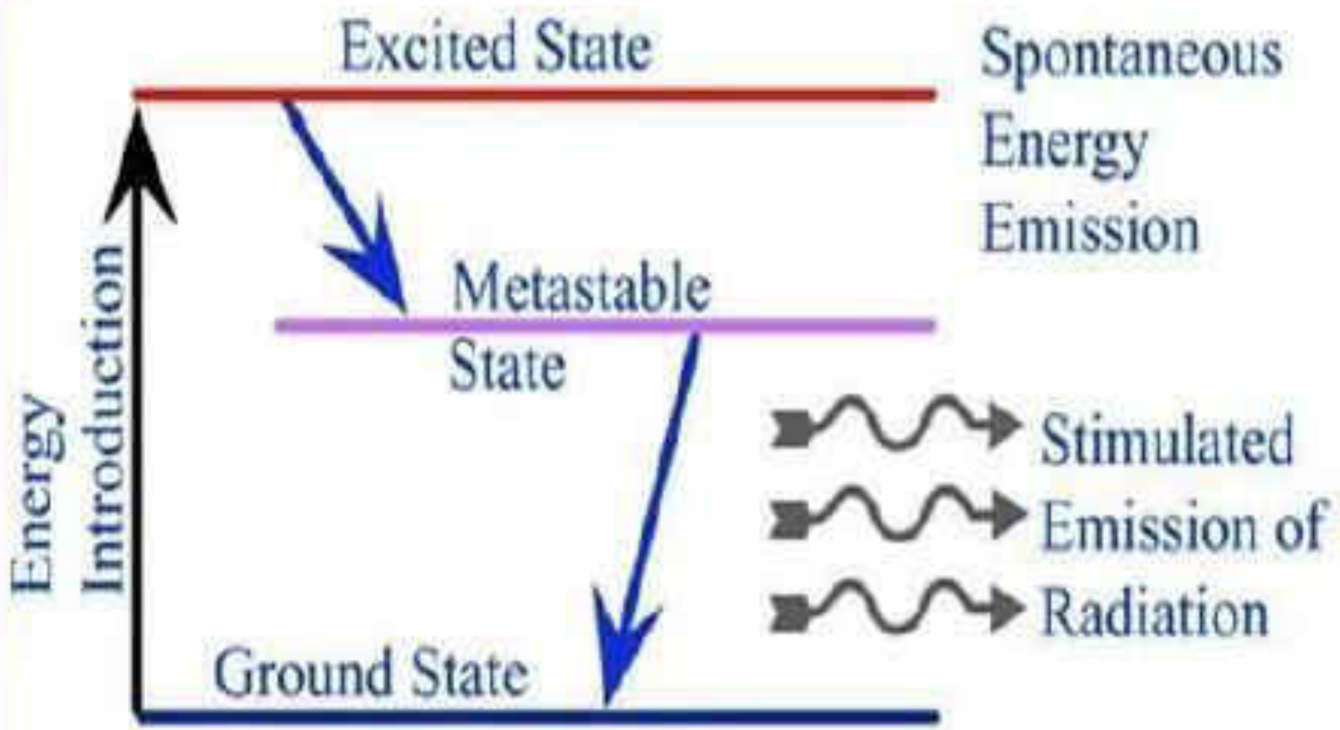


Figure-1 Mechanism of Energy Transfer in Laser Beam

Disadvantages

The LBM process offers the following main disadvantages:

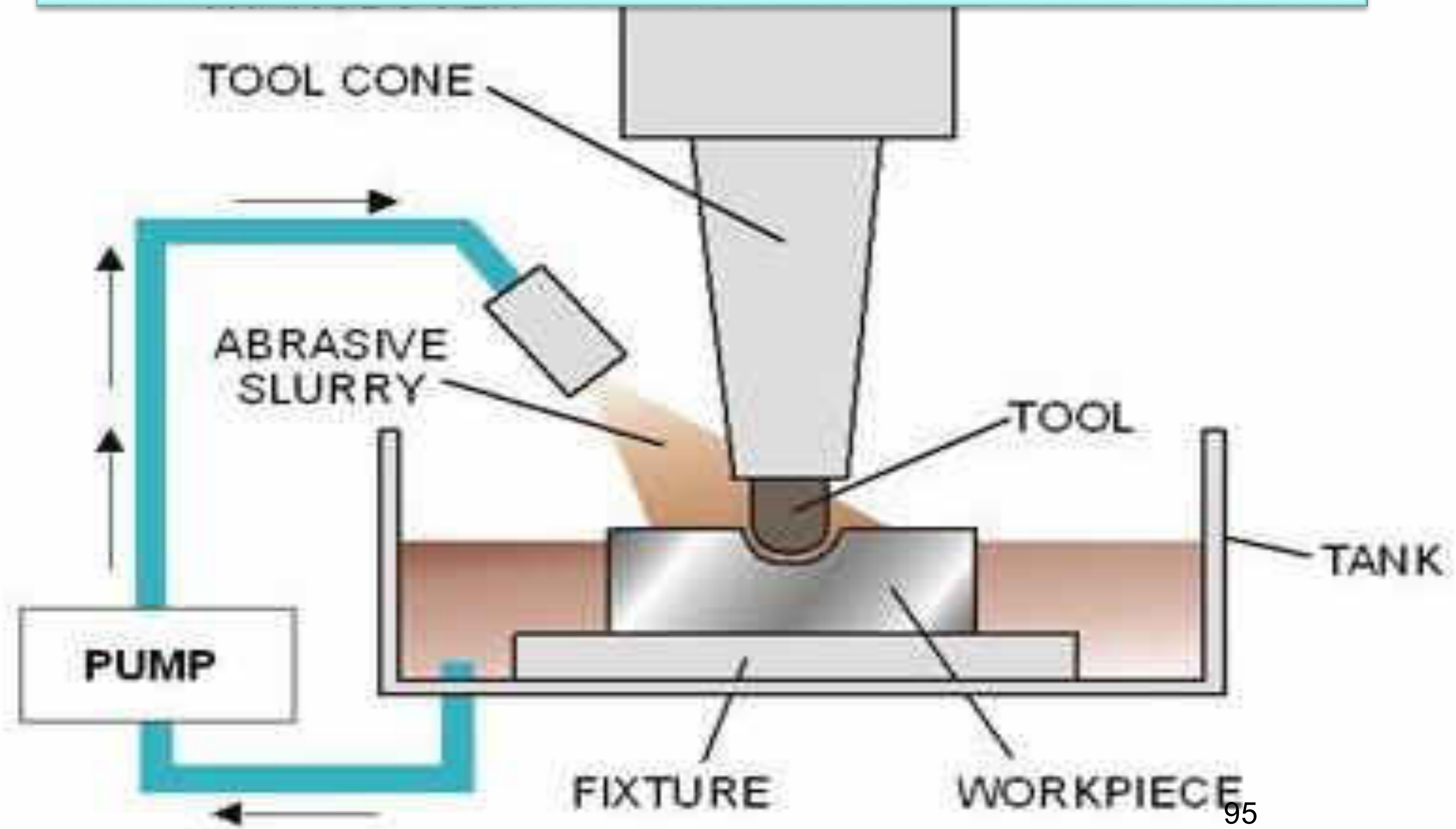
1. High capital investment needed.
2. Operating cost is also quite high.
3. Highly skilled operators are needed.
4. Production rate is low.
5. Its application is limited to only the thin sections and where a very small amount of metal removal is involved.
6. Cannot be effectively used to machine highly heat conductive and reflective materials.

Applications

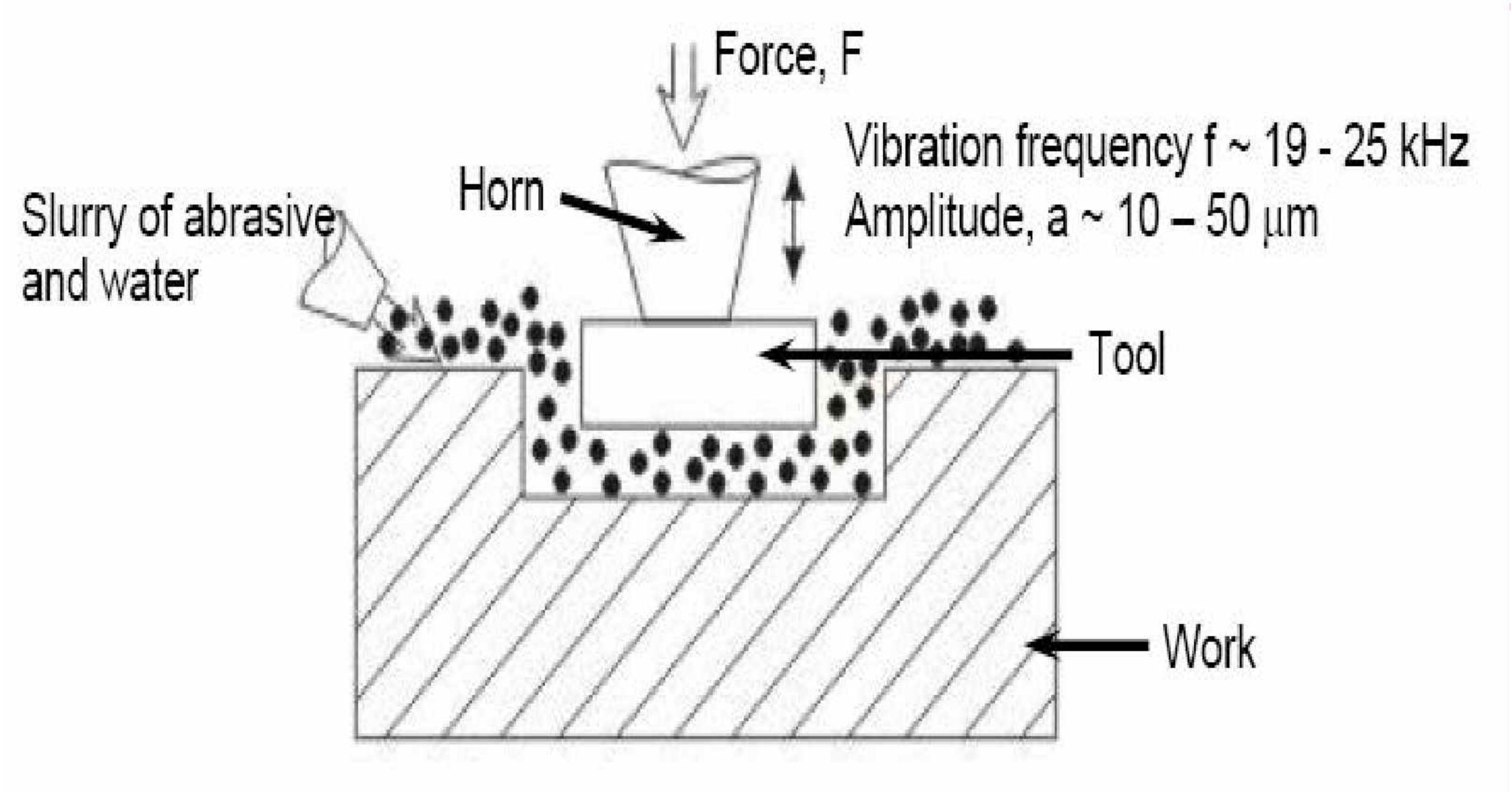
The LBM process offers the following main Applications:

1. Trimming of carbon resistors.
2. Drilling small holes in hard materials like tungsten and ceramics.
3. Cutting complex profiles on thin and hard materials.
4. Cutting or engraving patterns on thin films.
5. Dynamic balancing of precision rotating components, such as of watches.
6. Trimming of sheet metal and plastic parts.

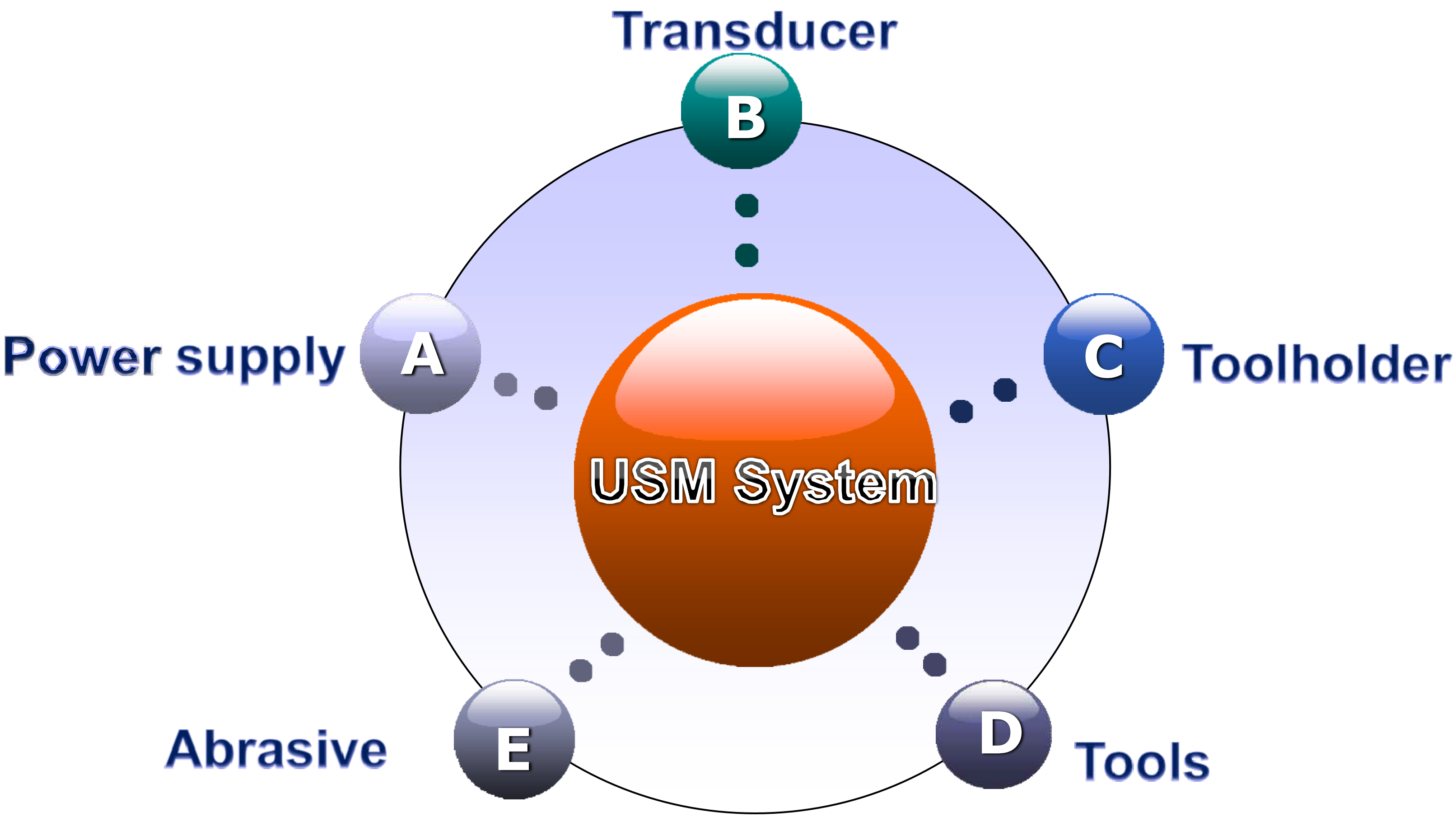
Ultrasonic Machining



Ultrasonic Machining



Subsystems of USM



Transducer

- The ultrasonic vibrations are produced by the transducer. The transducer is driven by suitable signal generator followed by power amplifier. The transducer for USM works on the following principle
  - Piezoelectric effect
  - Magnetostrictive effect
  - Electrostrictive effect
- Magnetostrictive transducers are most popular and robust amongst all.

Tool Electrode in USM

- The tool is made of relatively soft metal.
- It is applied to the workpiece surface and the Slurry applied either manually or through a pump.
- The tool can be attached to the arbor either by brazing, hard soldering or screwing.
- Sometimes hollow tools are used which facilitate feeding of the slurry through them.
- The main advantage of this process is that the workpiece after being machined is normally free from residual mechanical stresses and a high degree of surface finish can be obtained.

Ultrasonic Machining

- Slurry of small abrasive particles is forced against the work by means of a vibrating tool, removing the workpiece material in the form of extremely small chips.
- The grains used are of silicon carbide, aluminum oxide, boron carbide or diamond dust.
- This processes is suitable only for hard and brittle materials like carbides, glass, ceramics, silicon, precious stones, germanium, titanium, tungsten, tool steels, die steels, ferrite quartz, etc.
- The vibrating frequency used for the tool is of the order of over 20,000 oscillations second.
- Such a high frequency, which is more than the upper limit of audible frequency for human ear' makes the process inaudible (silent).

Water Jet Machining

- It is reckoned that the cut (slit) produced in the workpiece is lightly (about 0.025 mm) larger than the diameter of the jet.
- The water pressures used in the process vary from 2100kg/cm^2 to 3500kg/cm^2.
- Commonly used abrasives are silica, aluminium oxide and garnet and their grit sizes 60, 80, 100 and 120 .
- The mixing chamber or abrasive tube is usually made of extremely hard and wear resistant material like carbide.
- Usually a gap of 0.5 mm to 1.5 mm is necessary between the work surface and the tip of the tube.

Advantages

The WJM process offers the following main Advantages:

1. In most of the cases, no secondary finishing required
2. Low cutting forces on workpieces
3. Limited tooling requirements
4. Little to no cutting burr
5. Very good surface finish(125-250 microns)
6. No heat affected zone
7. Eliminates thermal distortion and structural change
8. Precise, multi plane cutting of contours, shapes, and bevels of any angle.

Disadvantages

The WJM process offers the following main Advantages:

1. Cannot drill flat bottom
2. Cannot cut materials that degrades quickly with moisture
3. Surface finish degrades at higher cut
4. High capital cost and high noise levels during operation.

Applications

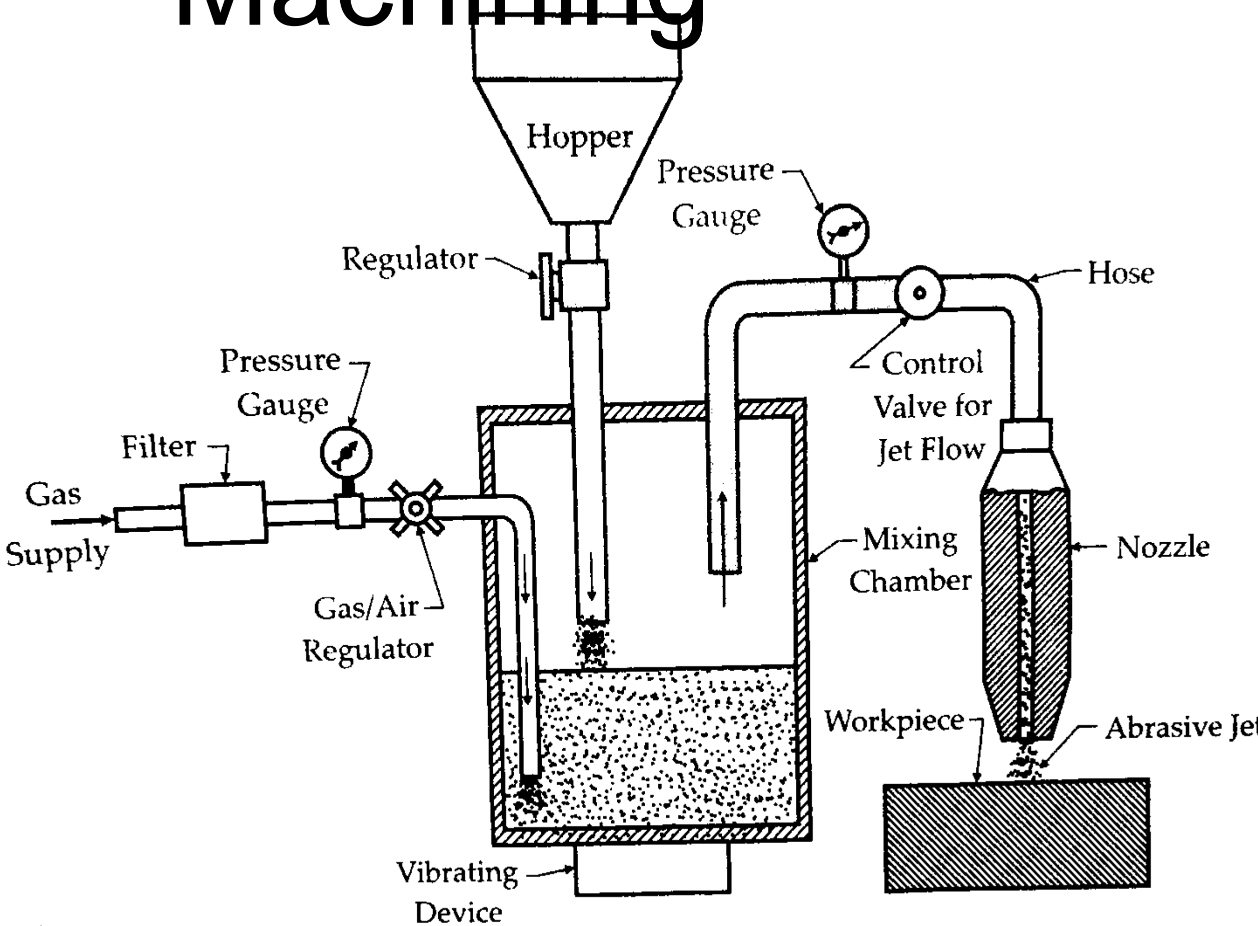
- The WJM process offers the following main Applications:

1. Cleaning and descaling operations.
2. To machine nonmetallic materials like paper boards, wood, plastics, asbestos and rubber etc.

Abrasive Jet Machining

- This process consists of directing a stream of fine abrasive grains mixed compressed air or some other gas at high pressure, through a nozzle on to the surface of the workpiece to be machined.
- These particles impinge on the work surface at high speed and the erosion, caused by their impact enables the removal of metal.
- The abrasive and fed into the mixing particles are contained in a suitable holding device, like hopper and fed into the mixing chamber.
- A regulator is incorporated in the line to control the flow of abrasive particles.
- Compressed air or high pressure gas is supplied to the mixing chamber through a pipe line.

Abrasive Jet Machining



Abrasive Jet Machining

- This pipe line carries a pressure gauge and a regulator to control the gas flow and its pressure. the mixing chamber, carrying the abrasive particles, is vibrated and the amplitude of these vibrations controls the flow of abrasive particles.
- These particles mix in the gas stream, travel further through a hose and finally pass through the nozzle at a considerably high speed, impinges on the work surface causes the removal of metal.
- This outgoing high speed stream mixture of gas and abrasive particles is known as Abrasive jet.

Advantages

The AJM process offers the following main Advantages:

1. Can be used in any material, conductive, non-conductive, ductile or brittle
2. Good dimensional accuracy (±0.05 mm)
3. Good Surface finish – 0.25 to 1.25 μm
4. Due to cooling action of gas stream no thermal damage on the work surface
5. Due to negligible force delicate workpiece can be machined.

Disadvantages

The AJM process offers the following main Advantages:

1. It is not suitable for machining of ductile materials.
2. Metal removal is slow.
3. Machining accuracy is relatively poorer.
4. There is always a danger of abrasive particles getting embedded in the work material. Hence, cleaning needs to be necessarily done after the operation.
5. The abrasive powder used in the process cannot be reclaimed or reused.
6. Possibility of stray cutting

Applications

- The AJM process offers the following main Applications:

1. Cutting and drilling on metal foils and thin sections of ceramics and glass
2. Intricate holes in electronic components such as resistor paths in insulation
3. Engraving of characters on toughened glass automobile

Economics of Advanced Machining Processes

- High cost of equipment, which typically includes computer control
- May use hard tooling, soft tooling, or both
- **Low production rates**
- Can be used with difficult-to-machine materials
- Highly repeatable
- Typically requires highly skilled operators

Coating Process

Coating Process Development

Coating Equipment & Process

- Extrusion coating process shears the polymer coating
- Shearing applies stresses to the coating material
  - Coating performance depends on the type of coating
- Control the coating process and equipment
  - Uniform & proper gap in space and time
  - Uniform & proper vacuum in space and time
  - Uniform & proper flow rate in space and time
  - Uniform & proper coating temperature in space and time
  - Uniform & proper solids concentration in space and time

Coating Process Development

Material To Be Coated

- Surface conditions are critical
  - Low and uniform surface tension
  - Surface tension too high: Delamination
  - Uniform surface tension: Uniform coating thicknesses
- Prepare the surface: Cannot "over clean" or "over dry"
  - Remove oils
  - Remove debris
  - Remove oxides
  - Dry the surface
  - How fast do oxides reform
- Coat immediately after the surface is dried

Coating Process Development

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  - Remove oxides
  - Dry the surface
  - How fast do oxides reform
- Coat immediately after the surface is dried
- Does the material being coated out-gasses: Delamination
- Microetch the surface-Increasing the surface area

Bibliography

Reading Material

WIKIPEDIA

Image

Google Image Search

Thank You

Government Polytechnic Nanakpur

DEPARTMENT OF MECHANICAL ENGINEERING

E - NOTES

Refrigeration and Air-conditioning

HOD/O.I. (Mechanical) : **Sh.SHALANDER MOR**

Faculty Name: **Er. Arvind**

Semester: 5^{th} Sem

By: Er. Amit Kumar
Designed, Mechanical Editing & Developmental Editing

LEARNING OUTCOMES

After undergoing this course, the students will be able to:
Explain the construction and tooling of CNC machine.

Prepare simple part programme.

Operate a CNC lathe.

Operate a CNC milling machine.

Diagnose common problems in CNC machines.

Explain the trends in the field of automation.

Use Advanced programming structures.

NC PART PROGRAMMING

HISTORICAL DEVELOPMENT

- 15th century - machining metal.
- 18th century - industrialization, production-type machine tools.
- 20th century - F.W. Taylor - tool metal - HSS

  Automated production equipment -

    Screw machines

    Transfer lines

    Assembly lines

    ...

    using cams and preset stops

  Programmable automation -

    NC

    PLC

    Robots

NEW NCs or CNCs

high speed spindle (> 20,000 rpm)

high feed rate drive (> 600 ipm)

high precision (< 0.0001" accuracy)

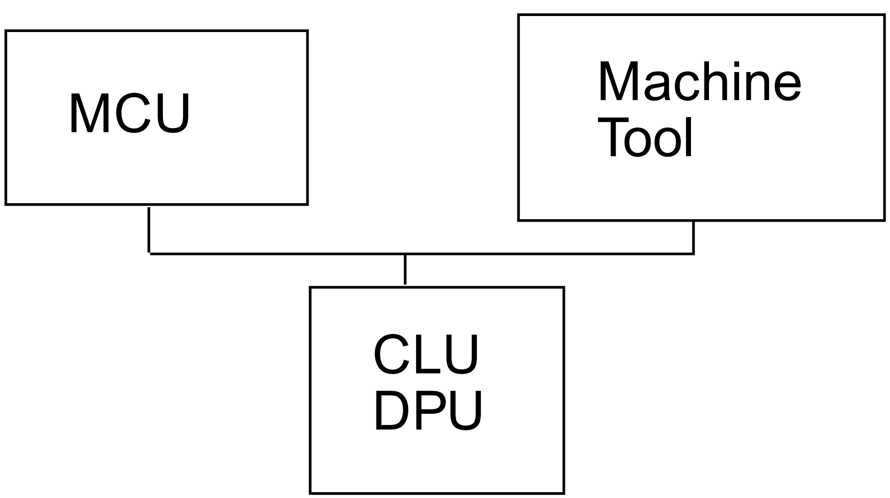
NC MACHINES

- Computer control
- Servo axis control
- Tool changers
- Pallet changers
- On-machine programming
- Data communication
- Graphical interface

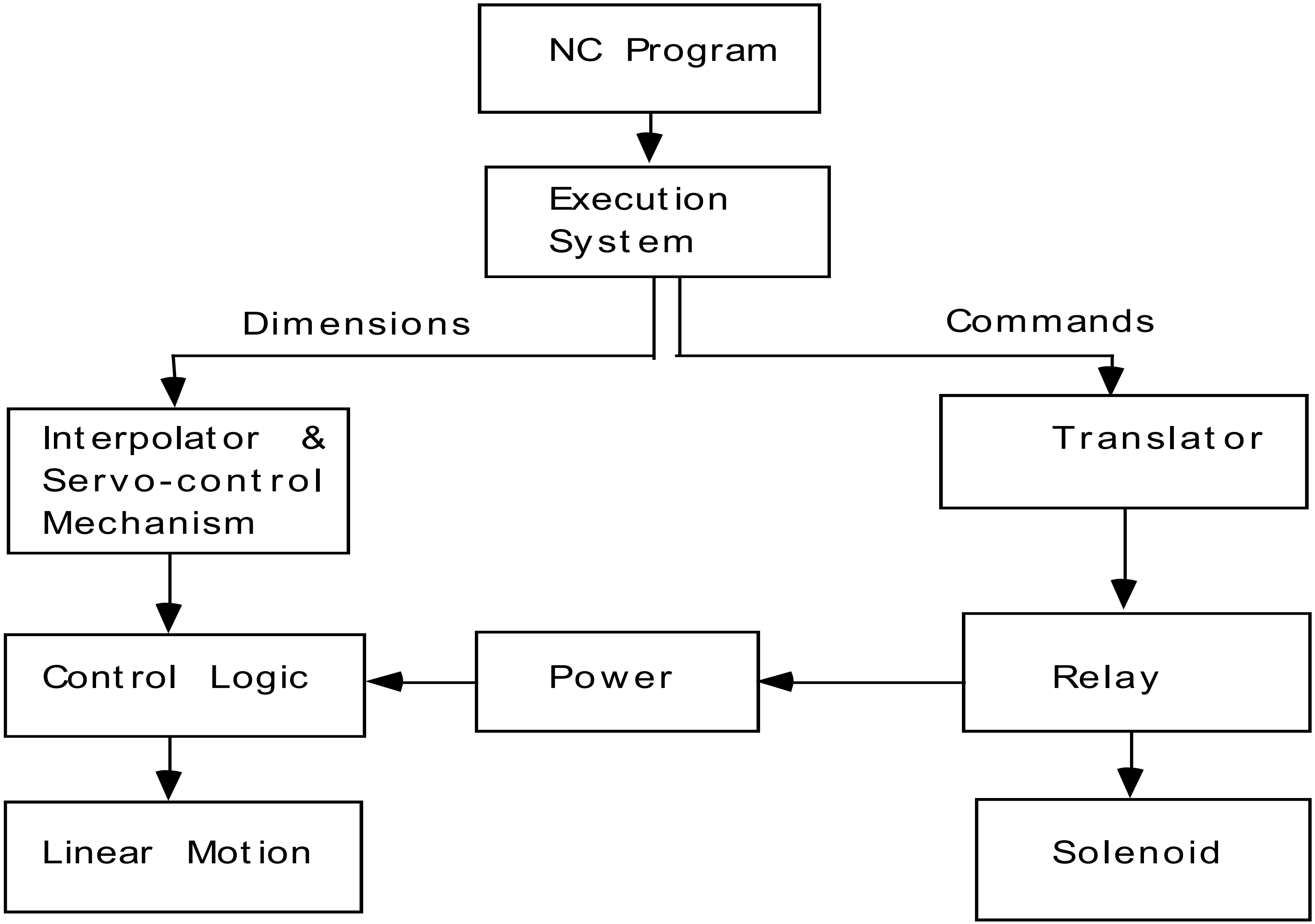
MCU - Machine control unit

CLU - Control-loops unit

DPU - Data processing unit



NC MOTION-CONTROL



NC MACHINE CLASSIFICATION

1. Motion control: point to point (PTP) and continuous (contouring) path

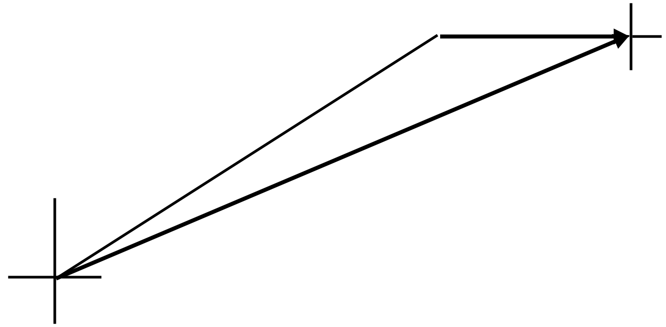
2. Control loops: open loop and closed loop

3. Power drives: hydraulic, electric, or pneumatic

4. Positioning systems: incremental and absolute positioning

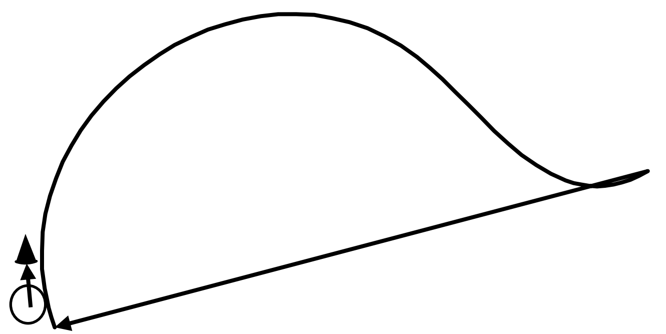
POINT TO POINT

- Moving at maximum rate from point to point.
- Accuracy of the destination is important but not the path.
- Drilling is a good application.

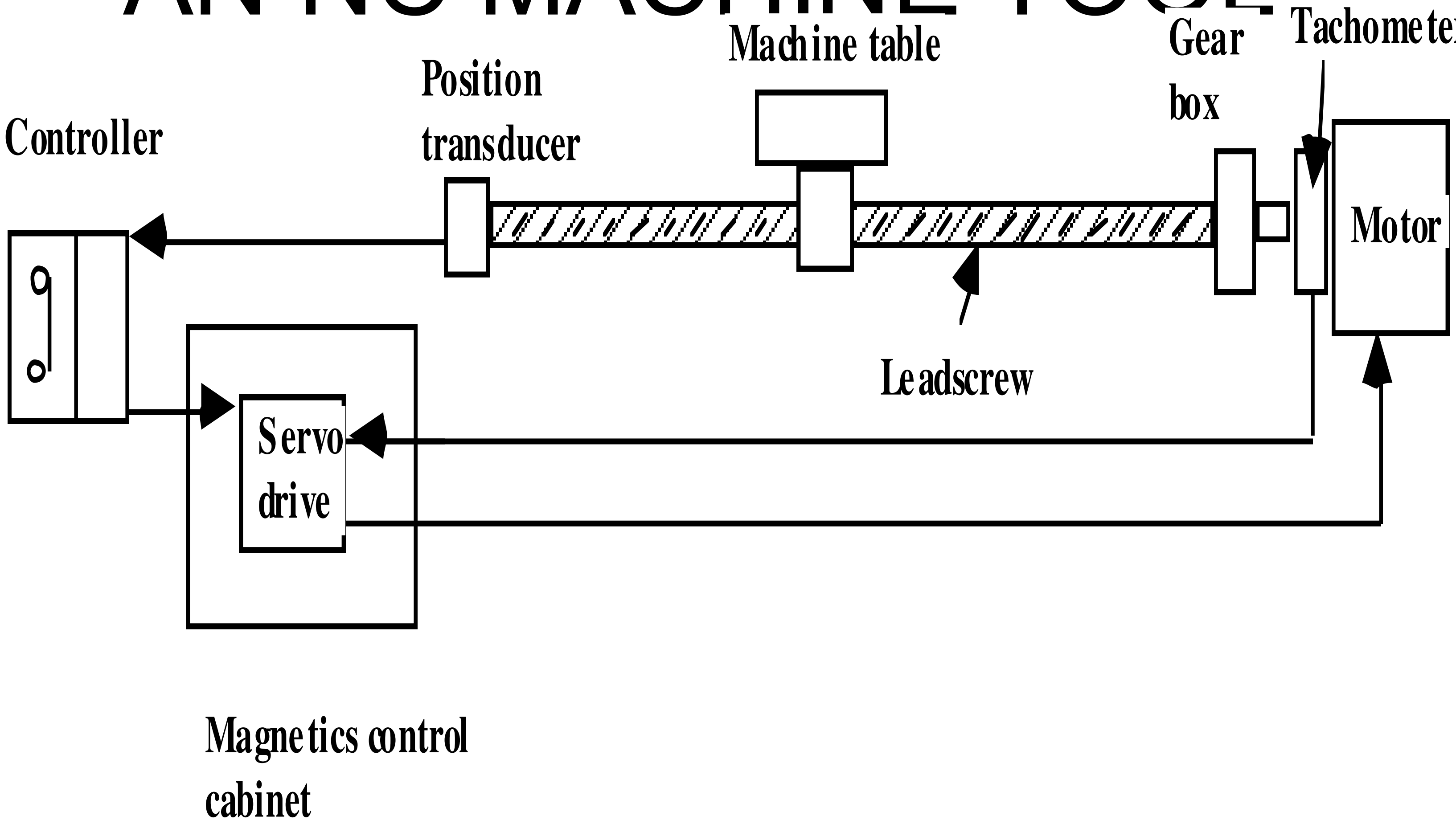


CONTINUOUS PATH

- Controls both the displacement and the velocity.
- Machining profiles.
- Precise control.
- Use linear and circular interpolators.



MAJOR COMPONENTS OF AN NC MACHINE TOOL



NC MACHINE RATING

Accuracy

Repeatability

Spindle and axis motor horsepower

Number of controlled axes

Dimension of workspace

Features of the machine and the controller.

C ACCURACY AND REPEATABILITY

- Accuracy = control instrumentation resolution and hardware accuracy.

- Control resolution: the minimum length distinguishable by the control unit (BLU).

- Hardware inaccuracies are caused by physical machine errors.

HARDWARE INACCURACIES

Component tolerances:

inaccuracies in the machine elements, machine-tool assembly errors, spindle runout, and leadscrew backlash.

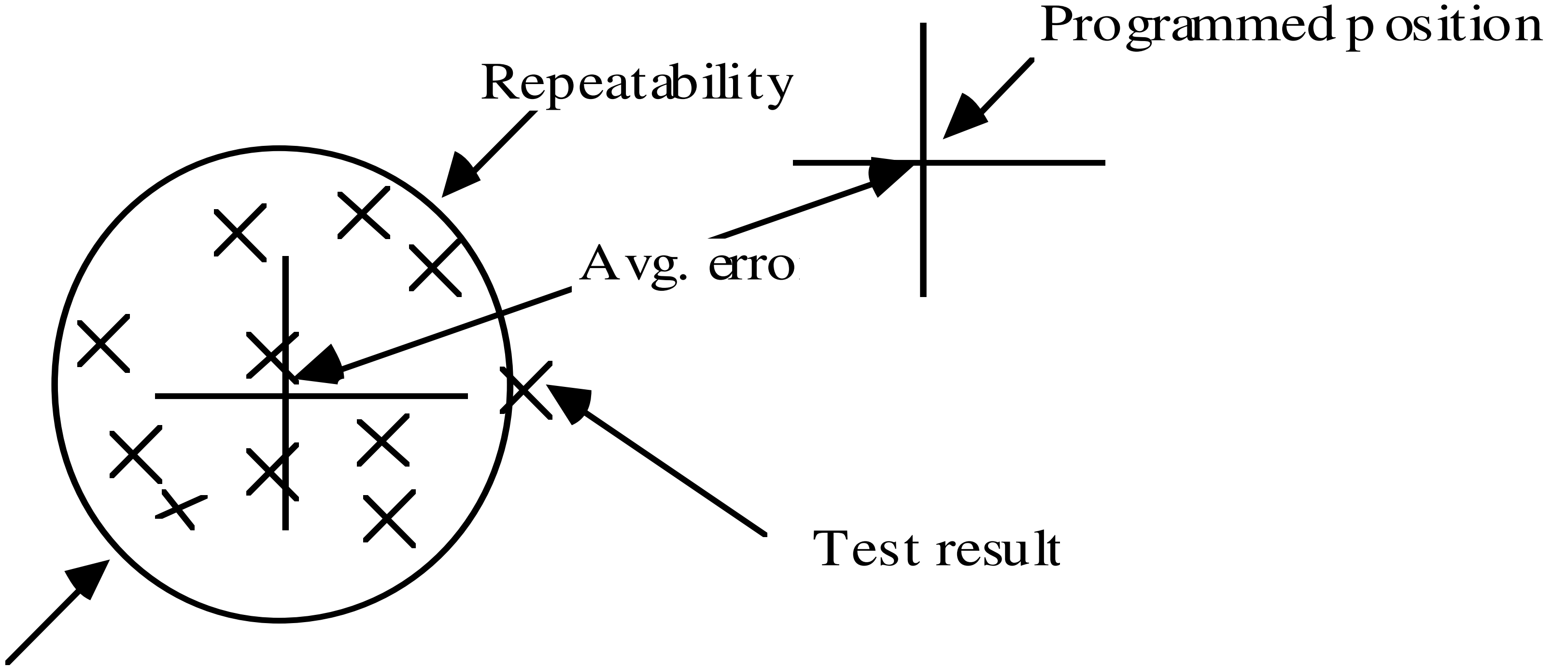
Machine operation:

Tool deflection (a function of the cutting force), produces dimensional error and chatter marks on the finished part.

Thermal error:

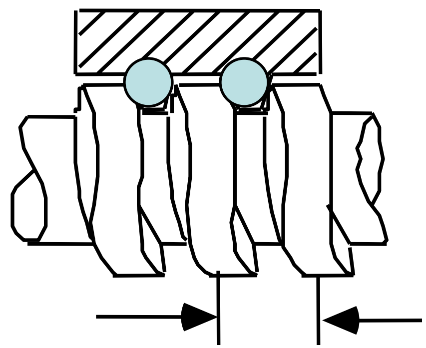
heat generated by the motor operation, cutting process, friction on the ways and bearings, etc. Use cutting fluids, locating drive motors away from the center of a machine, and reducing friction from the ways and bearings

REPEATABILITY



LEADSCREWS

Converting the rotational motion of the motors to a linear motion.



pitch (p): the distance between adjacent screw threads

the number of teeth per inch (n):

$n = 1 / p$

BLU: Basic Length Unit (machine resolution)

$BLU = p / N$

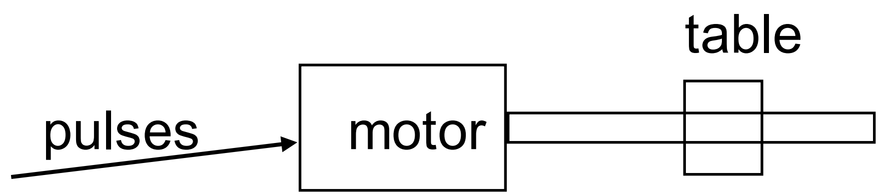
e.g. an NC machine uses a 0.1" pitch leadscrew and a 100 pulse/rev encoder.

$BLU = p / N = 0.1 \text{ (in/rev)} / 100 \text{ (pulses/rev)} = 0.001"$

CONTROL LOOPS

Open loop - No position feedback.

Use stepping motor.

