E-NOTES OF

Computer Numerical Control (CNC)

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Numerical control (NC)- Numerical control is a type of programmable automation in which the processing equipment is controlled by a means of numbers letters and other symbol.

BASIC COMPONENTS OF NC-

1. PROGRAM OF INSTRUCTION(PART PROGRAM)- It is detailed step by step commands given in a coded language using symbols, letters and numbers.
2. MCU (machine control unit)-   It is the brain of the machine. It consists of the electronic hardware that read and interpret the part program and converts it into mechanical actions of the machine tool/processing equipment.
3. Machine tool-It performs the actual work

CNC(COMPUTER NUMERICAL CONTROL)-   Computer Numerical Control (CNC)) is the numerical control system in which a dedicated computer is built into the control to perform basic and advanced NC functions.

BASIC COMPONENTS OF CNC :

1.Input Device : The input devices are floppy Disk drive,USB Flash drive,Serial communication,Ethernet connection.

2.**Central Processing Unit/ Machine Control Unit** : It is the brain of the machine. It consists of the electronic hardware that read and interpret the part program and converts it into mechanical actions of the machine tool/processing equipment.

3.**Machine Tool** : It performs the actual work.

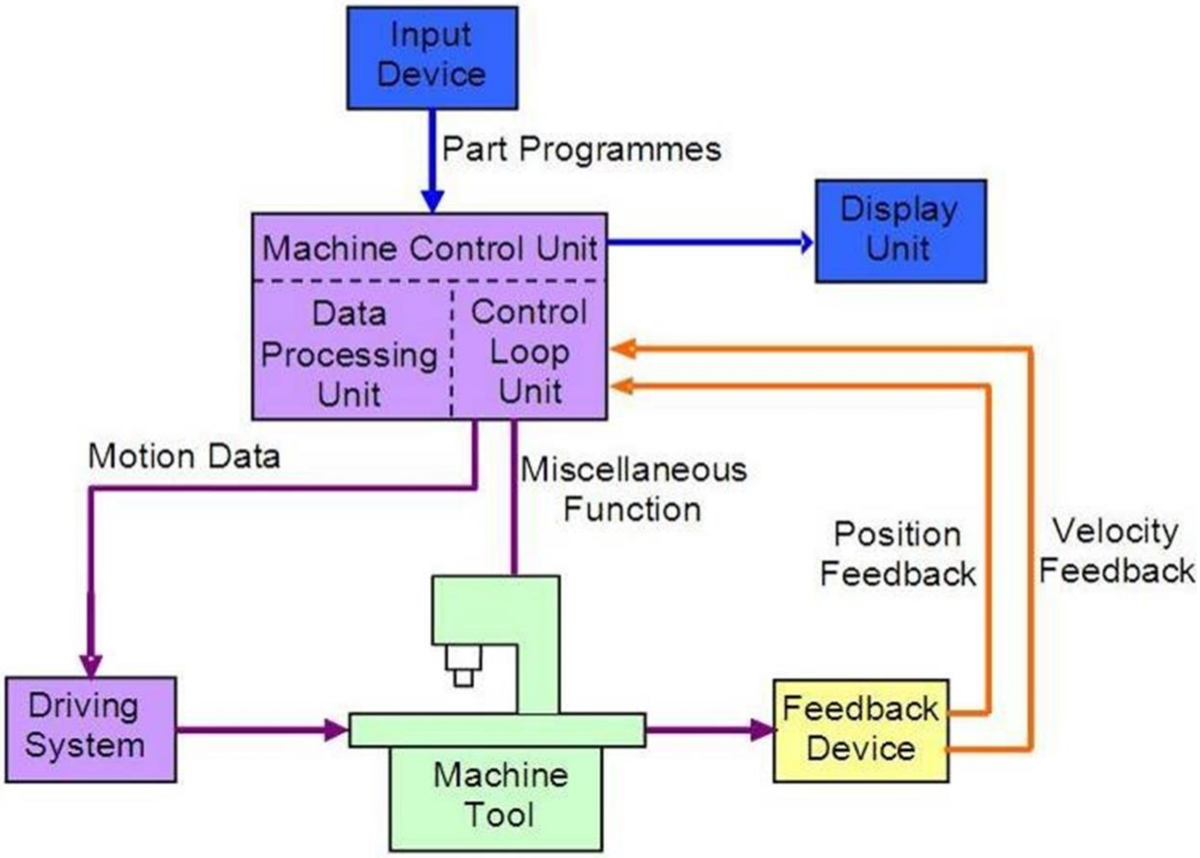
4. **Driving System** :the basic function of driving system is to move the slide and spindle as per the program. Three types of electrical motors are commonly used in driving system of cnc:

- DC Servo motor
- AC Servo motor
- Stepper motor

5 .**Feedback Devices** : Feedback devices are provided in CNC to give feedback to MCU. Two types of feedback i.e velocity feedback and displacement feedback devices are used.

6 .**Display Unit**:The machine communicate with the operator through its display unit. It displays

- position of the machine slide
- spindle RPM
- feed rate
- part programs
- graphics simulation of the tool path.



Direct numerical control(DNC)-DNC is a manufacturing system in which a number of machines are controlled by a computer .

BASIC COMPONENTS OF DNC:

1. Central computer-It calls the part programme from bulk memory and sends them to each machine and receive data back from machine.
2. Bulk Memory-It stores the part programme and other data.
3. Telecommunicatioon lines- It transfer data from central computer to machine and from machint to central computer.
4. Machine tool- it performs the actual work.

Types oDNC are of two types:

1.BTR (Behind the Tape Reader)- In this the tape reader is replaced by telecommunication lines.

2.Special MCU TYPE- In this a special MCU is used in place of NC Controller

Advantages of CNC

- High Repeatability and Precision.

- Volume of production is very high.
- Complex contours/surfaces can be easily machined.
- Flexibility in job change,
- Automatic tool settings and changing.
- Reduced scrap or wastage of raw material.
- More safety/reduced chances of accidents.
- Hgher productivity,
- Better quality of job.
- Less paper work.
- Faster prototype production.
- Reduction in lead times.
- Reduced tooling costs, tool wear.

Reduced setup time

Disadvantages:

- High initial cost.
- High power consumption.
- Costly setup,

Skilled programmers are required

- Computer programming knowledge required.
- Maintenance is difficult
- Leads to unemployment.

Q-What types of components should be machined on cnc machines

- Parts with complex shapes and contours.
- Parts requiring close tolerance .
- Parts requiring expensive jigs and fixtures if produced on conventional machines
- Parts that may have several engineering changes, such as during

the development stage of a prototype

- Parts in which there are more chances of human errors during processing..
- Parts that are needed in a huge quantity in small time.
- Parts whose raw material is costly.

Parts which are difficult to machine on conventional machines

AXIS DESIGNATION IN CNC MACHINES-

Z axis- The Z- axis is always the axis of the spindle. The tool moving away from Job is designated as positive Z direction.

X-axis-It is the axis parallel to work holding surface. When looking from the principal spindle to the column, the positive

X is to the right.

Y axis-*It* is perpendicular to x and z axis. and the direction is

identified by the right hand Cartesian coordinate system.

Rotary motions: A, B and C define the primary rotary motions.

Axis of CNC lathe--- A CNC Lathe has two axis Z Axis and X axis

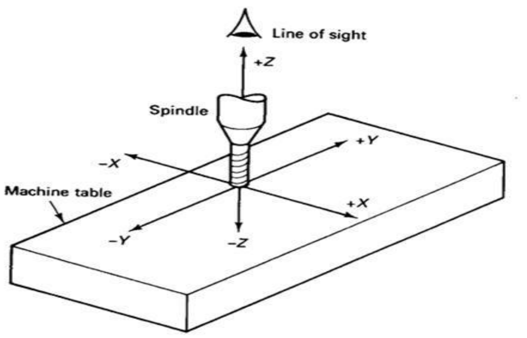
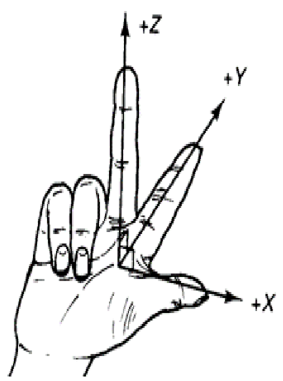
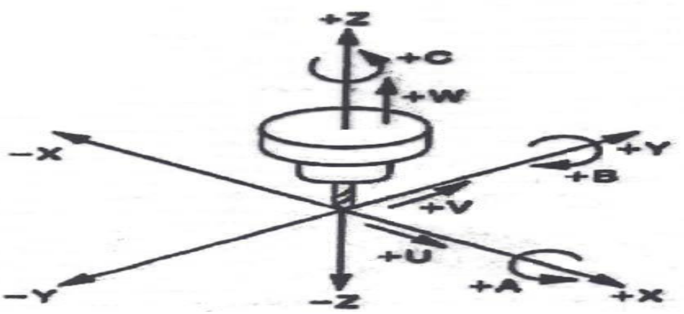


FIGURE 2–12 Machine axis for a three-axis vertical CNC machine (machine axis defined as spindle movement).





Machine axes of motion

Application of CNC technology-

- CNC mills and machining centers,
- CNC lathes and turning centers
- CNC electrical discharge machining (EDM)
- CNC grinding machines
- CNC cutting machines (laser, plasma, electron, or flame)
- CNC fabrication machines (sheet metal punch press, bending machine, or press brake)
- CNC welding machines
- Coordinate measuring machine
- Industrial robot

Chapter -2

Q-1- Slideways in cnc- The slideways to be used in cnc should have low friction, smooth movement and less wear and tear. Types of slideways used in cnc 1.Hydrostatic slideways 2. Linear Bearings with balls and rollers 3. Antifriction slideways.

Hydrostatic slideways: In hydrostatic slideways oil or air is pumped into small cavities machined into the carriage or slides which are in contact with slideways due to this friction is reduced bewteen slide and slideways and, the movement is smooth and there is less wear and tear.

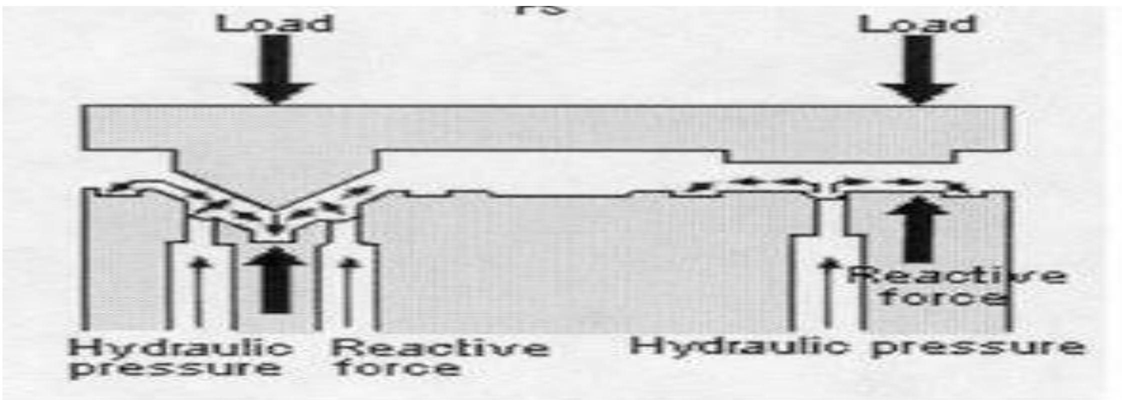


Figure 3-1. Hydrostatic Bearing Schematic

2.Linear Bearings with balls and rollers-IN these the sliding friction between the slide and slideways is replaced by rolling friction by the use of antifriction ball and rollers bearings.This reduces friction as rolling friction is less than sliding friction.

3.Surface coatings-in these slideways the guiding surface of the machines are coated with low friction material like Polytetrafluroethylene or replaceable strips of low friction material are used.

Q2- Swarf removal mechanism in cnc-The material removal rate in cnc is very high so the swarf /chips produced has to be regularly removed from cutting area .

<u>swarf removal from cutting zone IN CNC -</u>

1Multiple jets of pressurized coolant are arranged around the tool.

2.Multiple jets of compressed air are arranged around the tool.

3. Multiple jets of pressurized water are arranged around the tool

4. In some machines coolant wash stage is programmed where cutting area is flooded with coolant which washes the chips away.

Swarf removal from machine to bins-

For removing swarf from machine to the bins linear and rotary conveyors are used for removing the chips from machine to bins.

Q3--SAFETY PROVISIONS IN CNC MACHINE-Different safety provisions provided in cnc are

<u>Devices for for safety of machine</u>-Various types of collapsible guards and covers are provided in machine for protection of slideways,drive screw and transducers**.**All the sliding elements are fitted with wipers and drive screws are protected by using telescopic covers.

<u>Devices used in cnc for safety of operator-</u>

1. **Perimeter guards**- The perimeter guard covers/ encloses the cutting area and protect the operator from flying chips.
2. **Pressure mats**- These are safety devices and are placed in the area not safe for operator when operator steps on these due to pressure exerted by his weight an alarm signal is generated warning the operator.
3.
4. **Light barriers-**the light barrier consists of a light source usually infrared and a sensitive cell.if anything obstruct the light beam a warning signal is generated. the light barriers are placed around the machine.

Q4--<u>Cutting tools used in CNC</u> - The basic types of cutting tools used in CNC are

1. Preset tools 2.Qualified tools 3. Semi- Qualified tools.

1.Preset tools- Setting of tools in advance away from machine in special tool holders is called presetting and the tool thus obtained are called preset tools. A presetting device is used to preset axial and radial positions of the tool tip on the tool holder

2.Qualified tools- tools in which the position of cutting edge is specified from different datums are called qualified tools.these are of 3 types

a),**End, front and Back qualif**ied- Tools in which the position of cutting edge is specified from End, Front and Back datum .

b)**Front,End qualified**-Tools in which the position of cutting edge is specified from End,and Front datum.

c)**Back ,End Qualified**- Tools in which the position of cutting edge is specified from End,and Back datum.

3.Semi Qualified Tools-These tools are provided with adjustable buttons due to which the position of cotting edge can be changed.These have to be regularly checked and caliberated .

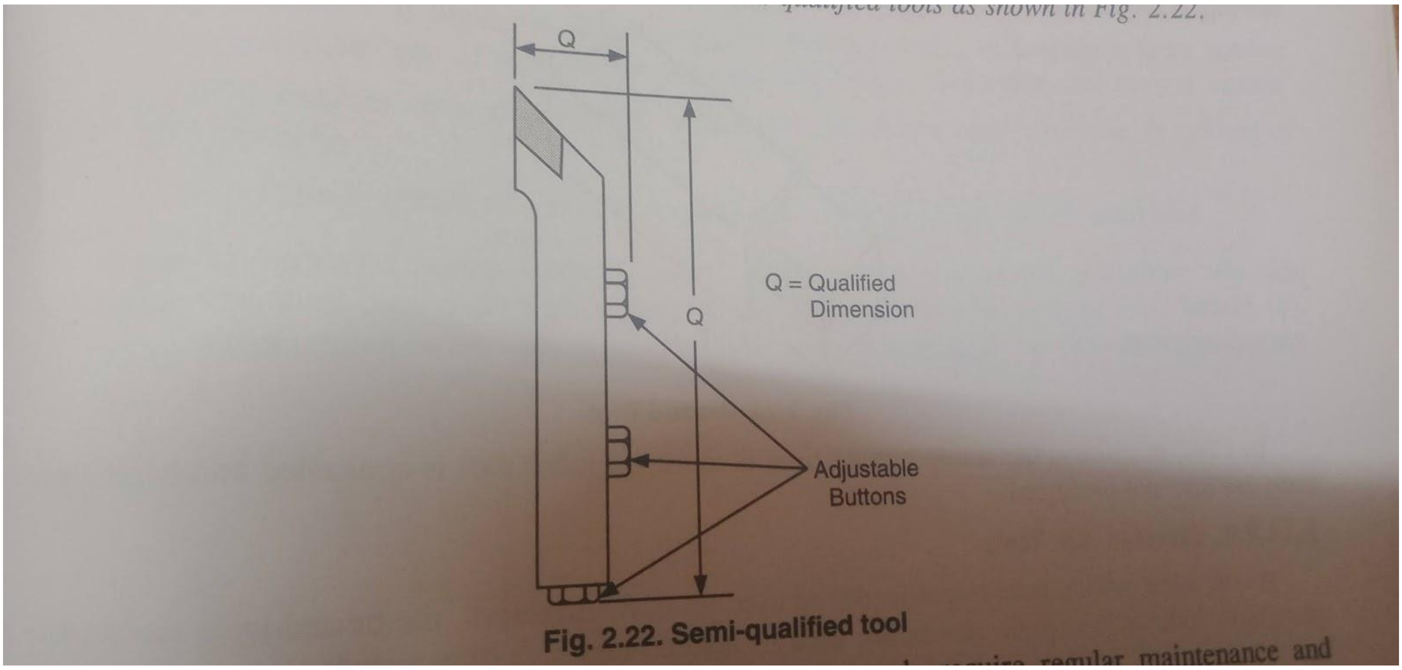


Fig. 2.22. Semi-qualified tool

Q-5- **Automatic Tool Changer** (ATC)- The function of ATC is to change the tool automatically as per the part program.It has two basuic components

1.Tool Magazine   2. Tool Changing Arm

Tool Magazine- Its basic function is to store tool. Types of tool magazines used in cnc are-