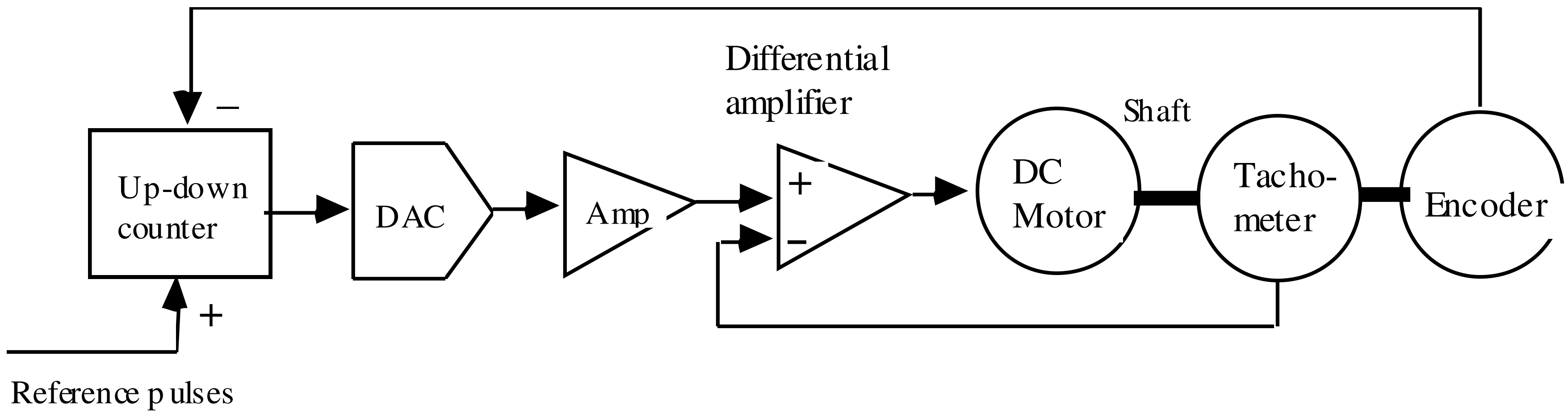


A machine has 1 BLU = 0.001". To move the table 5" on X axis at a speed (feed rate) of 6 ipm.

pulse rate = speed/BLU = 6 ipm/0.001 ipp = 6,000 pulse/min

pulse count = distance/BLU = 5/0.001 = 5,000 pulses

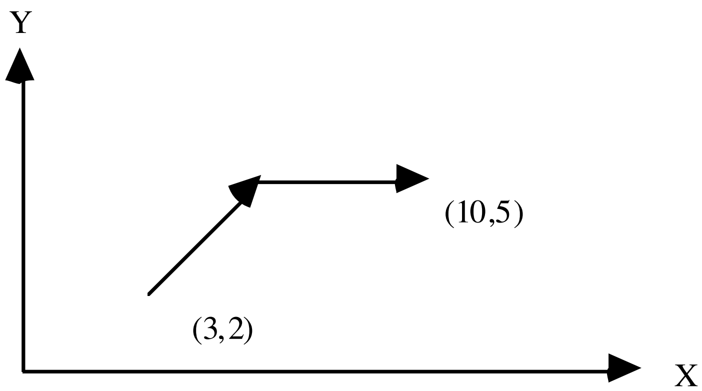
CLOSED LOOP



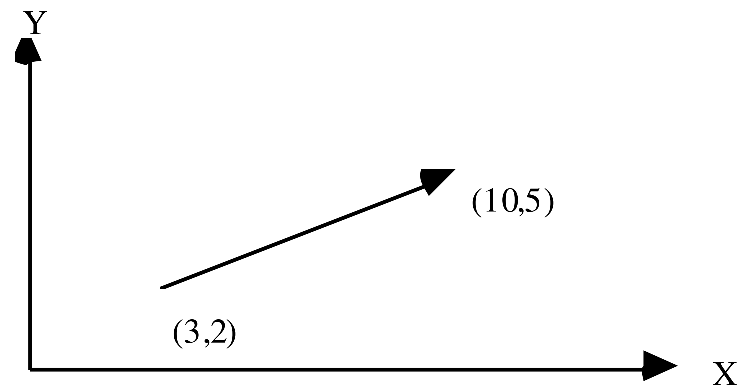
Closed-loop control mechanism

INTERPOLATION

Control multiple axes simultaneously to move on a line, a circle, or a curve.



Point-to-point control path



Linear path

$$V_x = 6\frac{(10-3)}{\sqrt{(10-3)^2 + (5-2)^2}} = 6\frac{7}{\sqrt{49+9}} = 5.5149$$

$$V_y = 6\frac{(5-2)}{\sqrt{(10-3)^2 + (5-2)^2}} = 6\frac{3}{\sqrt{49+9}} = 2.3635$$

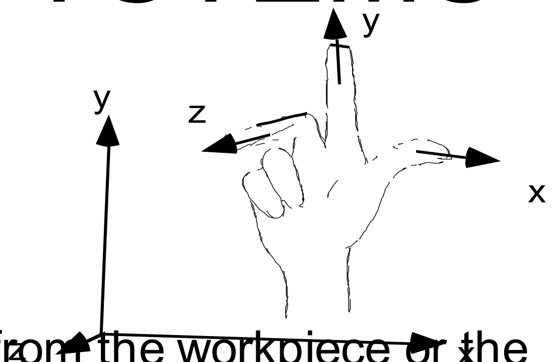
INTERPOLATORS

Most common interpolators are: linear and circular

Since interpolation is right above the servo level, speed is critical, and the process must not involve excessive computation.

Traditional NC interpolators: Digital Differential Analyzer (DDA)

COORDINATE SYSTEMS

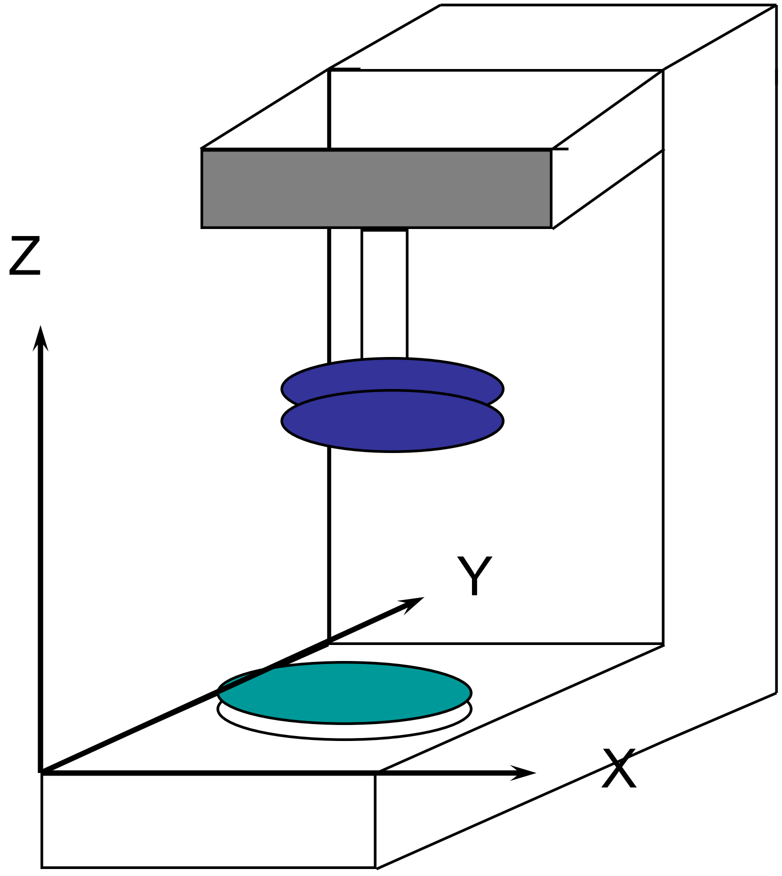


- Right hand rule
- Z axis align with the spindle - +Z moves away from the workpiece or the spindle.
- X axis - Lathe: perpendicular to the spindle.

  Horizontal machine: parallel to the table.

  Vertical machine: +X points to the right.

MACHINE COORDINATES



X - Primary Feed axis
Z - Spindle axis
Y - Remaining axis

PROGRAM STORAGE

- Paper tape

  Paper or Mylar coated paper.

- Diskettes
- From other computers through RS 232 or local area network (LAN)

SYMBOLIC CODES

- ASCII or ISO, use even parity
- EIA - Binary Coded Decimal (BCD), RS 244A standard, use odd parity.

NC WORDS

A G-code program consists the following words:

N, G, X, Y, Z, A, B, C, I, J, K, F, S, T, R, M

An EIA standard, RS-273 defines a set of standard codes.

BASIC REQUIREMENT OF NC MACHINE CONTROL

a. Preparatory functions: which unit, which interpolator, absolute or incremental programming, which circular interpolation plane, cutter compensation, etc.

b. Coordinates: three translational, and three rotational axes.

c. Machining parameters: feed, and speed.

d. Tool control: tool diameter, next tool number, tool change.

e. Cycle functions: drill cycle, ream cycle, bore cycle, mill cycle, clearance plane.

f. Coolant control: coolant on/off, flood, mist.

g. Miscellaneous control: spindle on/off, tape rewind, spindle rotation direction, pallet change, clamps control, etc.

h. Interpolators: linear, circular interpolation

NC WORDS

N code. sequence number

N0010

G code. preparatory word.

Table 9.1 G codes

g00	Rapid traverse	g40*	Cutter compensation - can
g01	Linear interpolation	g41	Cutter compensation - left
g02	Circular interpolation, CW	g42	Cutter compensation -righ
g03	Circular interpolation, CCV	g70*	Inch format
g04	Dwell	g71	Metric format
g08	Acceleration	g74	Full circle programming C
g09	Deceleration	g75*	Full circle programming C
g17*	X-Y Plane	g80	Fixed cycle cancel
g18	Z-X Plane	g81 -9	Fixed cycles
g19	Y-Z Plane	g90 *	Absolute dimension programming

NC WORDS (continue)

X, Y, Z, A, B, C Codes. coordinate positions of the tool.

The coordinates may be specified in decimal number (Decimal Programming), or integer number (BLU Programming).

BLU programming: leading zero, trailing zero.

In the leading zero format:

X00112 Y002275 Z001

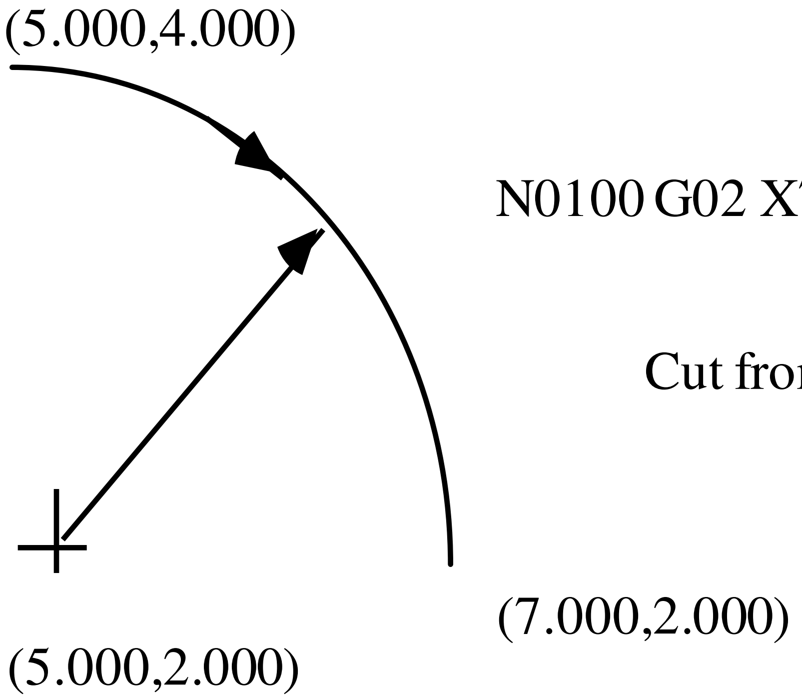
In the trailing zero format, the program looks like:

X11200 Y22750 Z10000

NC WORDS (continue)

Circular Interpolation:

Full circle ON



N0100 G02 X7.000 Y2.000 I5.000 J2.000

Cut from (5.000,4.000) to
(7.000,2.000) CW

NC WORDS (continue)

F Code. feed speed.

inch/min (ipm), or ipr.

F code must be given before either G01, G02, or G03 can be used.

N0100 G02 X7.000 Y2.000 I5.000 J2.000 F6.00

S Code. cutting speed code.

It is programmed in rpm.

S code does not turn on the spindle, spindle is turned on by a M code.

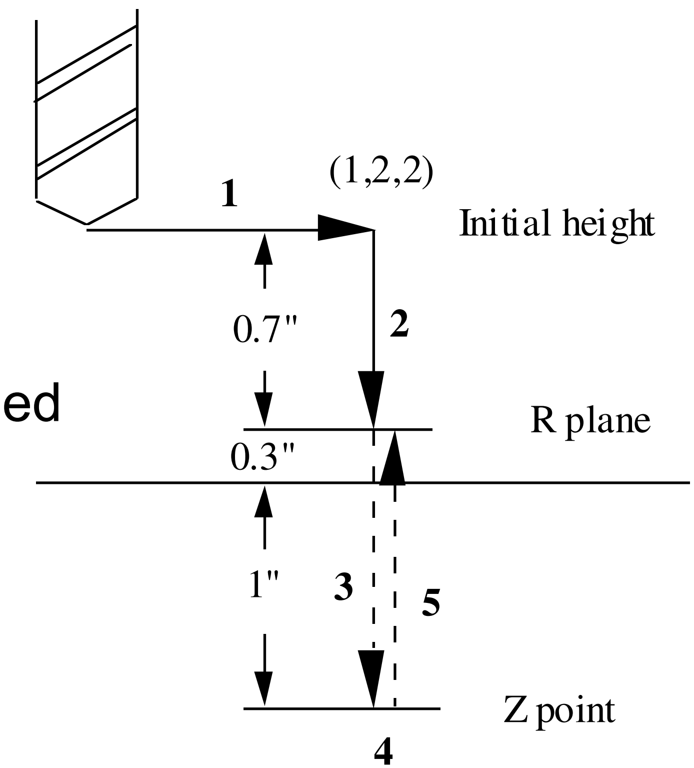
N0010 S1000

NC WORDS (continue)

T Code. tool number.

Actual tool change does not occur until a tool change M code is specified.

R Code. cycle parameter.



The cycle may be programmed in one block, such as: (cycle programming is vendor specific.)

N0010 G81 X1.000 Y2.000 Z0.000 R 1.300

NC WORDS (continue)

M Code. miscellaneous word.

Table 9.2. M code

m00	**Program stop**	**m06**	**Tool change**
m01	**Optional stop**	**m07**	**Flood coolant**
m02	**End of progra**	**m08**	**Mist coolant o**
m03	**Spindle CW**	**m09**	**Coolant off**
m04	**Spindle CCW**	**m30**	**End of tape**

MANUAL PART PROGRAMMING

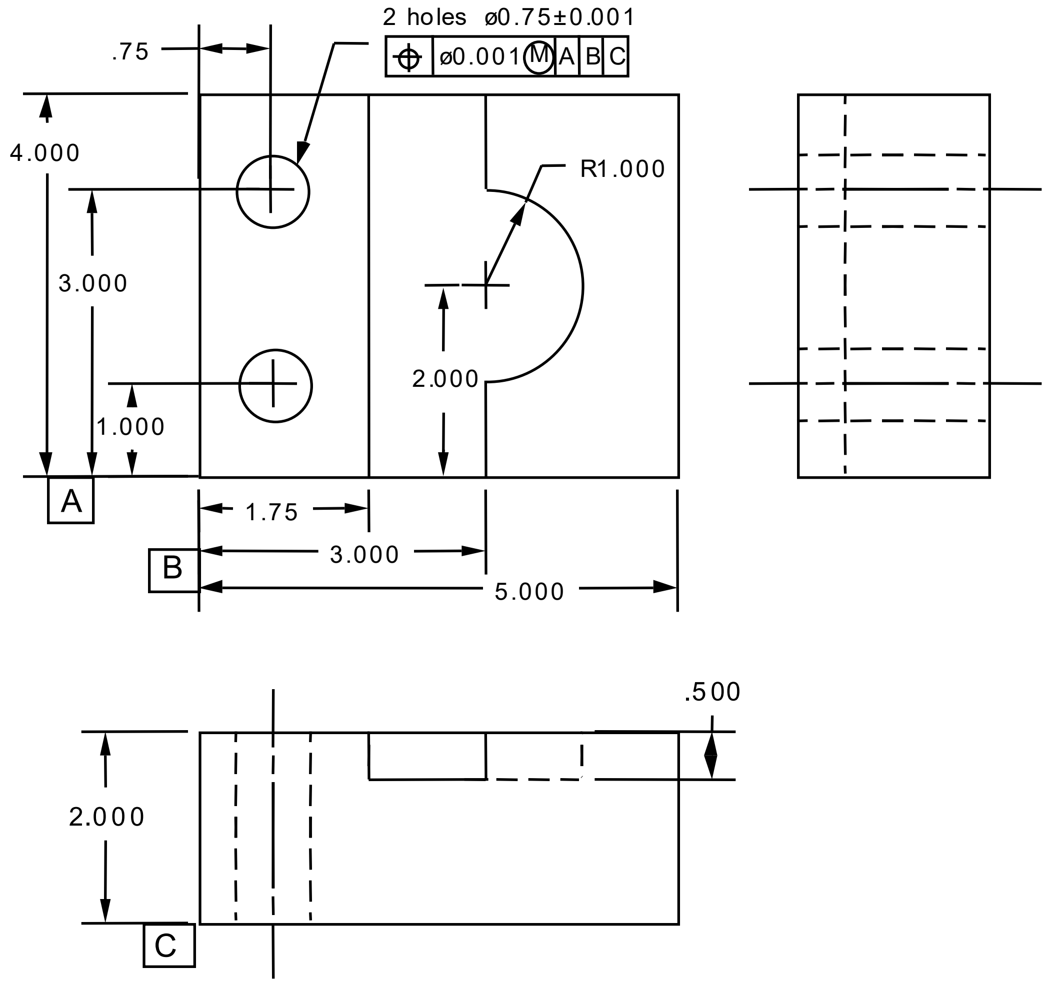
Example 9.1

Machined from a 5" x 4" x 2" workpiece. low carbon steel.

The process plan:

1. Set the lower left bottom corner of the part as the machine zero point (floating zero programming).
2. Clamp the workpiece in a vise.
3. Mill the slot with a 3/4" four flute flat end mill made of carbide. From the machinability data handbook, the recommended feed is 0.005 inch/tooth/rev, and the recommended cutting speed is 620 fpm.
4. Drill two holes with a 0.75" dia twist drill. Use 0.18 ipr feed and 100 fpm speed.

PART DRAWING



All dimension in inches. All tolerance ±0.001"

SOLUTION TO EXAMPLE

Solution:

The cutting parameters need be converted into rpm and ipm.

Milling:

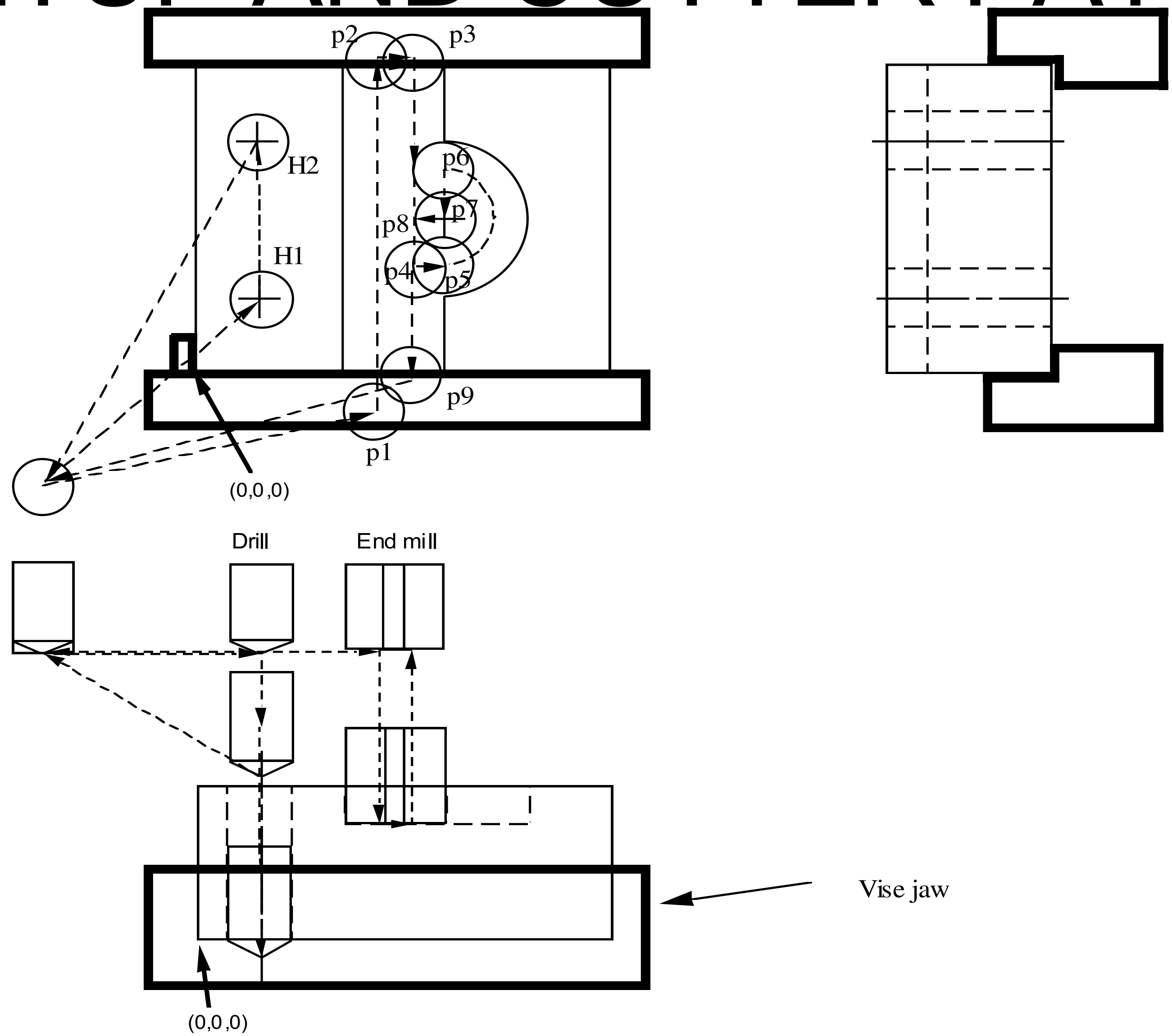
$$RPM = \frac{12\ V}{\text{B}D} = \frac{12 \text{ x } 620 \text{ fpm}}{\text{B}\, 0.75 \text{ inch}} = 3{,}157 \text{ rpm}$$

Drilling:

$$RPM = \frac{12\ V}{\text{B}D} = \frac{12 \text{ x } 100 \text{ fpm}}{\text{B}\, 0.75 \text{ inch}} = 509 \text{ rpm}$$

$$V_f = f\ RPM = 0.018\ ipr \text{ x } 509\ rpm = 9.16\ ipm$$

SETUP AND CUTTER PATH



CUTTER LOCATIONS

The coordinates of each point (cutter location) are calculated below:

p1': (1.75+0.375, -0.1-0.375, 4.00) = (2.125, -0.475, 4.000)

p1: (2.125,-0.475, 2.000-0.500) = (2.125,-0.475,1.500)

p2: (2.125,4.000+0.100,1.500) = (2.125,4.100,1.500)

p3: (3.000-0.375,4.100,1.500) = (2.625,4.100,1.500)

p4: (2.625,1.375,1.500)

p5: (3.000,2.000-1.000+0.375,1.500) = (3.000,1.375,1.500)

p6: (3.000,2.625,1.500)

p7: (3.000,2.000,1.500)

p8: (2.625,2.000,1.500)

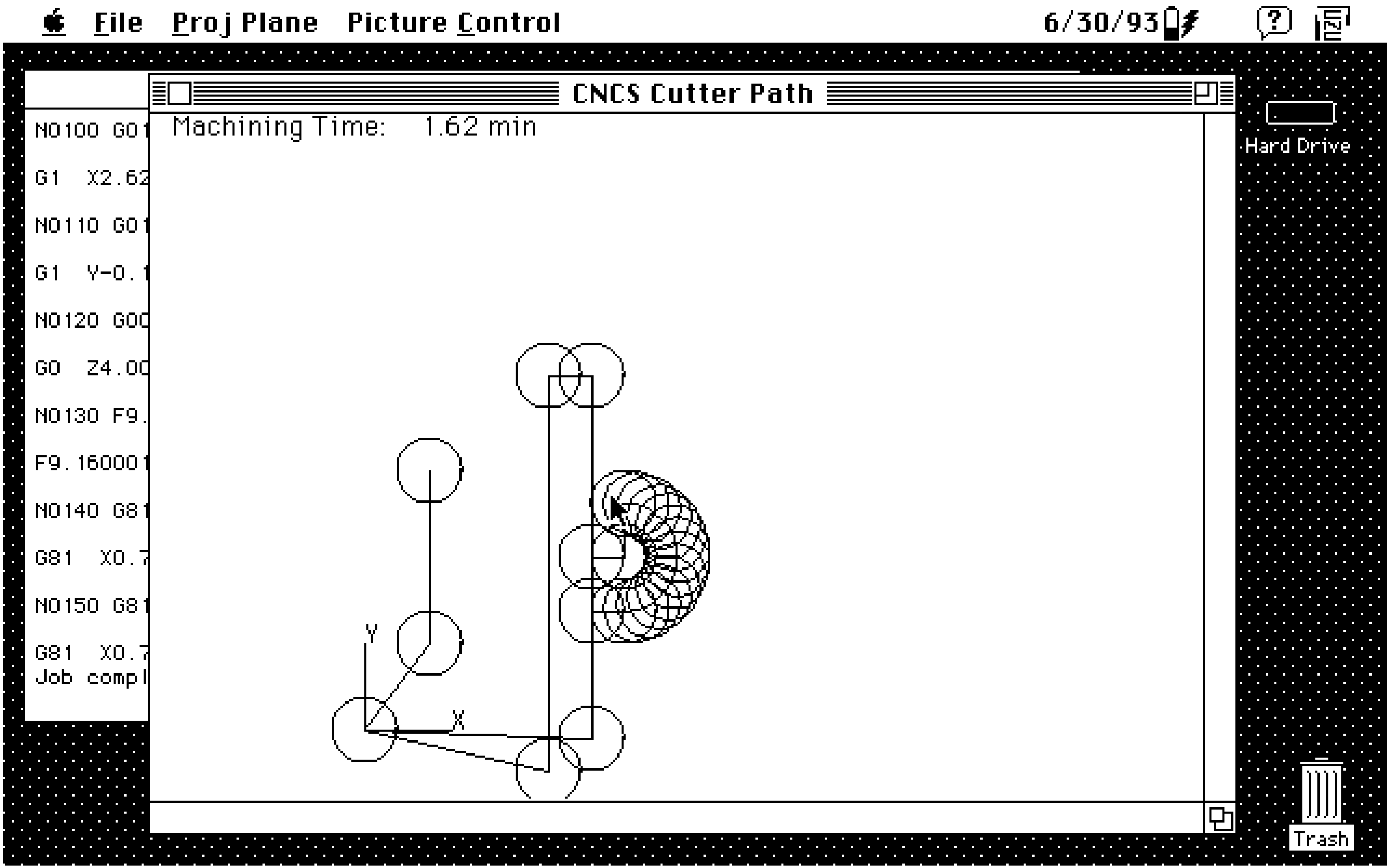
p9: (2.625,-0.100,1.500)

p9': (2.625,-0.100,4.000)

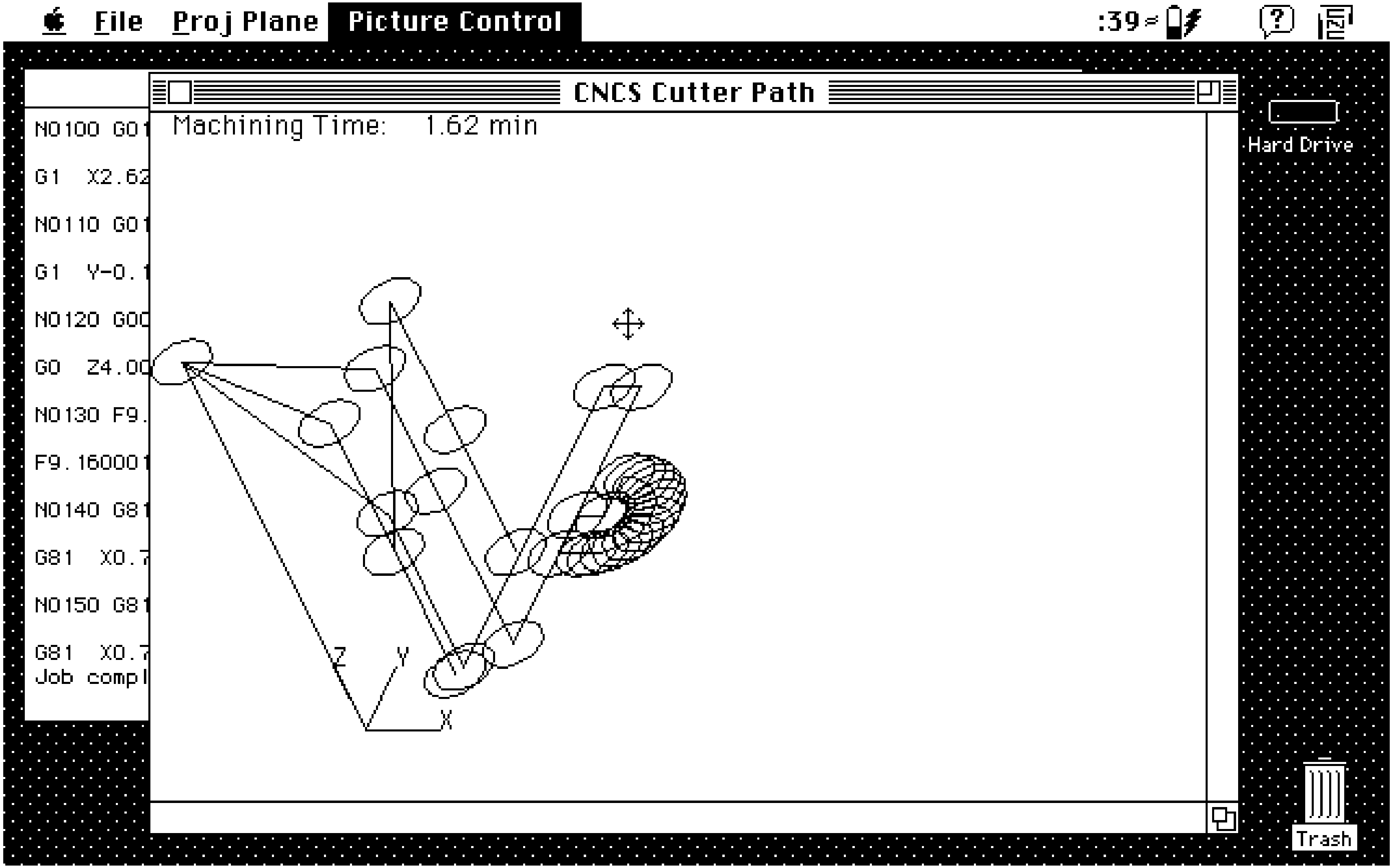
PART PROGRAM

Part program	Explanation
N0010 G70 G 90 T08 M06	Set the machine to inch format and absolute dimension programming.
N0020 G00 X2.125 Y-0.475 Z4.000 S3157	Rapid to p1'.
N0030 G01 Z1.500 F63 M03	Down feed to p1, spindle CW.
N0040 G01 Y4.100	Feed to p2.
N0050 G01 X2.625	To p3.
N0060 G01 Y1.375	To p4.
N0070 G01 X3.000	To p5.
N0080 G03 Y2.625 I3.000 J2.000	Circular interpolation to p6.
N0090 G01 Y2.000	To p7.
N0100 G01 X2.625	To p8.
N0110 G01 Y-0.100	To p9
N0120 G00 Z4.000 T02 M05	To p9', spindle off, tool #2.
N0130 F9.16 S509 M06	Tool change, set new feed and speed.
N0140 G81 X0.750 Y1.000 Z-0.1 R2.100 M03	Drill hole 1.
N0150 G81 X0.750 Y3.000 Z-0.1 R2.100	Drill hole 2.
N0160 G00 X-1.000 Y-1.000 M30	Move to home position, stop the machine.

CNCS VERIFICATION

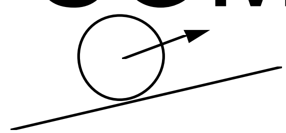


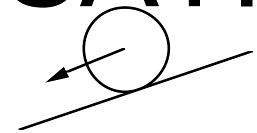
CNCS 3D DRAWING



TOOL-RADIUS COMPENSATION

Start of Compensation.

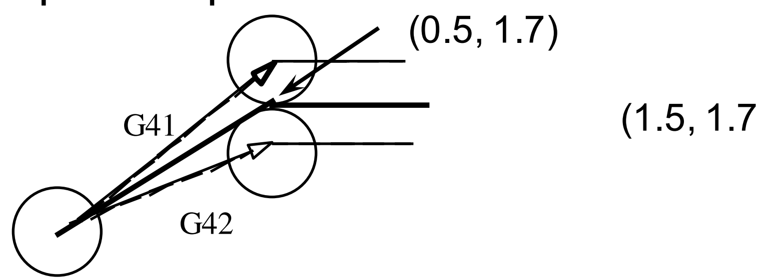

(a) G41


(b) G42

G41 (or G42) and G01 in the same block ramp takes place at block N0010.

N0010 G01 G42 X0.500 Y1.700

N0020 G01 X1.500

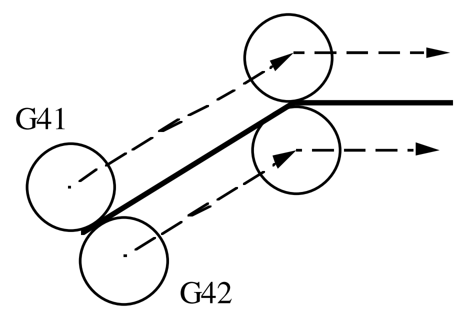


G41 (or G42) and G01 in separate blocks the compensation is effective from the start.

N0010 G41

N0020 G01 X0.500 Y1.700

N0030 G01 X1.500



TOOL-RADIUS COMPENSATION

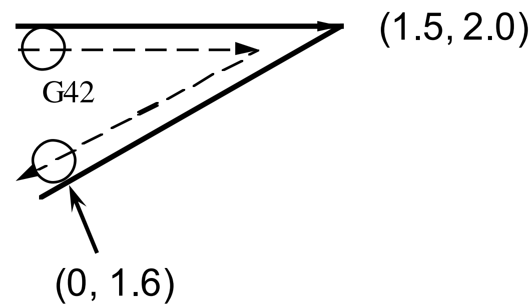
Inside Corner.

Cutter path is inside a corner, stops at the inside cutting point

N0010 G41

N0020 G01 X1.500 Y2.000

N0030 G01 X0.000 Y1.600



Use of M96 and M97.

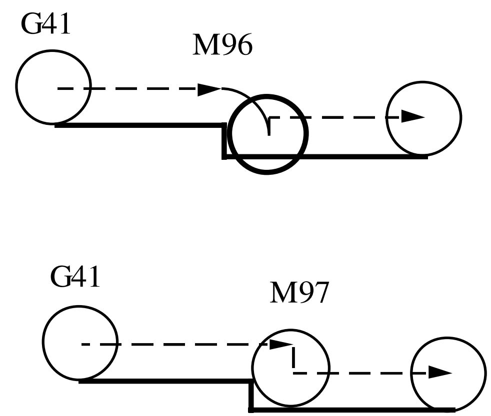
Cutting tool that is larger than the height of the step, M97 must be used

N0010 G41

N0020 G01 X1.000 Y1.000

N0030 G01 Y0.800 M97

N0040 G01 X2.000

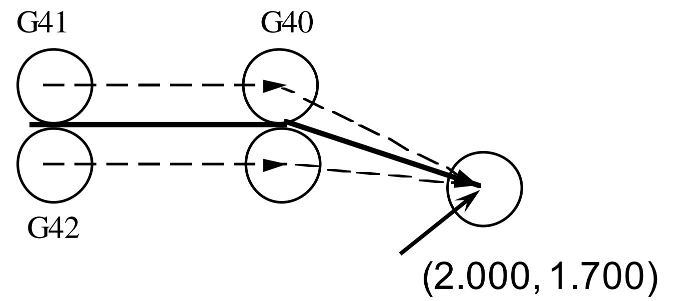


TOOL-RADIUS COMPENSATION

Cancel Tool Compensation.

G40 in the same block ramp off block.

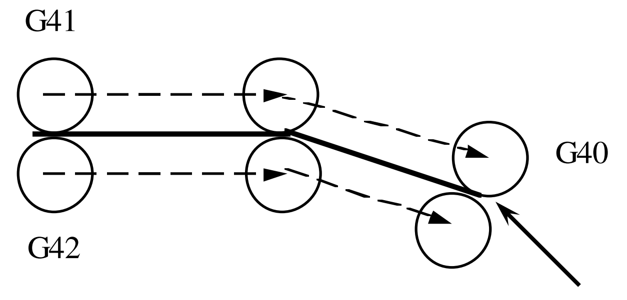
N0060 G40 X2.000 Y1.700 M02



G40 in a block following the last motion, the compensation is effective to the end point (2.000,1.700).

N0060 X2.000 Y1.700

N0070 G40 M02

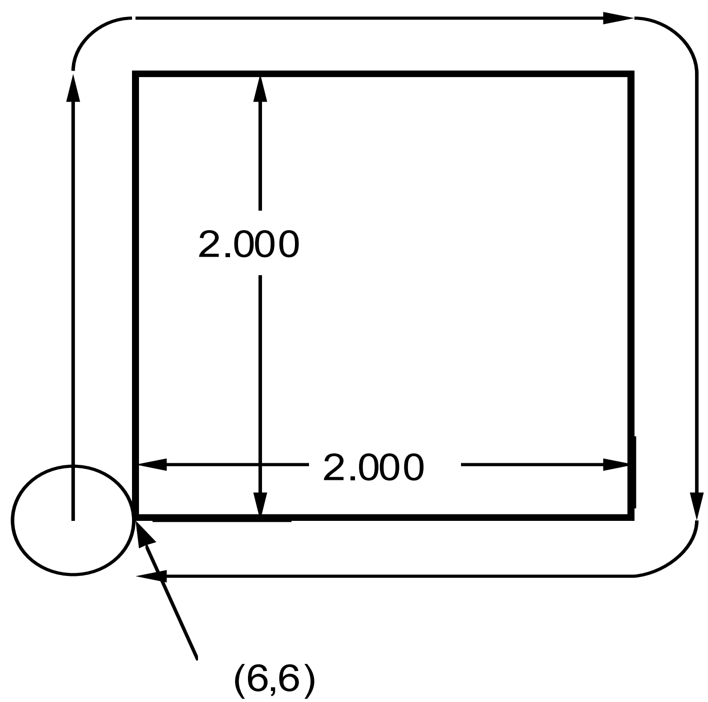


EXAMPLE

A square 2.0 in. x 2.0 in. is to be milled using a 1/2 in. end milling cutter. Write an NC part program to make the square.

Solution

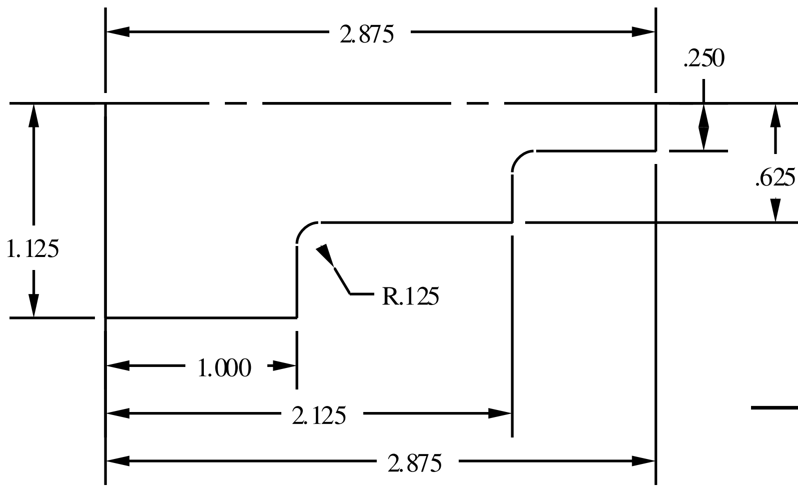
Let us set up the lower left corner of the square at (6.0,6.0). Using tool-radius compensation, the square can be produced.



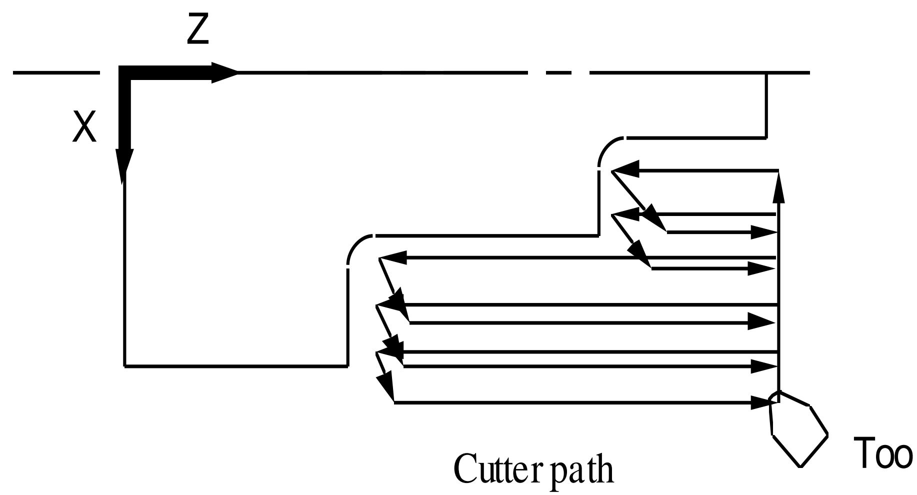
PART PROGRAM

Part Program	Explanation
N0010 G41 S1000 F5 M03 N0020 G00 X6.000 Y6.000 N0030 G01 Z-1.000 N0040 Y8.000 N0050 X8.000 N0060 Y6.000 N0070 X6.000 N0080 Z1.000 N0090 G40 M30	Begin compensation, set feed and speed, spindle on Move to lower left corner Plunge down the tool Cut to upper left corner Cut to upper right corner Cut to lower right corner Cut to lower left corner Lift the tool End compensation, stop the machine

TURNING

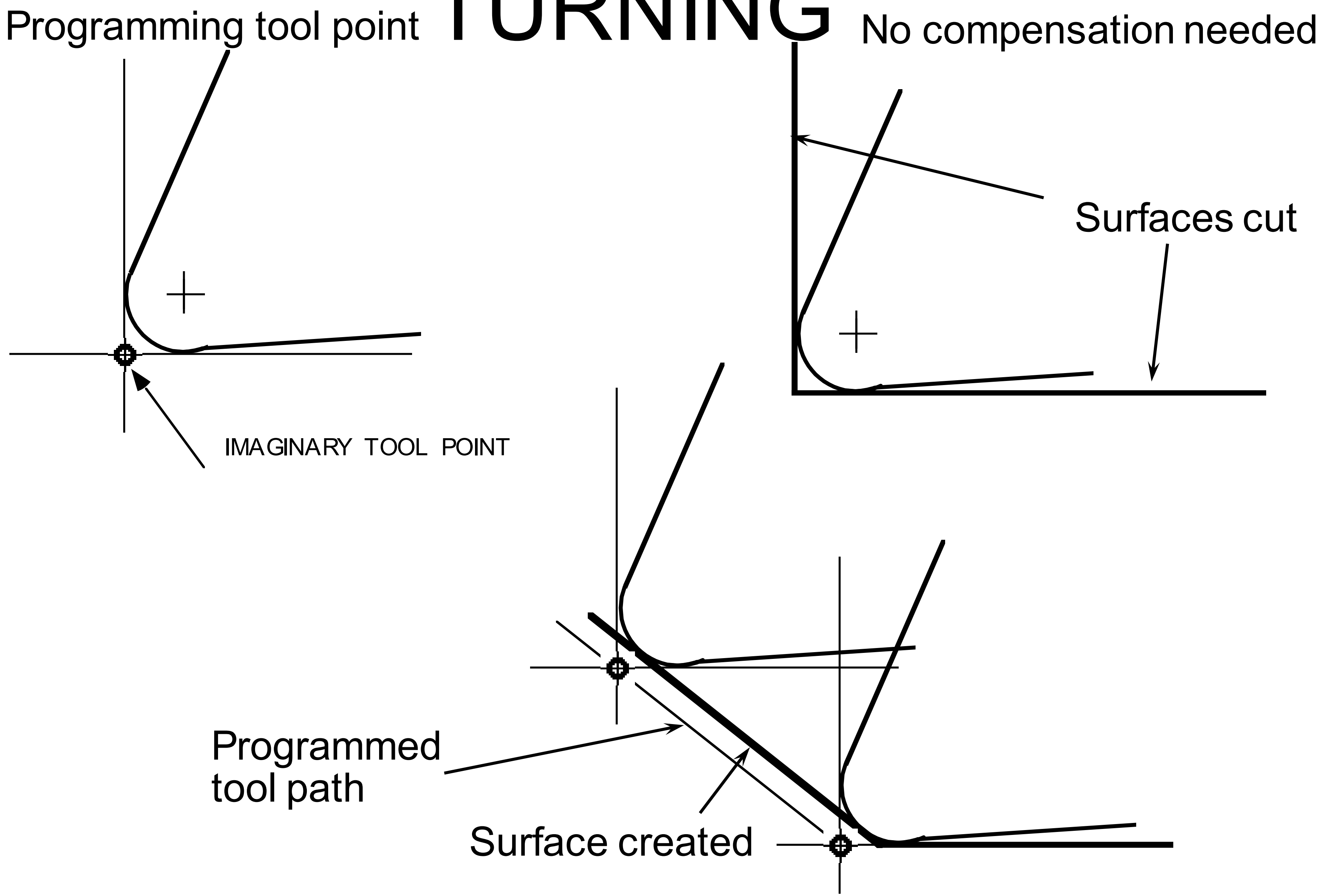


Part design



Cutter path

TURNING



Programming tool point
No compensation needed.
Surfaces cut
IMAGINARY TOOL POINT
Programmed tool path
Surface created

COMPUTER ASSISTED PART PROGRAMMING

Machine-oriented languages - machine specific

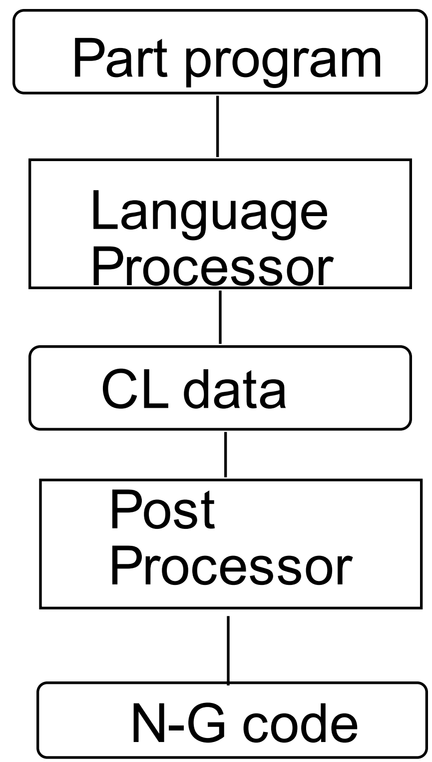
General-purpose languages - use post processors to generate machine specific code

Translate input symbols

Arithmetic calculation

Cutter offset calculations

Post processing



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BCL

RS-494

Thank You

Government Polytechnic Nanakpur

DEPARTMENT OF MECHANICAL ENGINEERING

E - NOTES

MACHINE DESIGN

HOD/O.I. (Mechanical) : **Sh.SHALANDER MOR**

Faculty Name: **Sh.Sanjay Kumar**

Semester: 5th Sem

By: Er. Amit Kumar

Designed, Mechanical Editing & Developmental Editing

LEARNING OUTCOMES

After undergoing this course, the students will be able to:

- Explain the terms related to design.
-
- Use codes and standards for designing a component.
-
- Select material for designing a component.
-
- Interpret the various causes of design failures.
-
- Design shaft on the basis of strength and rigidity.
-
- Design various machine elements (key, joint, flange coupling and screwed joints)

Machine Design:

Machine design is defined as the use of scientific principles, technical information & imagination in the description of a machine or a mechanical system to perform specific functions with maximum economy & efficiency.