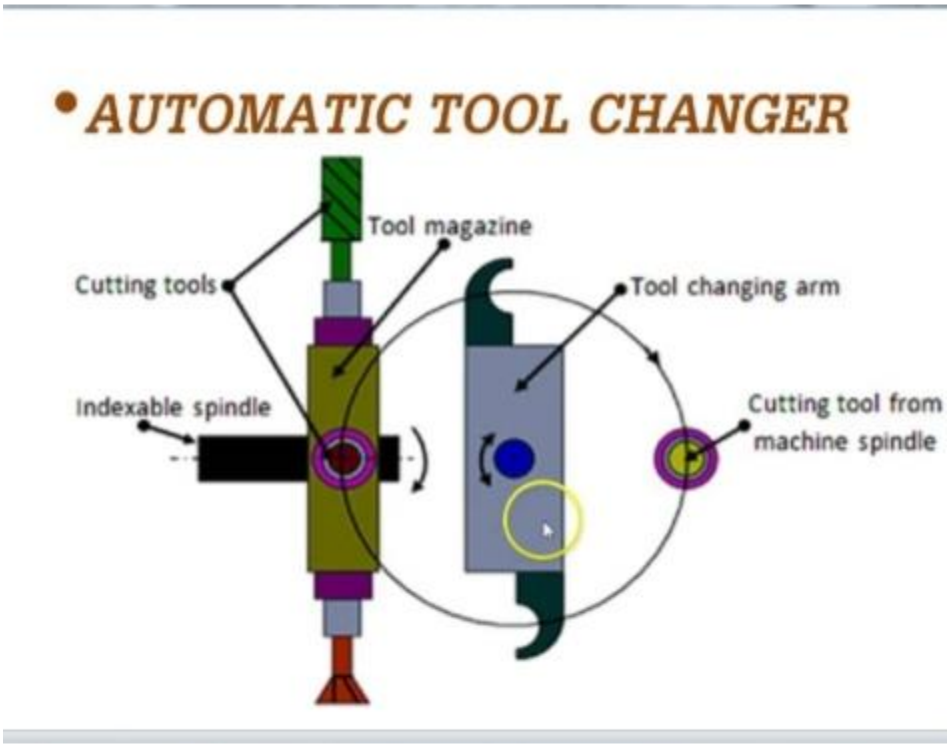
Turret type- It perform both the function of tool storage and tool change. Machine with this type of magazine do not have tool changing arm. Its storage capacity is less.

Drum type- this is most widely used tool magazine.The dia of drum decides its tool storage capacity. Can store upto 30 tools.

Chain type- IT is used when large number of tools are to be stored.it has max storage capacity .

Tool changing arm- its function is to change the tool .it is of 2 types

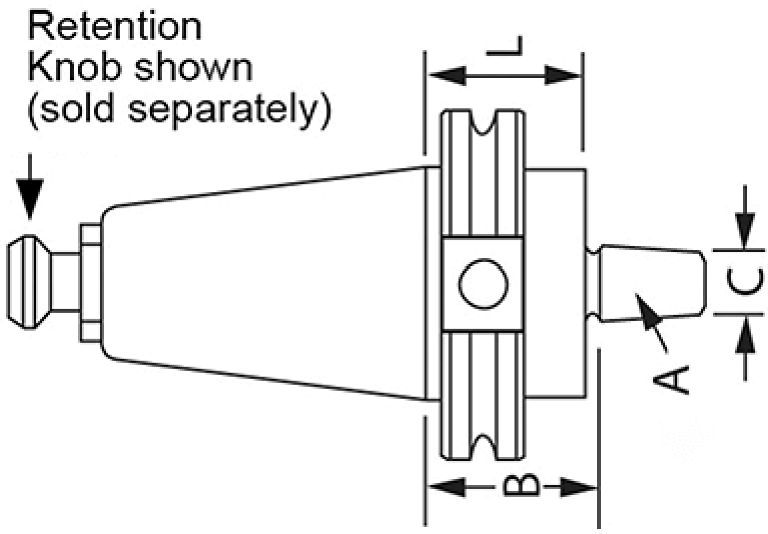
1. Single gripper 2. Double gripper



<u>Tool holder</u>- A tool holder is a device that act as a an interchangeable interface between the machine tool spindle and a cutting tool such that efficiency of either element is not diminished.(Tool holder is used for holding the tool. Cnc machines uses tools that have been precisely ground with a male taper that fits into machines female taper.)

A tool holder consists of **5** basic components

1.Pull Stud 2.Tapered Shank 3.Flange 4.Adapter 5.Opposed slot



Tapered shank fits the tool holder to the spindle.

The flange allows the tool holder to be grabbed by the tool gripper or the machine spindle.

The pull stud allows the locking drawbar of the spindle to pull the tool holder firmly into the spindle and to release the tool holder automatically.

WORK HOLDING DEVICES IN CNC/ PALLETS IN CNC – the work holding devices used in cnc should have these characterstics-

1. should hold the work firmly 2. Quick loading and unloading 3.should be fool proof 4.should not damage the work piece.5. should hold multiple jobs 6. Should be safe easily available and corrosion resistant. Types of work holding devices used are-

1.Vices 2. Collets.3.Chucks 4. Driving plates 5. Face plates

6. C arriers 7.Automatic pallet systems.8. Grid plate

.**AUTOMATIC PALLET CHANGE OVER SYSTEMS**- Automatic pallet change over systems are used in modern CNC machines. These pallets simply move for interchanging their positions on the machine table. While machining is being done on a job kept on one pallet, the other pallets are accessible to the operator for clamping and unclamping raw material or finished product. This saves a lot of material handling and set up time, resulting in higher productivity

POWER DRIVES-In machine tools,power is generally required for driving the main spindle,saddles and carriages and to some auxiliary units.

The motors used for CNC system are of two kinds
A)Electrical-1.AC,DC servomotors 2.Steppermotors
B)Fluid-Hydraulic or Pneumatic

STEPPERMOTOR –A steppe rmotor is a pulse-driven motor that changes the angular position of the rotor in steps.Due to this nature of a stepper motor,it is widely used in low cost,open loop position control systems.Types of stepper motors:

1.Permanent Magnet –Employ permanent magnet ,Lowspeed,relatively high torque

2.**VariableReluctance**-Does not have permanent magnet, Low torque

Hybridsteppermotor-Hybrid motors are more expensive than motors with permanent

magnets,but they use smaller steps, have greater torque and maximum speed.

Advantages of stepper motors

•Low cost

•Ruggedness

•Simplicity of construction

•Low maintenance

•Less likely to stall orslip

•Will work in any environment

•Excellent start-stop and reversing responses

Disadvantages of stepper motors

•Low torque capacity compared to DC motors

•Limited speed

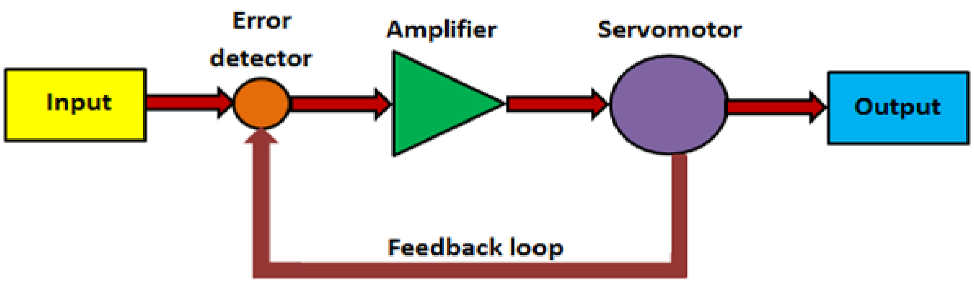
•During over loading, the synchronization will be broken .Vibration and noise occur when running at high speed

SERVOMOTORS- It is of two types- 1.AC servomotor 2. DCservomotor

Servomotors are special electromechanical devices that produce precise degrees of rotation. •A servo motor is a DC or AC or brushless DC motor combined with a position sensing device. •Servomotors are also called control motors as they are involved in controlling a mechanical system.•The servomotors are used in a closed-loop servo system as shown in Figure A reference input is sent to the servo amplifier, which controls the speed of the servomotor. A feedback device

is mounted on the machine,which is either an encoder or resolver.

Servo system block diagram



DCservomotors- DC operated servomotor usually respond to error signal abruptly and accelerate the load quickly.A DC servomotor is actually an assembly of four separate components, namely:
1.DC motor

2.gear assembly

3. position-sensing device

4 .control circuit

AC servo motor

•Magnetic force is generated by a permanent magnet and current which further produce the torque.•It has no brushe so there is little noise/vibration.This motor provides high precision control with the help of high resolution encoder.•The stator is composed of a core and a winding.The rotor part comprises of shaft,rotor core and a permanent magnet.

Advantages of servomotors

•Provides high intermittent torque,high torque to inertia ratio,and highspeeds

•Work well for velocity control

•Available in all sizes

•Quiet in operation

•Smoother rotationat lower speeds

Disadvantages of servomotors

•More expensive than stepper motors

•Require tuning of control loop parameters

•Not suitable for hazardous environments or in vacuum

•Excessive current can result in partial demagnetization of DC type servomotor

CNC PROGRAMMING

i) NC WORDS- A NC word is a collection of character used to form an instruction .

N- WORDS : Sequence number , it identify the block within an NC program . It is represented by a letter N followed by four digit number. It can be from N0001 to N9999.

X,Y&Z-WORDS: Coordinates.These give the coordinate positions of the tool.
. F- WORDS: Specifies Feed rate.The F word specifies the feed in the machining operation.e.g F200 means feed is 200.
•S- WORDS : Spindle speed.The S word specifies the cutting speed of the machining process.e.g S800 means spindle speed should be 800rpm.
•T- WORDS :Tool selection.TheT word specifies the tool to be used in a specific operation.e.g T01 meand tool no. 1 is to be used.

•M-CODE: Are also called Miscellaneous function.The M code is used to specify certain miscellaneous or auxillary function which are not related to the dimensional movement of the machine. Example- M02- PROGRAMME STOP,M30- SPINDLE START (CLOCKWISE), M04-SPINDLE START (ANTICLOCKWISE), M05-SPINDLE STOP,M06-TOOL CHANGE. M08-COOLANT ON.M09-COO;ANT OFF.

G –CODES-These are also called Preparatory functions.They prepares the control unit to execute/complete the instructions that are to follow.These are represented by a letter G followed by two digit number. They are from G00 TO G99.e.g- G00-RAPID TRAVERSE,G01-LINEAR INTERPOLATION,G02-CIRCULAR INTERPOLATION(CLOCKWISE),G03-CIRCULAR INTERPOLATION (ANTICLOCKWISE).
These are of two types-
1.Modal codes 2. Non Modal codes
Modal codes- These are the codes which when written once in a block remains active through out the program until they are cancelled by their corresponding opposite codes. E.g- G90 when written once will remain active until it is cancelled by G91.

Non Modal codes- These are the codes which remains active only in the block in which they are written.e.g-G04- DWELL
EOB- End of block- It specifies the end of the block.

ii)Programming formats- There are the different methods of writing a program. Different programming formats are
Fixed Block Format. 2. Tab Sequential Format 3. Word Address Format

Fixed Block Format- In this format the instructions are always given in the same sequence.All instructions must be given in every block including those which remains unchanged in preceding block.only data is provided in the programme and identifying letters are not given before the numbers.

Tab Sequential Format- In this format the instructions are always given in the same sequence as in fixed block format but in this each word is separated by the TAB character.Instruction that remain unchangrd need not be written again but TAB should be written below every TAB.

Word Address Format-In this format each data has an indentifying address letter before it.For e.g G is the address letter in G01. F identifies the feed .U nchanged instructions need not be repeated again in next block.This format is most widely used as it reduces the length of programme and saves time .Also the chances of error is less.

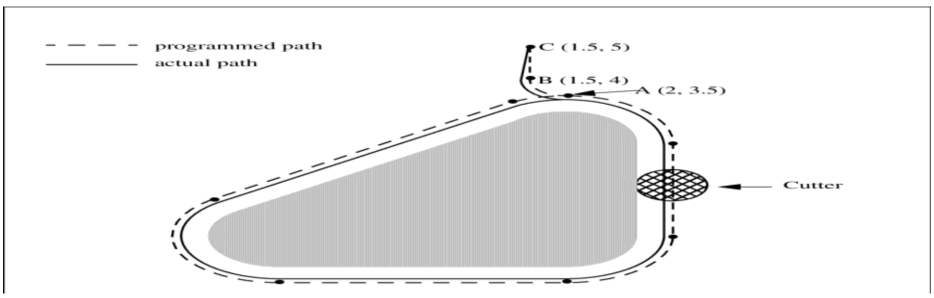
Iii) SUBROUTINE- These are powerful time saving technique. Subrotines are independent programmes which are used for frequently repeated patterns.It is always written in incremental system. The subroutine can be called any time and repeated any number of times. These are stored in the memory under separate programme numbers.
describe and use a subroutine following information is required-
1.Identification of subroutine- A letter L FOKLLOWED BY A NUMBER IS USED TO IDENTIFY THE START OF SUBROUTINE. E.G- L201 means subroutine programme 201.
2.END of subroutine- M17 indicates end of subroutine.
3.A means of calling subroutine- a subroutine can be called by writing the subroutine number precede by letter L.

iv)DO LOOPS- A do loop instruct the MCU to repeat a series of NC blocks a specified number of times.The do loop statement is given in the main programme itself .It is also used for used for repetitive programming in cases such as turning where it is not possible to remove material in single pass .IT reduces the length of programme and saves time.Following information in the form of symbols and code should be given.
1.Start of do loop
2.NUMBER OF REPEATS OF LOOP
3. END OF LOOP.

v)CANNED CYCLES- These are readymade cycles inbuilt or stored in the system memory .These are used for repetitive and commonly used machining operations.They are stored under G code address. CODES G81 TO G89 are reserved for canned cycles. G80 is used to cancel canned cycles.
G81- CANNED CYCLE FOR TURNING, G84- CANNED CYCLR FOR THREADING,

CUTTER RAIDUS COMPENSATION- The difference in the programmed diameter of the cutter and diameter of actual cutter is accounted for by cutter raidus compensation.the difference in the dia of the cutter is entered into the control system . the control system then generates a new cutter path. It should also be mentioned whether compensation is to be given in left or right.

For e.g- if programme has been written for cutter of dia 10 and actual cutter used during machining is of dia 20 then
Cutter raidus compensation to be entered= (10-20)/2=5
G codes for this are
G41- COMPENSATION APPLIED TO SHIFT THE PROGRAMMED PATH TO LEFT
G42- COMPENSATION APPLIED TO SHIFT THE PROGRAMMED PATH TO RIGHT
G40- CANCEL CUTTER RAIDUS COMPENSATION



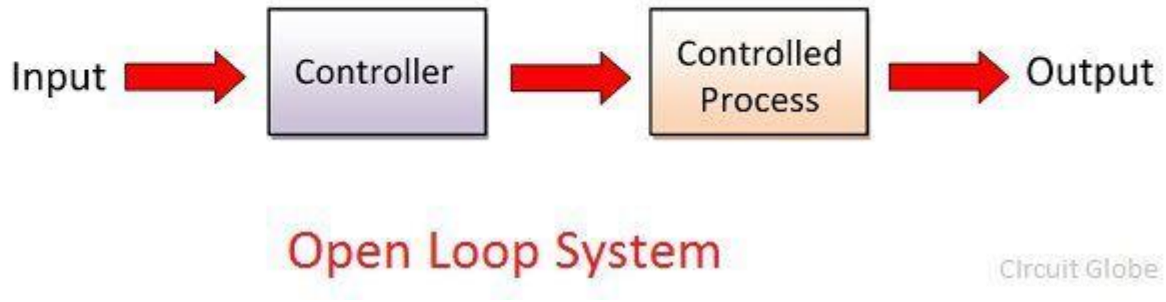
MACHINE ZERO- The machine zero is at the origin of the coordinate measuring system of machine.it is also called home position of machine.

Work zero- it may be defined as the point, line, surface on the component drawing to which all the dimensions are fixed.

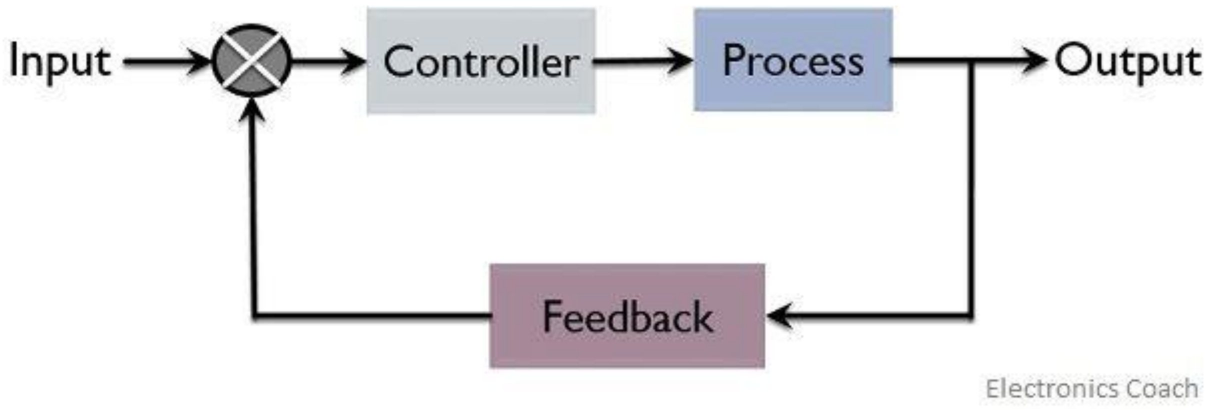
Chapter -3

Control system- Based on feedback control the cnc system are classified as
1. Open loop control system 2. Closed loop control system

Open loop control system - In this type of control there is no feedback mechanism to compare the actual position of the cutting tool or workpiece with the input command value.Open loop control system is cheaper than closed loop control system.The accuracy of this type of system is less as compared to open loop control system.Maintenance of open loop control system is easy and simple than closed loop control system. Machines with this type of system have to be periodically checked to compensate for changes due to various factors.