Machine Design is defined as the creation of new design or improving the exist one

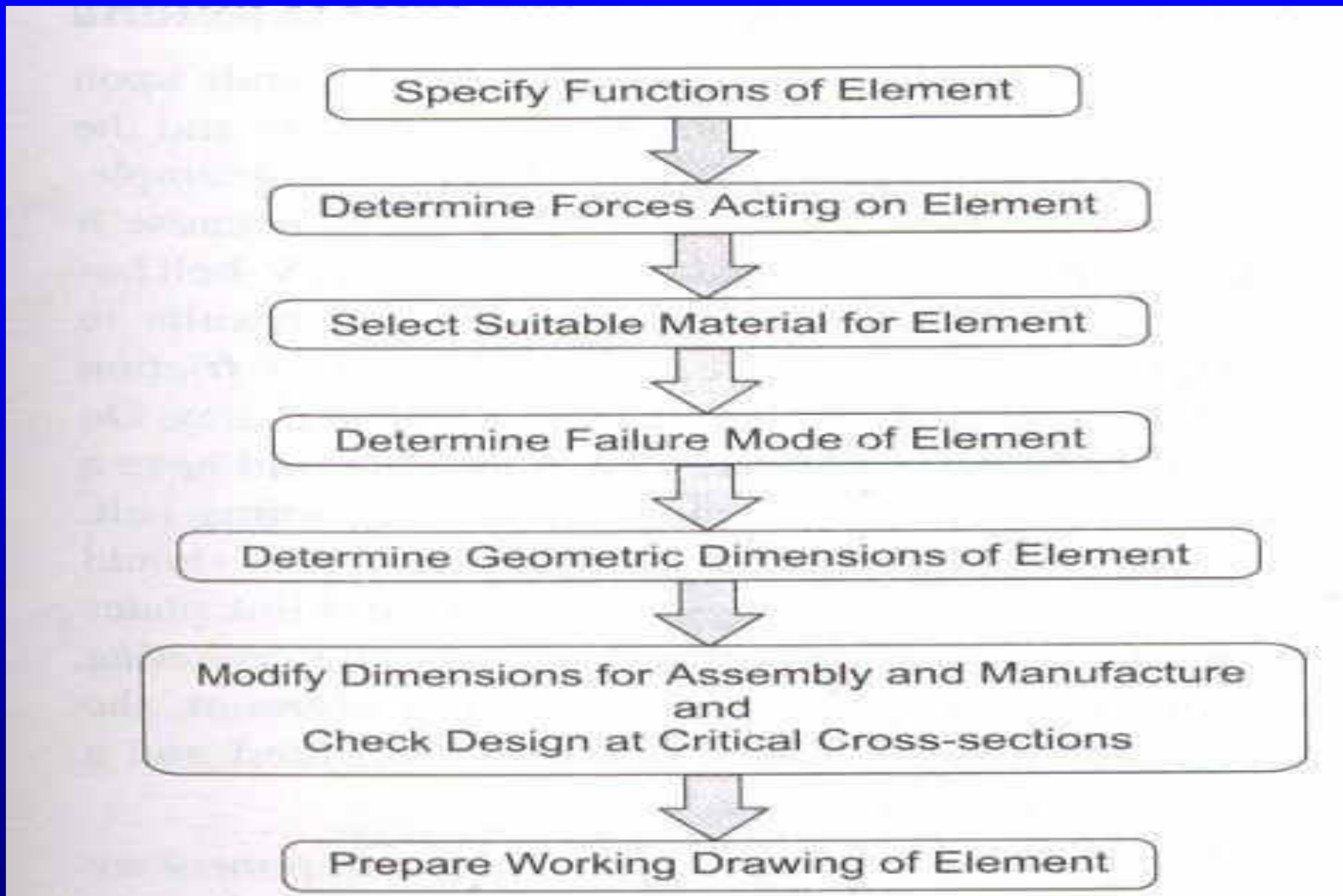
Basic Procedure of Machine Design

1. Market Survey
2. Define Specification of Product
3. Study alternative Mechanism for Product
   Select Proper Mechanism
4. Prepare General Layout of Configuration and Select joining method of individual Product
5. Design Individual Component
6. Prepare Assembly and Detail Drawings and Modify Drawing after Testing Prototype model

Basic Requirement of Machine Element

- Strength
- Rigidity
- Wear resistance
- Minimum Dimensions and Weight
- Manufacturability
- Safety
- Conformance to Standards
- Reliability
- Maintainability
- Minimum Life Cycle Cost

Basic Procedure of Design of Machine Elements



Design of Machine Elements

Specification of Function

–Specify Functions of Elements

–Determine Forces Acting on Element

–Select suitable Material for Element

–Determine failure mode of element

–Determine geometric dimensions of element

–Modify dimensions for assembly and manufacture and check design at critical cross section

–Prepare working drawing of element

Determination of Forces

Selection of material Failure criterion

Determination of dimensions

Design modifications

Working Drawing

Material Selection

- **Selection of proper material for the machine components is one of the most important steps in process of machine design**
- **The best material is one which will serve the *desired purpose at minimum costs***

Factors Considered while selecting the material:

i) ***Availability:*** **Material should be readily available in market in large enough quantities to meet the requirement**

Material Selection

ii)Cost:

iii)Mechanical properties: Manufacturing

Considerations:

In some applications machinability of material is an important consideration in selection

Where the product is of complex shape, castability or ability of the molten metal to flow into intricate passages is the criterion of material selection

In fabricated assemblies of plates & rods, weldability becomes the governing factor

Properties of Material

- ***Strength:*** **Ability of the material to resist, without rupture, external forces causing various types of stresses**
- ***Elasticity:*** **Ability to regain its original shape & size after deformation, when the external forces are removed**
- ***Plasticity:*** **Ability to retain the deformation produced under the load on a permanent basis**
- ***Stiffness or Rigidity:*** **Ability to resist deformation under the action of an external load**

Properties of Material

- ***Toughness:*** **Ability to absorb energy before fracture takes place**
- ***Malleability:*** **Ability to deform to a greater extent before the sign of crack, when it is subjected to compressive force**
- ***Ductility:*** **Ability to deform to a greater extent before the sign of crack, when subjected to tensile force**
- ***Brittleness:*** **Property of the material which shows negligible plastic deformation fracture takes place**
- ***Hardness:*** **Resistance to penetration or permanent deformation**

Cast Iron

Cast iron is an alloy of iron & carbon, containing more than 2% of carbon

- Typical composition of ordinary cast iron

is: Carbon = 3-4%

Silicon = 1-3%

Manganese = 0.5-1% Sulphur = up to 0.1%

Phosphorous = up to 0.1% Iron =

Remainder

Cast Iron

Advantages:

Available in large quantities, higher compressive strength,

components can be given any complex shape without involving costly machining operations,

excellent ability to damp vibrations,

more resistance to wear even under the conditions of boundary lubrication,

mechanical properties of parts do not change between room temperature and 350 degree centigrade

Engineering Material

Plain Carbon Steel

Depending upon the percentage of carbon, plain carbon steels are classified as:

i) *Low carbon steel* – Less than 0.3% carbon, popularly known as mild steel, its soft & ductile, easily machined & welded, however due to low carbon content unresponsive to heat treatment

ii) *Medium carbon steel* – carbon content in the range of 0.3% to 0.5%, popularly known as machinery steel, easily hardened by heat treatment , stronger & tougher than low carbon steel, well machined, respond readily to heat treatment

Engineering Material

Plain Carbon Steel

iii) *High carbon steel* – more than 0.5% carbon, popularly known as hard steels or tool steels, respond readily to heat treatment, when heat treated attain high strength combined with hardness, less ductile than low carbon steels & medium carbon steels, difficult to weld, excessive hardness accompanied by excessive brittleness

In applications like automobile bodies & hoods, the ability of the material to deform to a greater extent or 'ductility' is the most important consideration so a plain carbon is preferred

Engineering Material

Plain Carbon Steel

In applications like gears, machine tool spindles & transmission shaft, strength toughness & response to heat treatment are important considerations, medium & high carbon steels are preferred

Spring wires are subjected to severe stress & strength is the most important consideration so high carbon steel is selected for helical & leaf springs

Alloy Steel

- **Carbon steel to which one or more alloying elements are added to obtain certain beneficial effects**
- **The commonly added elements include *silicon, manganese, nickel, chromium, molybdenum and tungsten***
- **The term 'alloy steels' usually refers to 'low' alloy steels containing from *1-4%* of alloying elements**
- **Alloy steels have higher strength, hardness & toughness, higher hardenability, retain their strength & hardness at elevated temperatures, higher resistance to corrosion and oxidation**

Engineering Material

Alloy Steel

-*Silicon* increases strength & hardness without lowering the ductility. Silicon is added in spring steel to increase its toughness

-*Manganese* increases hardness and toughness and also increases the depth of hardening

-*Nickel* increases strength, hardness and toughness without sacrificing ductility

-*Chromium* increases hardness & wear resistance, steel containing more than 4% chromium have excellent corrosion resistance

-*Molybdenum* increases hardness & wear resistance, resists softening of steel during tempering and heating

Manufacturing considerations in Machine design

Manufacturing Processes

Primary shaping processes. The processes used for the preliminary shaping of the machine component are known as primary shaping processes. The common operations used for this process are casting, forging, extruding, rolling, drawing, bending, shearing, spinning, powder metal forming, squeezing, etc.

Machining processes. The processes used for giving final shape to the machine component, according to planned dimensions are known as machining processes. The common operations used for this process are turning, planning, shaping, drilling, boring, reaming, sawing, broaching, milling, grinding, hobbing, etc.

Surface finishing processes. The processes used to provide a good surface finish for the machine component are known as surface finishing processes. The common operations used for this process are polishing, buffing, honing, lapping, abrasive belt grinding, barrel tumbling, electroplating, super finishing, sheradizing, etc

Joining processes. The processes used for joining machine components are known as joining processes. The common operations used for this process are welding, riveting, soldering, brazing, screw fastening, pressing, sintering, etc.

Processes effecting change in properties. These processes are used to impart certain specific properties to the machine components so as to make them suitable for particular operations or uses. Such processes are heat treatment, hot-working, cold-working and shot peening.

Factor of Safety-It is defined, in general, as the ratio of the maximum stress to the working stress.

Mathematically- Factor of safety = Maximum stress/ Working or design stress

Factor of safety = Yield point stress/ Working or design stress, In case of ductile materials e.g. mild steel, where the yield point is clearly defined, the factor of safety is based upon the yield point stress. In such cases,

Factor of safety = Ultimate stress/ Working or design stress

In case of brittle materials e.g. cast iron the factor of safety for brittle materials is based on ultimate stress.

Assembly and Cost

Standards and codes

Standardization is defined as obligatory norms, to which various characteristics of product a should conform. The include characteristics materials, dimensions of component shape, methods of testing and method of marking, packing and storing of products

Standards for shapes and dimensions of commonly used machine elements

Standards for fits, tolerances and surface finish of component

Standards for engineering drawing of components

Standards for materials, their chemical compositions, mechanical properties and heat treatment For Example. IS 210 specifies seven grade of grey cast iron designated as FG150,FG200,FG220,FG260,FG300,FG350 and FG400 the number indicates Ultimate tensile strength in N/mm2

Use of preferred series,

The size of product is general term, which includes different parameters like power transmitting capacity, load carrying capacity, speed, and dimensions of the component such as height, length and width and volume of product. These parameters expressed numerically, e.g. 5kw, 10kw, or 1000 rpm

Preferred numbers are used to specify the 'size' of the product in these cases.

The system is based on the use geometric progression to develop a set of numbers

There are five basic series denoted as R5, R10, R20, R40, and R80 series which increases in steps of 56%, 26%, 12%, 6% and 3% respectively

Each series has its own series factor as shown below

R5 Series	$\sqrt[5]{10} = 1.58$
R10 Series	$\sqrt[10]{10} = 1.26$
R20 Series	$\sqrt[20]{10} = 1.12$
R40 Series	$\sqrt[40]{10} = 1.06$
R80 Series	$\sqrt[80]{10} = 1.03$

Factor of safety

Is used to provide a **design margin** over the **theoretical design**

capacity to allow for uncertainty in the design process.

In the calculations, Material strengths, Manufacturing process

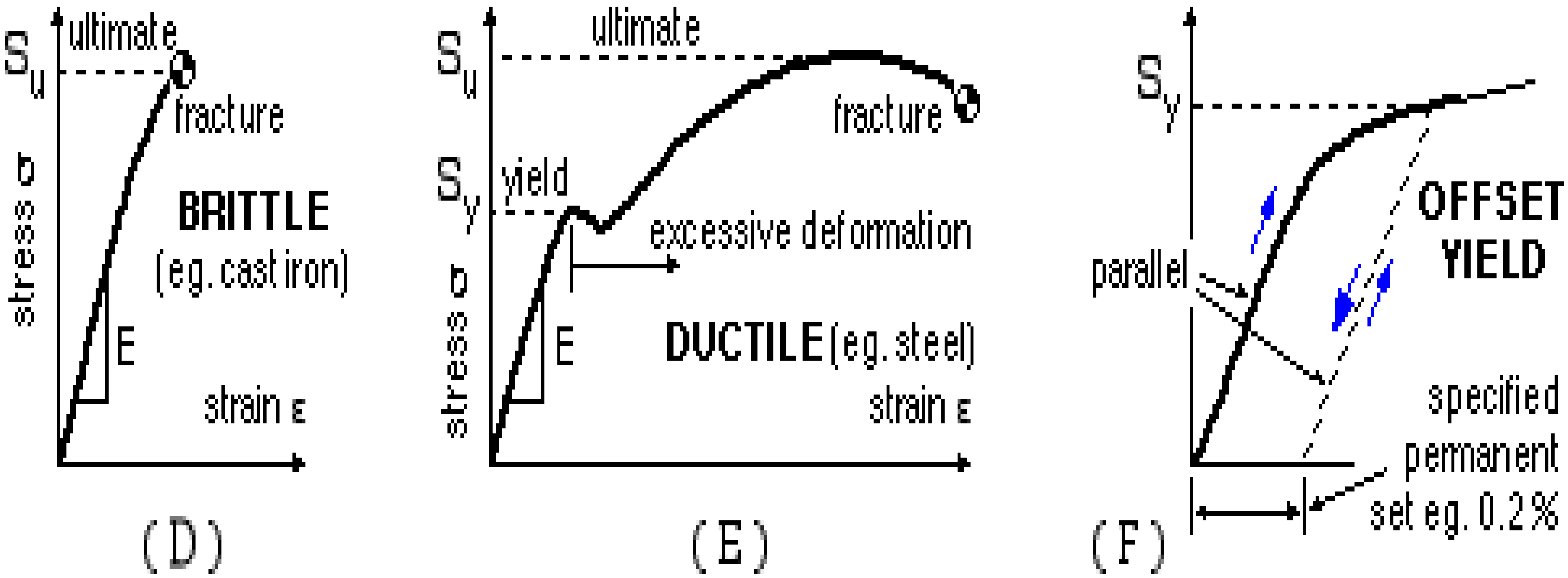
FoS = Strength of the component (Max load) Load on the component (Actual load)

Factor of Safety (Safety Factor)

FoS (Based on yeild strength)	Application
1.25 – 1.5	Material properties known in detail Operating conditions known in detail Load and the resulting stresses and strains are known to a high degree of accuracy Low weight is important
2 – 3	For less tried materials or Brittle materials under average conditions of environment, load and stress
3 – 4	For untried materials under average conditions of environment, load and stress Better known materials under uncertain environment or uncertain stresses

Above FoS should consider fatigue strength, Impact shock forces, Vibration, Brittle materials

Factor of Safety (Safety Factor)



$$\text{FoS} = \frac{\text{Strength of the component } (S_u, S_y)}{\text{Stress in the component due to the actual load}}$$

Factor of Safety (Safety Factor)

- How critical that component is
- The cost factor (cost of material, manufacture)
- Whether failure could cause serious injury or death (a steam boiler or pressure vessel would use 8 – 10 FoS)
- Unknown stresses in the manufacturing process (casting would use 10 – 14 FoS)
- Environmental conditions (used in harsh environment or not)
- Knowledge of the environment
- Knowledge of the properties of the material used
- Knowledge of the loads (tension, compressive, shear, bending, cyclic loads, impact loads etc)
- Weight factor (aerospace 1.5 – 3 to reduce weight but strict quality control)
- Quality control, maintenance

Service factor

Overload capacity built into a component, device, engine, motor, etc., as a safety factor. It is expressed usually a number greater than one: a SF of 1.15 means the item can take 15 percent more load than its rated capacity without breakdown.

A multiplier which when applied rated power, indicates permissible power loading that may be carried under the condition specified for service factor

Introduction: Machine Elements

- Springs
- Fasteners
- Bearings
- Shafts
- Gears

Machined

Universal Joint

Coiled

Cotter joint

- Cotter joint is used to connect two rods subjected to axial tensile or compressive loads.
- It is not suitable to connect rotating shafts which transmit torque.
- Axes of the rods to be joined should be collinear. There is no relative angular movement between rods.
- Cotter joint is widely used to connect the piston rod and crosshead of a steam engine, as a joint between the piston rod and the tailor pump rod, foundation bolt etc.

COTTER JOINTS

Temporary fastening and is used to connect rigidly ***two co-axial rods or bars*** which are subjected to ***axial tensile or compressive types of load.***

Flat wedge shaped piece of rectangular cross-section and its width is tapered (either on one side or both sides) from one end to another for an easy adjustment.

Taper varies from 1 in 48 to 1 in 24 and may be increased up to 1 in 8, if a locking device is provided.

The locking device: taper pin or a set screw.

Material: Mild Steel or Wrought Iron

Applications: Cross-head of a reciprocating steam engine, piston rod and its extension as a tail or pump rod, strap end of connecting rod etc.

Types of Cotter Joints:

1. Socket and Spigot Cotter Joint
2. Sleeve and Cotter Joint
3. Gib and Cotter Joint

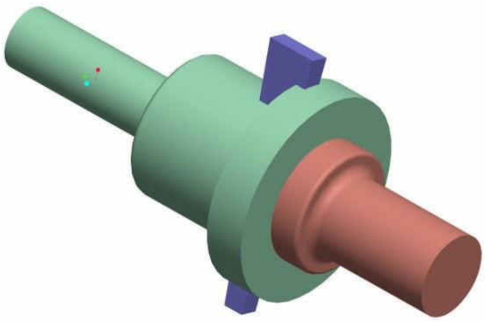


FIG 01: ASSEMBLED COTTERED JOINT

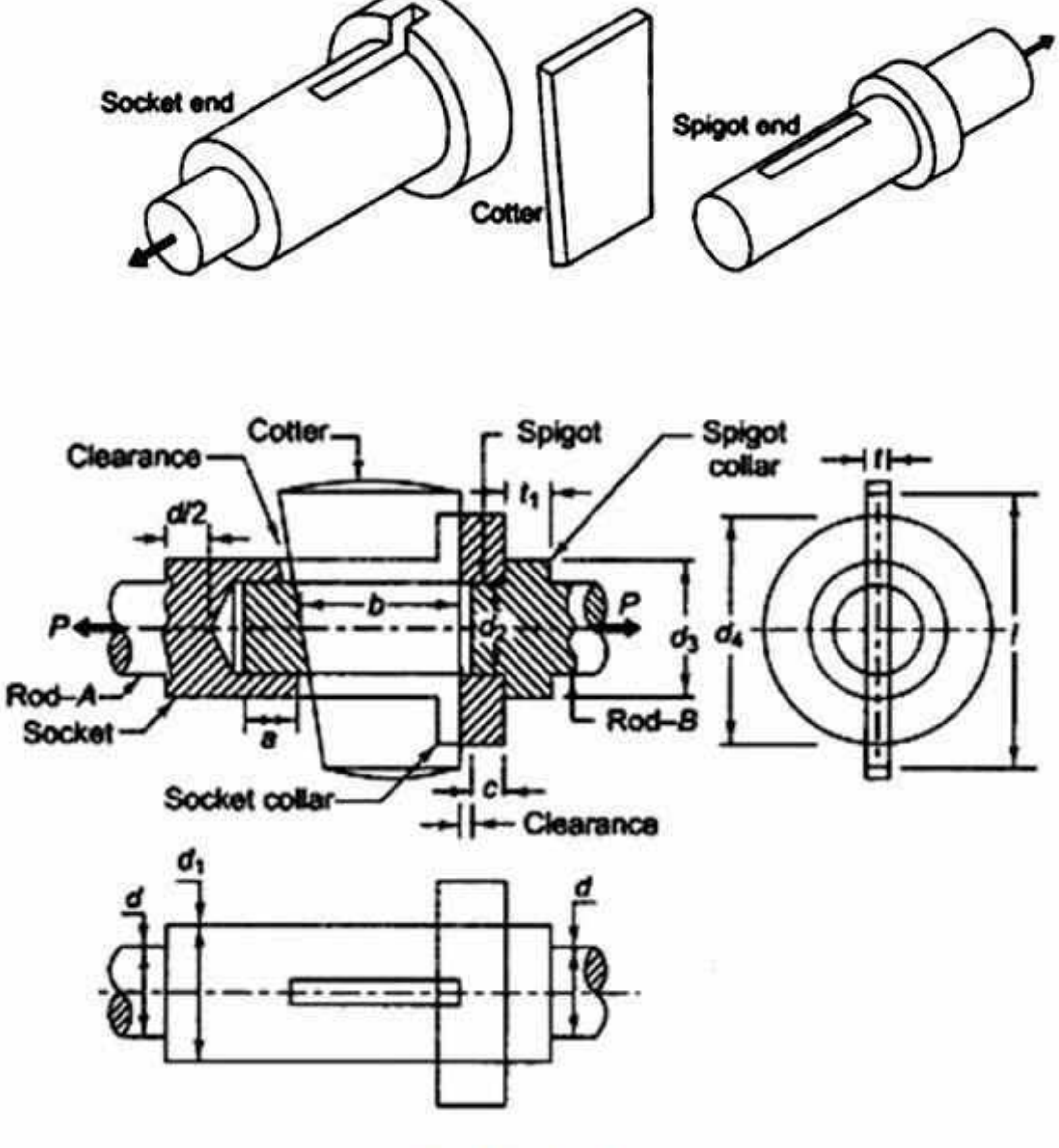
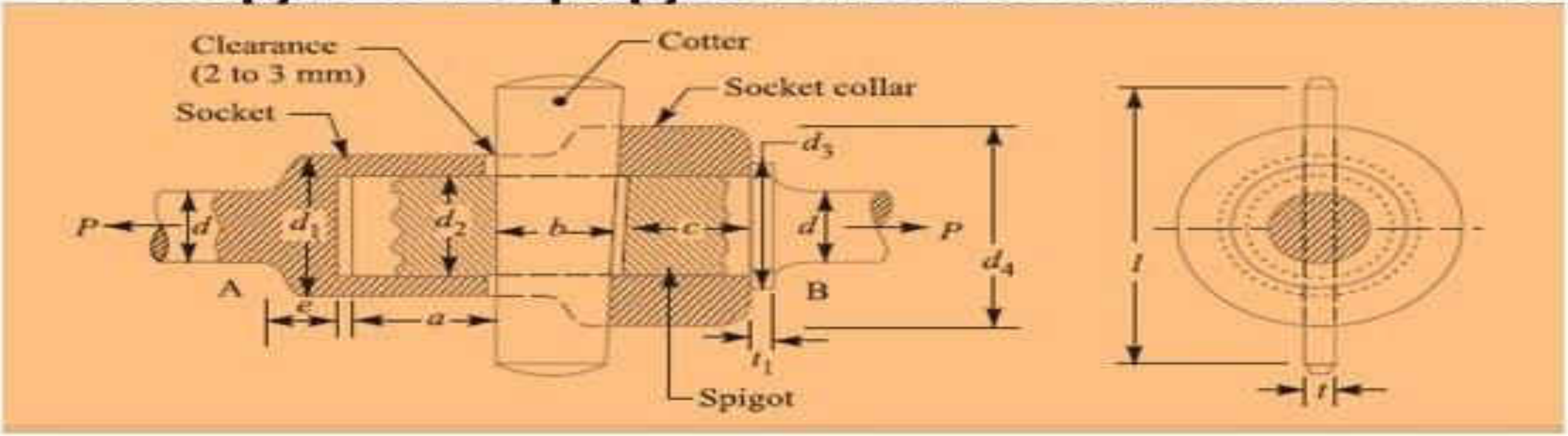


Figure 9.1 Cotter Joint

- Cotter Joint has mainly three components – spigot, socket and cotter as shown in Figure
- Spigot is formed on one of the rods and socket is formed on the other.
- The socket and the spigot are provided with a narrow rectangular slot.
- The cotter is tightly fitted in this slot. Spigot fits inside the socket and the cotter is passed through both the socket and the spigot
- A cotter is a wedge shaped piece made of a steel plate. It has uniform thickness and the width dimension is given a slight taper.
- cotter becomes tight in the slot due to wedge action.

Design of Spigot and Socket Cotter



Let *P = Load carried by the rods,*
d = Diameter of the rods,
d1 = Outside diameter of socket,
d2 = Diameter of spigot or inside diameter of socket,
d3 = Outside diameter of spigot collar,
t1 = Thickness of spigot collar,
d4 = Diameter of socket collar,
c = Thickness of socket collar,
b = Mean width of cotter,
t = Thickness of cotter,
l = Length of cotter,
a = Distance from the end of the slot to the end of rod,
σt = Permissible tensile stress for the rods material,
τ = Permissible shear stress for the cotter material, and
σc = Permissible crushing stress for the cotter material.

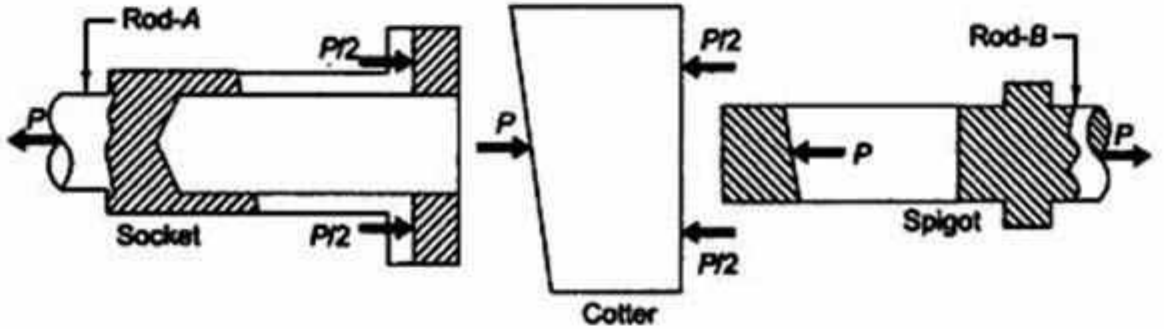


Figure 9.2 Free Body Diagrams of Different Components of Knucle Joint, subjected to Tensile Load

Notations Used :

d = diameter of each rod (mm)

d_1 = outside diameter of socket (mm)

d_2 = diameter of spigot or inside diameter of socket (mm) d_3 = diameter of spigot-collar (mm)

d_4 = diameter of socket-collar (mm)

a = distance from end of slot to the end of spigot on rod-B (mm) b = mean width of cotter (mm)

c = axial distance from slot to end of socket collar (mm) t = thickness of cotter (mm)

t_1 = thickness of spigot collar (mm)

l = length of cotter (mm)

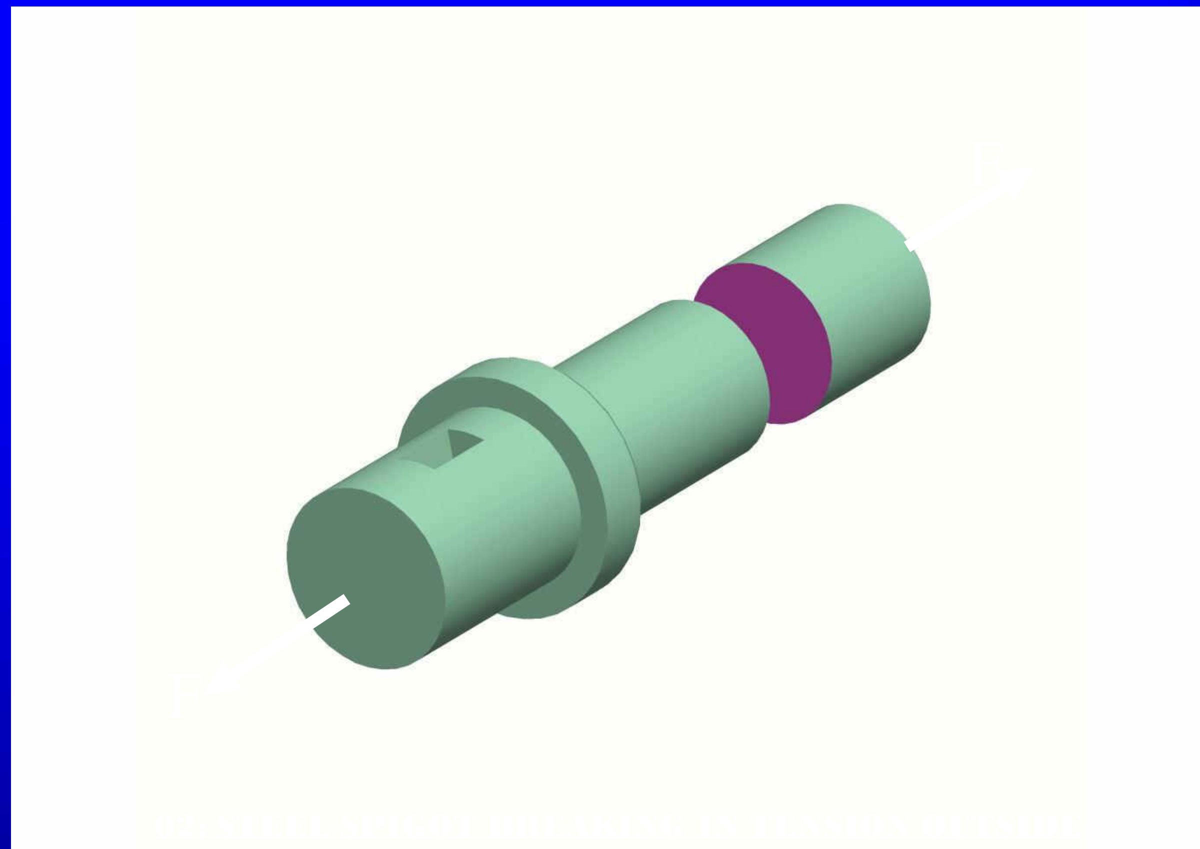
Assumption for stress analysis of Cotter Joint :

-The rods are subjected to axial tensile force.

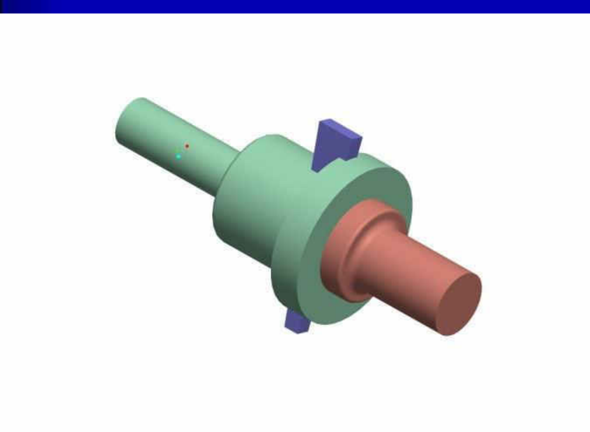
-The effect of stress concentration due to holes is neglected

-The force is uniformly distributed in different parts.

Cotter joint – modes of failure



JOINT



Cotter joint – modes of failure

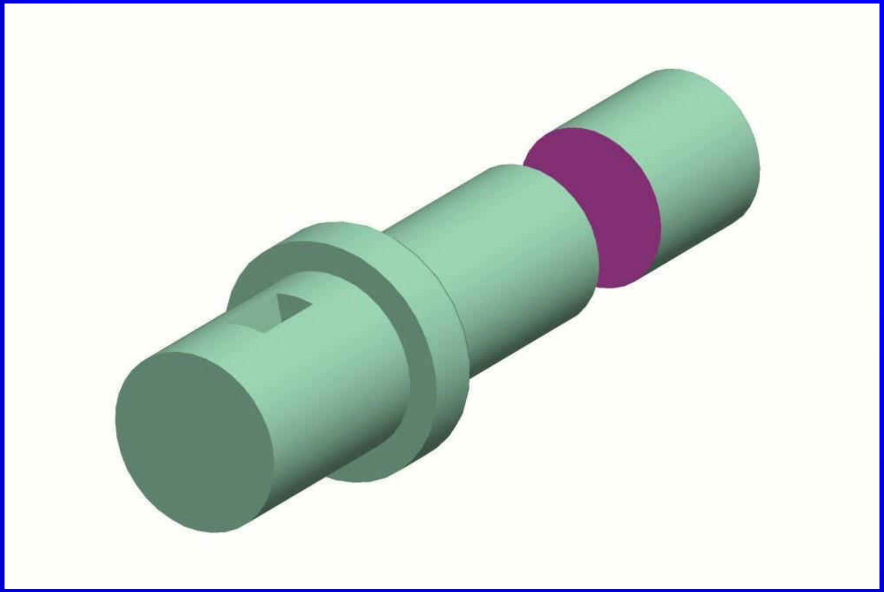


FIG 02: STEEL SPIGOT BREAKING IN TENSION OUTSIDE THE JOINT

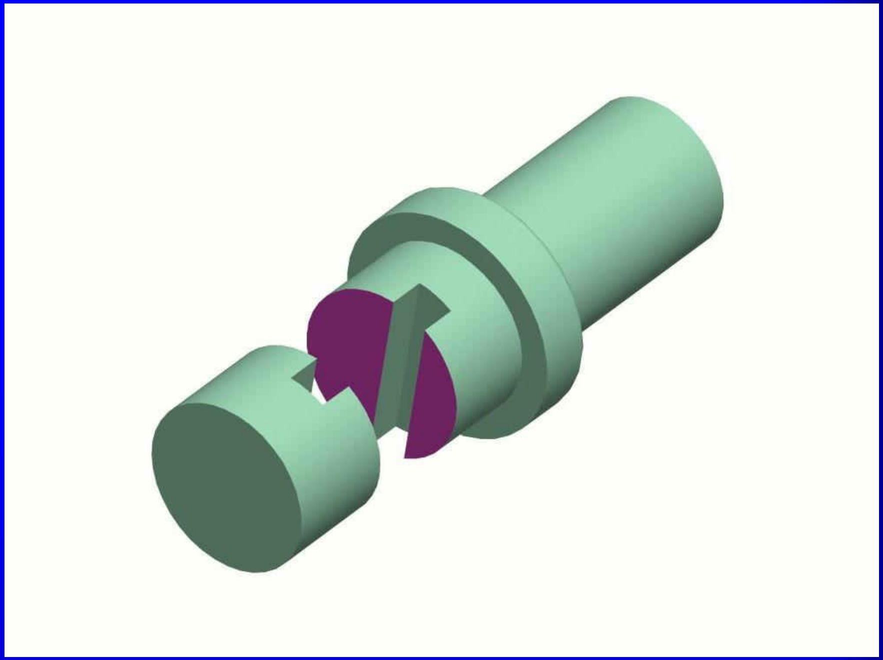
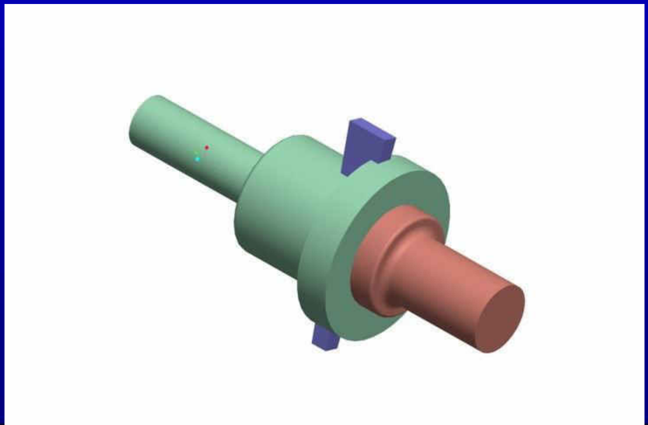
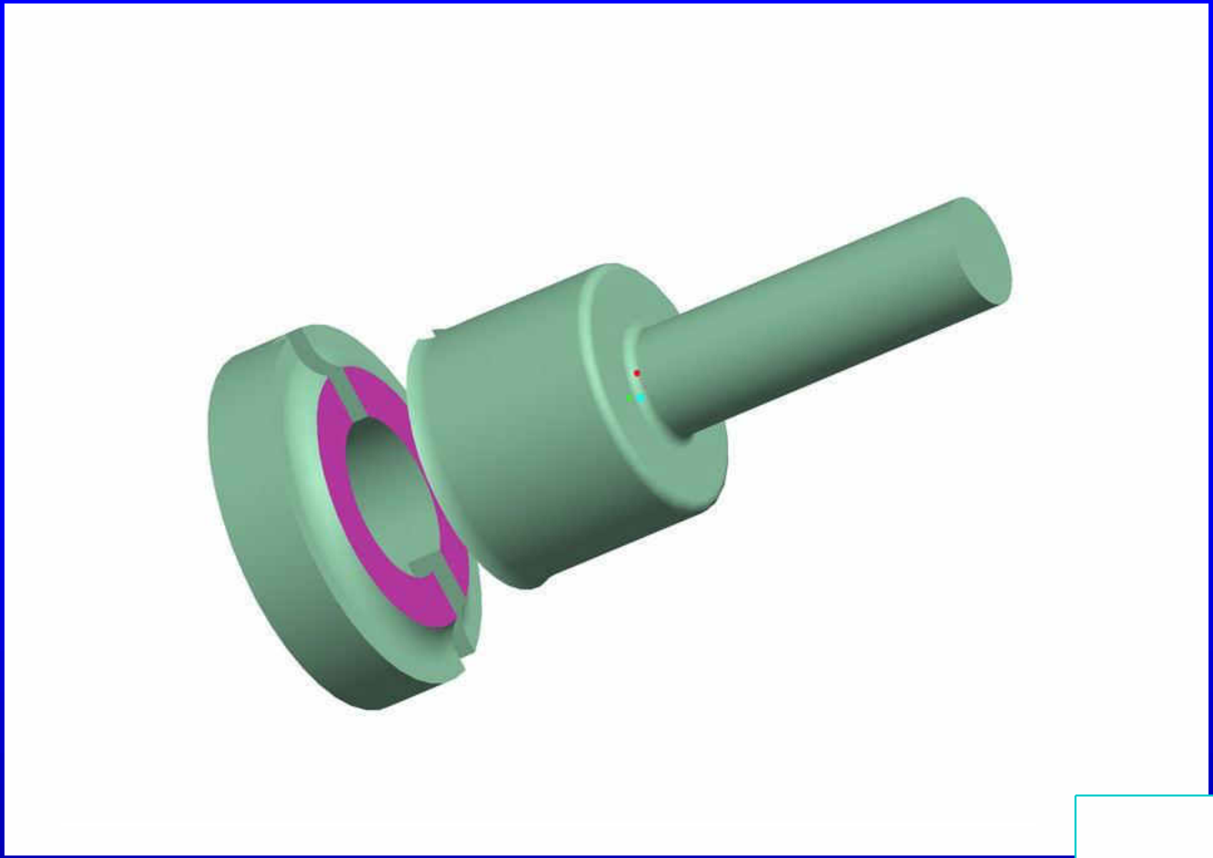


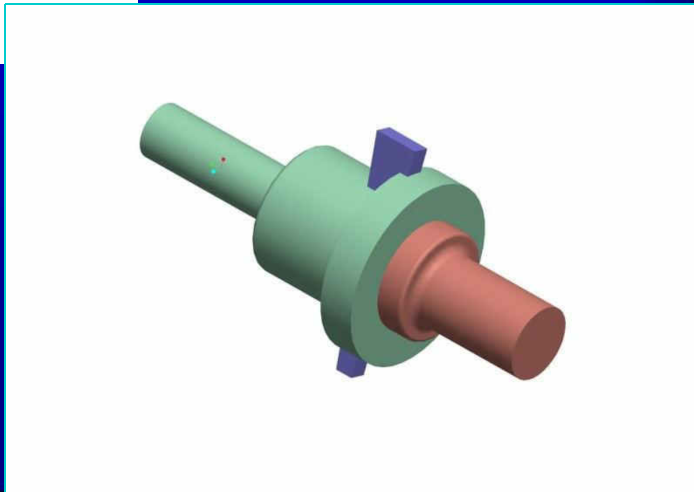
FIG 05: SPIGOT BREAKING IN TENSION ACROSS SLOT

WROUGHT IRON ROD BREAKING IN TENSION OUTSIDE THE JOINT



Cotter joint – modes of failure





Cotter joint – modes of failure

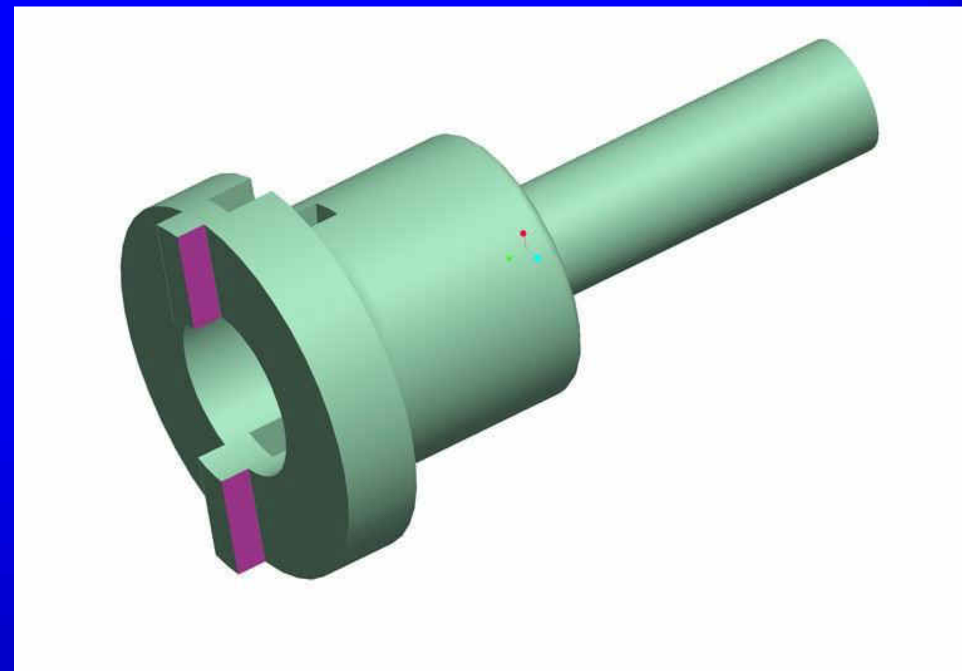


FIG 09: DOUBLE SHEARING OF SOCKET END

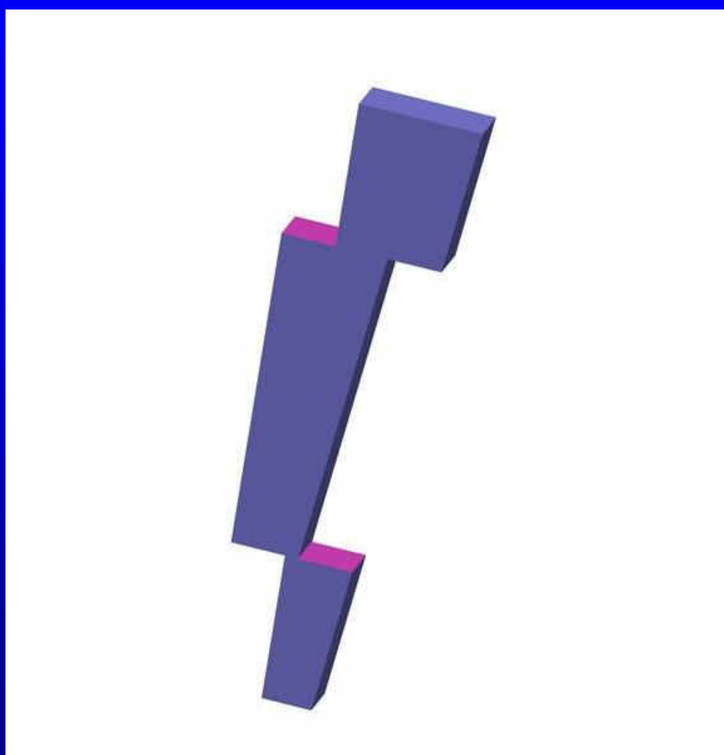
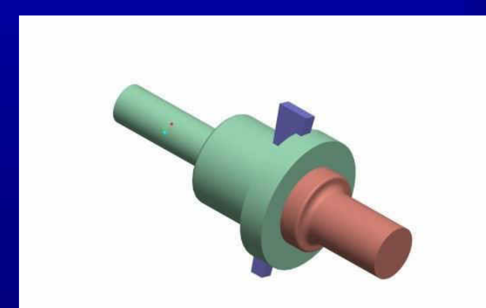
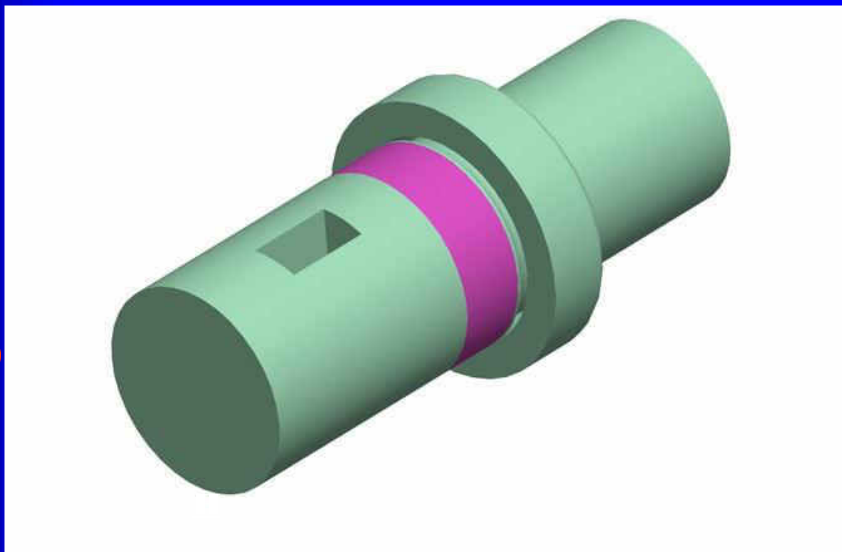


FIG 06: DOUBLE SHEARING OF COTTER PIN



Cotter joint – modes of failure



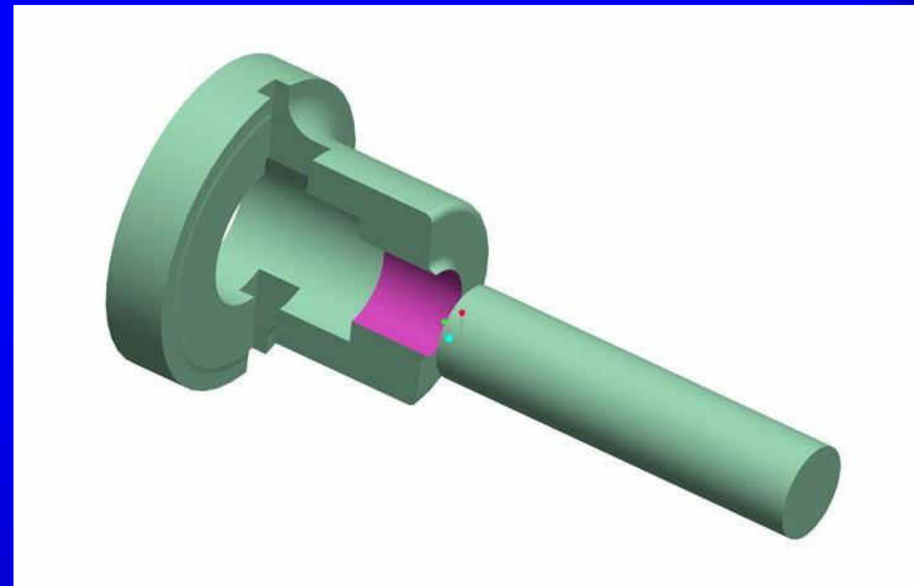
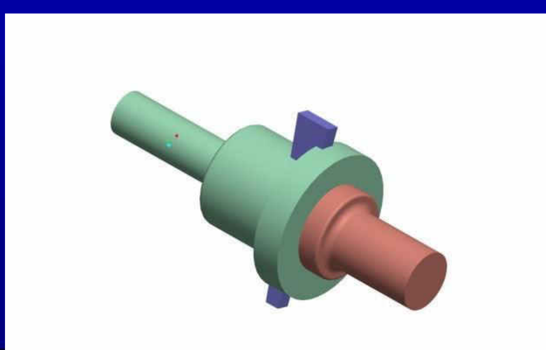


FIG 12: SHEARING AWAY OF SOCKET (IF $d_w < d_1$)



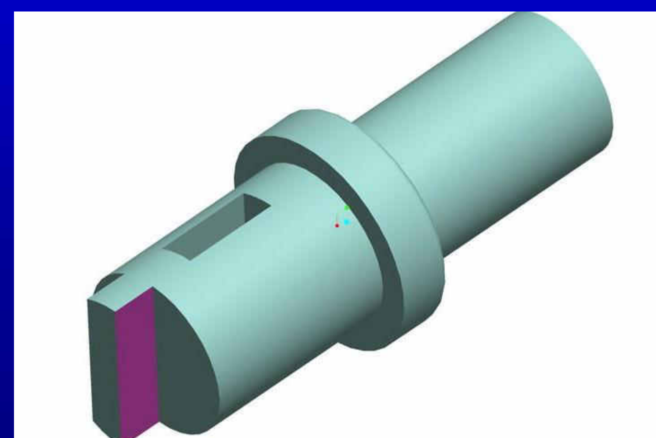


FIG 10: SHEARING OF SPIGOT END

Cotter joint – modes of failure

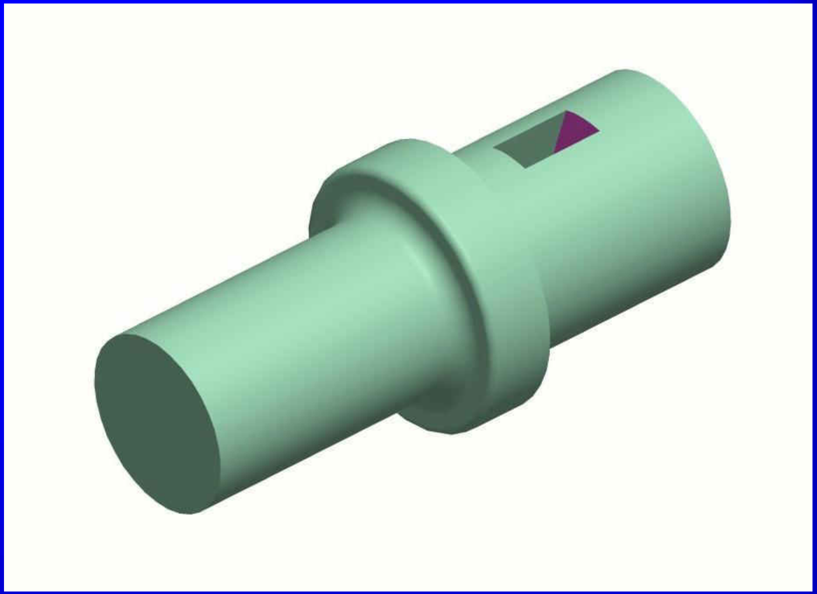
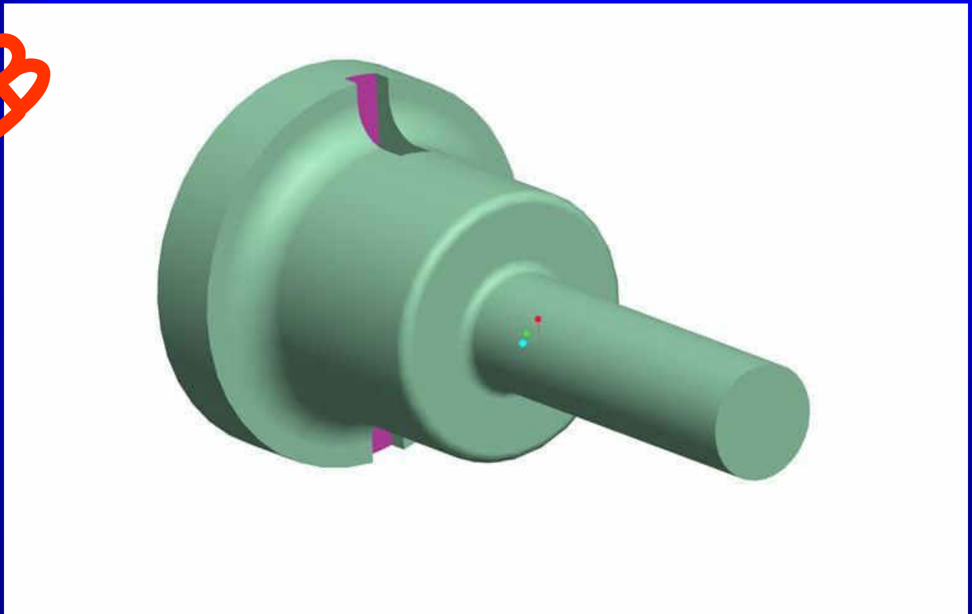
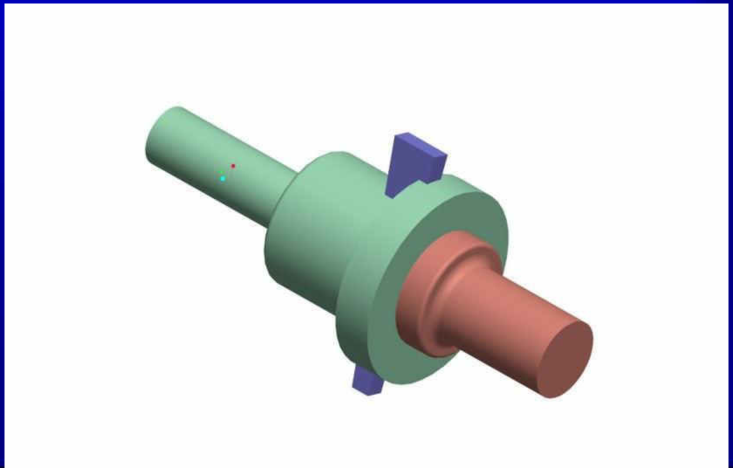


FIG 04: CRUSHING OF COTTER PIN AGAINST ROD END





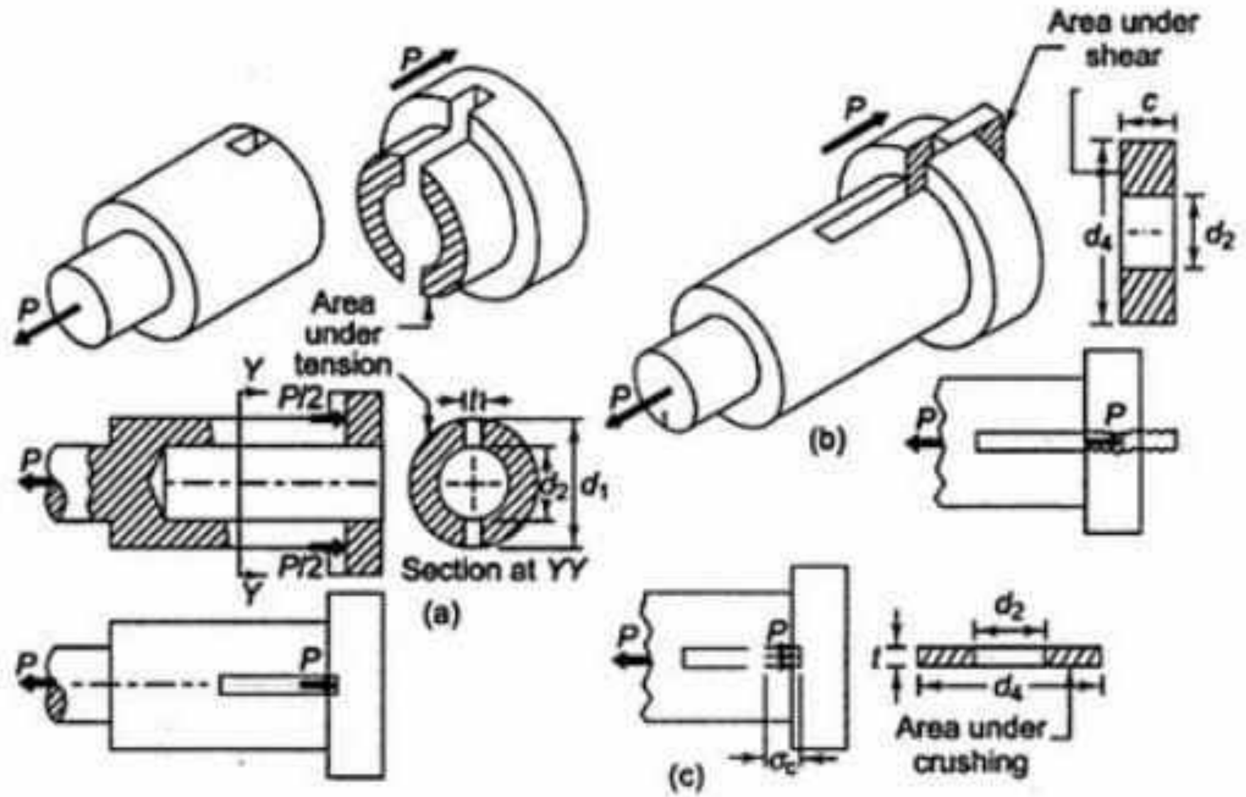


Fig. 4.14 *Stresses in Socket End (a) Tensile Stress (b) Shear stress (c) Compressive Stress*

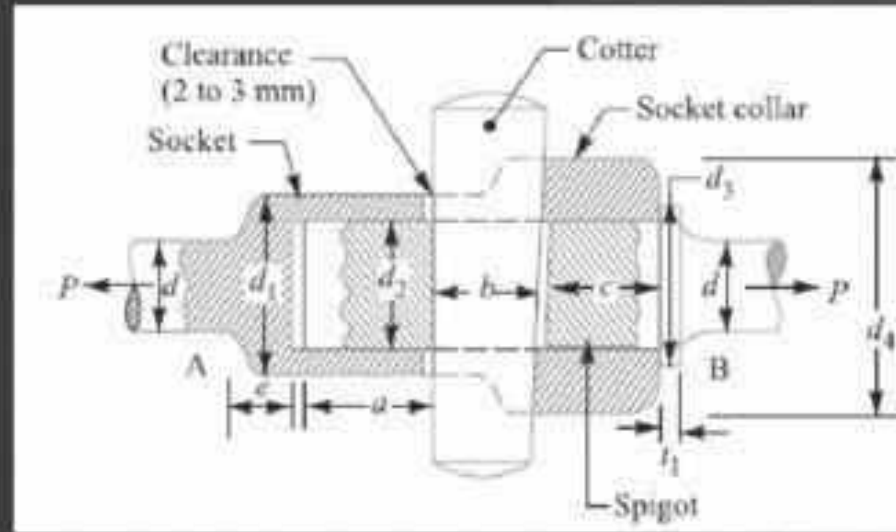
Tensile Failure of Rods :

where [σ] = allowable tensile stress for the material selected.

1. **Failure of the rods in tension:**

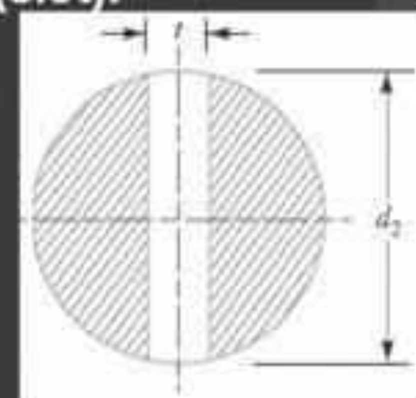
$$P = \frac{\pi}{4} \times d^2 \times \sigma_t$$

From this equation, diameter of the rods (d) may be determined.



2. **Failure of spigot in tension across the weakest section (slot):**

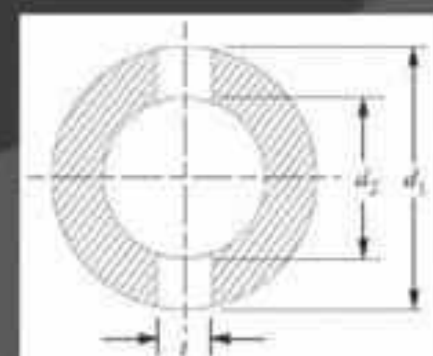
$$P = \left[\frac{\pi}{4}(d_2)^2 - d_2 \times t\right]\sigma_t$$



3. **Failure of cotter in crushing:** $P = d_2 \times t \times \sigma_c$

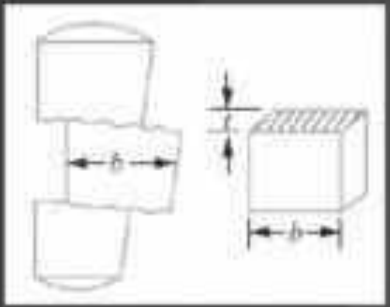
4. **Failure of the socket in tension across the slot:**

$$P = \left\{\frac{\pi}{4}[(d_1)^2 - (d_2)^2] - (d_1 - d_2)\,t\right\}\sigma_t$$



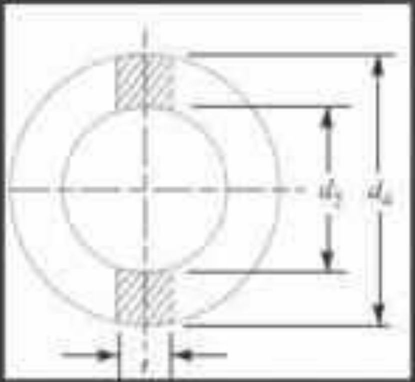
5. **Failure of cotter in shear:**

$$P = 2b \times t \times \tau$$



6. **Failure of socket collar in crushing:**

$$P = (d_4 - d_2)\, t \times \sigma_c$$

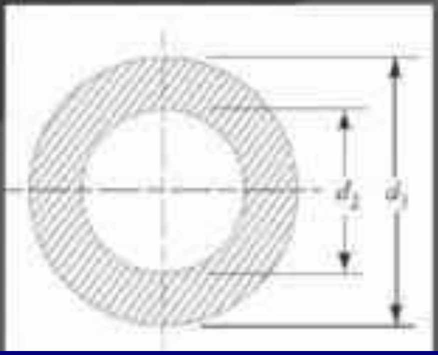


7. **Failure of socket end in shearing:** $P = 2\,(d_4 - d_2)\, c \times \tau$

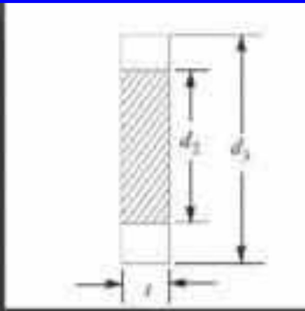
8. **Failure of rod end in shear:** $P = 2\, a \times d_2 \times \tau$

9. **Failure of spigot collar in crushing:**

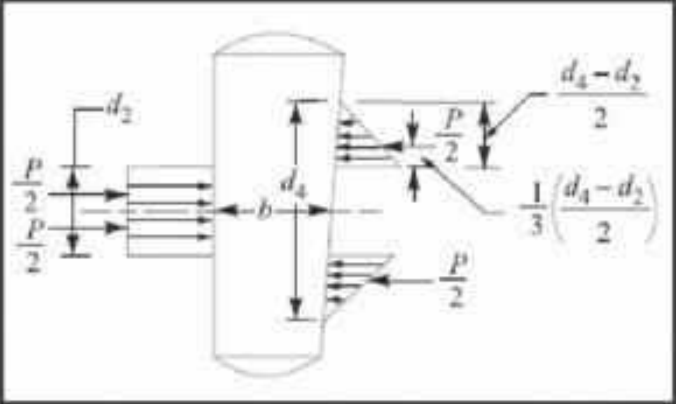
$$P = \frac{\pi}{4}\left[(d_3)^2 - (d_2)^2\right] \sigma_c$$



10. Failure of the spigot collar in shearing: $P = \pi d_2 \times t_1 \times \tau$



11. Failure of cotter in bending:



$$M_{max} = \frac{P}{2}\left(\frac{1}{3}\times\frac{d_4 - d_2}{2} + \frac{d_2}{2}\right) - \frac{P}{2}\times\frac{d_2}{4}$$

$$= \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{2} - \frac{d_2}{4}\right) = \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)$$

We know that section modulus of the cotter,

$$Z = t \times b^2 / 6$$

∴ Bending stress induced in the cotter,

$$\sigma_b = \frac{M_{max}}{Z} = \frac{\frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)}{t \times b^2 / 6} = \frac{P\,(d_4 + 0.5\, d_2)}{2\,t \times b^2}$$

12. Length of cotter (l): 4d

13. Taper : 1 in 24, for greater taper locking device must be provided.

14. **Draw of cotter:** 2 to 3 mm

Note:

When all the parts of the joint are made of steel, the following proportions in terms of diameter of the rod (d) are generally adopted:

$d_1 = 1.75\,d$, $d_2 = 1.21\,d$, $d_3 = 1.5\,d$, $d_4 = 2.4\,d$, $a = c = 0.75\,d$, $b = 1.3\,d$, $l = 4\,d$, $t = 0.31\,d$, $t_1 = 0.45\,d$, $e = 1.2\,d$.

Taper of cotter = 1 in 25, and draw of cotter = 2 to 3 mm.

If the rod and cotter are made of steel or wrought iron, then $\tau = 0.8\,\sigma_t$ and $\sigma_c = 2\,\sigma_t$ may be taken.

………….Design Data Handbook

Design and draw a cotter joint to support a load varying from 30 kN in compression to 30 kN in tension. The material used is carbon steel for which the following allowable stresses may be used. The load is applied statically. Tensile stress = compressive stress = 50 MPa ; shear stress = 35 MPa and crushing stress = 90 MPa.

Solution. Given : $P = 30\text{ kN} = 30 \times 10^3\text{ N}$; $\sigma_t = 50\text{ MPa} = 50\text{ N/mm}^2$; $\tau = 35\text{ MPa} = 35\text{ N/mm}^2$; $\sigma_c = 90\text{ MPa} = 90\text{ N/mm}^2$

1. *Diameter of the rods*

Let d = Diameter of the rods.

Considering the failure of the rod in tension. We know that load (P),

$$30 \times 10^3 = \frac{\pi}{4} \times d^2 \times \sigma_t = \frac{\pi}{4} \times d^2 \times 50 = 39.3\, d^2$$

$$\therefore \quad d^2 = 30 \times 10^3 / 39.3 = 763 \quad \text{or} \quad d = 27.6 \text{ say } 28 \text{ mm} \quad \textbf{Ans.}$$

2. *Diameter of spigot and thickness of cotter*

Let d_2 = Diameter of spigot or inside diameter of socket, and

t = Thickness of cotter. It may be taken as $d_2/4$.

Considering the failure of spigot in tension across the weakest section. We know that load (P),

$$30 \times 10^3 = \left[\frac{\pi}{4}(d_2)^2 - d_2 \times t\right]\sigma_t = \left[\frac{\pi}{4}(d_2)^2 - d_2 \times \frac{d_2}{4}\right]50 = 26.8\,(d_2)^2$$

$$\therefore \quad (d_2)^2 = 30 \times 10^3 / 26.8 = 1119.4 \quad \text{or} \quad d_2 = 33.4 \text{ say } 34 \text{ mm}$$

and thickness of cotter, $t = \dfrac{d_2}{4} = \dfrac{34}{4} = 8.5\text{ mm}$

Let us now check the induced crushing stress. We know that load (P),

$$30 \times 10^3 = d_2 \times t \times \sigma_c = 34 \times 8.5 \times \sigma_c = 289\,\sigma_c$$

$$\therefore \quad \sigma_c = 30 \times 10^3 / 289 = 103.8\text{ N/mm}^2$$

Since this value of σ_c is more than the given value of $\sigma_c = 90\text{ N/mm}^2$, therefore the dimensions $d_2 = 34$ mm and $t = 8.5$ mm are not safe. Now let us find the values of d_2 and t by substituting the value of $\sigma_c = 90\text{ N/mm}^2$ in the above expression, *i.e.*

$$30 \times 10^3 = d_2 \times \frac{d_2}{4} \times 90 = 22.5\,(d_2)^2$$

$$\therefore \quad (d_2)^2 = 30 \times 10^3 / 22.5 = 1333 \quad \text{or} \quad d_2 = 36.5 \text{ say } 40 \text{ mm} \quad \textbf{Ans.}$$

and $t = d_2/4 = 40/4 = 10$ mm **Ans.**

3. *Outside diameter of socket*

Let d_1 = Outside diameter of socket.

Considering the failure of the socket in tension across the slot. We know that load (P),

$$30 \times 10^3 = \left[\frac{\pi}{4}\left\{(d_1)^2 - (d_2)^2\right\} - (d_1 - d_2)\,t\right]\sigma_t$$

$$= \left[\frac{\pi}{4}\left\{(d_1)^2 - (40)^2\right\} - (d_1 - 40)\,10\right]50$$

$$30 \times 10^3/50 = 0.7854\,(d_1)^2 - 1256.6 - 10\,d_1 + 400$$

or $(d_1)^2 - 12.7\, d_1 - 1854.6 = 0$

$$\therefore \quad d_1 = \frac{12.7 \pm \sqrt{(12.7)^2 + 4 \times 1854.6}}{2} = \frac{12.7 \pm 87.1}{2}$$

$$= 49.9 \text{ say } 50 \text{ mm Ans.} \qquad \text{...(Taking +ve sign)}$$

4. *Width of cotter*

Let b = Width of cotter.

Considering the failure of the cotter in shear. Since the cotter is in double shear, therefore load (P),

$$30 \times 10^3 = 2\, b \times t \times \tau = 2\, b \times 10 \times 35 = 700\, b$$

$$\therefore \quad b = 30 \times 10^3 / 700 = 43 \text{ mm Ans.}$$

5. *Diameter of socket collar*

Let d_4 = Diameter of socket collar.

Considering the failure of the socket collar and cotter in crushing. We know that load (P),

$$30 \times 10^3 = (d_4 - d_2)\, t \times \sigma_c = (d_4 - 40) 10 \times 90 = (d_4 - 40)\, 900$$

$$\therefore \quad d_4 - 40 = 30 \times 10^3 / 900 = 33.3 \text{ or } d_4 = 33.3 + 40 = 73.3 \text{ say } 75 \text{ mm Ans.}$$

6. *Thickness of socket collar*

Let c = Thickness of socket collar.

Considering the failure of the socket end in shearing. Since the socket end is in double shear, therefore load (P),

$$30 \times 10^3 = 2(d_4 - d_2)\, c \times \tau = 2\,(75 - 40)\, c \times 35 = 2450\, c$$

$$\therefore \quad c = 30 \times 10^3 / 2450 = 12 \text{ mm Ans.}$$

7. *Distance from the end of the slot to the end of the rod*

Let a = Distance from the end of slot to the end of the rod.

Considering the failure of the rod end in shear. Since the rod end is in double shear, therefore load (P),

$$30 \times 10^3 = 2\, a \times d_2 \times \tau = 2a \times 40 \times 35 = 2800\, a$$

$$\therefore \quad a = 30 \times 10^3 / 2800 = 10.7 \text{ say } 11 \text{ mm Ans.}$$

8. *Diameter of spigot collar*

Let d_3 = Diameter of spigot collar.

Considering the failure of spigot collar in crushing. We know that load (P),

$$30 \times 10^3 = \frac{\pi}{4}\left[(d_3)^2 - (d_2)^2\right] \sigma_c = \frac{\pi}{4}\left[(d_3)^2 - (40)^2\right] 90$$

or $$(d_3)^2 - (40)^2 = \frac{30 \times 10^3 \times 4}{90 \times \pi} = 424$$

$$\therefore \quad (d_3)^2 = 424 + (40)^2 = 2024 \text{ or } d_3 = 45 \text{ mm Ans.}$$

9. Thickness of spigot collar

Let t_1 = Thickness of spigot collar.

Considering the failure of spigot collar in shearing. We know that load (P),

$$30 \times 10^3 = \pi\, d_2 \times t_1 \times \tau = \pi \times 40 \times t_1 \times 35 = 4400\, t_1$$

$\therefore$ $t_1 = 30 \times 10^3 / 4400 = 6.8$ say 8 mm **Ans.**

10. The length of cotter (l) is taken as 4 d.

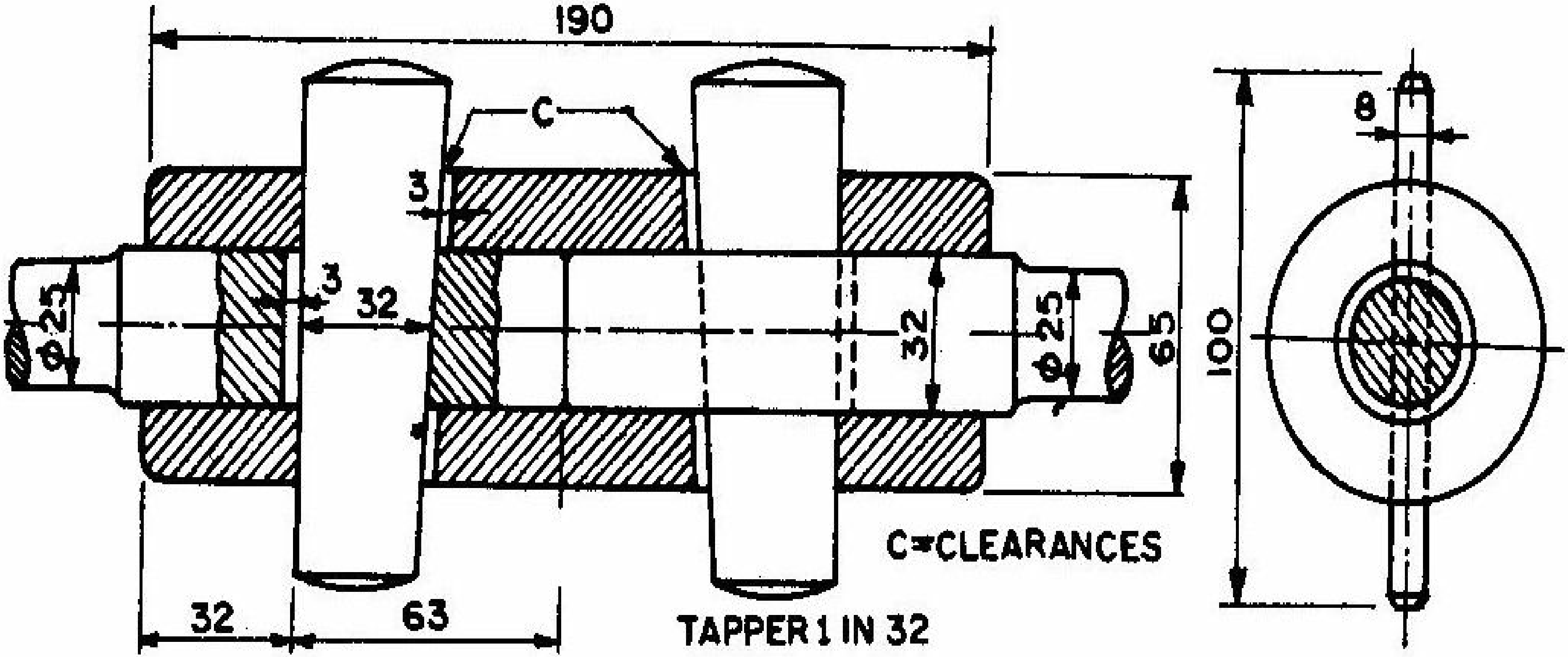
$\therefore$ $l = 4\,d = 4 \times 28 = 112$ mm **Ans.**

11. The dimension e is taken as 1.2 d.

$\therefore$ $e = 1.2 \times 28 = 33.6$ say 34 mm **Ans.**

Sleeve and cotter joint

For circular rods



The enlarged ends of the rods butt against each other with a common sleeve over them

- The rod ends are enlarged to take care of the weakening effect caused by slots

Sleeve and Cotter Joint

Sometimes, a sleeve and cotter joint bars. In this type of joint, a sleeve or on each rod end) are inserted in the of cotter is usually 1 in 24. It may be each other as shown in Fig.

The various proportions for the sleeve cotter joint in terms of the diameter of rod(d) are as follows

Outside diameter of sleeve,**d1= 2.5 d**

Diameter of enlarged end of rod,**d2= Inside diameter of sleeve = 1.25 d**

Length of sleeve, **L = 8 d** , Thickness of cotter, **t = d2/4** or **0.31d**

Width of cotter, **b = 1.25 d**, Length of cotter, **l = 4 d**

Distance of the rod end (a) from the beginning to the cotter hole (inside the sleeve end)=Distance of the rod end (c) from its end to the cotter hole=**1.25d**

Design of Sleeve and Cotter Joint

The sleeve and cotter joint is shown in Fig.

Let P = Load carried by the rods,

d = Diameter of the rods,

d_1 = Outside diameter of sleeve,

d_2 = Diameter of the enlarged end of rod,

t = Thickness of cotter,

l = Length of cotter,

b = Width of cotter,

a = Distance of the rod end from the beginning to the cotter hole (inside the sleeve end),

c = Distance of the rod end from its end to the cotter hole,

σ_t, τ and σ_c = Permissible tensile, shear and crushing stresses respectively for the material of the rods and cotter.

The dimensions for a sleeve and cotter joint may be obtained by considering the various modes of failure as discussed below:

1. Failure of the rods in tension

The rods may fail in tension due to the tensile load P. We know that

$$P = \frac{\pi}{4} \times d^2 \times \sigma_t$$

From this equation, diameter of the rods (d) may be obtained.

2. Failure of the rod in tension across the weakest section (i.e. slot)

$$P = \left[\frac{\pi}{4}(d_2)^2 - d_2 \times t\right]\sigma_t$$

From this equation, the diameter of enlarged end of the rod (d_2) may be obtained. The thickness of cotter is usually taken as $d_2 / 4$.

3. Failure of the rod or cotter in crushing

$$P = d_2 \times t \times \sigma_c$$

From this equation, the induced crushing stress may be checked.

4. Failure of sleeve in tension across the slot

$$P = \left[\frac{\pi}{4}[(d_1)^2 - (d_2)^2] - (d_1 - d_2)\, t\right]\sigma_t$$

From this equation, the outside diameter of sleeve (d_1) may be obtained.

5. Failure of cotter in shear

$$P = 2b \times t \times \tau$$

From this equation, width of cotter (b) may be determined.

6. Failure of rod end in shear

$$P = 2\,a \times d_2 \times \tau$$

From this equation, distance (a) may be determined.

7. Failure of sleeve end in shear

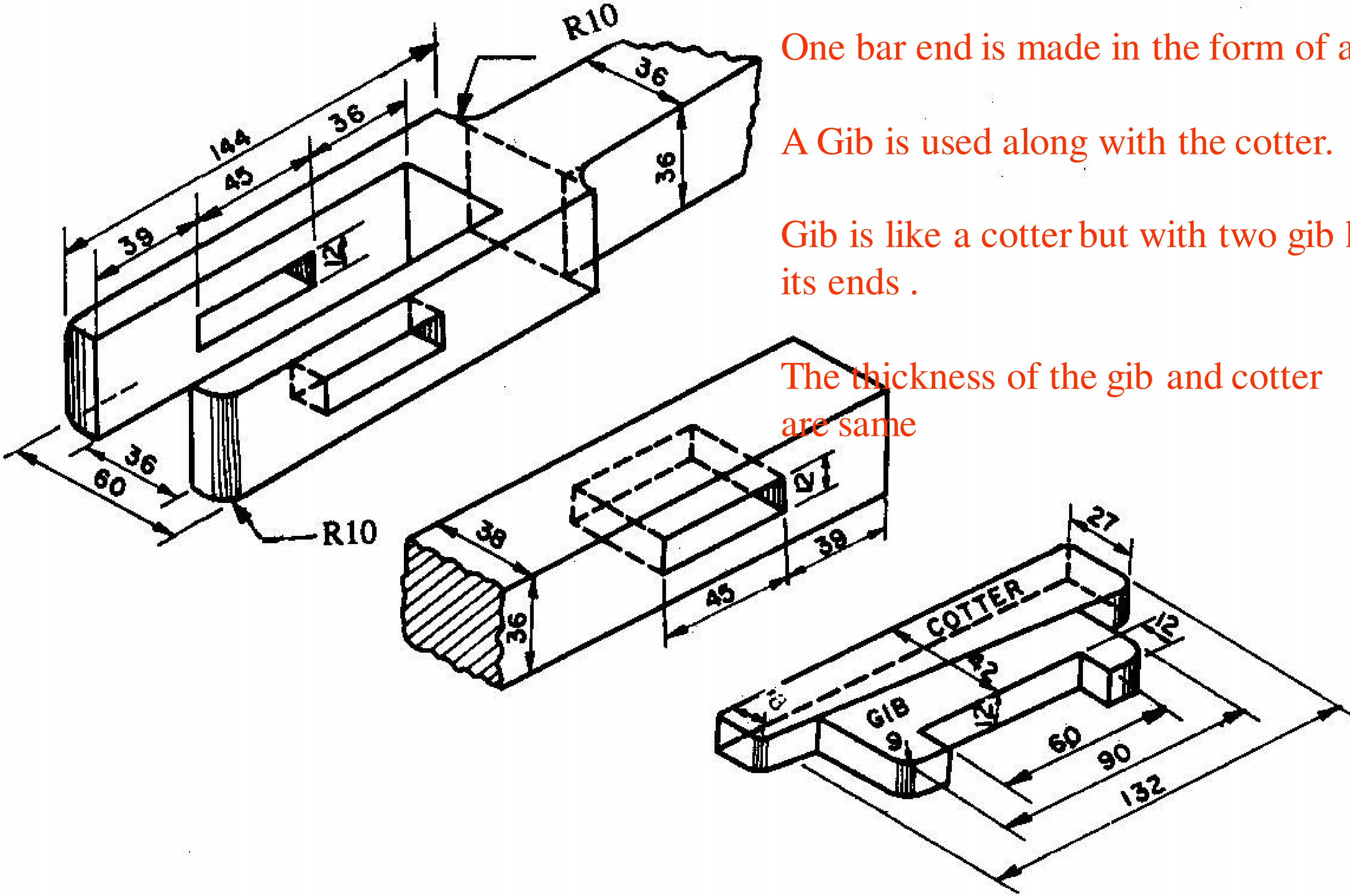
$$P = 2\,(d_1 - d_2)\,c \times \tau$$

From this equation, distance (c) may be determined.

Cotter joint with a gib

Gib and cotter joints are used for rods of square or rectangular cross section .the end of one rod fits the end of the other rod which is made in the form of a strap. A gib is used along with the cotter to make this joint. Gib is likely a cotter but with two gib heads at its ends . The thickness of the gib and cotter are same.

Gib and cotter joint for rectangular rods



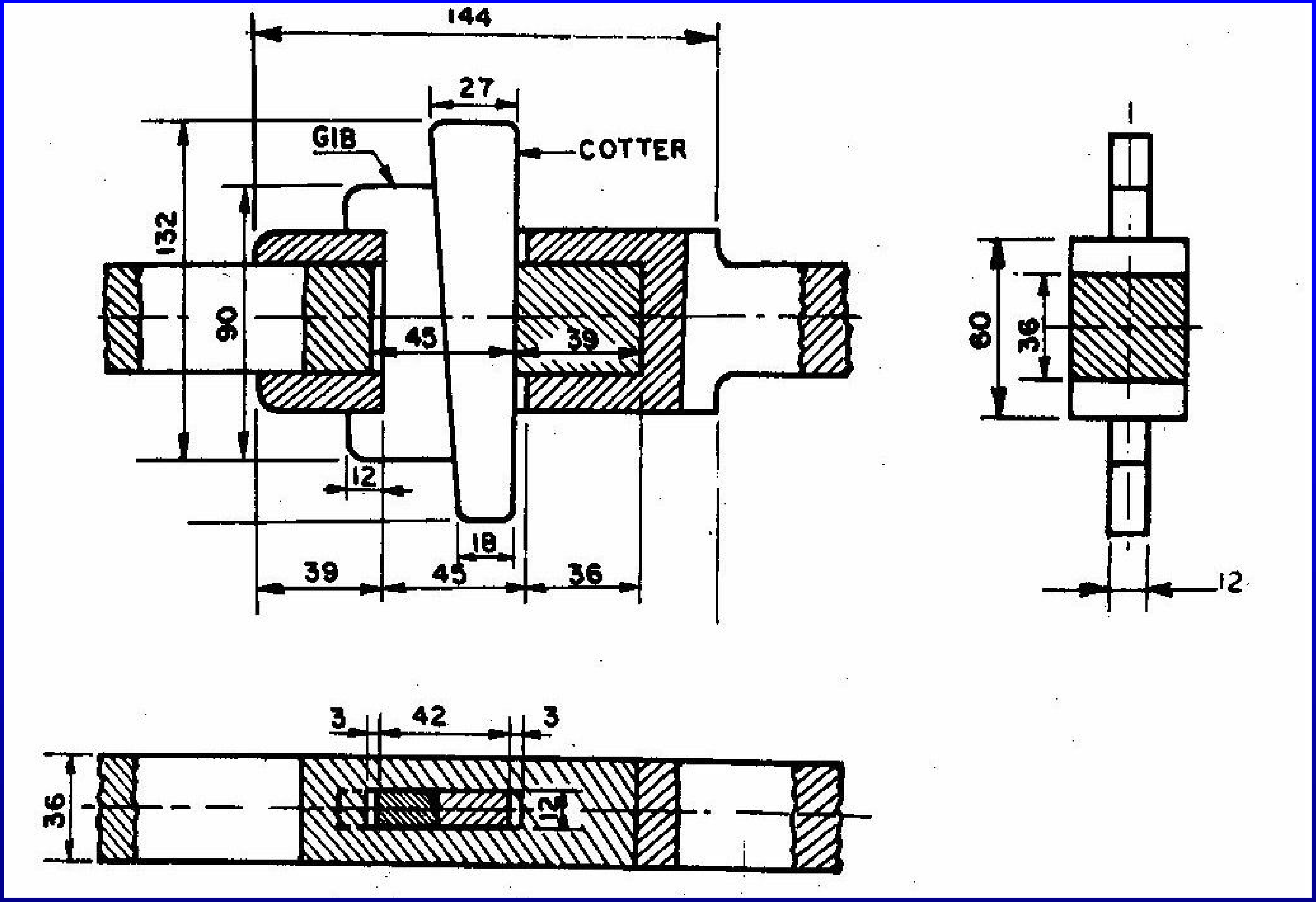
One bar end is made in the form of a strap

A Gib is used along with the cotter.