Closed loop control system - In this type of control there is feedback mechanism to compare the actual position of the cutting tool or workpiece with the input command value. Closed loop control system is costlier than open loop control system.The accuracy of this type of system is more as compared to closed loop control system.Maintenance of closed loop control system is complex ale than open loop control system.



Sensor- A sensor is an element that produce an output in response to change in quantity.

Transducer- A transducer is a device that converts one form of energy into another form.

classification of transducers-

1.Active and passive transducers

Active Transducers- The transducers that doesnot require any external power source for their operation are called active transducers.

e.g- thermopile,Piezoelectric type.

Passive transducers- The transducers that require any external power source for their operation are called active transducers.

e.g-LVDT, RESISTIVE TYPE.

2. on the basis of transduction principle.

a)Resistive type b) Inductive type c) Capacacitive type

3. Analog and Digital type

Characteristics / requirement of transducer-

1. Ruggedness 2. Linearity 3. Repeatability 4. High stability and reliability. 5. Speed Response

LVDT- Linear Variable Differential Transducer

PRINCIPLE- LVDT is based on the principle of mutual induction and is used for the measurement of displacement. The displacement is converted into an electrical signal.

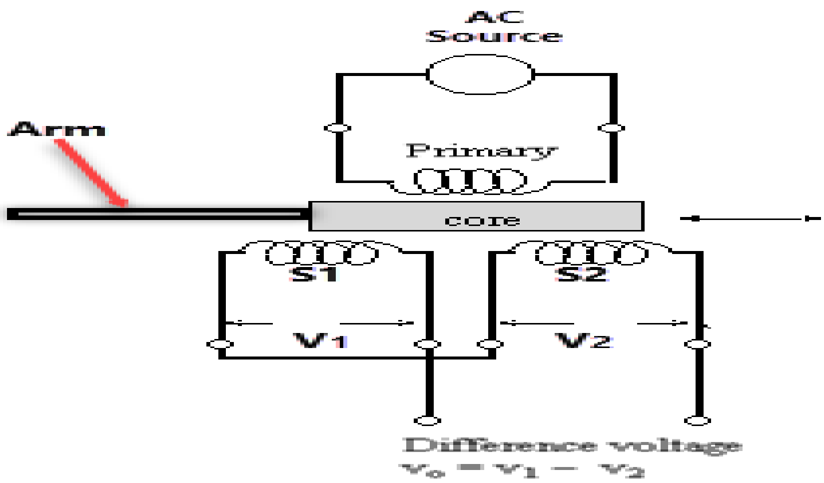
Construction- the basic components of LVDT ARE-

1.A constant amplitude AC source

2. A primary coil.

3.Two secondary coils- The two secondary coils are identical i.e the number of turns in both secondary coils is same. These secondary coils are connected in series opposition

3. An iron core.- iron core is placed in the centre of these coils.

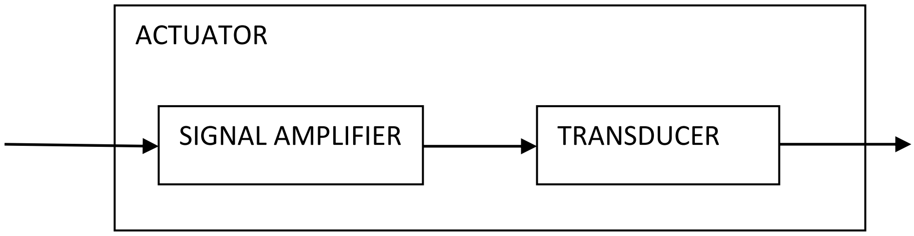


WORKING-When the primary coils are energised by the AC source a magnetic flux is generated and voltage is induced in the two secondary coils. If the core is located midway between the two secondary coils same voltage is induced in both the coils and zero output voltage is obtained this is the null point. Now when the core is displaced it moves neare to one coil and moves away from the other so voltage induced in the two coils will be different i.e is more in coil towards which the core has shifted in less in the other and we get an output voltage. This voltage is calibrated in terms of displacement.

Tachometer- A tachometer is a device that is used to measure roration speed of an object.e.g- rpm of a shat,motor etc.
Types-

1. Contact and non contact type 2. Analog and Digital type

ACTUATORS-



Types of actuators- Based on the source of power used actuators are classified as

1. **Electrical actuators**- Electrical actuators uses electrical energy and convert it into mechanical action.these are commonly used in control system as they can be easily interfaced with them.
   Types of electrical actuators-

A) A.C Motors B) D.C Motors C) Stepper motors

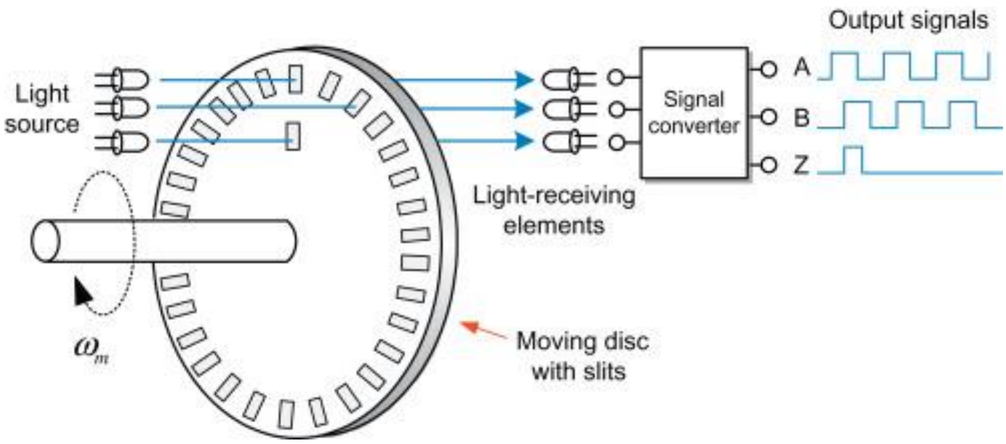
2. **Hydraulic actuators**- Hydraulic actuators uses fluid energy and convert it into mechanical action.these can produce linear, rotary and oscillatory motion. E.g- hydraulic cylinder, hydraulic jack
3. **Pneumatic actuators**- Pneumatic actuators uses compressed energy and convert it into mechanical action. These can also produce linear, rotary and oscillatory motion. E.g- Pneumatic cylinder. They have problem of leakage which makes them less suitable.
4. **Mechanical actuators**-Mechanical actuators generally converts rotary motion into linear with the help of gears ,pulleys or chains.

Encoders- Any transducer that generates a coded reading of a measurement can be termed an encoder.•Shaft Encodersare digital transducers that are used for measuring angular displacements and velocities.

Encoders are non contact position sensing devices.They are extensively used in CNC machines to measure the position and motion of the controlled components of machine.

They are of two types-

1. **Incremental Encoders**- these encoders can measure the angular position with respect to a starting point. An incremental encoder can be rotary or linear.



2. **Absolute encoders**- In these types of encoder all the position dimensions are measured with respect to a common datum point .A transducer presents, the direct reading of position with reference to common datum in this sustem.

E- CONTENTS OF MACINE DESIGN

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BKN GP NNL

KEYS

DESIGN OF KEYS

Introduction

Definition of Key and function of key

Key is a machine element which is used to connect the transmission shaft to rotating machine elements like pulley, gear, sprocket or flywheel.

Keys provide a positive means of transmitting torque between shaft and hub of the mating element.

Definition of keyway

A slot is machined in the shaft or in the hub or both to accommodate the key is called keyway. Keyway reduces the strength of the shaft as it results in stress concentration.

Keys are made of ductile materials.

Types of Keys

Common types of keys are:

1. Sunk keys   2. Saddle keys

Sunk Keys

A sunk key is a key in which half of the thickness of key fits into the keyway in the shaft and half in the keyway of the hub.

The sunk keys are of the following types:

Rectangular sunk key:

It is the simplest type of key and has a rectangular cross-section. A taper of about 1 in 100 is provided on its top side. Rectangular sunk key is shown in Figure.The usual proportions of this key are:

Width of key, $w = d / 4$;

and thickness of key, $t = 2w / 3 = d / 6$

where d = Diameter of the shaft or diameter of the hole in the hub.

The key has taper 1 in 100 on the top side only.