Gib is like a cotter but with two gib heads at its ends .

The thickness of the gib and cotter are same

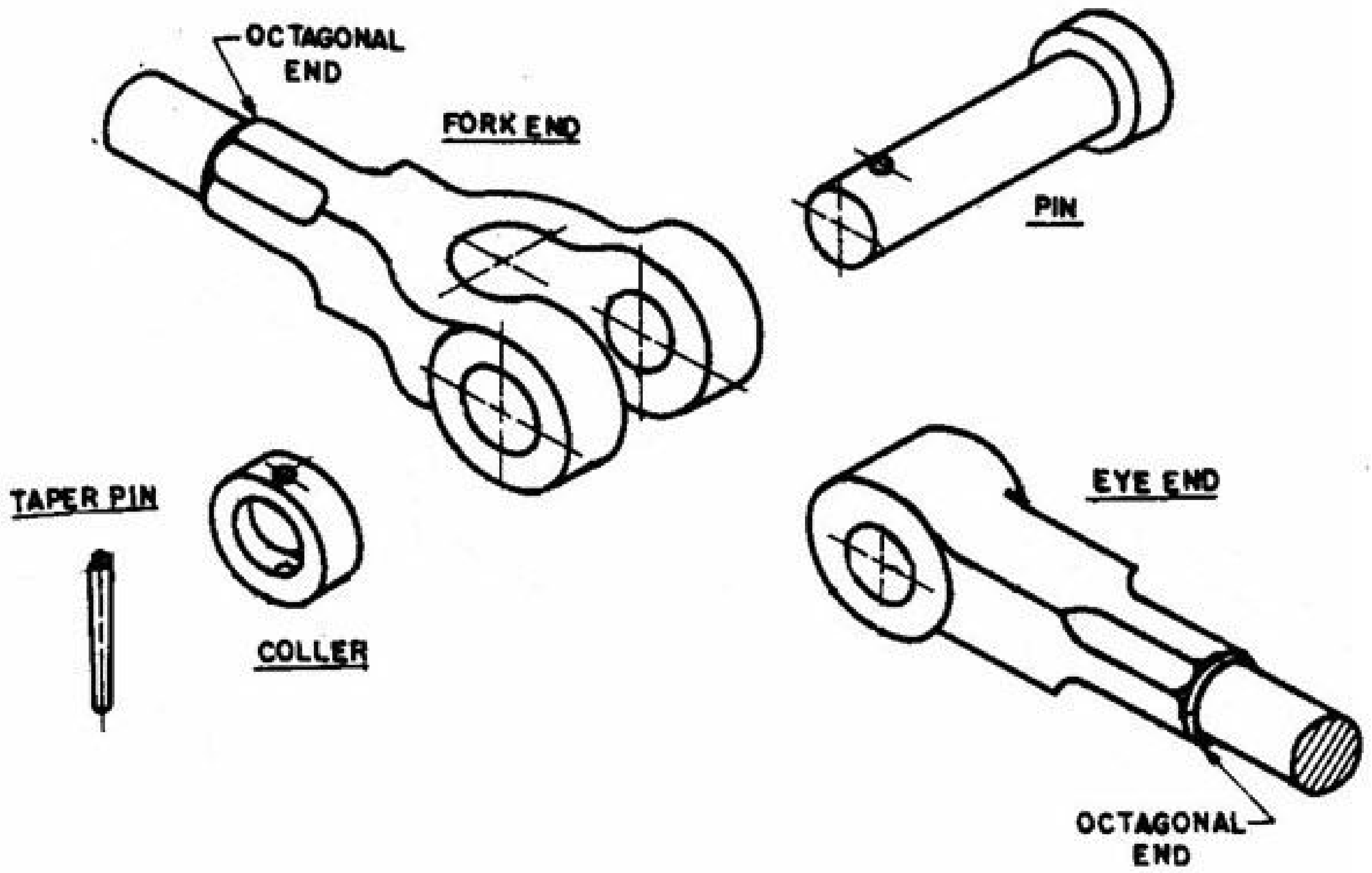
Gib and cotter joint or rectangular rods



Knuckle joint

- Knuckle joint is used to connect two rods subjected to axial tensile loads. It may also be used to support the compressive load if the joint is guided. It is not suitable to connect rotating shafts which transmit torque.
- Axes of the shafts to be joined should lie in the same plane and may coincide or intersect. Its construction permits limited relative angular movement between rods, about the axis of the pin.
- Knuckle joint is widely used to connect valve rod and eccentric rod, in the link of a cycle chain, levers, Elevator chains, tie rod joint for roof truss and many other links.
- Knuckle Joint has mainly three components – eye, fork and pin as shown in Figure 8.1.
- Eye is formed on one of the rods and fork is formed on the other. Eye fits inside the fork and the pin is passed through both the fork and the eye. This pin is secured in its place by means of a split-pin.
- The ends of the rods are made octagonal to some distance for better grip and are made square for some portion before it is forged to

Knuckle joint



Knuckle joint

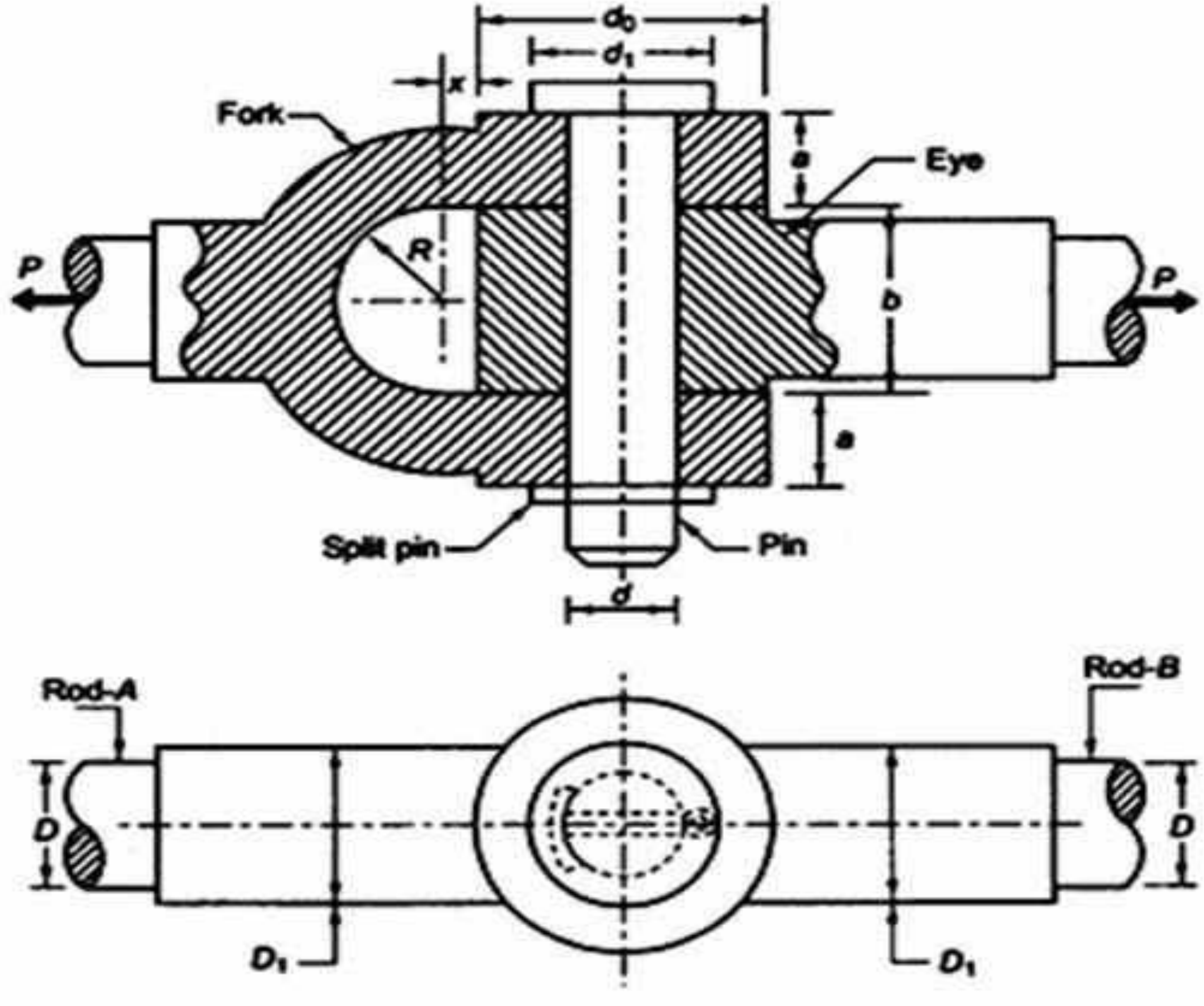


Figure 8.1 Knucle Joint

DESIGN OF KNUCKLE JOINT

The following figure shows a knuckle joint with the size parameters and proportions indicated. In general, the rods connected by this joint are subjected to tensile loads, although if the rods are guided, they may support compressive loads as well.

Let F. = tensile load to be resisted by the joint

d = diameter of the rods

d_1 = diameter of the knuckle pin

D = outside diameter of the eye

A =thickness of the fork

B =thickness of the eye

Obviously, if the rods are made of the same material, the parameters, *A* and *B* are related as,

B=2A

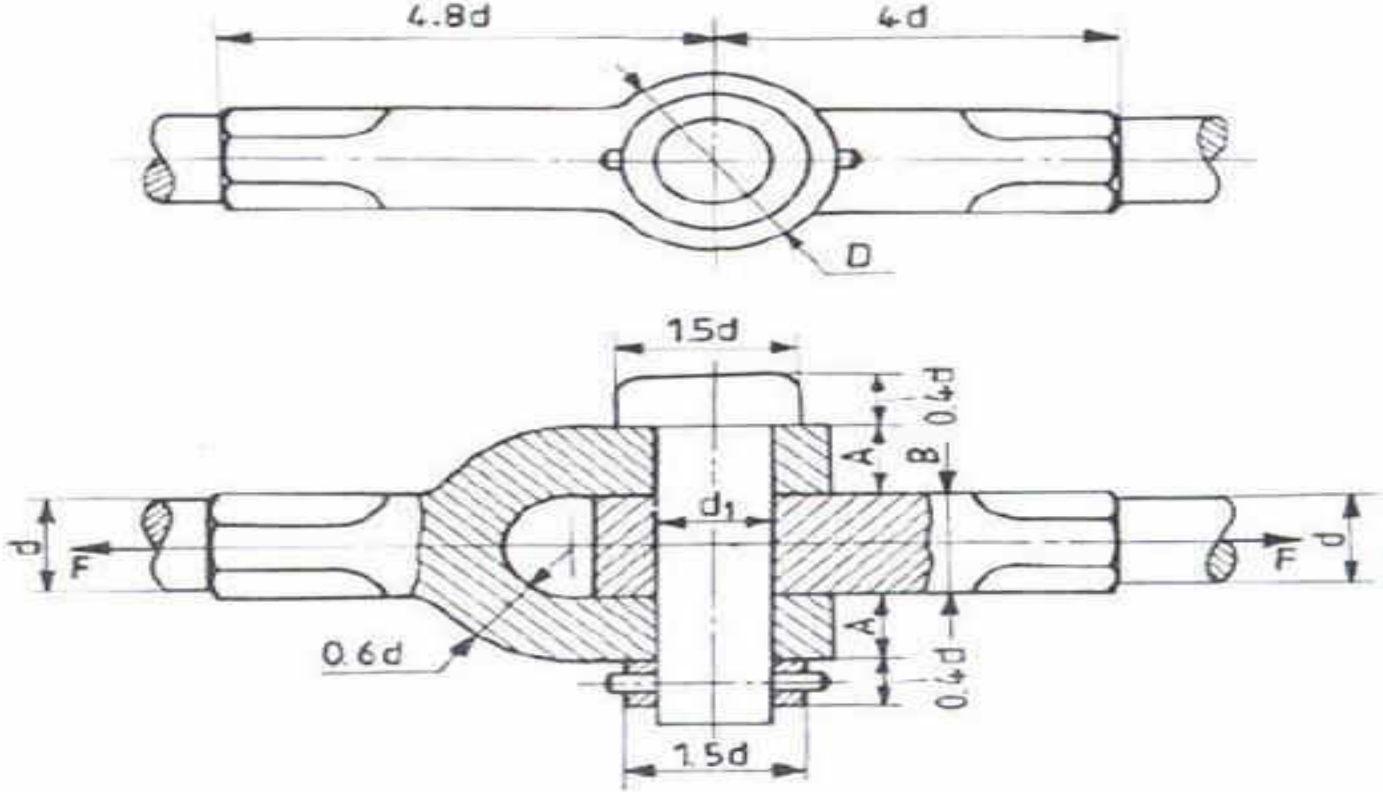


Fig. Knuckle Joint

Let the rods and pin are made of the same material, with σ_t, σ_c and τ as the permissible stresses. The following are the possible modes of failure, and the corresponding design equations, which may be considered for the design of the joint:

1. Tension failure of the rod, across the section of diameter, *d*

$$F = \frac{\pi d^2}{4}\tau$$

2. Tension failure of the eye (fig.1)

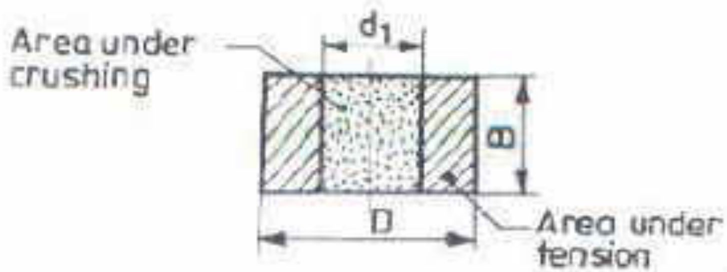


Fig.1

$$F = (D - d_1)\, B\, \sigma_t$$

3. Tension failure of the fork (fig.2)

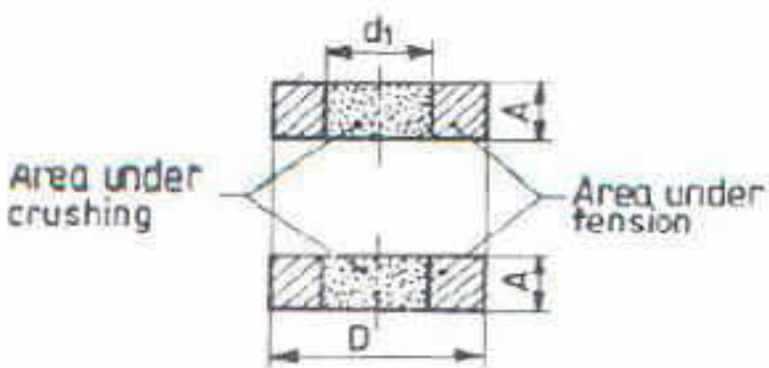


Fig.2

$$F = 2\,(D - d_1)\, A\, \sigma_t$$

4. Shear failure of the eye (Fig.3)

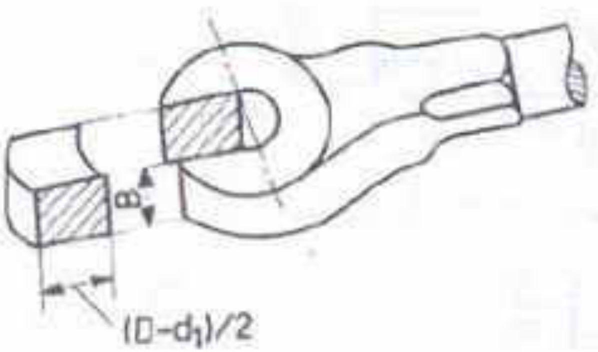


Fig.3

$$F = (D-d_1)\,B\,\tau$$

5. Shear failure of the fork (Fig.4)

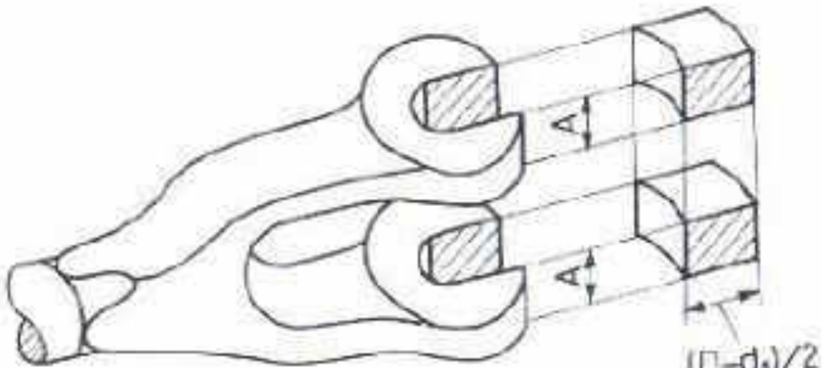


Fig.4

$$F = 2\,(D-d_1)\,A\,\tau$$

6. Shear failure of the pin. It is under double shear.

$$F = 2x\frac{\pi}{4}d^2 x\tau$$

7. Crushing between the pin and eye (fig.1)

$$F = d_1\,B\,\sigma_c$$

8. Crushing between the pin and fork (fig.2)

$$F = 2\,d_1\,A\,\sigma_c$$

Problem:

Design a knuckle joint to transmit 150 kN. The design stresses may be taken as 75 MPa in tension, 60 MPa in shear and 150 MPa in compression.

Solution. Given : $P = 150$ kN $= 150 \times 10^3$ N ; $\sigma_t = 75$ MPa $= 75$ N/mm^2 ; $\tau = 60$ MPa $= 60$ N/mm^2 ; $\sigma_c = 150$ MPa $= 150$ N/mm^2

1. *Failure of the solid rod in tension*

Let d = Diameter of the rod.

We know that the load transmitted (P),

$$150 \times 10^3 = \frac{\pi}{4} \times d^2 \times \sigma_t = \frac{\pi}{4} \times d^2 \times 75 = 59\, d^2$$

$\therefore$ $d^2 = 150 \times 10^3 / 59 = 2540$ or $d = 50.4$ say 52 mm **Ans.**

Now the various dimensions are fixed as follows :

Diameter of knuckle pin,

$$d_1 = d = 52 \text{ mm}$$

Outer diameter of eye, $d_2 = 2d = 2 \times 52 = 104$ mm

Diameter of knuckle pin head and collar,

$$d_3 = 1.5\,d = 1.5 \times 52 = 78 \text{ mm}$$

Thickness of single eye or rod end,

$$t = 1.25\,d = 1.25 \times 52 = 65 \text{ mm}$$

Thickness of fork, $t_1 = 0.75\,d = 0.75 \times 52 = 39$ say 40 mm

Thickness of pin head, $t_2 = 0.5\,d = 0.5 \times 52 = 26$ mm

2. *Failure of the knuckle pin in shear*

Since the knuckle pin is in double shear, therefore load (P),

$$150 \times 10^3 = 2 \times \frac{\pi}{4} \times (d_1)^2\,\tau = 2 \times \frac{\pi}{4} \times (52)^2\,\tau = 4248\,\tau$$

$\therefore \quad \tau = 150 \times 10^3 / 4248 = 35.3 \text{ N/mm}^2 = 35.3 \text{ MPa}$

3. *Failure of the single eye or rod end in tension*

The single eye or rod end may fail in tension due to the load. We know that load (*P*),

$$150 \times 10^3 = (d_2 - d_1)\, t \times \sigma_t = (104 - 52)\, 65 \times \sigma_t = 3380\, \sigma_t$$

$$\therefore \quad \sigma_t = 150 \times 10^3 / 3380 = 44.4 \text{ N/mm}^2 = 44.4 \text{ MPa}$$

4. *Failure of the single eye or rod end in shearing*

The single eye or rod end may fail in shearing due to the load. We know that load (*P*),

$$150 \times 10^3 = (d_2 - d_1)\, t \times \tau = (104 - 52)\, 65 \times \tau = 3380\, \tau$$

$$\therefore \quad \tau = 150 \times 10^3 / 3380 = 44.4 \text{ N/mm}^2 = 44.4 \text{ MPa}$$

5. *Failure of the single eye or rod end in crushing*

The single eye or rod end may fail in crushing due to the load. We know that load (*P*),

$$150 \times 10^3 = d_1 \times t \times \sigma_c = 52 \times 65 \times \sigma_c = 3380\, \sigma_c$$

$$\therefore \quad \sigma_c = 150 \times 10^3 / 3380 = 44.4 \text{ N/mm}^2 = 44.4 \text{ MPa}$$

6. *Failure of the forked end in tension*

The forked end may fail in tension due to the load. We know that load (*P*),

$$150 \times 10^3 = (d_2 - d_1)\, 2\, t_1 \times \sigma_t = (104 - 52)\, 2 \times 40 \times \sigma_t = 4160\, \sigma_t$$

$$\therefore \quad \sigma_t = 150 \times 10^3 / 4160 = 36 \text{ N/mm}^2 = 36 \text{ MPa}$$

7. *Failure of the forked end in shear*

The forked end may fail in shearing due to the load. We know that load (*P*),

$$150 \times 10^3 = (d_2 - d_1)\, 2\, t_1 \times \tau = (104 - 52)\, 2 \times 40 \times \tau = 4160\, \tau$$

$$\therefore \quad \tau = 150 \times 10^3 / 4160 = 36 \text{ N/mm}^2 = 36 \text{ MPa}$$

8. *Failure of the forked end in crushing*

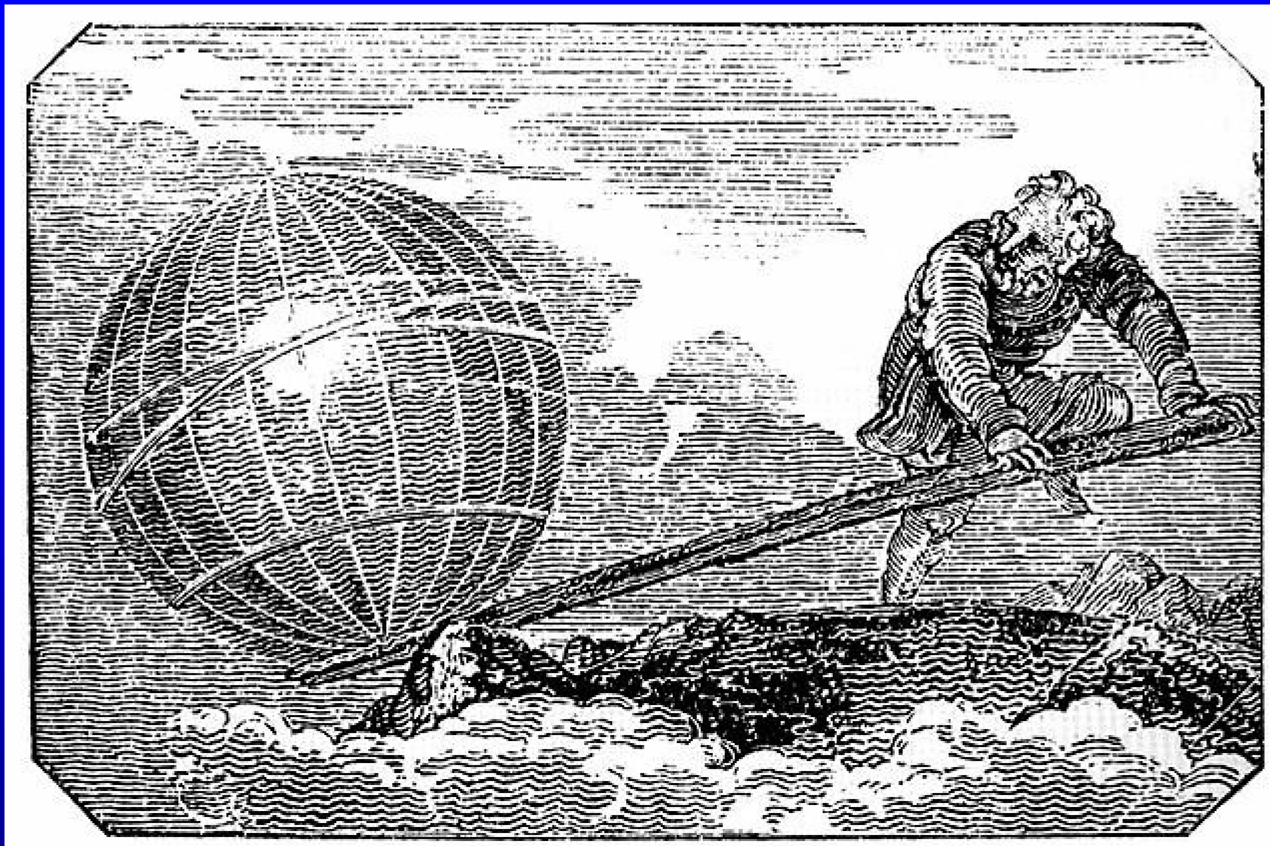
The forked end may fail in crushing due to the load. We know that load (*P*),

$$150 \times 10^3 = d_1 \times 2\, t_1 \times \sigma_c = 52 \times 2 \times 40 \times \sigma_c = 4160\, \sigma_c$$

$$\therefore \quad \sigma_c = 150 \times 10^3 / 4180 = 36 \text{ N/mm}^2 = 36 \text{ MPa}$$

From above, we see that the induced stresses are less than the given design stresses, therefore the joint is safe.

LEVERS



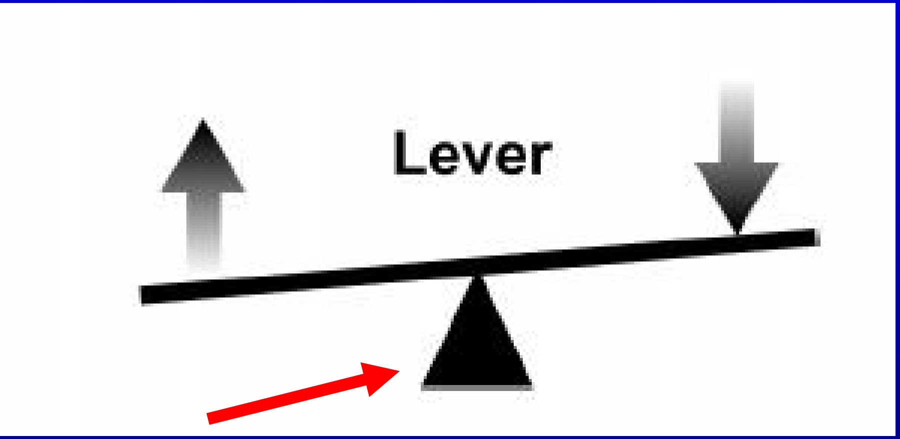
ΔΟΣ ΜΟΙ ΠΟΥ ΣΤΩ ΚΑΙ ΚΙΝΩ ΤΗΝ ΓΗΝ

Give me where [to] stand and [I will] move the earth

~ Archimedes

Introducing… The Lever

A lever includes a stiff structure (the lever) that rotates around a fixed point called the fulcrum.



fulcrum

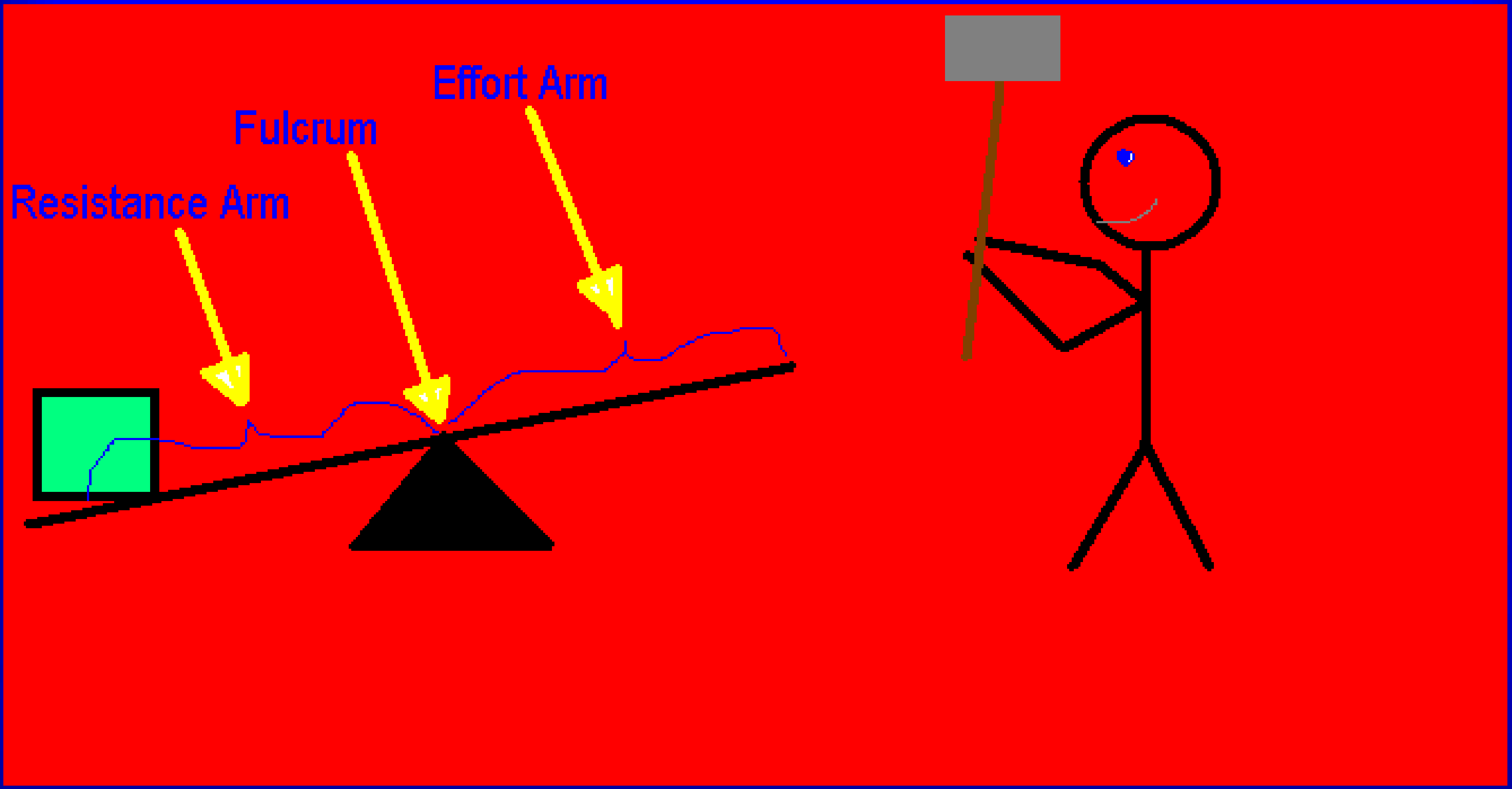
Lever – A bar that is free to move about a fixed point

– Parts of a lever

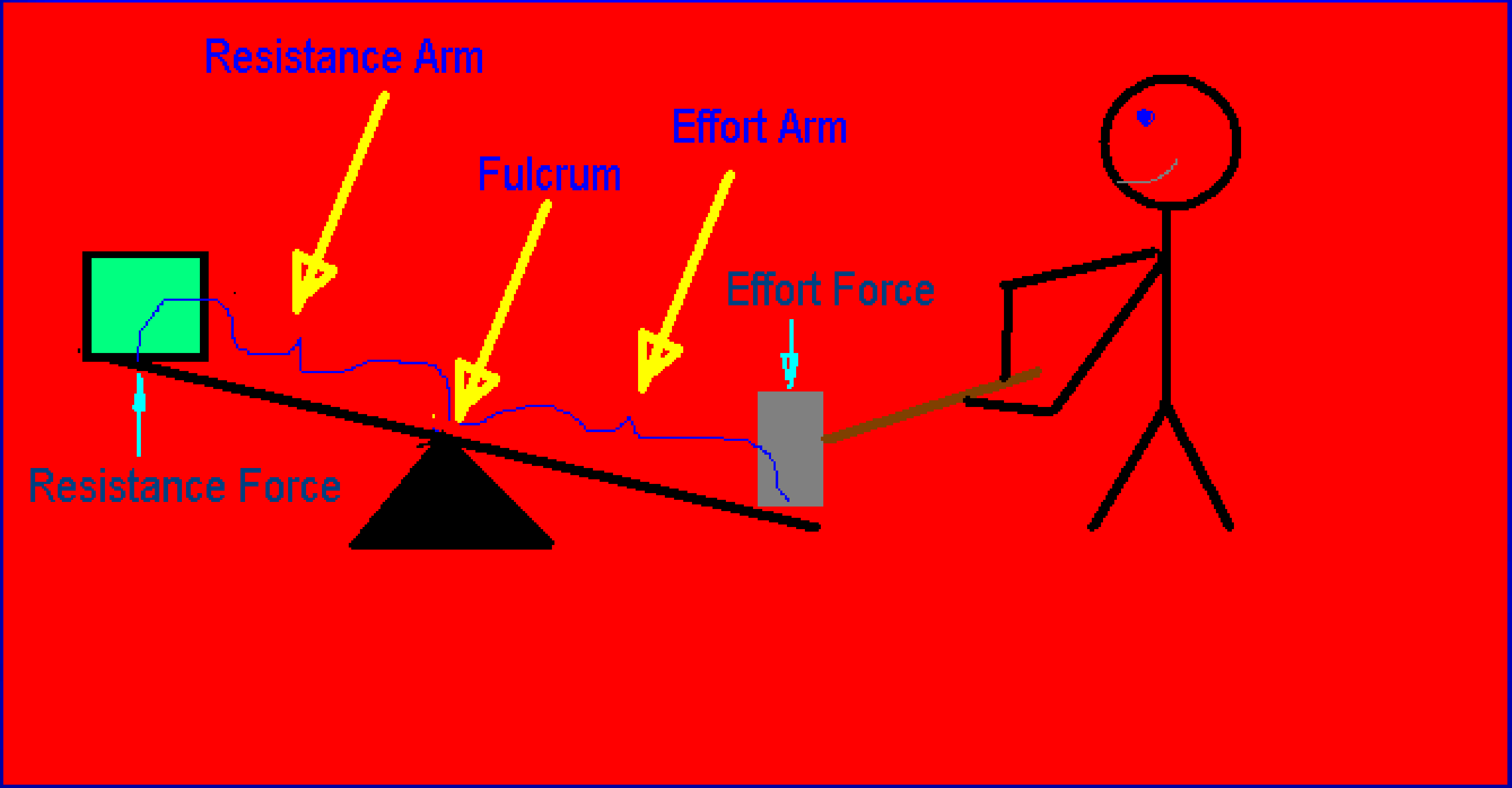
Fulcrum – The fixed point of a lever

Effort Arm – The part of the lever that the effort force is applied to (measured from the fulcrum to the point at which the force is applied)

Resistance Arm – The part of the lever that applies the resistance force (measured from the fulcrum to the center of the resistance force)



Effort Arm
Fulcrum
Resistance Arm

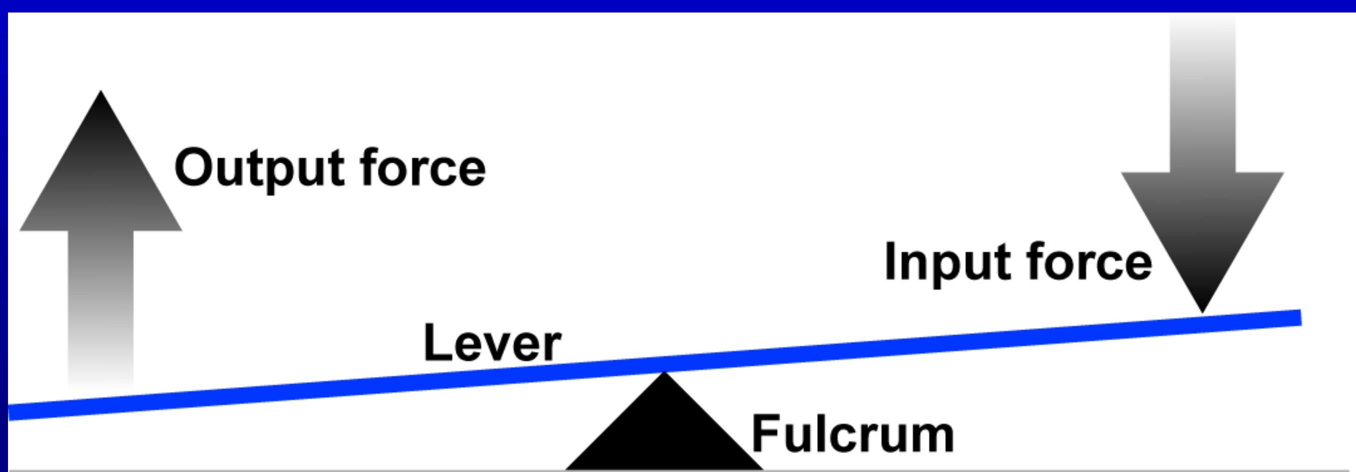

Resistance Arm
Effort Arm
Fulcrum
Effort Force
Resistance Force

Anatomy of the lever

Fulcrum point around which the lever rotates

Input Force Force exerted ON the lever

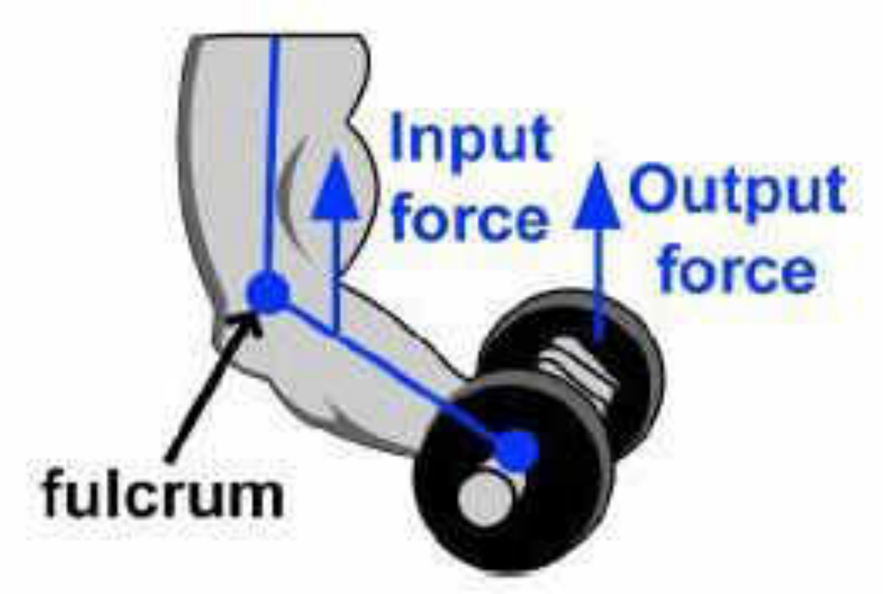
Output Force Force exerted BY the lever



Levers and the human body

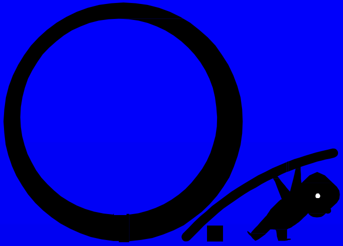
Your body contains muscles attached to bones in ways that act as levers.

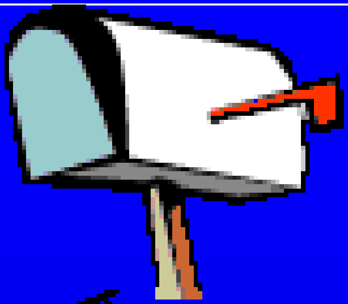
Here the biceps muscle attached in front of the elbow opposes the muscles in the forearm.

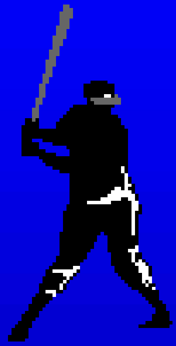


Can you think of other muscle levers in your body?

Eureka - Levers



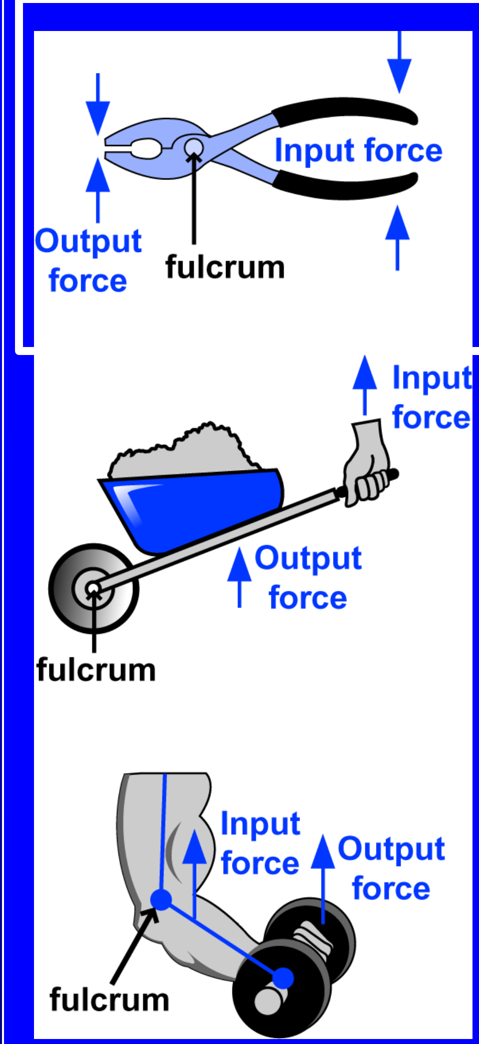




Three Classes of Levers

First Class - fulcrum between Input and output

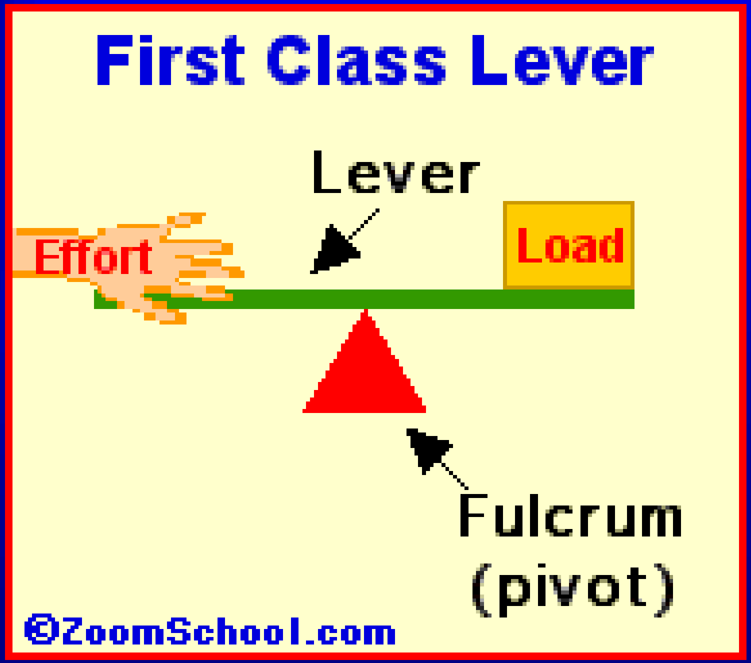
- **Second Class – output between fulcrum and input**
- **Third Class – input between fulcrum and output**

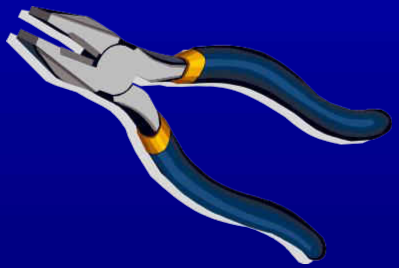


1st Class Lever - The fulcrum is located between the effort arm and the resistance arm.

First class levers can multiply force and distance.

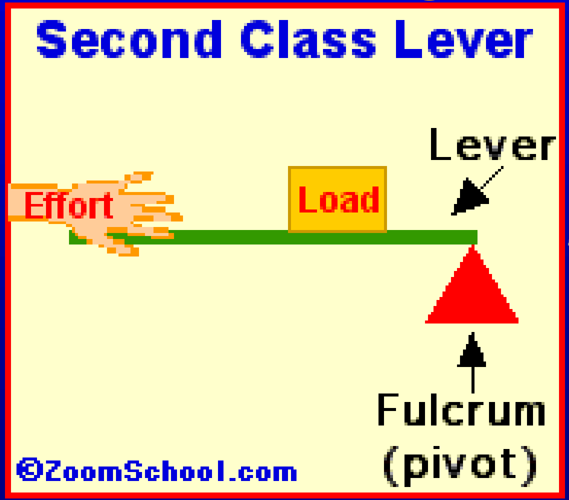
– Examples: scissors, see-saw, hammer's claws, pliers,





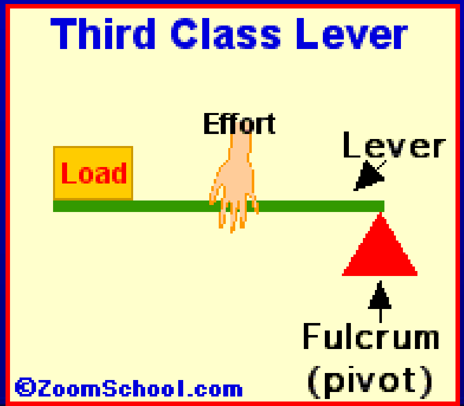
2nd Class Lever - resistance is located between the effort arm and the fulcrum. These levers multiply the force but the direction stays the same.

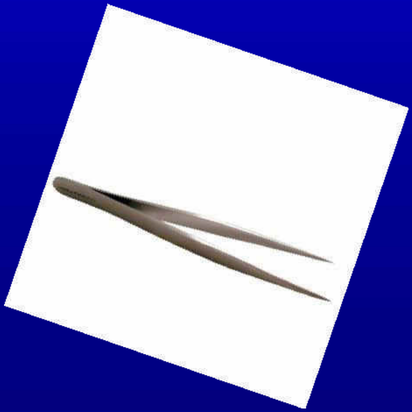
– Example: wheelbarrow, stapler, bottle opener, finger nail clippers, nut cracker.



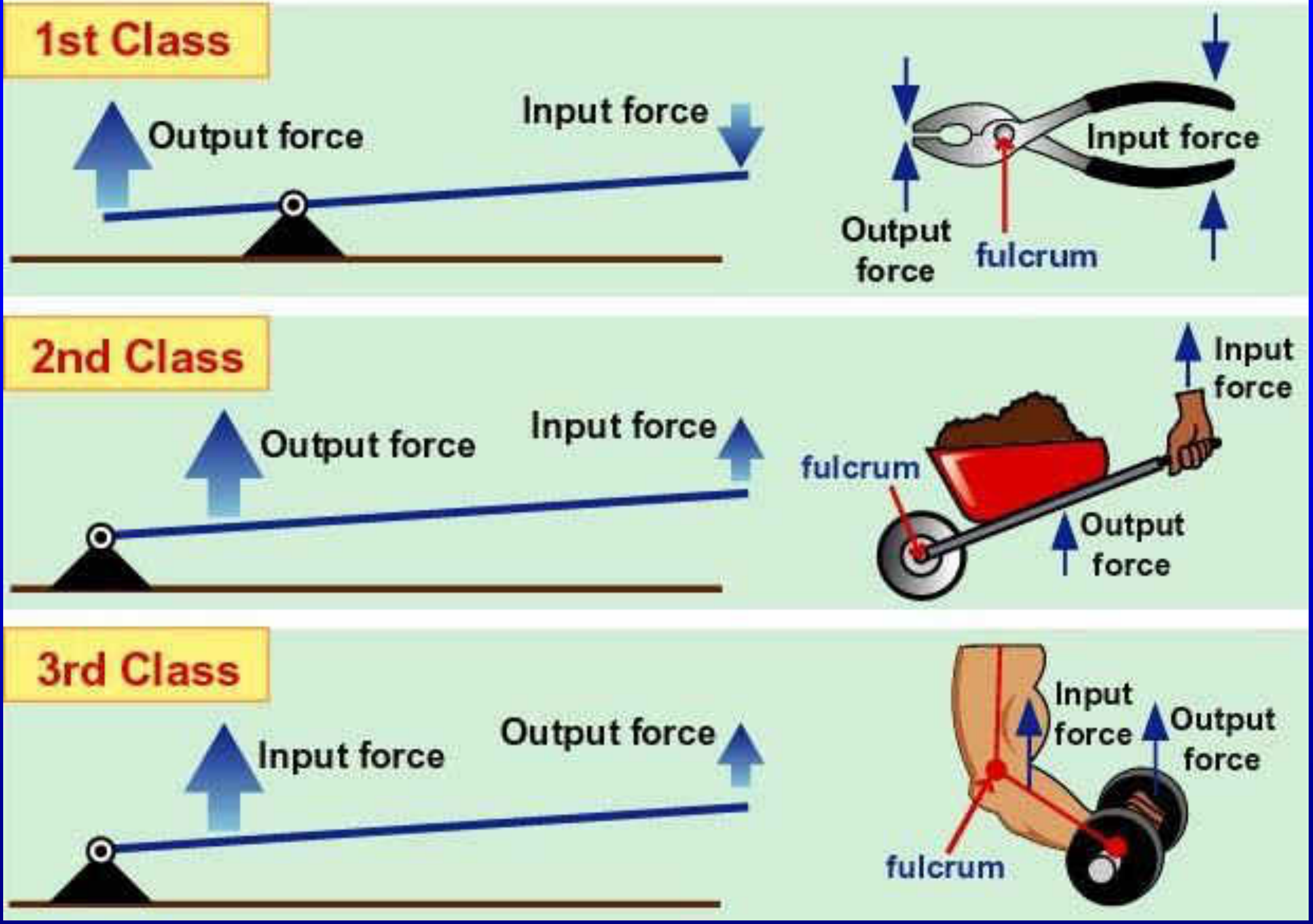
3rd Class Lever - The effort force is located between the fulcrum and the resistance. The effort arm is always shorter than the resistance arm so it cannot multiply the force and the MA is always less than 1.

– Examples: rake, hockey stick, broom, shovel, fishing pole, tweezers, tongs





The 3 Classes of Levers



- Lever is a simple mechanical device, in the form of a straight or curved link or a rigid rod, pivoted about the fulcrum.
- It works on the principle of moments and is used to get mechanical advantage and sometimes to facilitate the application of force in a desired direction.
- Examples of levers are: straight tommy bar used to operate screw jack, bell crank lever, rocker arm, lever of lever loaded safety valve etc.
- Figure shows the construction of a simple lever. P is the applied effort required to overcome load, W.
- Ratio of load to effort is called Mechanical Advantage and ratio of effort arm length to load arm length is called leverage.

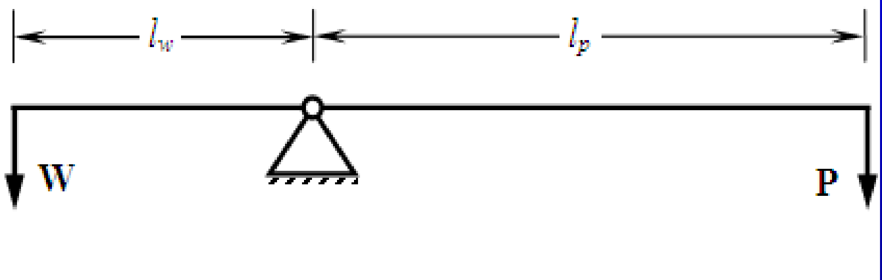


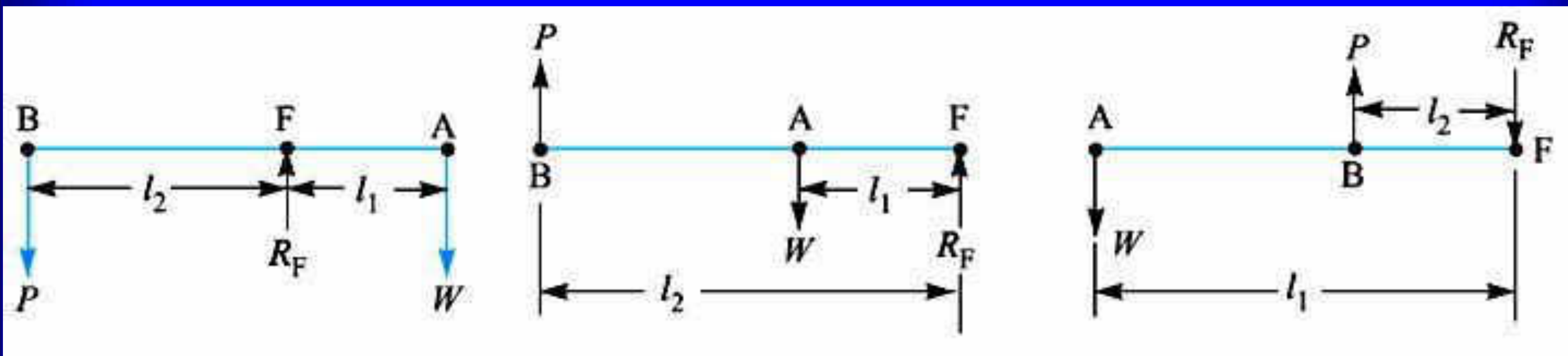
Figure 29.1 Lever

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}} = \frac{W}{P}$$

$$\text{Leverage} = \frac{\text{Effort Arm Length}}{\text{Load Arm Length}} = \frac{l_p}{l_w}$$

Classes of Levers

Class I Levers	Lever having the fulcrum located between the load point and effort point is called Class I lever. Examples are rocker arm, bell crank lever etc. Mechanical advantage of such levers is greater than one as effort arm is larger than the load arm.
Class II Levers	Lever having load point located between the fulcrum and effort point is called Class II lever. Lever used in safety valve is an example of lever of this class. The effort arm is larger than the load arm; therefore the mechanical advantage is more than one.
Class III Levers	Lever having effort point located between the fulcrum and load point is called Class III lever. The effort arm, in this case, is smaller than the load arm; therefore the mechanical advantage is less than one. Due to this, the use of such type of levers is not recommended. However a pair of tongs, the treadle of a sewing machine etc. are examples of this type of lever.


B
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R_F
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W
P
A
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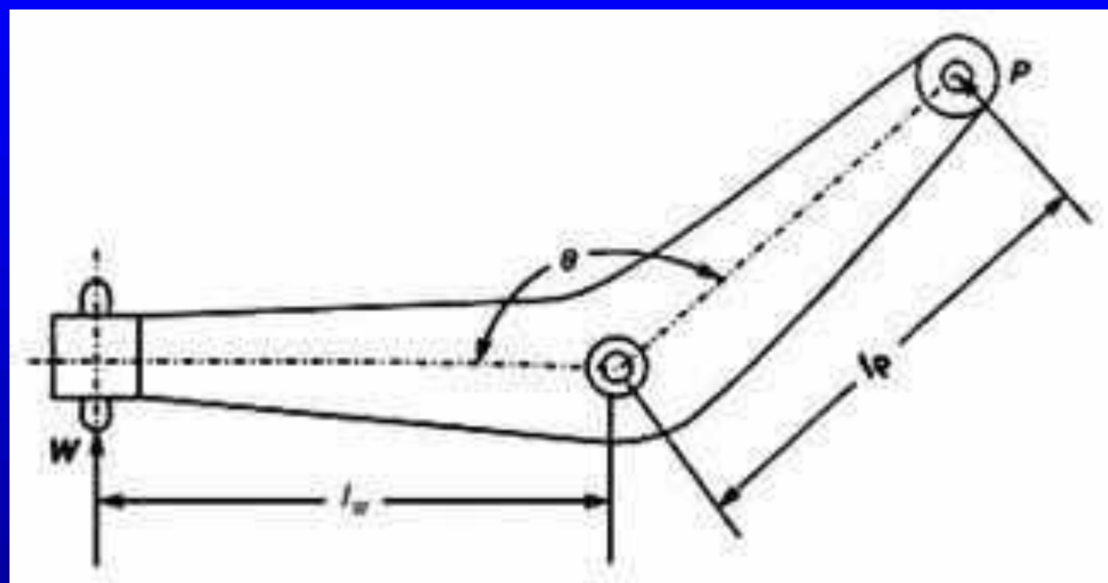
R_F
P
l_2
A
B
F
W
l_1

Design of Lever

- Design of lever involves determination of various dimensions of the lever for a specified load or output force required.
- For a specified load or output force desired, effort required can be calculated using principle of moments.
- Due to these forces, arms of the lever are subjected to bending and are designed based on that. Reaction force acting on the fulcrum can be calculated.
- Fulcrum of the lever is a pin joint and is designed based on bending and bearing considerations.

Determination of Forces

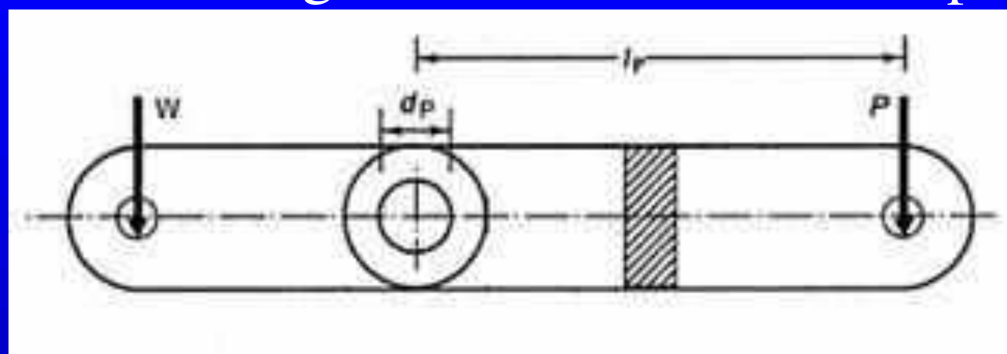
If the load and effort are parallel to each other, as shown in figure, reaction on the fulcrum is the algebraic sum of these two forces. But if the load and effort are inclined to each other at an angle q, as shown in figure, reaction (R) at the fulcrum can be determined as:



$$R = \sqrt{W^2 P^2 - 2WP\cos\theta}$$

Design of Lever Arms

Arms are subjected to bending moment and their section is estimated from bending stress consideration. Figure shows lever with fulcrum located between the load and the effort point. Bending moment is zero at the point of application



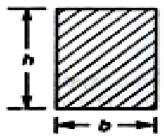
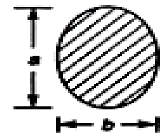
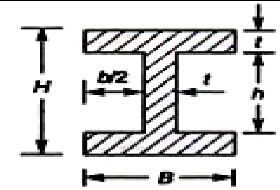
at the fulcrum.

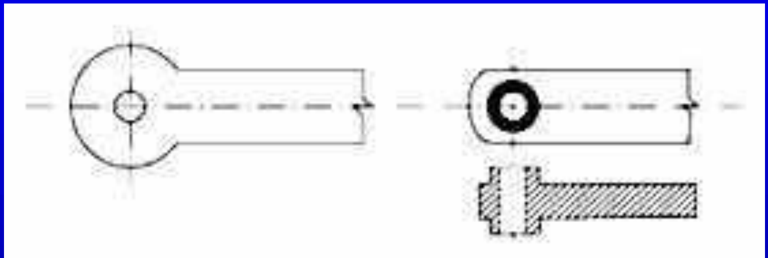
en by,

Maximum Bending Stress is then given by, $M=Pl_p$

Most commonly used sections for lever arms are: rectangular, elliptical and I-section. Values of moment of inertia, I and distance of farthest fibre from neutral axis, y for these sections are given in table

Common Sections used for Lever Arms

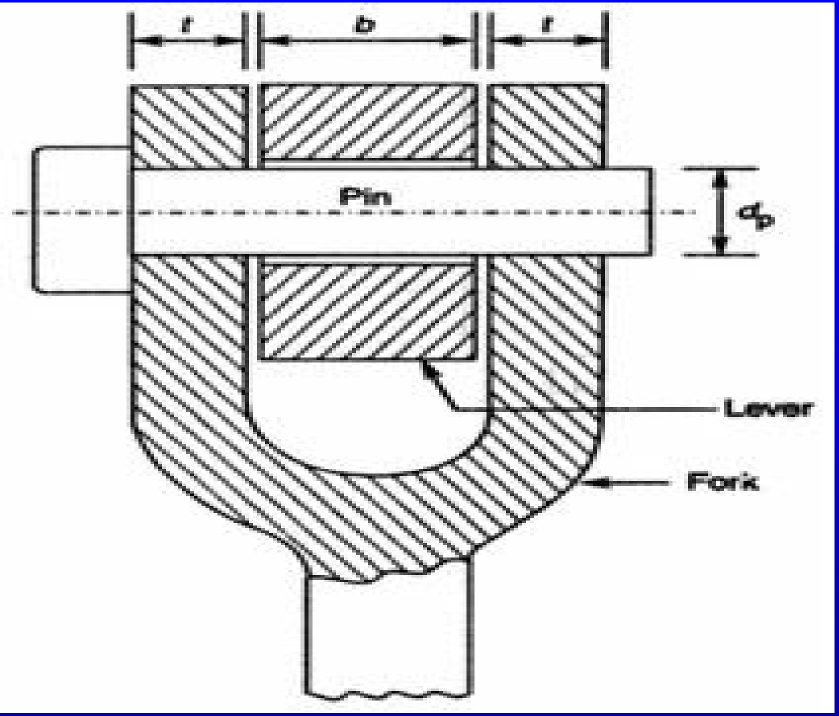
Section	Rectangular	Elliptical	I-section
Shape			
I	$\frac{bh^3}{12}$	$\frac{\pi a^3 b}{64}$	$\frac{BH^3 - bh^3}{12}$
y	h/2	a/2	H/2
Typical Proportions	h = (2 to 5)b	a = (2 to 3)b	H = (4 to 6)t B = (3 to 4)t



Therefore using suitable values of I and y for selected section, its dimensions can be finalised so that the bending stress remains within the allowable limits. Often the arms are made with cross-section reducing from central portion to the point of application of load. This is done to save material using uniform strength condition. Critical section of the lever (section of maximum bending moment) becomes weak due to hole made for pin. To compensate for the reduced strength, width of that section is increased or boss is provided as shown in figure

Design of Fulcrum

Fulcrum of lever is a pin joint as shown in figure. Pin is designed based on bearing and bending considerations as discussed below.



Bearing Failure

The permissible bearing pressure ($[P_{bearing}]$) depends upon relative velocity, frequency of relative motion and the lubrication condition between the pin and the bush. The usual range of allowable bearing pressure for brass/bronze bush and steel pin is 10-25 N/mm^2. Lower values are used for high relative velocity, frequent motion and intermittent lubrication conditions. If d_p and l_p are diameter and length

of the pin respectively, bearing pressure is given by,

$$P_{bearing} = \frac{\text{load}}{\text{projected area}} = \frac{R}{d_p\, l_p} \text{ should be } \leq [P_{bearing}]$$

Shear Failure

Pin is subjected to double shear and maximum shear stress is given by

$$\tau = \frac{R}{2\left(\frac{\pi}{4} d_p^2\right)} = \frac{2R}{\pi d_p^2} \text{ should be } \leq [\tau]$$

Bending Failure

As discussed in the design of pin for knuckle joint, when the pin is loose in the eye, which is a desired condition here for relative motion, pin is subjected to bending moment. It is assumed that: Load acting on the pin is uniformly distributed in the eye and uniformly varying in the two parts of the fork. Maximum Bending Moment (at centre) is given by

$$M = \frac{R}{2}\left(\frac{b}{2} + \frac{a}{3}\right) - \frac{R}{2}\left(\frac{b}{4}\right) = \frac{R}{2}\left(\frac{b}{4} + \frac{a}{3}\right)$$

Maximum Bending Stress in the pin, $\sigma_b = \frac{My}{I}$ should be $\leq [\sigma]$

where, $I = \frac{\pi d_p^4}{64}$ and $y = \frac{d_p}{2}$

Lever Material & Factor of Safety

- Levers are generally forged or cast. It is difficult to forge curved levers with complicated cross-sections and have to be cast.
- As the levers are subjected to tensile stress due to bending, cast iron is not recommended to be used as material for levers.
- Aluminium alloys are generally used for levers.
- For severe loading and corrosive conditions, alloy steels are used. Suitable heat treatment processes are also often employed to improve wear and shock resistance of lever. Factor of safety of 2 to 3 on yield strength is generally used.
- For severe loading conditions or fatigue loading higher factor of safety is also taken.

References

- Design of Machine Elements by VB Bhandari
- Analysis and Design of Machine Elements by V.K. Jadon
- Design of Machine Elements by C.S. Sharma & K. Purohit
- Machine Design by P.C. Sharma & D.K. Aggarwal
- Machine Design by R.S. Khurmi

References

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Thank You

Government Polytechnic Nanakpur

DEPARTMENT OF MECHANICAL ENGINEERING

E - NOTES

Refrigeration and Air-conditioning

HOD/O.I. (Mechanical) : **Sh.SHALANDER MOR**

Faculty Name: **Er. AMIT KUMAR**

Semester: 5th Sem

By: Er. Amit Kumar
Designed, Mechanical Editing & Developmental Editing

LEARNING OUTCOMES

After undergoing this course, the students will be able to:

Explain the working and construction features of refrigeration and air conditioning systems

Draw and interpret various refrigeration cycles.

Make basic calculation of psychometric properties and processes.

Calculate heating and cooling load requirements of a room.

Explain latest developments in the field of refrigeration and air conditioning.

Calculate the properties of air by using psychometric chart.

Detect faults in an air-conditioner/refrigerator.

Carry out charging of air conditioner.

Chapter One

Fundamentals of Refrigeration

Objective of the chapter

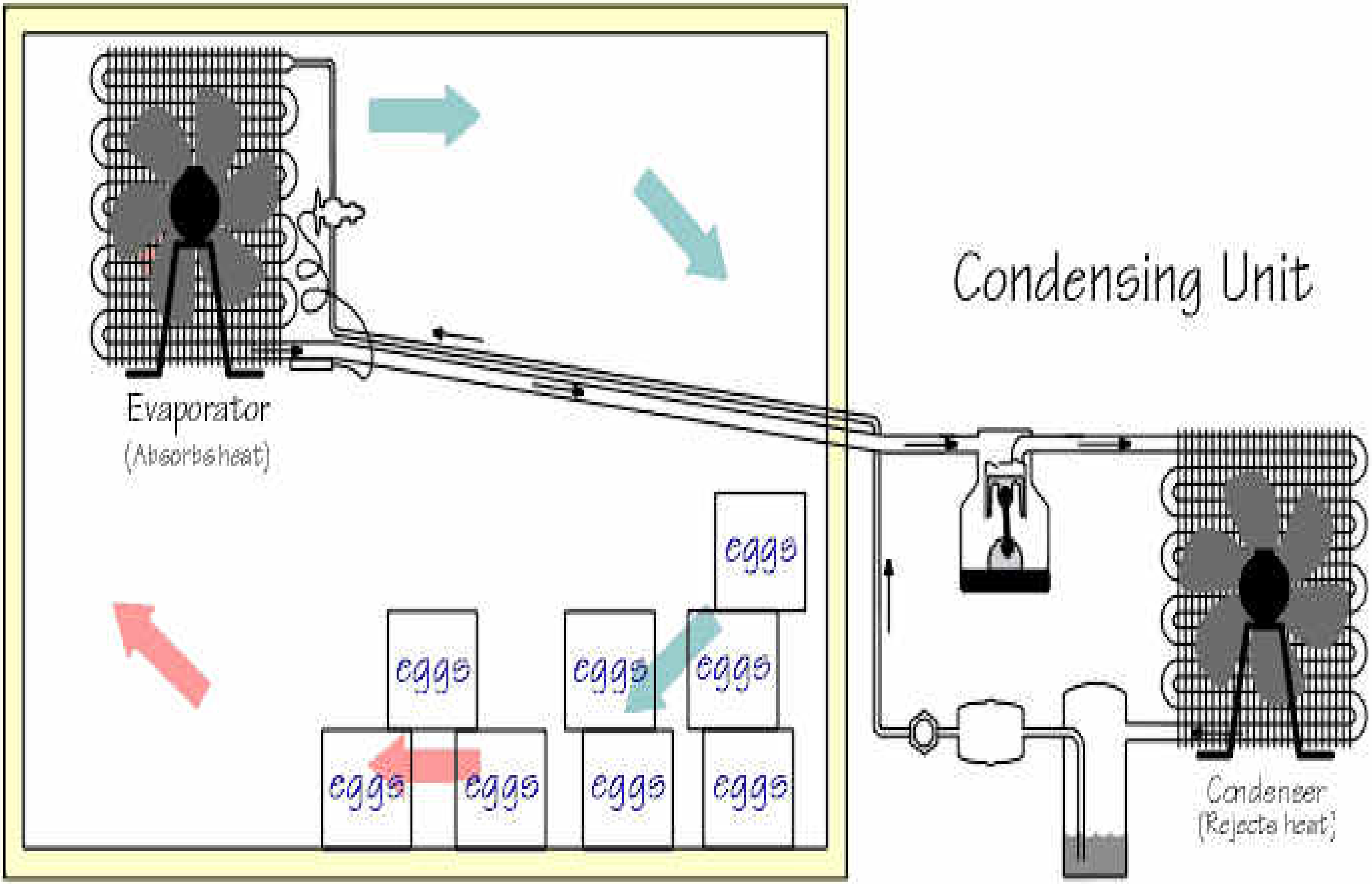
- To introduce students about the basics of refrigeration

Introduction

- Refrigeration is concerned with the production of cool confinement absorbing heat from the space where cooling is required
- The branch of science which deals with the process of reducing and maintaining the temperature of a space or material below the temperature of the surrounding
- The heat is then rejected to some natural sink such as:
    - The atmospheric air
    - Surface water
    - Any external body lower in temperature compared to the space

Continued………

- A refrigeration system is a combination of components, equipment and piping connected in a sequence to produce the refrigeration effect
- Refrigeration Cycle: when a refrigerant undergoes a series of processes like evaporation, compression, condensation, throttling and expansion, it is said to have undergone a refrigeration cycle


Condensing Unit
Evaporator
(Absorbs heat)
Condenser
(Rejects heat)
eggs
eggs
eggs
eggs
eggs
eggs
eggs
eggs

Continued……

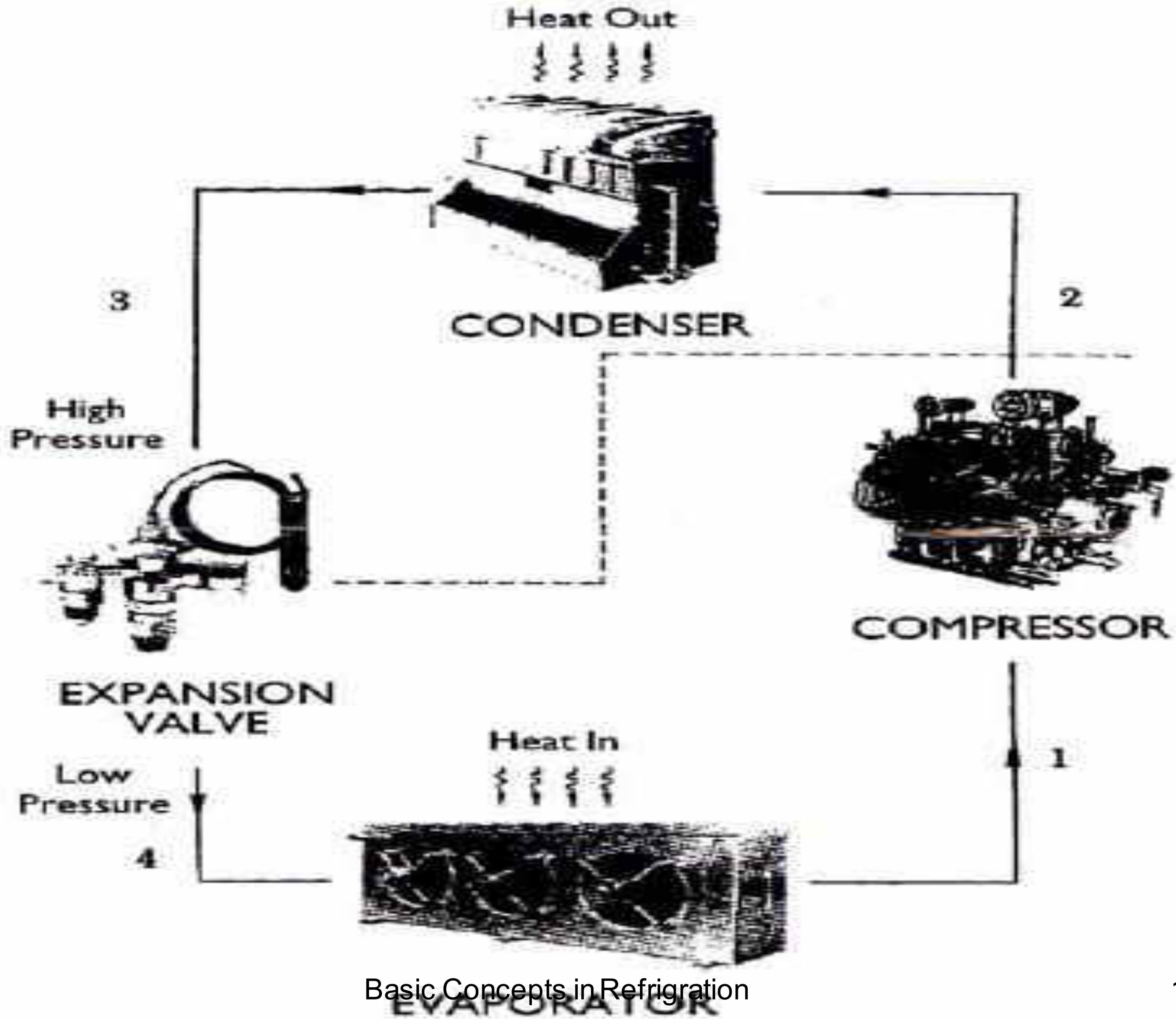
- Refrigeration cycle are classified mainly in to the following :
  - Vapor compression refrigeration cycle
  - Vapor absorption refrigeration cycle
  - Air refrigeration cycle and
  - Steam- jet refrigeration cycle

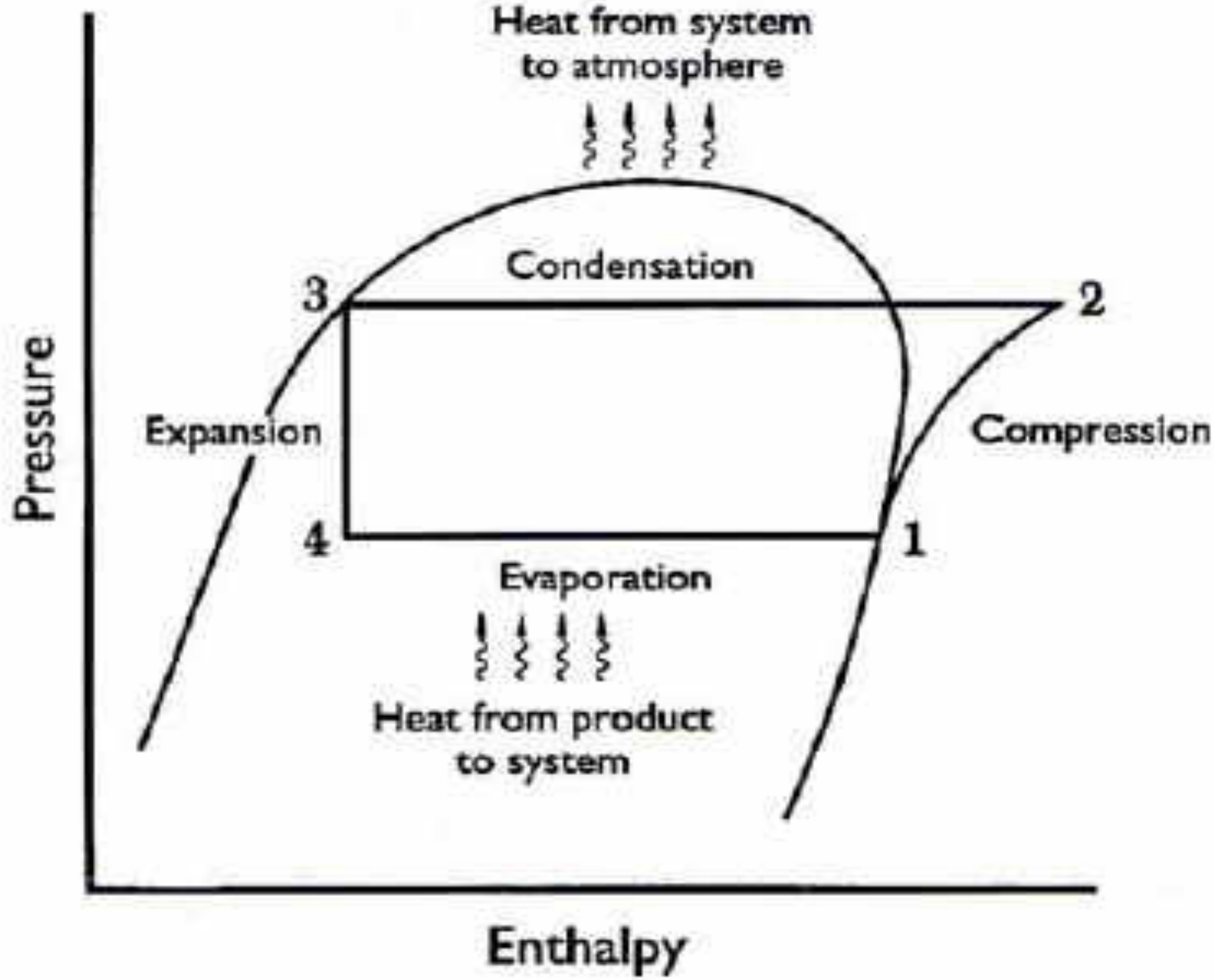
Principles of Refrigeration

REFRIGERATION SYSTEM COMPONENTS

The basic components of a refrigeration system are:

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


Heat Out
CONDENSER
3
2
High
Pressure
COMPRESSOR
EXPANSION
VALVE
Heat In
Low
Pressure
1
4
EVAPORATOR


Heat from system
to atmosphere
Condensation
3
2
Pressure
Expansion
Compression
4
1
Evaporation
Heat from product
to system
Enthalpy

Need for Refrigeration

- The growth of microorganisms is temperature-dependent, that growth declines as temperature falls, and that growth becomes very slow at temperatures below *+10 °C*
- Use of refrigeration to conserve foodstuffs and natural ice came into use for this purpose

Application of Refrigeration

- Foodstuff production, conservation and preservation
- Chemical processing industry
- Industrial and comfort air conditioning plants
- Drying plants, etc

Methods of Refrigeration

- There are different methods of refrigeration. Among them:
  - Solution (dissolution of salts in water) and
  - Change of Phase

Are mostly used in the refrigeration processes

Solution (dissolution of Salts in water)

When certain salts such as NaCl or $CaCl_2$ are dissolved in water, they absorb heat

$CaCl_2$ lowers the temperature of water up to -50^oC while NaCl up to -20^oC

The salts used for refrigeration has to be regained by evaporating the solution

The refrigeration produced is quite small compared to the large amount of energy required in salt regaining process

Change of Phase

- If a substance such as ice is available, it is possible to get refrigeration due to the change of phase
  - Solid change to liquid, the cooling produced is:

$$Q_{s1}=m_1 h_{sf}$$

Where m1 is the rate of fission of ice &

$h_{s\,f}$ is the enthalpy of fission (340kj/kg)

Continued………

– Refrigeration can be produced by change of phase from solid to vapor-Sublimation. This occurs when the pressure of the system is lower than the triple point pressure

$$Q_{c2}=m_2h_{sv}$$

Where $h_{s\,v}$ is the enthalpy of sublimation

– Solid carbon dioxide (dry ice) at one atmospheric pressure produces about 570kJ/Kg of refrigeration maintaining it self at a temperature of about -75 oC

Continued………

- Refrigeration can be created due to the phase transformation from liquid to vapor

$$Q_{c3}=m_3\,(h_g-h_f)$$

$$=m_3 h_{fg}$$

Requirements of Refrigerant

- There are certain desirable characteristics which a fluid used as a refrigerant should posses:
  - non-poisonous
  - Non-explosive
  - Non-corrosive
  - Non-inflammable
  - Leaks should be easily detected
  - Leaks should be easy to locate
  - Should operate under low pressure
  - Stable gas

Continued……..

- Parts moving in the fluid should be easy to lubricate
- Non- toxic
- Well balanced enthalpy of evaporation per unit mass
- Small relative displacement to obtain a certain refrigerating effect
- A minimum difference between the vaporizing and condensing pressure is desirable

- The standard comparison of refrigerants as used in refrigeration industry is based on an evaporator temperature of -15^{o}C and condensing temperature of 30^{o}C

Identification Refrigerant by Number

Refrigerant No Name and chemical formula

R-11 Trichloromonofluoromethane (CCl_3F)

R-12 Dichlorodifluoromethane (CCl_2F_2)

R-22 Monochlorodifluoromethane ($CHClF_2$)

R-500 Mixture of 73.8% R-12 and 26.2% R-152a

R-502 mixture of 48.8% R-22 and 51.2% R-115

R-717 Ammonia (NH_3)

R-134a Tetrafluoroethane (CH_2FCF_3)

Formula generation $C_m H_n F_p Cl_q$

Designated by R-(m-1)(n+1)(P)

Classification of Refrigerants

- The National Refrigeration Safety Code, USA (NRSC) catalogues all the refrigerants into three groups. Some of these are:
  - Group one – (Safest of the refrigerants)

  R-113, R-11, R-21, R-114, R-12, R-30, R-22, R-744, R-502, R-13, R-14, R-500, R-134a

  - Group two- (Toxic and somewhat Inflammable Refrigerants)

  R-1130, R-611, R-160, R-764, R-40, R-717

  - Group Three- (inflammable Refrigerants)

  R-600, R-290, R-170, R-1150, R-50

Evaporator

- The purpose of the evaporator is to remove unwanted heat from the product
- Refrigerant contained within the evaporator is boiling at a low-pressure. The level of this pressure is determined by two factors:
  - The rate at which the heat is absorbed from the product to the liquid refrigerant in the evaporator
  - The rate at which the low-pressure vapor is removed from the evaporator by the compressor
- When leaving the evaporator coil the liquid refrigerant is in vapor form.

Compressor

- The purpose of the compressor is to draw the low-temperature, low-pressure vapor from the evaporator via the suction line.
- When vapor is compressed it rises in temperature.
- The compressor transforms the vapor from a low-temperature vapor to a high-temperature vapor, in turn increasing the pressure.

Condenser

- The purpose of the condenser is to extract heat from the refrigerant to the outside air.
- Fans mounted above the condenser unit are used to draw air through the condenser coils.
- The temperature of the high-pressure vapor determines the temperature at which the condensation begins.
- As heat has to flow from the condenser to the air, the condensation temperature must be higher than that of the air.
- The high-pressure vapor within the condenser is then cooled to the point where it becomes a liquid refrigerant once more, whilst retaining some heat.

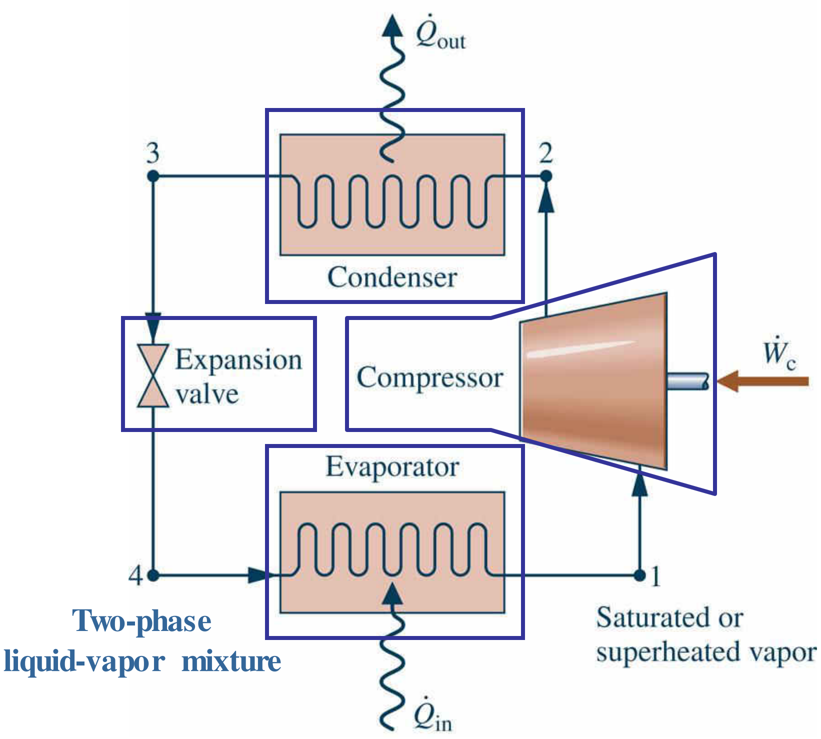
Expansion Valve

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

Vapor-Compression Refrigeration Cycle

Vapor-Compression Refrigeration Cycle

- ► Most common refrigeration cycle in use today
- ► There are four principal control volumes involving these components:
  - ► Evaporator
  - ► Compressor
  - ► Condenser
  - ► Expansion valve



All energy transfers by work and heat are taken as positive in the directions of the arrows on the schematic and energy balances are written accordingly.

The Vapor-Compression Refrigeration Cycle

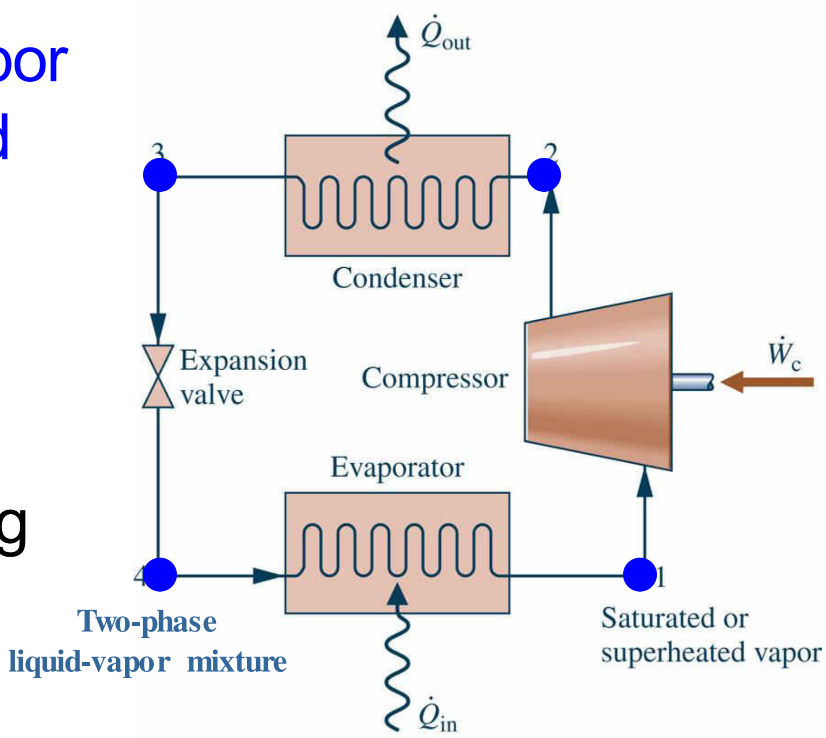
► The processes of this cycle are

Process 4-1: two-phase liquid-vapor mixture of refrigerant is evaporated through heat transfer from the refrigerated space.