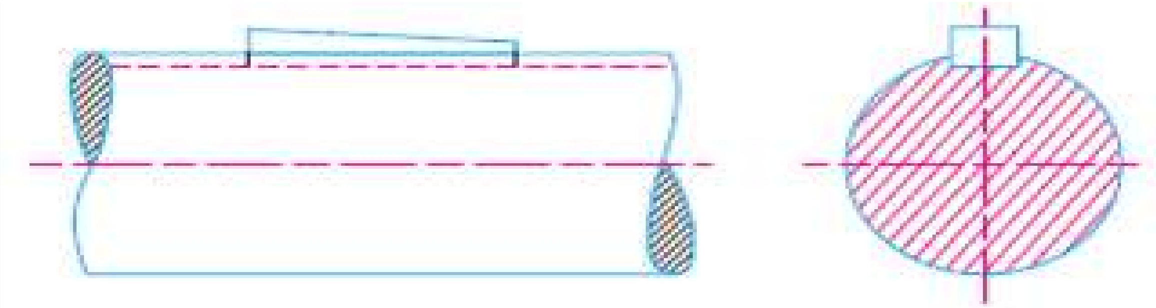


Figure: - Rectangular Sunk Key

Square sunk key:

Rectangular sunk key having equal width and thickness is called square sunk key. i.e. w = t = d /4

Parallel sunk key:

If no taper is provided on the rectangular or square sunk key, it is called parallel sunk key i.e. it is uniform in width and thickness throughout. It is used where the pulley, gear or other mating piece is required to slide along the shaft.

Gib-head key:

It is a rectangular sunk key with a head at one end known as gib head, which is provided to facilitate the removal of key. Gib Head key is shown in Figure.

The usual proportions of the gib head key are:

Width, w = d / 4;

and thickness at large end,

t = 2w / 3 = d /6

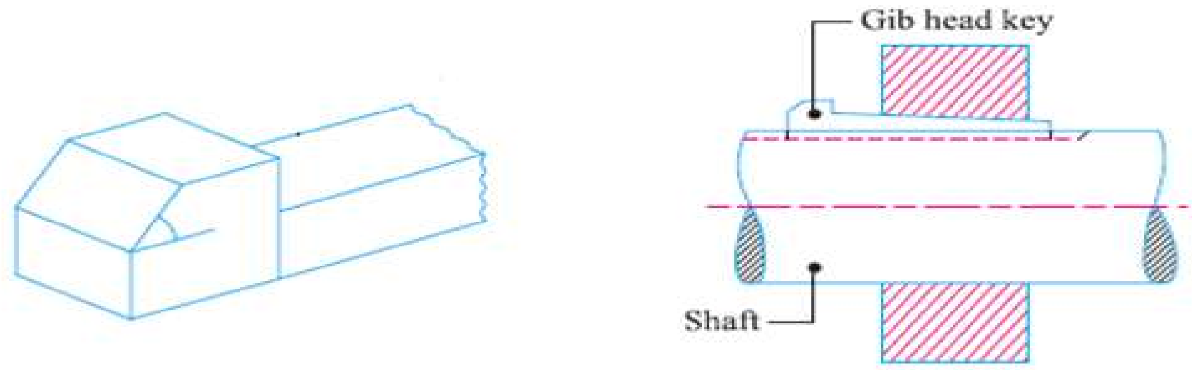


Figure: Gib Head Key

Feather key:

Feather key is a parallel key made as an integral part of the shaft with the help of machining or using set-screws. It permits axial movement and has a sliding fit in the key way of the moving piece. Feather keys are shown in Figure.

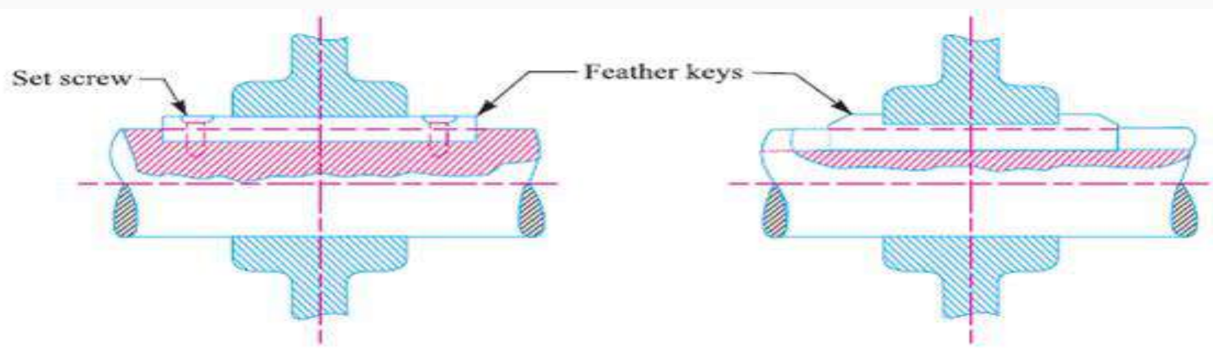


Figure: -Feather Key

Woodruff key:

Woodruff key is a sunk key in the form of a semi-circular disc of uniform thickness. Lower portion of the key fits into the circular keyway of the shaft. It can be used with tapered shafts as it can tilt and align itself on the shaft. But the extra depth of keyway in the shaft increases stress concentration and reduces strength of the shaft. Woodruff key is shown in Figure.

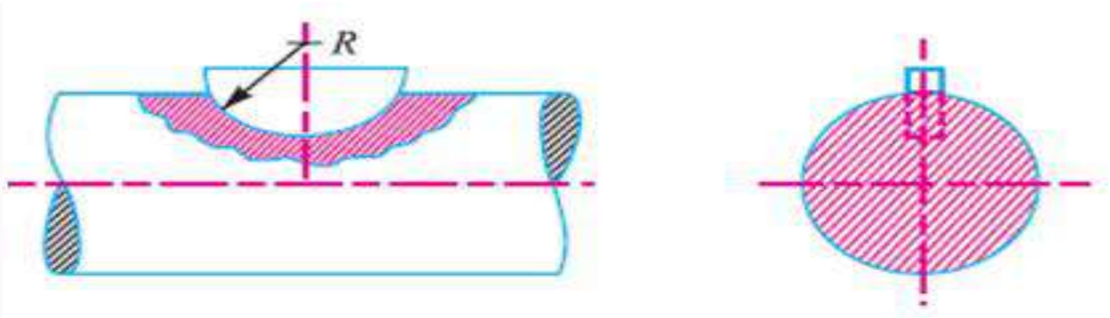


Figure: -Woodruff Key

Round Keys

The round keys have a circular cross-section and fit into holes drilled partly in the shaft and partly in the hub. Slot is drilled after the assembly so the shafts can be properly aligned. These are used for low torque transmission. Round keys are shown in Figure

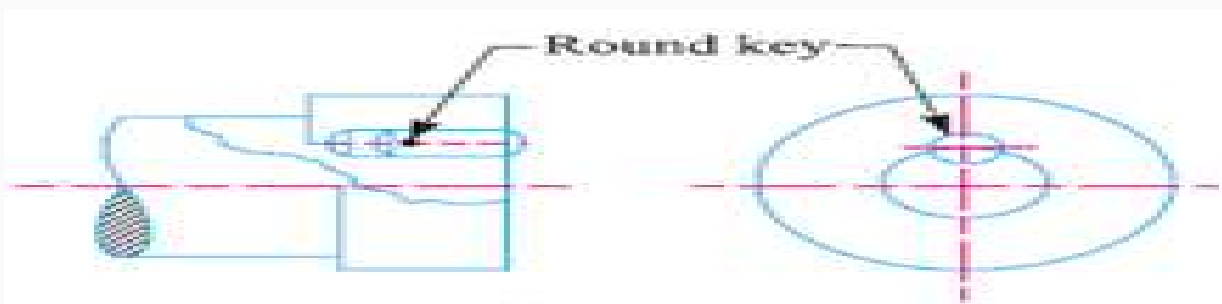


Figure: - Round key

Saddle Keys

Slot for this type of is provided only in the hub as shown in Figure. Torque is transmitted by friction only and cannot therefore transmit high torque and is used only for light applications.

The saddle keys are of two types:

Flat Saddle Key and Hollow Saddle Key.

In flat saddle key, the bottom surface touching the shaft is flat and it sits on the flat surface machined on the shaft.

Hollow saddle key has a concave surface at the bottom to match the circular surface of the shaft. Chances of slip in case of the flat saddle key are relatively lesser and can transmit more power than the hollow saddle key.

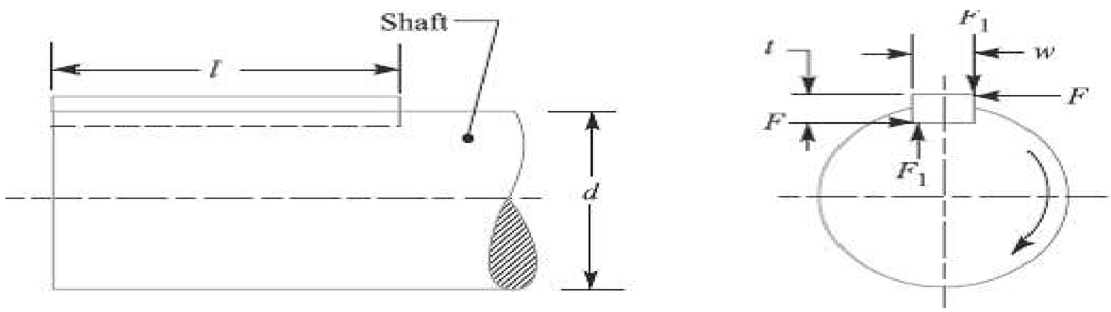
Saddle Keys Figure Tangent Keys

Stresses in Keys:

Forces acting on a Sunk Key

When a key is used in transmitting torque from a shaft to a rotor or hub, the following two types of forces act on thekey:

- Forces (F1) due to fit of the key in its keyway, as in a tight fitting straight key or in a tapered key driven in place. These forces produce compressive stresses in the key which are difficult to determine inmagnitude.
- Forces (F) due to the torque transmitted by the shaft. These forces produce shearing and compressive (or crushing) stresses in thekey.
- The forces acting on a key for a clockwise torque being transmitted from a shaft to a hub are shown in Fig.
- In designing a key, forces due to fit of the key are neglected and it is assumed that the distribution of forces along the length of key is uniform.



Strength of a Sunk Key

A key connecting the shaft and hub is shown in Fig.

Let T = Torque transmitted by theshaft,

F = Tangential force acting at the circumference ofthe shaft,

d = Diameter ofshaft,

l = Length of key,

w = Width of key.

t = Thickness of key, and

ı and σc = Shear and crushing stresses for the material of key.

A little consideration will show that due to the power transmitted by the shaft, the key may fail due to shearing or crushing. Considering shearing of the key, the tangential shearing force acting at the circumference of theshaft,

F = Area resisting shearing × Shear stress = l × w × ı

Therefore, Torque transmitted by the shaft,

$$T = F \times \frac{d}{2} = l \times w \times \tau \times \frac{d}{2} \quad \ldots(i)$$

Considering crushing of the key, the tangential crushing forceacting at the circumference of theshaft,

F = Area resisting crushing × Crushing stress

$$= l \times \frac{t}{2} \times \sigma_c$$

Therefore, Torque transmitted by the shaft,

$$T = F \times \frac{d}{2} = l \times \frac{t}{2} \times \sigma_c \times \frac{d}{2} \qquad \ldots(ii)$$

The key is equally strong in shearing and crushing, if

$$l \times w \times \tau \times \frac{d}{2} - l \times \frac{t}{2} \times \sigma_c \times \frac{d}{2}$$

Or

$$\frac{w}{t} - \frac{\sigma_c}{2\tau}$$

The permissible crushing stress for the usual key material is at least twice the permissible shearing stress. Therefore, from the above equation, we have w = t. In other words, a square key is equally strong in shearing and crushing.

In order to find the length of the key to transmit full power of the shaft, the shearing strength of the key is equal to the torsional shear

$$T = l \times w \times \tau \times \frac{d}{2}$$

strength of the shaft. We know that the shearing strength of key,

And torsional shear strength of the shaft,

$$T = \frac{\pi}{16} \times \tau_1 \times d^3$$

From the above

$$l \times w \times \tau \times \frac{d}{2} = \frac{\pi}{16} \times \tau_1 \times d^3$$

$$l = \frac{\pi}{8} \times \frac{\tau_1 d^2}{w \times \tau} = \frac{\pi d}{2} \times \frac{\tau_1}{\tau} = 1.571\, d \times \frac{\tau_1}{\tau}$$

When the key material is same as that of the shaft, then $ı = ı_1$. So, l = 1.571 d.

Joints

Introduction

Mechanical joints or fasteners are used for making connections between different elements of machine or structure. A machine or a structure is made of a large number of parts and they need be joined suitably for the machine to operate satisfactorily. In manufacturing industries, joining of two or more components is necessary for assembly purposes. Joining makes the production system more reliable, efficient and profitable. In fact, joining can be defined as one of the manufacturing processes by which two or more solid components can be assembled together.

Types of joints

Mechanical joints are broadly classified into following two categories:

1. **Permanent joints**

   Permanent joints cannot be easily disassembled without damaging the connecting elements. Different types of permanent joints are welded joints, brazed joints, soldered joints, adhesive joints, riveted joints and interference joints.

2. **Temporary joints**

   Temporary joints can be easily disassembled without damaging the connecting elements. Different types of detachable joints are threaded joints, pin joints, cotter joints and key joints.

Knuckle Joint

A knuckle joint is used to connect two rods which are under the action of tensile loads. However, if the joint is guided, the rods may support a compressive load. A knuckle joint may be readily disconnected for adjustments or repairs.

Its use may be found in the link of a cycle chain, tie rod joint for roof truss, valve rod joint with eccentric rod, pump rod joint, tension link in bridge structure and lever and rod connections of various types.

In knuckle joint one end of one of the rods is made into an eye and the end of the other rod is formed into a fork with an eye in each of the fork leg.

The knuckle pin passes through both the eye hole and the fork holes and may be secured by means of a collar and taper pin or spilt pin. The knuckle pin may be prevented from rotating in the fork by means of a small stop, pin, peg or snug. In order to get a better quality of joint, the sides of the fork and eye are machined, the hole is accurately drilled and pin turned.

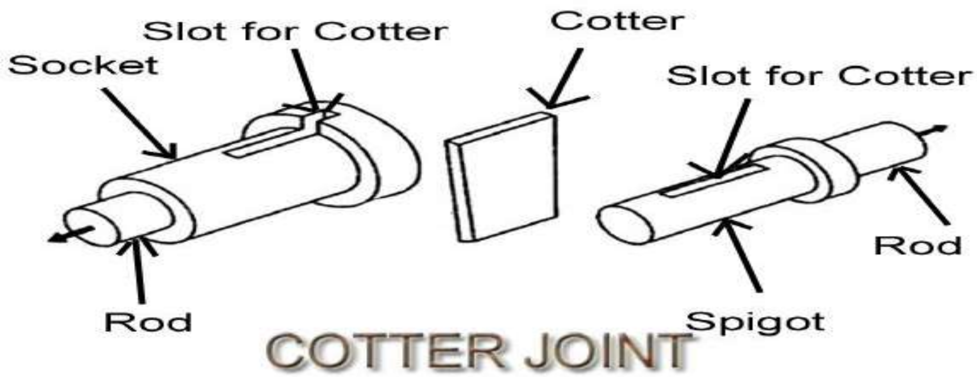
The material used for the joint may be steel or wrought iron.

Cotter Joint – Parts and Applications

Cotter joint is a type of mechanical joint which is used to join two axial rods or bars. It is also known as spigot and socket joint. This joint doesn't allow any angular movements of rods which it connects. This joint is applicable for tensile loads as well as compressive loads. It is a detachable joint.

It consists of mainly three parts –

1. Spigot
2. Socket
3. Cotter.



The above three parts spigot, socket and cotter together forms the cotter joint. Spigot and socket are formed in one of the two connecting rods. Firstly, Spigot enters into the circular hole of socket and then cotter fits tightly into the rectangular slots of spigot and socket which coincides with each other. This cotter fixes the spigot and socket with each other.

A tapper is used to lock the joint.

This tapper is easy to remove and makes dismantle of joint an easy process.

Tapper also ensures the tightness of the joints and prevents loosening of the parts.

There are **three types** of cotter joints:-

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

In according to your syllabus there is only 1(Socket and spigot joint) that's numerical comes to your exam.

1. Socket and Spigot joint

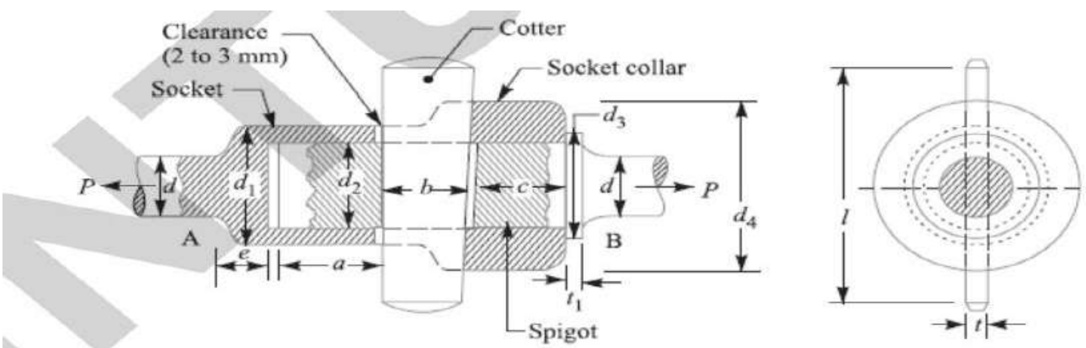


Fig. Socket and spigot cotter joint

Design of Socket and Spigot Cotter Joint

The socket and spigot cotter joint is shown in Fig.

Let P = Load carried by the rods,

d = Diameter of the rods,

d_1 = Outside diameter of socket,

d_2 = Diameter of spigot or inside diameter of socket,

d_3 = Outside diameter of spigot collar,

t_1= Thickness of spigot collar,

d_4 = 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,

σ_t = Permissible tensile stress for the rods material,

τ = Permissible shear stress for the cotter material, and

σ_c = Permissible crushing stress for the cotter material.