Process 1-2: vapor refrigerant is compressed to a relatively high temperature and pressure requiring work input.

Process 2-3: vapor refrigerant condenses to liquid through heat transfer to the cooler surroundings.

Process 3-4: liquid refrigerant expands to the evaporator pressure.



The Vapor-Compression Refrigeration Cycle

- ►Engineering model:
  - ►Each component is analyzed as a control volume at steady state.
  - ►Dry compression is presumed: the refrigerant is a vapor.
  - ►The compressor operates adiabatically.
  - ►The refrigerant expanding through the valve undergoes a throttling process.
  - ►Kinetic and potential energy changes are ignored.

The Vapor-Compression Refrigeration Cycle

► Applying mass and energy rate balances

Evaporator

$$\frac{\dot{Q}_{\text{in}}}{\dot{m}} = h_1 - h_4 \qquad \textbf{(Eq. 10.3)}$$

► The term $\dot{Q}_{\text{in}}$ is referred to as the refrigeration capacity, expressed in kW in the SI unit system or Btu/h in the English unit system.

► A common alternate unit is the ton of refrigeration which equals **200 Btu/min** or about **211 kJ/min**.

The Vapor-Compression Refrigeration Cycle

► Applying mass and energy rate balances

Compressor

Assuming adiabatic compression

$$\frac{\dot{W}_c}{\dot{m}} = h_2 - h_1 \quad \textbf{(Eq. 10.4)}$$

Condenser

$$\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3 \quad \textbf{(Eq. 10.5)}$$

Expansion valve

Assuming a throttling process

$$h_4 = h_3 \quad \textbf{(Eq. 10.6)}$$

The Vapor-Compression Refrigeration Cycle

► Performance parameters

Coefficient of Performance (COP)

$$\text{C.O.P} = \frac{Q_{in}/\dot{m}}{\dot{W_c}/\dot{m}} = \frac{h_1 - h_4}{h_2 - h_1}$$

Carnot Coefficient of Performance

$$\text{C.O.P} = \frac{T_C}{T_H - T_C}$$

This equation represents the maximum theoretical coefficient of performance of any refrigeration cycle operating between cold and hot regions at T_C and T_H, respectively.

Example 11-1

Refrigerant-134a is the working fluid in an ideal compression refrigeration cycle. The refrigerant leaves the evaporator at -20°C and has a condenser pressure of 0.9 MPa. The mass flow rate is 3 kg/min. Find COP_R and $COP_{R,\ Carnot}$ for the same T_{max} and T_{min}, and the tons of refrigeration.

Using the Refrigerant-134a Tables, we have

$$\left.\begin{array}{l} State\,1 \\ Compressor\ inlet \\ T_1 = -20^o C \\ x_1 = 1.0 \end{array}\right\} \left\{\begin{array}{l} h_1 = 238.41\dfrac{kJ}{kg} \\ s_1 = 0.9456\dfrac{kJ}{kg\cdot K} \end{array}\right.$$

$$\left.\begin{array}{l} State\,2 \\ Compressor\ exit \\ P_{2s} = P_2 = 900\,kPa \\ s_{2s} = s_1 = 0.9456\dfrac{kJ}{kg\cdot K} \end{array}\right\} \left\{\begin{array}{l} h_{2s} = 278.23\dfrac{kJ}{kg} \\ T_{2s} = 43.79^o C \end{array}\right.$$

$$\left.\begin{array}{l} State\,3 \\ Condenser\ exit \\ P_3 = 900\,kPa \\ x_3 = 0.0 \end{array}\right\} \left\{\begin{array}{l} h_3 = 101.61\dfrac{kJ}{kg} \\ s_3 = 0.3738\dfrac{kJ}{kg\cdot K} \end{array}\right.$$

$$\left.\begin{array}{l} State\,4 \\ Throttle\ exit \\ T_4 = T_1 = -20^o C \\ h_4 = h_3 \end{array}\right\} \left\{\begin{array}{l} x_4 = 0.358 \\ s_4 = 0.4053\dfrac{kJ}{kg\cdot K} \end{array}\right.$$

$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} = \frac{h_1 - h_4}{h_2 - h_1}$$

$$= \frac{(238.41 - 101.61)\frac{kJ}{kg}}{(278.23 - 238.41)\frac{kJ}{kg}}$$

$$= 3.44$$

The tons of refrigeration, often called the cooling load or refrigeration effect, are

$$\dot{Q}_L = \dot{m}(h_1 - h_4)$$

$$= 3\frac{kg}{\min}(238.41 - 101.61)\frac{kJ}{kg}\frac{1Ton}{211\frac{kJ}{\min}}$$

$$= 1.94 Ton$$

$$COP_{R,\,Carnot} = \frac{T_L}{T_H - T_L}$$

$$= \frac{(-20 + 273)\,K}{(43.79 - (-20))K}$$

$$= 3.97$$

Another measure of the effectiveness of the refrigeration cycle is how much input power to the compressor, in horsepower, is required for each ton of cooling.

The unit conversion is 4.715 hp per ton of cooling.

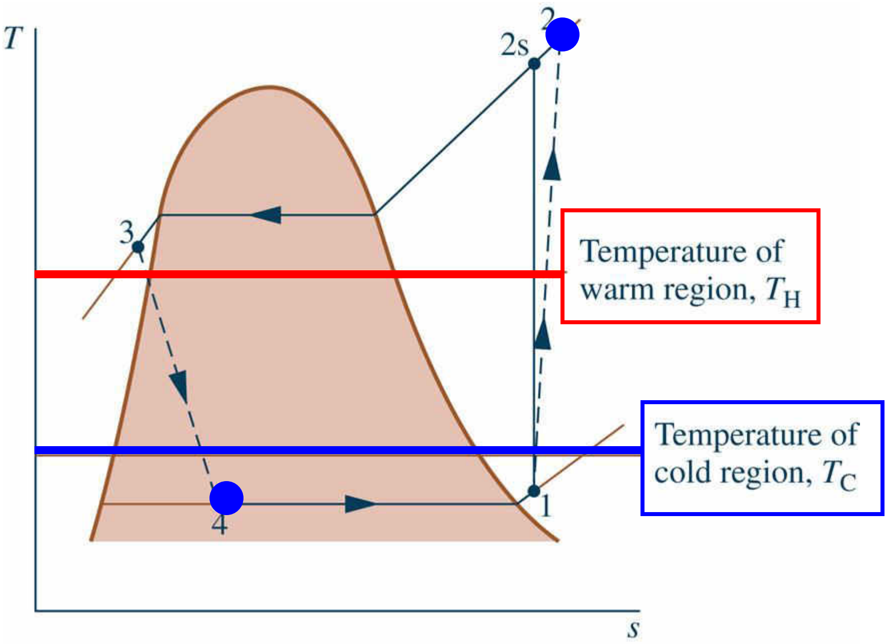
$$\frac{\dot{W}_{net,\,in}}{\dot{Q}_L} = \frac{4.715}{COP_R}$$

$$= \frac{4.715}{3.44}\frac{hp}{Ton}$$

$$= 1.37\frac{hp}{Ton}$$

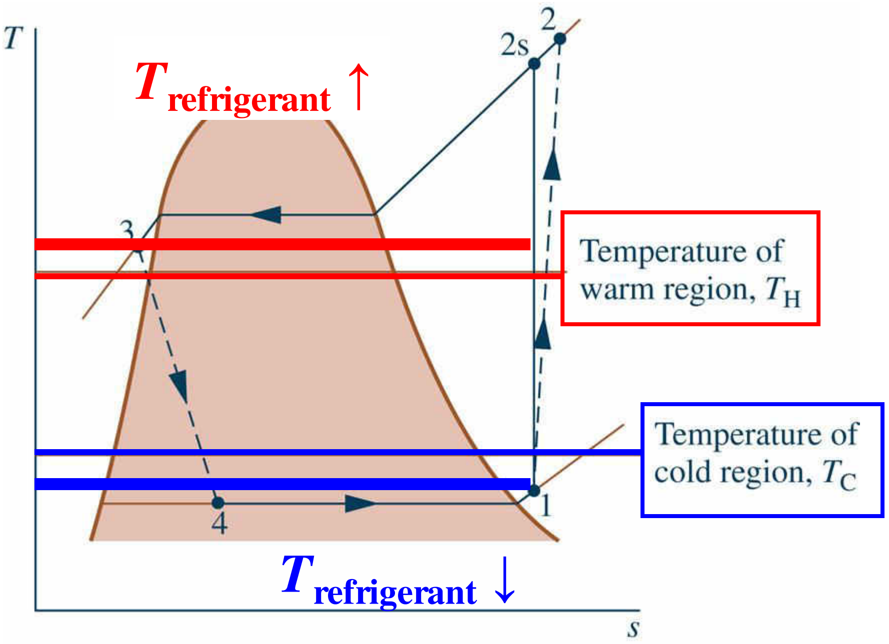
Features of Actual Vapor-Compression Cycle

- ►Heat transfers between refrigerant and cold and warm regions are not reversible.
  - ►Refrigerant temperature in evaporator is less than T_C.
  - ►Refrigerant temperature in condenser is greater than T_H.
  - ►Irreversible heat transfers have negative effect on performance.



Features of Actual Vapor-Compression Cycle

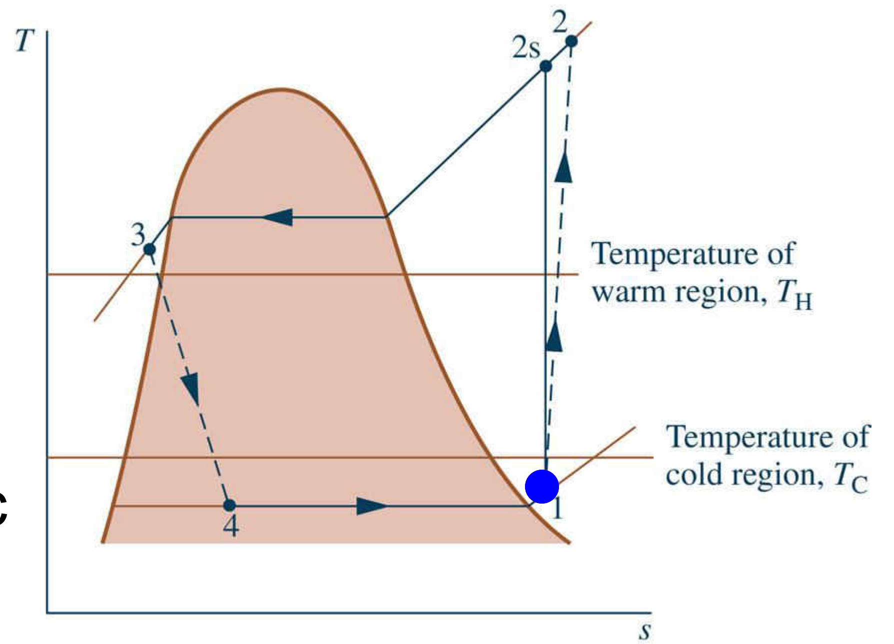
- The COP decreases – primarily due to increasing compressor work input – as the
  - temperature of the refrigerant passing through the evaporator ***is reduced*** relative to the temperature of the cold region, T_C.
  - temperature of the refrigerant passing through the condenser ***is increased*** relative to the temperature of the warm region, T_H.



Features of
Actual Vapor-Compression Cycle

► Irreversibilities during the compression process are suggested by dashed line from state **1** to state **2**.

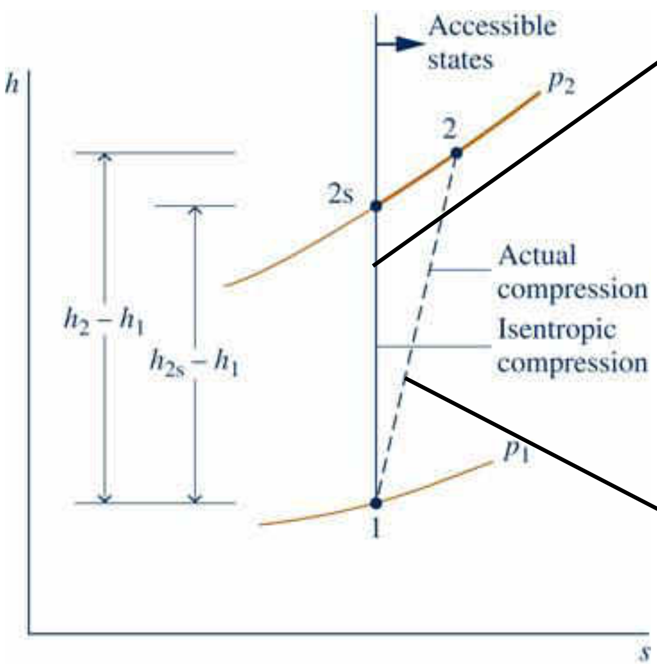
► An increase in specific entropy accompanies an adiabatic irreversible compression process. The work input for compression process **1-2** is greater than for the counterpart isentropic compression process **1-2s**.



► Since process **4-1**, and thus the refrigeration capacity, is the same for cycles **1-2-3-4-1** and **1-2s-3-4-1**, cycle **1-2-3-4-1** has the lower COP.

Isentropic Compressor Efficiency

► The isentropic compressor efficiency is the ratio of the minimum theoretical work input to the actual work input, each per unit of mass flowing:



work required in an isentropic compression from compressor inlet state to the exit pressure

$$\eta_c = \frac{(-\dot{W}_{cv}/\dot{m})_s}{(-\dot{W}_{cv}/\dot{m})} = \frac{h_{2s} - h_1}{h_2 - h_1}$$ **(Eq. 6.48)**

work required in an actual compression from compressor inlet state to exit pressure

Actual Vapor-Compression Cycle

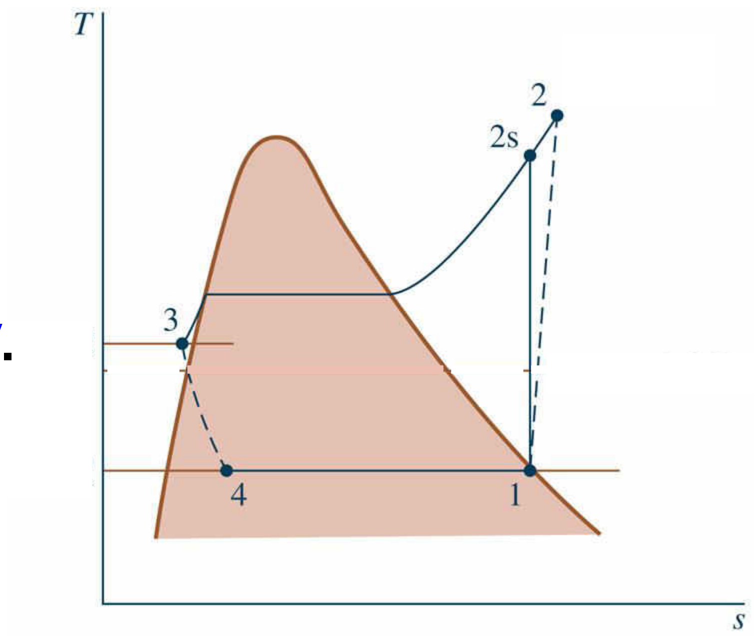
Example: The table provides steady-state operating data for a vapor-compression refrigeration cycle using **R-134a** as the working fluid. For a refrigerant mass flow rate of **0.08 kg/s**, determine the

(a) compressor power, in **kW**,

(b) refrigeration capacity, in **tons**,

(c) coefficient of performance,

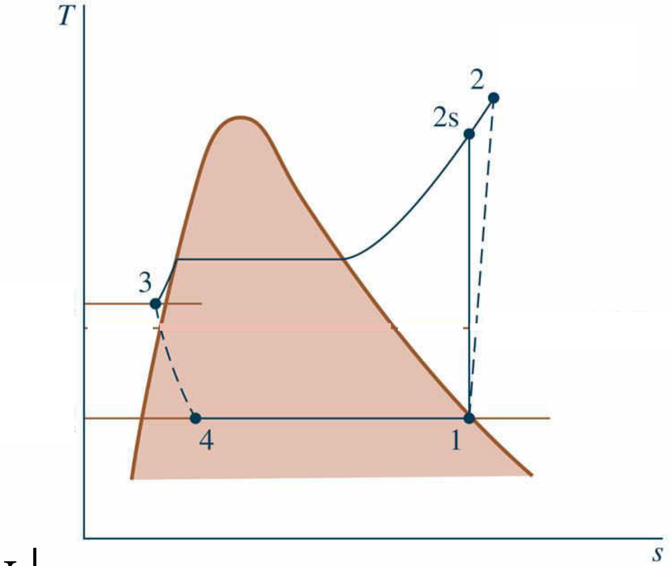
(d) isentropic compressor efficiency.



State	1	2s	2	3	4
h (kJ/kg)	241.35	272.39	280.15	91.49	91.49

Actual Vapor-Compression Cycle

State	1	2s	2	3	4
h (kJ/kg)	241.35	272.39	280.15	91.49	91.49



(a) The **compressor power** is

$$\dot{W}_c = \dot{m}(h_2 - h_1)$$

$$\dot{W}_c = \left(0.08\,\frac{\text{kg}}{\text{s}}\right)(280.15 - 241.35)\,\frac{\text{kJ}}{\text{kg}}\left|\frac{1\,\text{kW}}{1\,\text{kJ/s}}\right| = \mathbf{3.1\ kW}$$

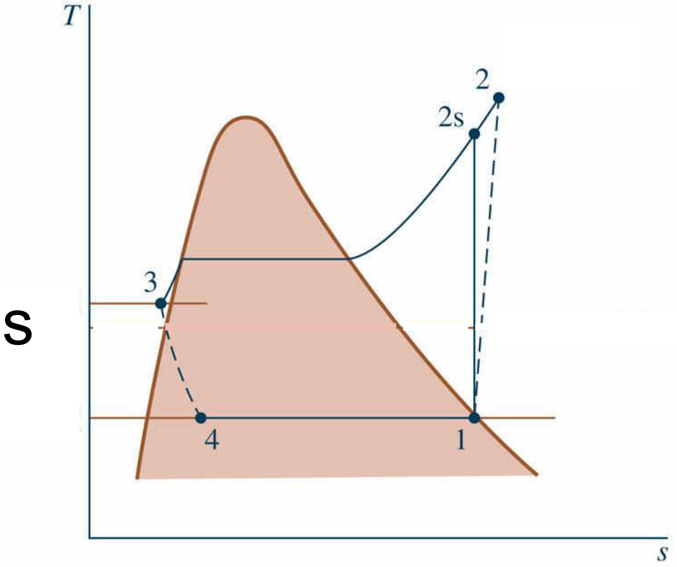
(b) The **refrigeration capacity** is

$$\dot{Q}_{in} = \dot{m}(h_1 - h_4)$$

$$\dot{Q}_{in} = \left(0.08\,\frac{\text{kg}}{\text{s}}\right)(241.35 - 91.49)\,\frac{\text{kJ}}{\text{kg}}\left|\frac{1\,\text{ton}}{211\,\text{kJ/min}}\right|\left|\frac{60\,\text{s}}{\text{min}}\right| = \mathbf{3.41\ tons}$$

Actual Vapor-Compression Cycle

State	1	2s	2	3	4
h (kJ/kg)	241.35	272.39	280.15	91.49	91.49



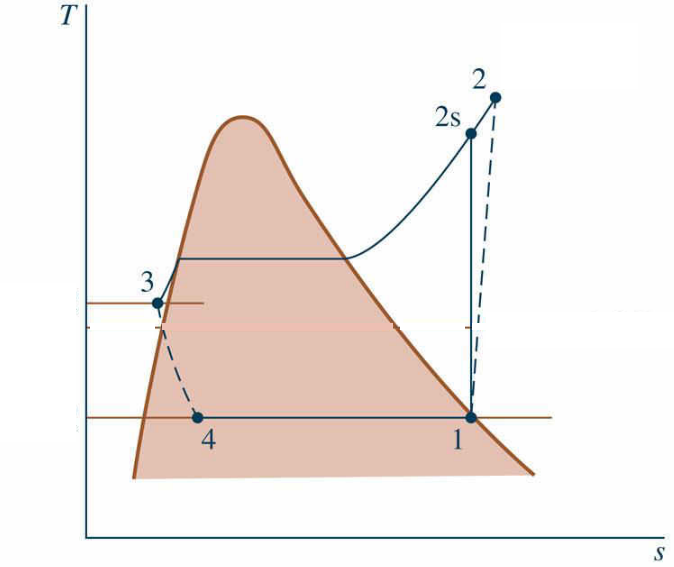
(c) The **coefficient of performance** is

$$C.O.P = \frac{(h_1 - h_4)}{(h_2 - h_1)}$$

$$C.O.P = \frac{(241.35 - 91.49)\text{kJ/kg}}{(280.15 - 241.35)\text{kJ/kg}} = 3.86$$

Actual Vapor-Compression Cycle

State	1	2s	2	3	4
h (kJ/kg)	241.35	272.39	280.15	91.49	91.49



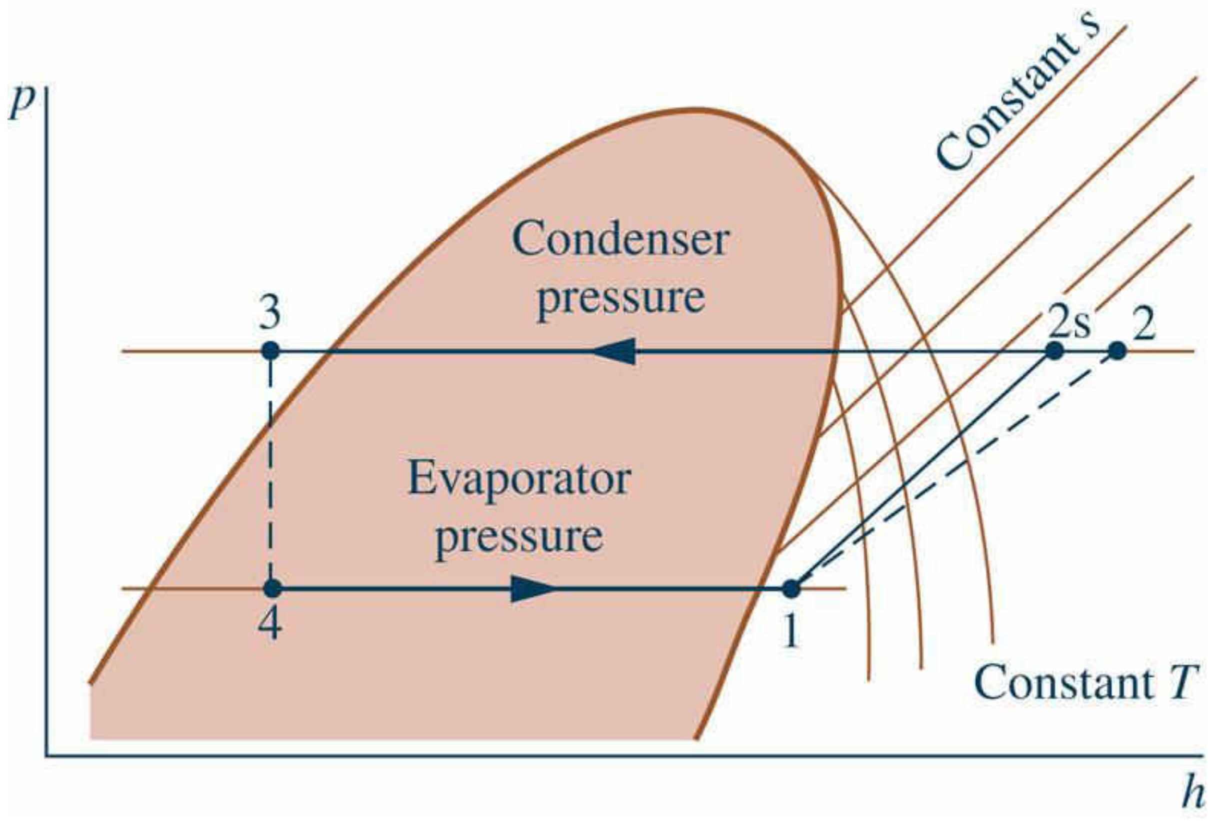
(d) The **isentropic compressor efficiency** is

$$\eta_c = \frac{(\dot{W}_c / \dot{m})_s}{\dot{W}_c / \dot{m}} = \frac{(h_{2s} - h_1)}{(h_2 - h_1)}$$

$$\eta_c = \frac{(272.39 - 241.35)\text{kJ/kg}}{(280.15 - 241.35)\text{kJ/kg}} = \mathbf{0.8 = 80\%}$$

p-h Diagram

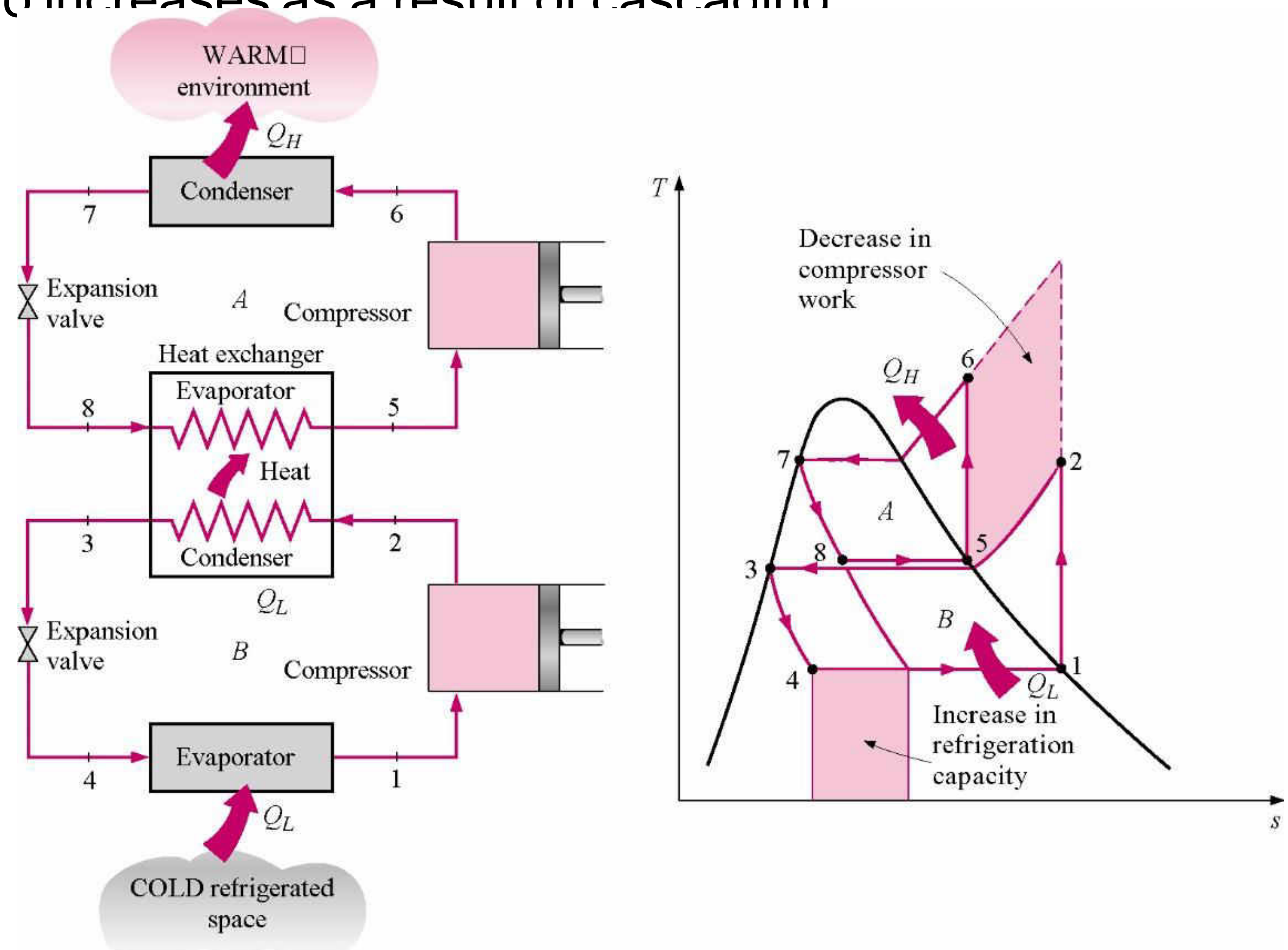
► The pressure-enthalpy (*p-h*) diagram is a thermodynamic property diagram commonly used in the refrigeration field.



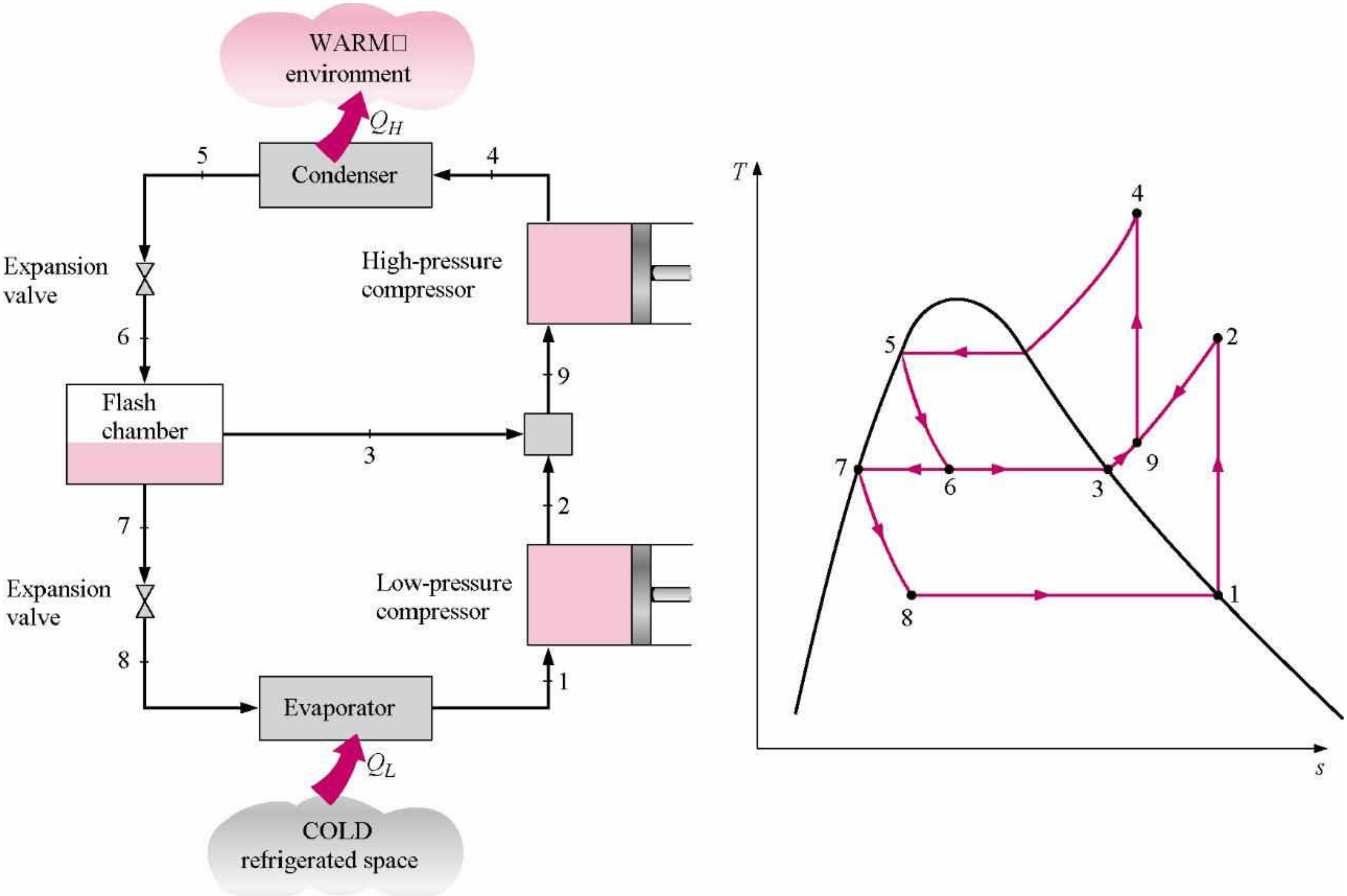
Other Refrigeration Cycles

Cascade refrigeration systems

Very low temperatures can be achieved by operating two or more vapor-compression systems in series, called *cascading.* The COP of a refrigeration system also increases as a result of cascading.

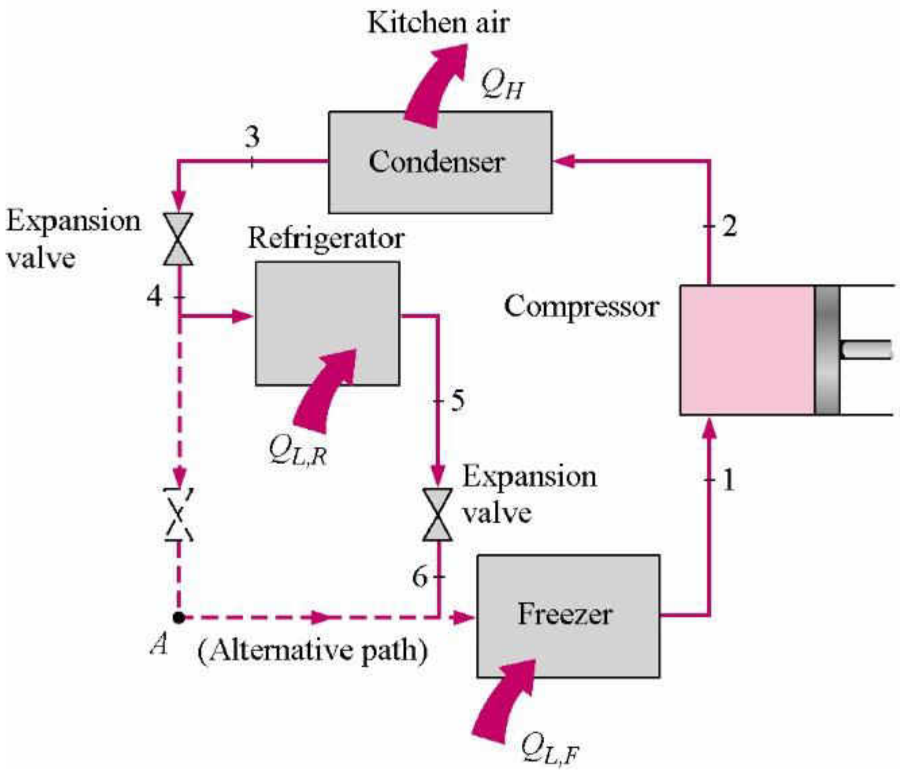


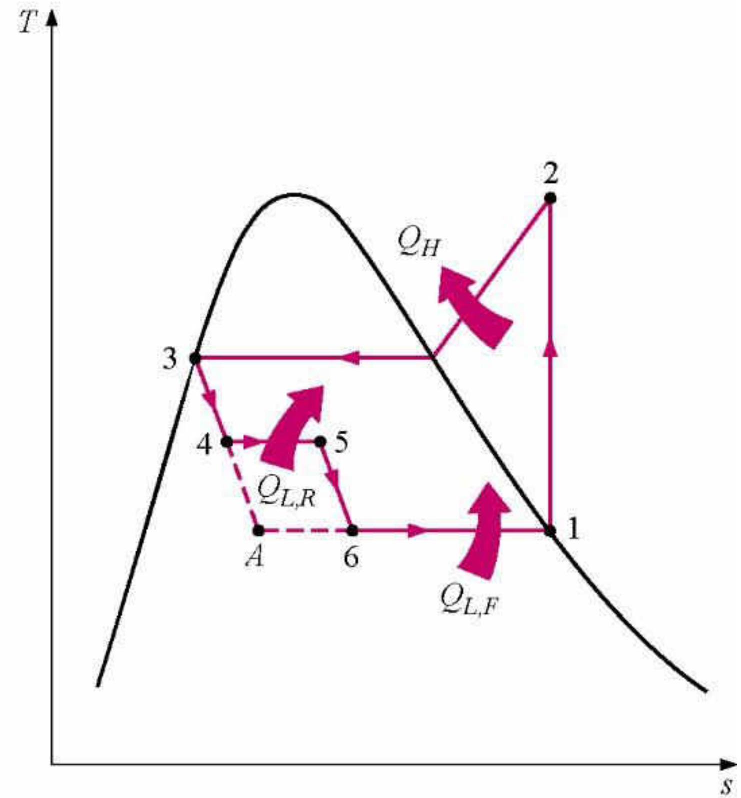
Multistage compression refrigeration systems



Multipurpose refrigeration systems

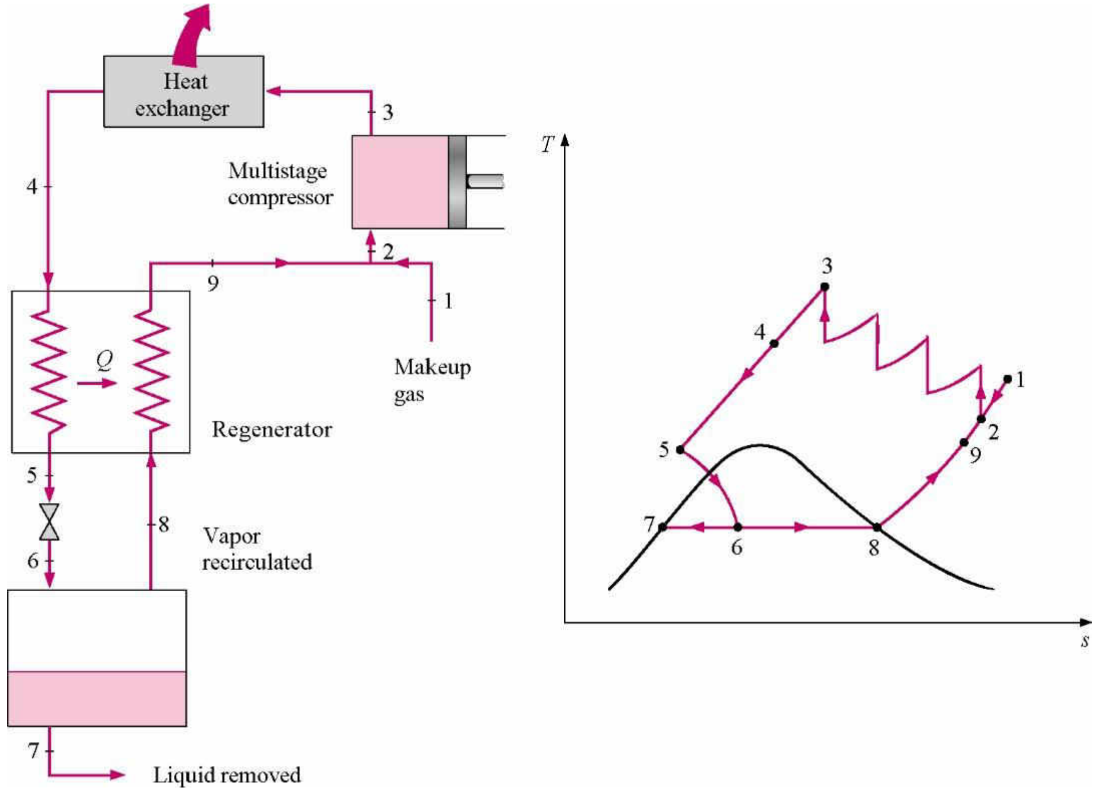
A refrigerator with a single compressor can provide refrigeration at several temperatures by throttling the refrigerant in stages.





Liquefaction of gases

Another way of improving the performance of a vapor-compression refrigeration system is by using *multistage compression with regenerative cooling.* The vapor-compression refrigeration cycle can also be used to liquefy gases after some modifications.



Selecting Refrigerants

► Refrigerant selection is based on several factors:

- ► Performance: provides adequate cooling capacity cost-effectively.
- ► Safety: avoids hazards (i.e., toxicity).
- ► Environmental impact: minimizes harm to stratospheric ozone layer and reduces negative impact to global climate change.

Refrigerant Types and Characteristics

Refrigerant Data Including Global Warming Potential (GWP)

Refrigerant Number	Type	Chemical Formula	Approx. GWP
R-12	CFC	CCl_2F_2	10900
R-11	CFC	CCl_3F	4750
R-114	CFC	$CClF_2CClF_2$	10000
R-113	CFC	CCl_2FCClF_2	6130
R-22	HCFC	$CHClF_2$	1810
R-134a	HFC	CH_2FCF_3	1430
R-1234yf	HFC	$CF_3CF{=}CH_2$	4
R-410A	HFC blend	R-32, R-125 (50/50 Weight %)	1725
R-407C	HFC blend	R-32, R-125, R-134a (23/25/52 Weight %)	1526
R-744 (carbon dioxide)	Natural	CO_2	1
R-717 (ammonia)	Natural	NH_3	0
R-290 (propane)	Natural	C_3H_8	10
R-50 (methane)	Natural	CH_4	25
R-600 (butane)	Natural	C_4H_{10}	10

Global Warming Potential (GWP) is a simplified index that estimates the ***potential future influence on global warming*** associated with different gases when released to the atmosphere.

Refrigerant Types and Characteristics

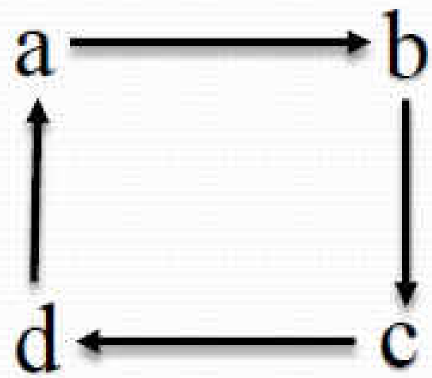
► **Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs)** are early synthetic refrigerants each containing chlorine. Because of the adverse effect of chlorine on Earth's stratospheric ozone layer, use of these refrigerants is regulated by international agreement.

► **Hydrofluorocarbons (HFCs) and HFC blends** are chlorine-free refrigerants. Blends combine two or more HFCs. While these chlorine-free refrigerants do not contribute to ozone depletion, with the exception of R-1234yf, they have high GWP levels.

► **Natural refrigerants** are nonsynthetic, naturally occurring substances which serve as refrigerants. These include carbon dioxide, ammonia, and hydrocarbons. These refrigerants feature low GWP values; still, concerns have been raised over the toxicity of NH_3 and the safety of the hydrocarbons.

PRINCIPLE OF ADSORPTION REFRIGERATION

- Refrigerant
- Adsorbent
- Adsorption
- Desorption



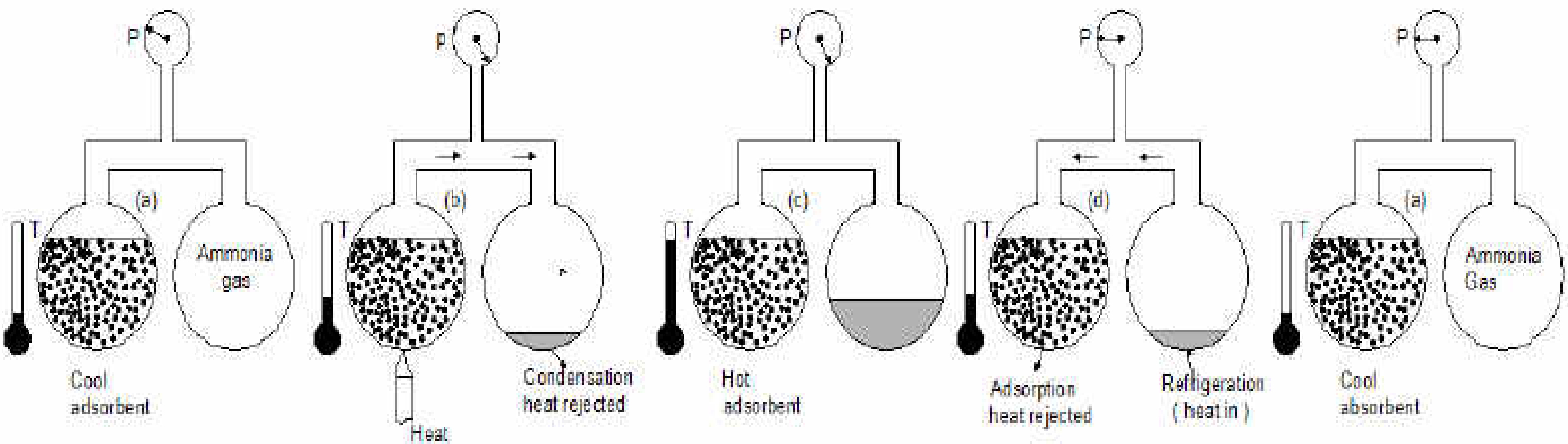
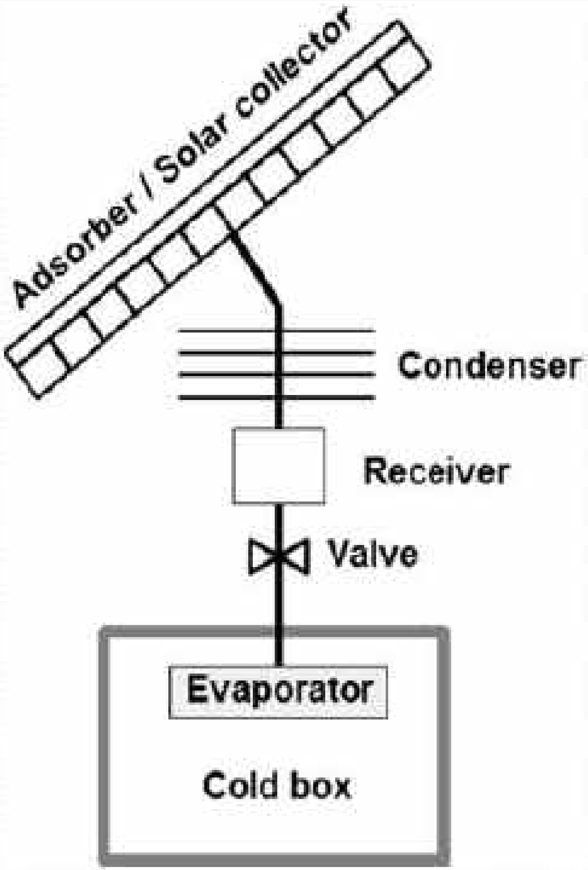
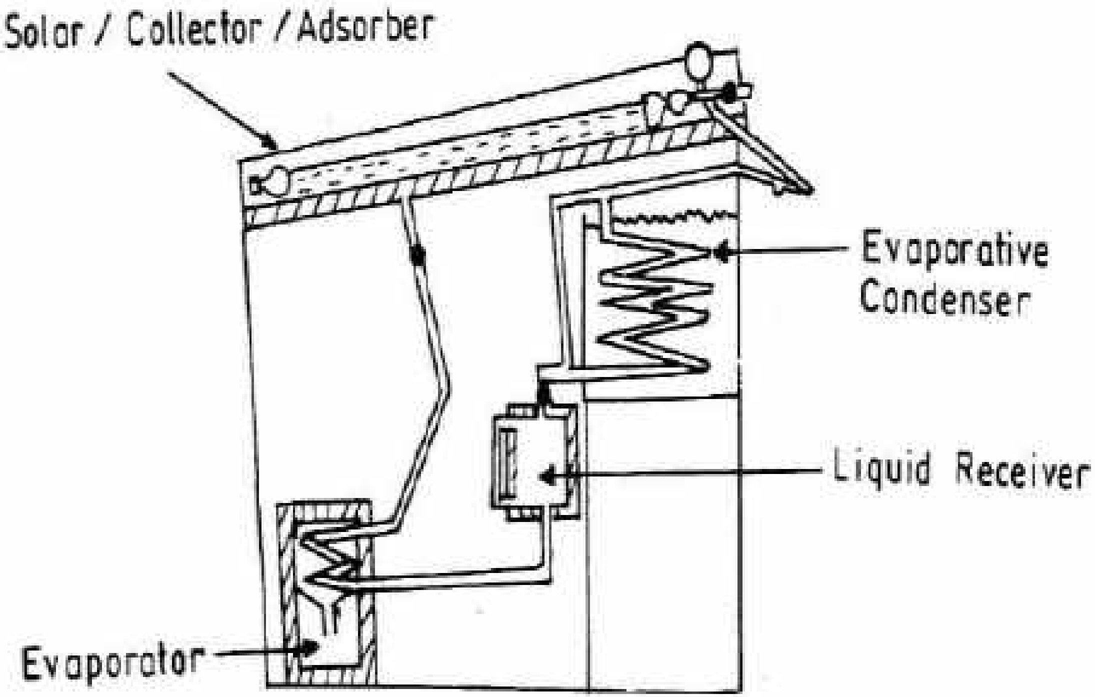


Fig. 1 - Principle of adsorption refrigeration technology

BASIC SOLAR VAdRS



(a) Schematic, intermittent cycle



(b) constructive, continuous cycle

Figure- Simple Solar Adsorption Refrigeration System

THERMODYNAMIC CYCLE

Processes Involved,

- Process (a-b)-Isosteric desorption
- Process (b-c)-Isobaric desorption
- Process (c-d)-Isosteric adsorption
- Process (d-a)-Isobaric adsorption

Isosteric Process- Constant Concentration Process
(Achieved by isolating the bed and evaporator)

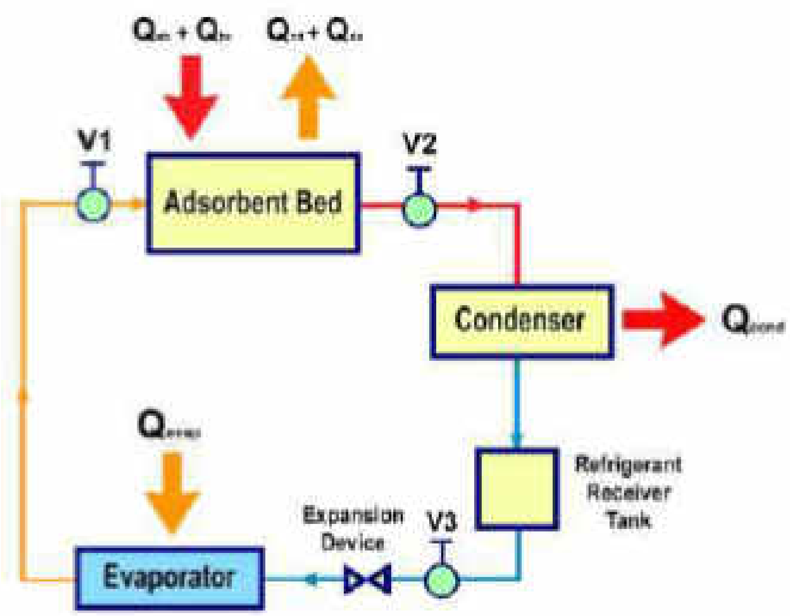


Figure- Schematic diagram

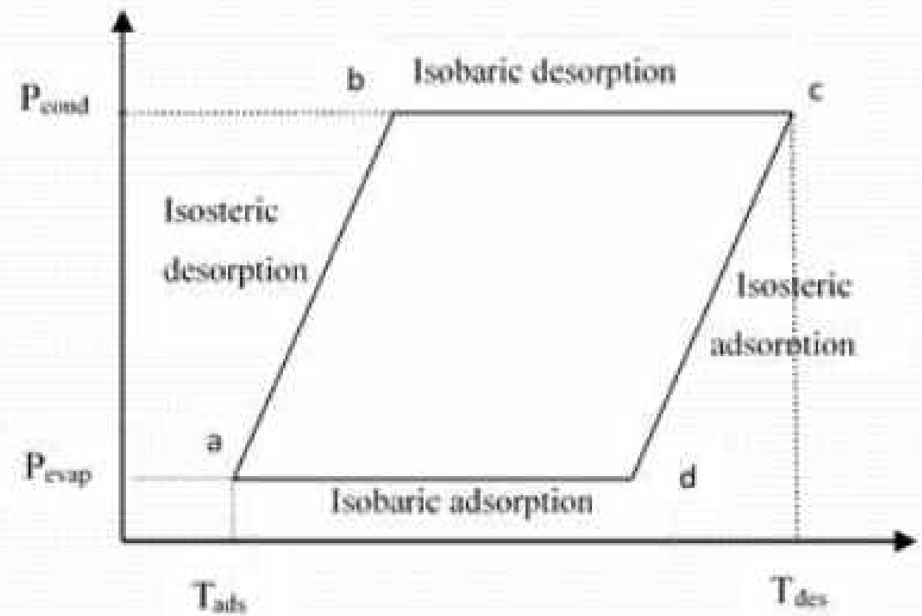


Figure- Thermodynamic Cycle

COMPONENTS

1. Solar Collector
2. Generator/Adsorber
3. Condenser
4. Condensate receiver tank
5. Expansion device
6. Evaporator

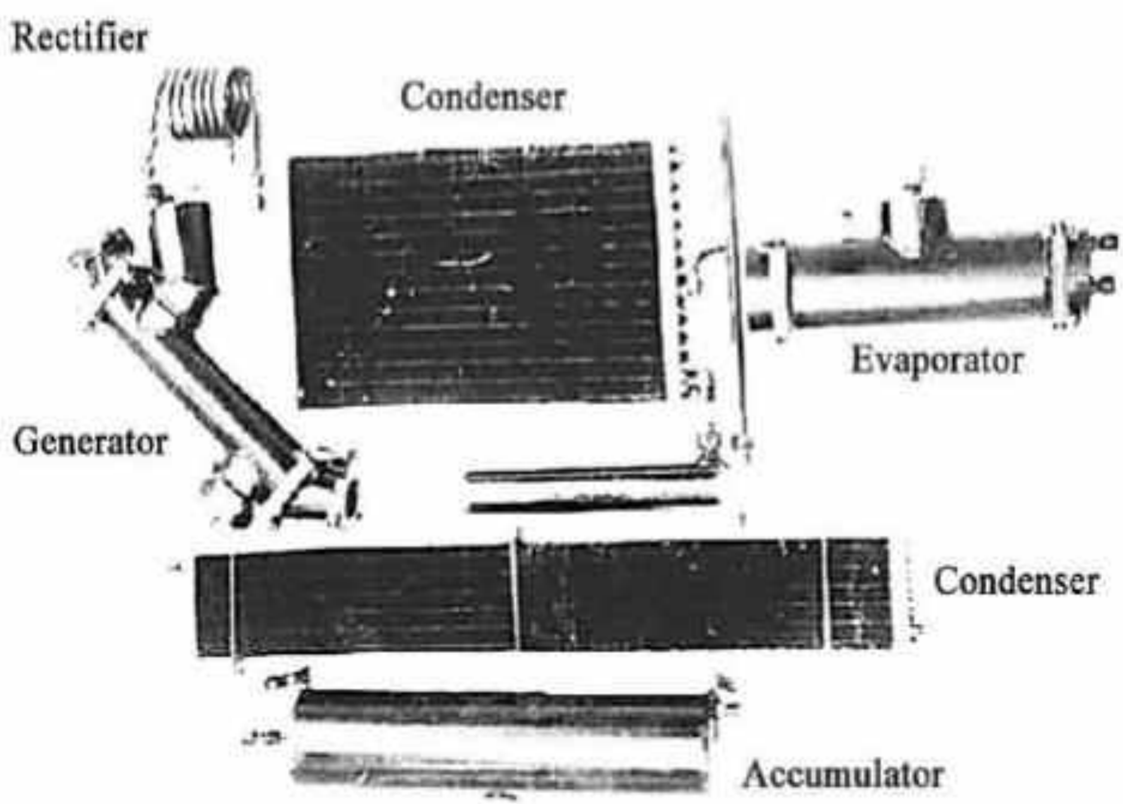


Figure- Components of VAdS

Refrigeration Equipment

Introduction to the Refrigeration Cycle and Equipment

Compressors – reciprocating

- Equipped with pistons and cylinders
- Suction and discharge valves
- Valve position is controlled by the pressure difference across it
- Can be open, semi-hermetic or fully hermetic

Introduction to the Refrigeration Cycle and Equipment

Compressors – rotary

- Uses circular motion to obtain compression
- Rotating blade (vane) type
  - Refrigerant is trapped by the rotating vanes
  - Refrigerant compresses as volume decreases
- Stationary blade (vane) type
  - Equipped with only one blade or vane

Introduction to the Refrigeration Cycle and Equipment

Compressors – helical rotary (screw type)

- Utilizes two rotors: a male and a female
- Compressor capacity controlled by a slide valve
- A continuous, flowing output is produced
- The volume of the refrigerant decreases as it flows through the compressor

Introduction to the Refrigeration Cycle and Equipment

Compressors – scroll type

- Utilizes two identically machined scrolls
- One scroll is stationary, the other orbits
- The nesting of the scrolls traps vapor
- Gas is introduced from the outer edge
- Refrigerant is discharged from the center

Introduction to the Refrigeration Cycle and Equipment

Compressors – centrifugal type

- Rely on centrifugal force
- No pistons, valves or cylinders
- Utilizes an impeller
- Capacity is controlled by inlet vanes
- Used for very large applications

Introduction to the Refrigeration Cycle and Equipment

Air-cooled condensers

- Desuperheating – removes sensible heat (superheat) from the vapor refrigerant
- Condensing – Vapor condenses into a liquid (latent heat)
- Subcooling – Addition sensible heat is removed from the liquid refrigerant

Introduction to the Refrigeration Cycle and Equipment

Water-cooled condensers

- Shell-and-tube
  - Water circulates through the tubes
  - Water makes several passes before exiting
  - Hot gas enters the shell and condenses
  - Mechanically cleanable

Introduction to the Refrigeration Cycle and Equipment

- Shell-and-coil
  - Similar to the shell-and-tube
  - Used in smaller applications
  - Tubes are now in a coil shape
  - Must be cleaned chemically

Introduction to the Refrigeration Cycle and Equipment

- Tube-within-a-tube
  - Water flows in the inner tube
  - Refrigerant flows in the outer tube
  - Heat travels from the refrigerant
    - To the surrounding air, and
    - To the water in the coil

Introduction to the Refrigeration Cycle and Equipment

Evaporative condenser

- Utilizes air and water
- Air flows over the coil
- Water can also flow over the coil if needed
- Latent and sensible heat transfers take place
- Water is heated and evaporated

Introduction to the Refrigeration Cycle and Equipment

Metering devices

- Thermostatic expansion valve
- Constant pressure expansion valve
- Capillary tube
- High side float
- Orifice plates

Thermostatic expansion valve

- Maintains constant superheat in the evaporator
- Three pressures control the valve position
  - Bulb, spring and evaporator
- As the load increases the valve opens
- As the load decreases the valve closes

Introduction to the Refrigeration Cycle and Equipment

Constant pressure expansion valve

- Maintains constant evaporator pressure
- An increase in evaporator pressure will cause the valve to close
- A decrease in evaporator pressure will cause the valve to open
- Commonly used on systems with constant loads

Introduction to the Refrigeration Cycle and Equipment

Capillary tubes

– Seamless tubing with a small inside diameter

– No moving parts

High side float valve

– Introduces refrigerant to the evaporator at the same rate as it leaves

– A float on the high side maintains proper flow

Orifice plates

- Used primarily on centrifugal chillers
- Two plates with a series of holes in each
- The pressure drop across the plates changes with the load
- High load → liquid passes the plates
- Low load → some liquid flashes to a vapor

Introduction to the Refrigeration Cycle and Equipment

Direct expansion coils

- Warm air passes over the cool coil
- Heat is transferred to the liquid refrigerant
- The liquid refrigerant begins to boil
- Vapor refrigerant leaves the evaporator
- Expansion valves control flow to the coil

Introduction to the Refrigeration Cycle and Equipment

Evaluators for liquid chillers

- Direct expansion chilled water evaporator
  - Refrigerant flows in the tubes
  - Water fills the shell
- Flooded shell-and-tube
  - Refrigerant is in the shell
  - Water flows in the tubes

Introduction to the Refrigeration Cycle and Equipment

Introduction to absorption refrigeration cycle

- Uses the physical properties of absorbents
- Low concentrations are weak or dilute solutions
- High concentrations are concentrated
- Systems use an absorbent and a refrigerant
- Absorbent: Lithium bromide
- Refrigerant: Water

Introduction to the Refrigeration Cycle and Equipment

Absorption refrigeration cycle components

- Evaporator
- Absorber
- Concentrator
- Condenser

Introduction to the Refrigeration Cycle and Equipment

Evaporator

- Operates at very low pressures (0.25 psia)
- Refrigerant (water) is sprayed into the shell
- Conditioned liquid gives up heat to the water
- The refrigerant boils and passes to the absorber
- Chilled water returns to the remote location

Introduction to the Refrigeration Cycle and Equipment

Absorber

- Refrigerant from the evaporator enters absorber
- The refrigerant is absorbed by the absorber
- The rate of absorption is determined by the concentration of the solution
- Higher concentration → lower chilled water temperature

Introduction to the Refrigeration Cycle and Equipment

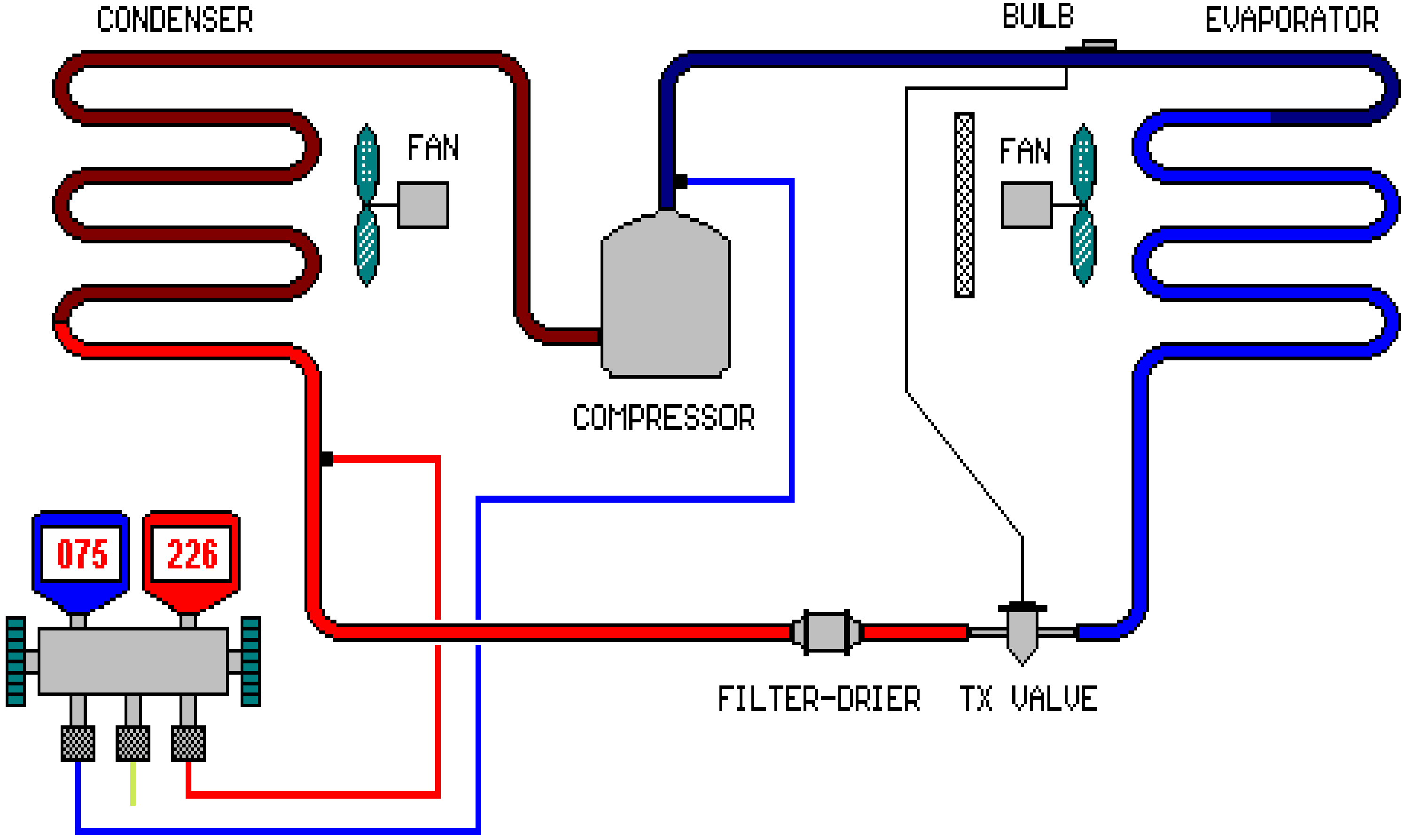
Concentrator

- Dilute absorbent solution flows to the concentrator
- Heat sources boil the refrigerant from the absorbent
- The solution now becomes highly concentrated
- The concentrated solution returns to the absorber

Introduction to the Refrigeration Cycle and Equipment

Condenser

- Responsible for supplying liquid refrigerant to the evaporator
- The refrigerant vapor leaves the concentrator
- This vapor is condensed back to a liquid
- This liquid refrigerant returns to the evaporator


CONDENSER
BULB
EVAPORATOR
FAN
FAN
COMPRESSOR
075
226
FILTER-DRIER
TX VALVE

- Refrigeration is the removal of heat from a material or space, so that it's temperature is lower than that of it's surroundings.
- When refrigerant absorbs the unwanted heat, this raises the refrigerant's temperature ("Saturation Temperature") so that it changes from a liquid to a gas — it evaporates. The system then uses condensation to release the heat and change the refrigerant back into a liquid. This is called "Latent Heat".
- This cycle is based on the physical principle, that a liquid extracts heat from the surrounding area as it expands (boils) into a gas.
- To accomplish this, the refrigerant is pumped through a closed looped pipe system.
- The closed looped pipe system stops the refrigerant from becoming contaminated and controls its stream. The refrigerant will be both a vapor and a liquid in the loop.

“Saturation Temperature” – can be defined as the temperature of a liquid, vapor, or a solid, where if any heat is added or removed, a change of state takes place.

- **A change of state transfers a large amount of energy.**
- **At saturation temperature, materials are sensitive to additions or removal of heat.**
- **Water is an example of how saturation property of a material, can transfer a large amount of heat.**
- **Refrigerants use the same principles as ice. For any given pressure, refrigerants have a saturation temperature.**
- **If the pressure is low, the saturation temperature is low. If pressure is high, saturation temperature is high.**

"Latent Heat"- The heat required to change a liquid to a gas (or the heat that must be removed from a gas to condense it to a liquid), without any change in temperature.

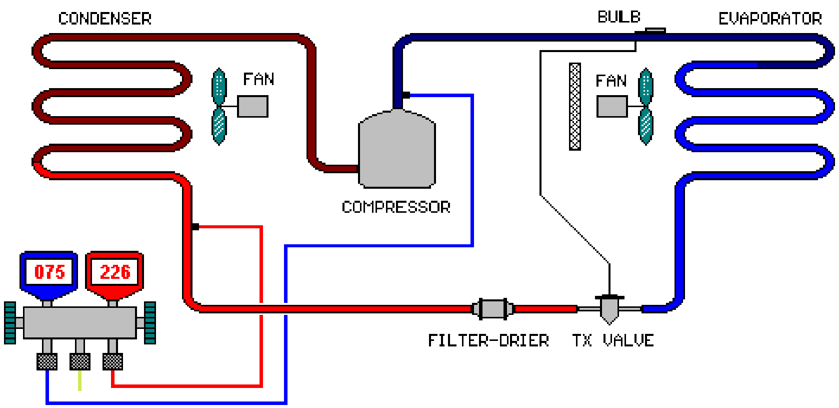
- Heat is a form of energy that is transferred from one object to another object.
- Heat Is a form of energy transferred by a difference in temperature.
- Heat transfer can occur, when there is a temperature difference between two or more objects. Heat will only flow from a warm object to a colder object.
- The heat transfer is greatest, when there is a large temperature difference between two objects.

The Refrigeration Cycle Graphic Demo

There are four main components in a refrigeration system:

- The Compressor
- The Condensing Coil
- The Metering Device
- The Evaporator

- Two different pressures exist in the refrigeration cycle. The evaporator or low pressure, in the "low side" and the condenser, or high pressure, in the "high side". These pressure areas are divided by the other two components. On one end, is the metering device which controls the refrigerant flow, and on the other end, is the compressor.



The Compressor Demo

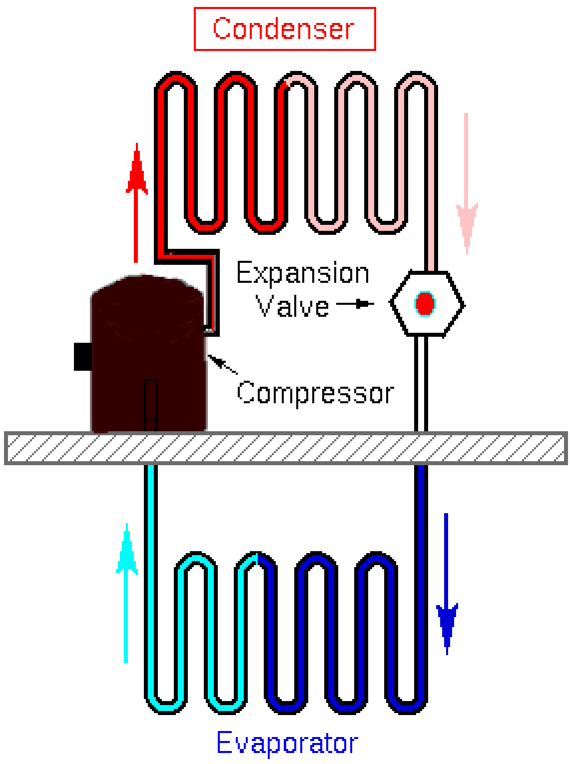
- **The compressor is the heart of the system. The compressor does just what it's name is. It compresses the low pressure refrigerant vapor from the evaporator and compresses it into a high pressure vapor.**

- **The inlet to the compressor is called the "Suction Line". It brings the low pressure vapor into the compressor.**

- **After the compressor compresses the refrigerant into a high pressure Vapor, it removes it to the outlet called the "Discharge Line".**

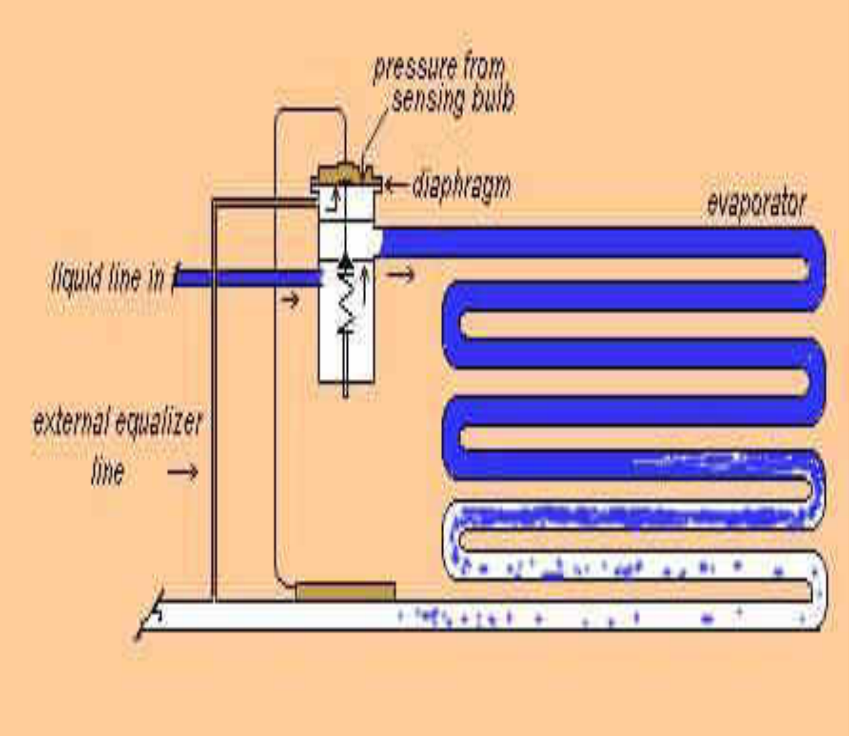
The Condenser Demo

- The “Discharge Line” leaves the compressor and runs to the inlet of the condenser.
- Because the refrigerant was compressed, it is a hot high pressure vapor (as pressure goes up – temperature goes up).
- The hot vapor enters the condenser and starts to flow through the tubes.
- Cool air is blown across the out side of the finned tubes of the condenser (usually by a fan or water with a pump).
- Since the air is cooler than the refrigerant, heat jumps from the tubing to the cooler air (energy goes from hot to cold – “latent heat”).
- As the heat is removed from the refrigerant, it reaches it’s “saturated temperature” and starts to “flash” (change states), into a high pressure liquid.
- The high pressure liquid leaves the condenser through the “liquid line” and travels to the “metering device”. Sometimes running through a filter dryer first, to remove any dirt or foreign particles.



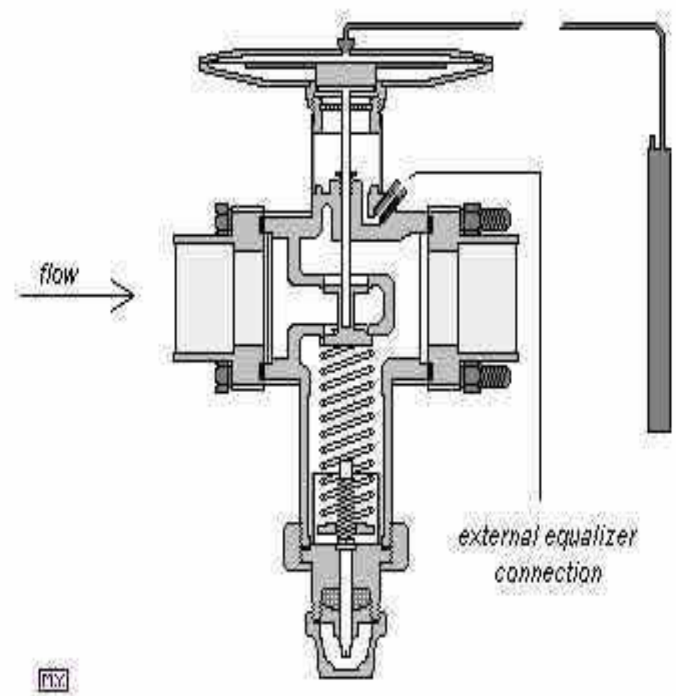
Metering Devices Demo

- Metering devices regulate how much liquid refrigerant enters the evaporator .
- Common used metering devices are, small thin copper tubes referred to as "cap tubes", thermally controller diaphragm valves called "TXV's" (thermal expansion valves) and single opening "orifices".
- The metering device tries to maintain a preset temperature difference or "super heat", between the inlet and outlet openings of the evaporator.
- As the metering devices regulates the amount of refrigerant going into the evaporator, the device lets small amounts of refrigerant out into the line and looses the high pressure it has behind it.
- Now we have a low pressure, cooler liquid refrigerant entering the evaporative coil (pressure went down – so temperature goes down).



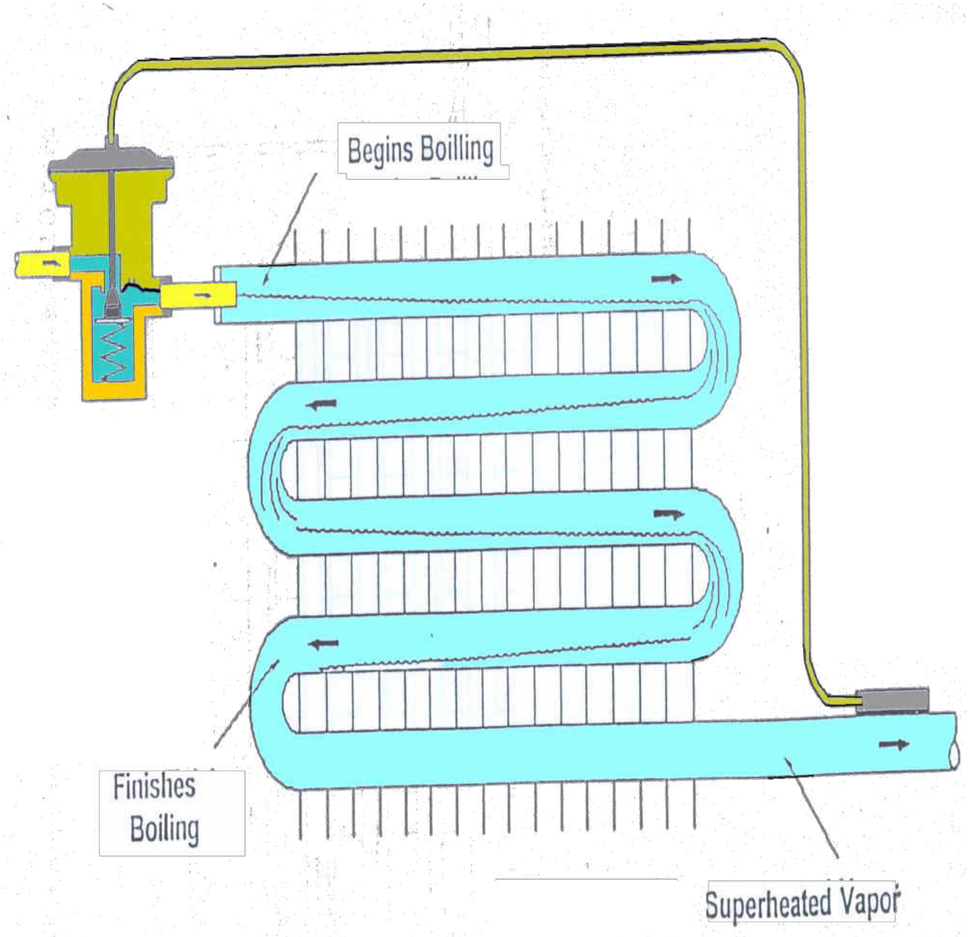
Thermal Expansion Valve Demo

- A very common type of metering device is called a TX Valve (*Thermostatic Expansion Valve).* This valve has the capability of controlling the refrigerant flow. If the load on the evaporator changes, the valve can respond to the change and increase or decrease the flow accordingly.
- The TXV has a sensing bulb attached to the outlet of the evaporator. This bulb senses the suction line temperature and sends a signal to the TXV allowing it to adjust the flow rate. This is important because, if not all, the refrigerant in the evaporator changes state into a gas, there could be liquid refrigerant content returning to the compressor. This can be fatal to the compressor. Liquid can not be compressed and when a compressor tries to compress a liquid, mechanical failing can happen. The compressor can suffer mechanical damage in the valves and bearings. This is called" liquid slugging".
- Normally TXV's are set to maintain 10 degrees of superheat. That means that the gas returning to the compressor is at least 10 degrees away from the risk of having any liquid.



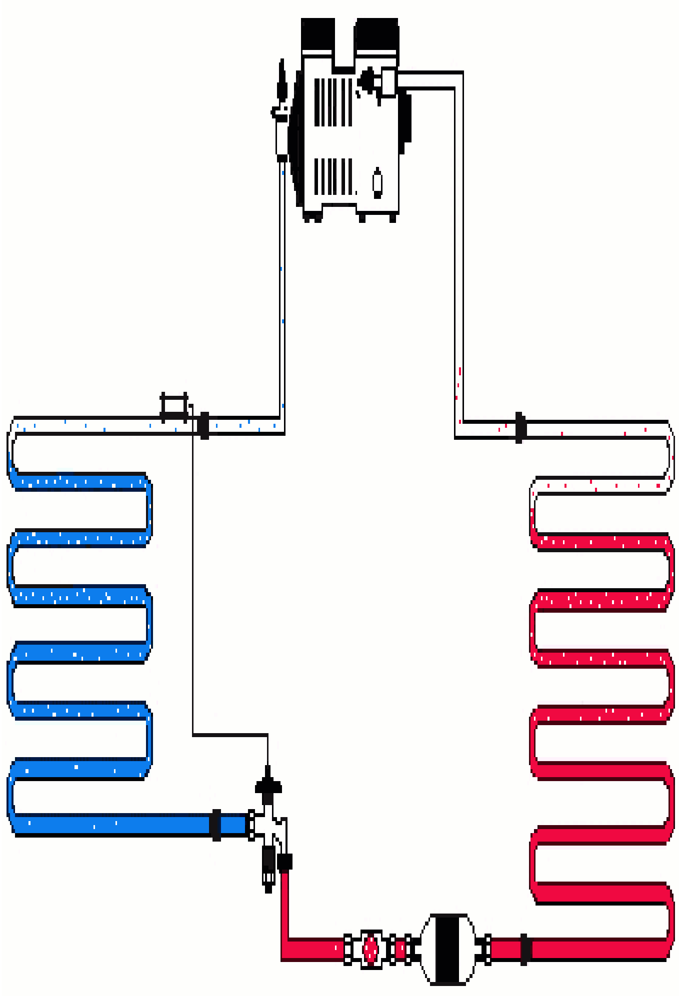
Evaporator Demo

- The evaporator is where the heat is removed from your house , business or refrigeration box.
- Low pressure liquid leaves the metering device and enters the evaporator.
- Usually, a fan will move warm air from the conditioned space across the evaporator finned coils.
- The cooler refrigerant in the evaporator tubes, absorb the warm room air. The change of temperature causes the refrigerant to “flash” or “boil”, and changes from a low pressure liquid to a low pressure cold vapor.
- The low pressure vapor is pulled into the compressor and the cycle starts over.
- The amount of heat added to the liquid to make it saturated and change states is called “Super Heat”.
- One way to charge a system with refrigerant is by super heat.



Review of Refrigeration Cycle

- Starting at the compressor;
- Low pressure vapor refrigerant is compressed and discharged out of the compressor.
- The refrigerant at this point is a high temperature, high pressure, "superheated" vapor.
- The high pressure refrigerant flows to the condenser by way of the "Discharge Line".
- The condenser changes the high pressure refrigerant from a high temperature vapor to a low temperature, high pressure liquid and leaves through the "Liquid Line".
- The high pressure refrigerant then flows through a filter dryer to the Thermal Expansion valve or TXV.
- The TXV meters the correct amount of liquid refrigerant into the evaporator.
- As the TXV meters the refrigerant, the high pressure liquid changes to a low pressure, low temperature, saturated liquid/vapor.
- This saturated liquid/vapor enters the evaporator and is changed to a low pressure, dry vapor.
- The low pressure, dry vapor is then returned to the compressor in the "Suction line".
- The cycle then starts over.



References

- Refrigeration and Air Conditioning Book PDF Free Download
- https://www.pinterest.co.uk/pin/856176579145155395/

- Air Conditioning and Refrigeration | Engineering Books Pdf
- https://www.engineeringbookspdf.com/mechanical-engineering/air-conditioning-and-refrigeration/


THANK YOU...!!

Government Polytechnic Nanakpur

DEPARTMENT OF MECHANICAL ENGINEERING

E - NOTES

SOFT SKILLS – III

HOD/O.I. (Mechanical) : **Sh.SHALANDER MOR**

Faculty Name: **Sh.SHALANDER MOR**

Semester: 5^{th} Sem

By: Er. Amit Kumar
Designed, Mechanical Editing & Developmental Editing

LEARNING OUTCOMES

After undergoing this course, the students will be able to:

- Develop communication skills.
- Learn how to speak without fear and get rid of hesitation
-
- Use effective presentation techniques
- Understand entrepreneurial traits
- Exhibit attitudinal changes

Soft skill-III

Employability can be best defined as 'the capability of getting and keeping satisfactory work'.

Soft skill consist of character traits that decide how well one interacts with others, and are a definite part of one's personality.

Official and business correspondence:

Business correspondence can take place between organizations, within organizations or between customers and organization.

Types:

Business letters (addressed to a particular person or organization)

E-mail

Memorandum (document used for internal communication)

Official Letters. It contains following parts:

- **Your address (at either corner of letter)**
- **Date (under the address and never write date month and year all in numbers)**
- **Address of the recipient**
- **Subject**
- **Greeting**
- **Body of the letter**
- **Complimentary close**
- **Signature**
- **Your typed name**

Job Application-Covering Letter and Resume

A

- **Solicited letter (sent in response to an announced job opening)**

- **Unsolicited letter (sent to an org. that has not announced any vacancy)**

Note: Unsolicited letter must attract reader's attention and interest.

An application letter must consists of two parts:

- **Cover letter (accompanying letter that serves introduction to resume.**

- **Resume (personal data sheet)**

Contents of resume:

- Heading
- Career objective
- Education and training
- Work experience
- Relevant skills
- Activities and achievements
- Personal data
- References

Report Writing

A report is a communication from someone who has some information to someone who wants to use that in decision making.

Types:

1. **Oral report**
2. **Written Report**

Written reports are of three types:

1. **Informal report (contains only data collected or facts observed)**
2. **Formal report (collects and interprets data and report information)**
3. **Interpretive report (not only contains facts but also recommendation and conclusions)**

Overall communication skill

A good advice can benefit a person. In this case it is necessary yourself in a better way so that the other can take advantage without getting hurt.

Making Comparison

While talking of two things of same type, telling one better or inferior than the other all this comes under comparison.

Agreeing and Disagreeing

We have the full right to be agree and disagree with anyone over a context but this should be done in a dignified way so that we are able to impress the other. This becomes more important in case commercials establishments.

Taking turns in conversation

By waiting for your turn to speak and avoiding interrupting another person, you not only show desire to work together with the other members of your society, but also show respect for your fellow members.

Fixing and cancelling appointment

Making or cancelling an appointment has become an integral part of our life. it can be in business dealings, job profile or with doctors or other persons. Being able to make and cancel an appointment is an important skill in English as it helps for better future prospects.

- Making an appointment (we can use phrases like-Are you available on -----, would next----be ok).
- Cancelling appointment (we can use phrases like Unfotunately, due to some unforeseen business----,would it be possible to arrange another time---?).

Stress management

Stress is something which makes us tensed, angry, frustrated and annoyed.

Common reasons:

- Unemployment
- Serious disease to a family member
- Business problems
- Social aspects
- Serious problem in family

Symptoms:

- Behavioral Symptoms (lack of forgiveness, forgetfulness, not mixing with peoples)
- Physiological symptoms (migraines, rapid breathing, high blood pressure)
- Psychological symptoms (depression, memory loss, less concentration)

Techniques of stress management:

- Positive self talk
- Emergency stress stoppers (e.g. count 1-10 before you speak, take 3-5 deep breaths etc.)
- Finding pleasure (e.g. take up a hobby, read a favourite book etc.)
- Relaxation techniques (e.g. focus on breathing slowly and deeply, picture yourself in a peaceful place)

Time management

- Managing time effectively so that right time is allocated to right activity.
- Assigning specific time slots to activities as per their importance.

Time management techniques:

- Effective planning
- Setting goals and objectives
- Setting deadlines
- Delegation of responsibilities
- Prioritizing activities

Negotiations and conflict resolution

"A process in which two parties exchange goods or services. it includes bargaining strategies, process of negotiations and its issues.

Negotiation strategies:

- Distributive strategy (negotiation over price- lose-win strategy)
- Integrative bargaining (a decision in favor of both parties- a win-win strategy)

Negotiation process:

- Planning
- Preparing rules
- Clarification
- Bargaining and problem solving
- Conclusion

Conflict resolution

Conflict is any tension which arises due to difference of opinion or interests.

Levels of conflict:

- Individual level (dissatisfaction with oneself)
- Interpersonal level (conflict between two or more person)
- Group level
- Organization level

Conflict resolution:

- Making common goals
- Less interdependence
- Reduction in shared resources
- Trust
- Communication
- Coordination

Team Work And leadership Qualities

- Team is a group of people working together to meet the needs of customer by accomplishing individual as well as common purpose and goal.
- Team work is work that all members try to accomplish.

Importance of team work:

- Satisfaction of the customers
- Improved employee motivation
- Positive and confident attitude
- Better communication skill
- Effective work

Leadership:

A leader is one who influences others and makes them follow him.

Leadership qualities:

- Good public relation man
- shoulder the responsibility
- good organization of things
- maturity of mind
- Desire to progress
- Farsightedness
- Effective decision making

Thank You