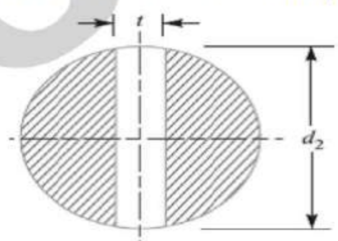
The dimensions for a socket and spigot cotter joint may be obtained by considering the various modes of failure as discussed below:

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 (or slot)



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

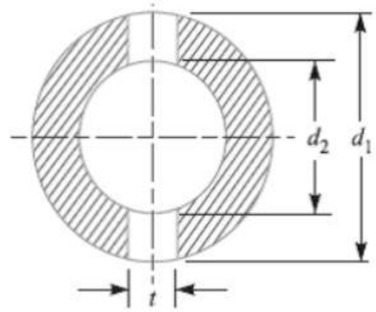
From this equation, the diameter of spigot or inside diameter of socket (d_2) may be determined. In actual practice, the thickness of cotter is usually taken as d_2 / 4.

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.

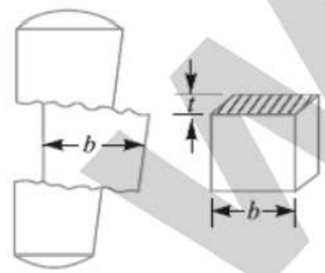
4. Failure of the socket in tension across the slot



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

From this equation, outside diameter of socket (d_1) may be determined.

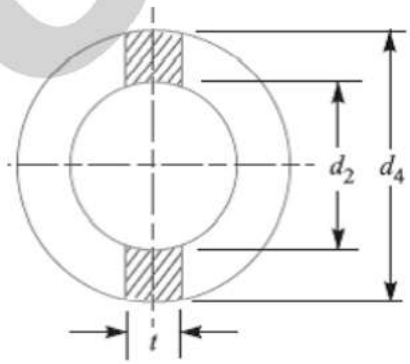
5. Failure of cotter in shear



$$P \; - 2\, b \times t \times \tau$$

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

6. Failure of the socket collar in crushing



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

From this equation, the diameter of socket collar (d_4) may be obtained.

7. Failure of socket end in shearing

$$P = 2\,(d_4 - d_2)\, c \times \tau$$

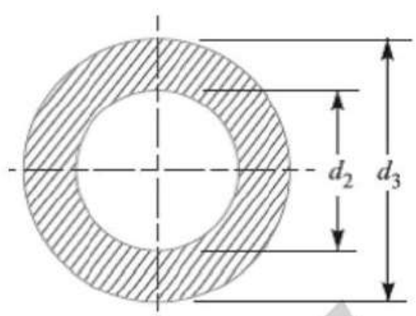
From this equation, the thickness of socket collar (c) may be obtained.

8. Failure of rod end in shear

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

From this equation, the distance from the end of the slot to the end of the rod (a) may be obtained.

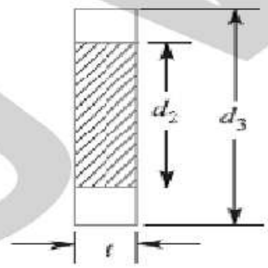
9. Failure of spigot collar in crushing



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

From this equation, the diameter of the spigot collar (d_3) may be obtained.

10. Failure of the spigot collar in shearing

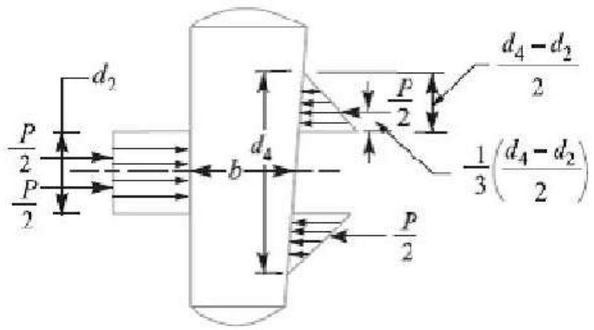


$$P = \pi\, d_2 \times t_1 \times \tau$$

From this equation, the thickness of spigot collar (t_1) may be obtained.

11. Failure of cotter in bending

The maximum bending moment occurs at the centre of the cotter and is given by



$$M_{max} = \frac{P}{2}\left(\frac{1}{3} \times \frac{d_4 - d_2}{2} + \frac{d_2}{2}\right) - \frac{P}{2} \times \frac{d_2}{4}$$
$$= \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{2} - \frac{d_2}{4}\right) = \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)$$

We know that section modulus of the cotter,

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

Bending stress induced in the cotter,

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

This bending stress induced in the cotter should be less than the allowable bending stress of the cotter.

12. The length of cotter (l) in taken as 4 d.

13. The taper in cotter should not exceed 1 in 24. In case the greater taper is required, then a locking device must be provided.

14. The draw of cotter is generally taken as 2 to 3 mm.

Notes: 1. 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.

2. 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.

Problem:

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 $\quad t = d_2 / 4 = 40 / 4 = 10\text{ mm}$ **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),

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

$$\therefore \quad t_1 = 30 \times 10^3 / 4400 = 6.8 \text{ say } 8 \text{ mm Ans.}$$

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

$$\therefore \quad l = 4\,d = 4 \times 28 = 112 \text{ mm Ans.}$$

11. The dimension e is taken as 1.2 d.

$$\therefore \quad e = 1.2 \times 28 = 33.6 \text{ say } 34 \text{ mm Ans.}$$

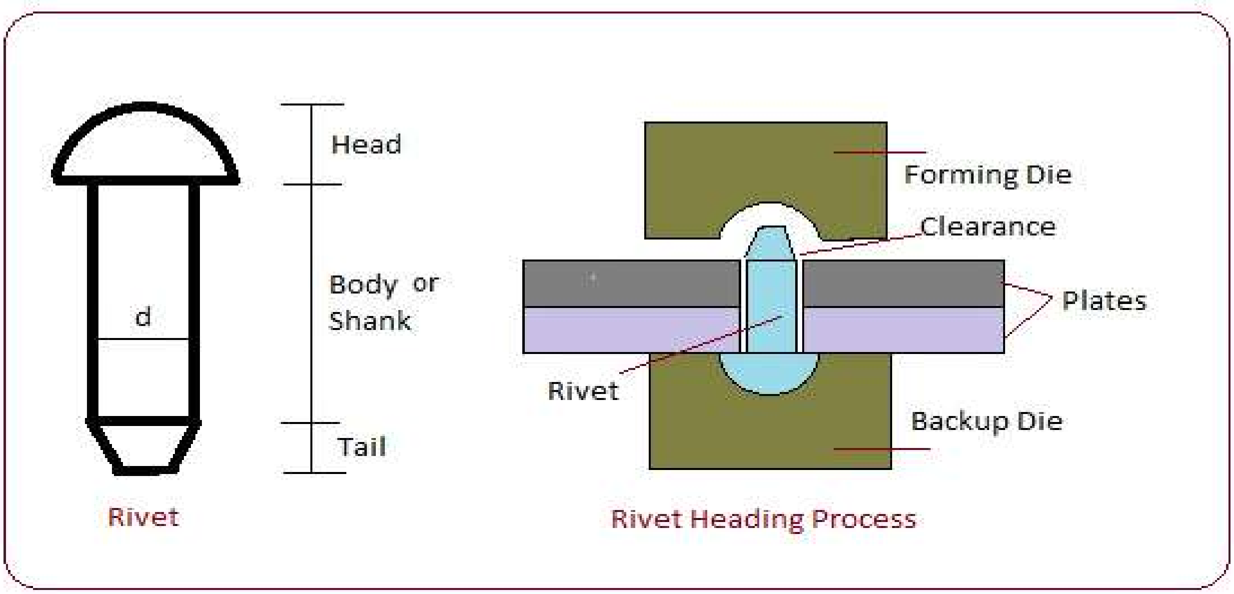
4.

Chapter 7

Design of riveted joint

Rivet Joints

A rivet is a short cylindrical bar with a head integral to it. The cylindrical portion of the rivet is called shank or body and lower portion of shank is known as tail.



The fastenings (i.e. joints) may be classified into the following two groups:

1. **Permanent fastenings and**
2. **Temporary or detachable fastenings.**

The permanent fastenings are those fastenings which cannot be disassembled without destroying the connecting components. The examples of permanent fastenings in order of strength are soldered, brazed, welded and riveted joints.

The temporary or detachable fastenings are those fastenings which can be disassembled without destroying the connecting components. The examples of temporary fastenings are screwed, keys, cotters, pins and splined joints.

Material of Rivets

The material of the rivets must be tough and ductile. They are usually made of steel (low carbon steel or nickel steel), brass, aluminum or copper, but when strength and a fluid tight joint is the main consideration, then the steel rivets are used.

Applications of Rivets

The rivets are used to make permanent fastening between the plates such as in structural work, ship building, bridges, tanks and boiler shells.

The riveted joints are widely used for joining light metals.

Types of Rivets

All types of rivets have round body. Only the head of the rivets differ from one another. Generally, there are three types of rivets which are used for different works:

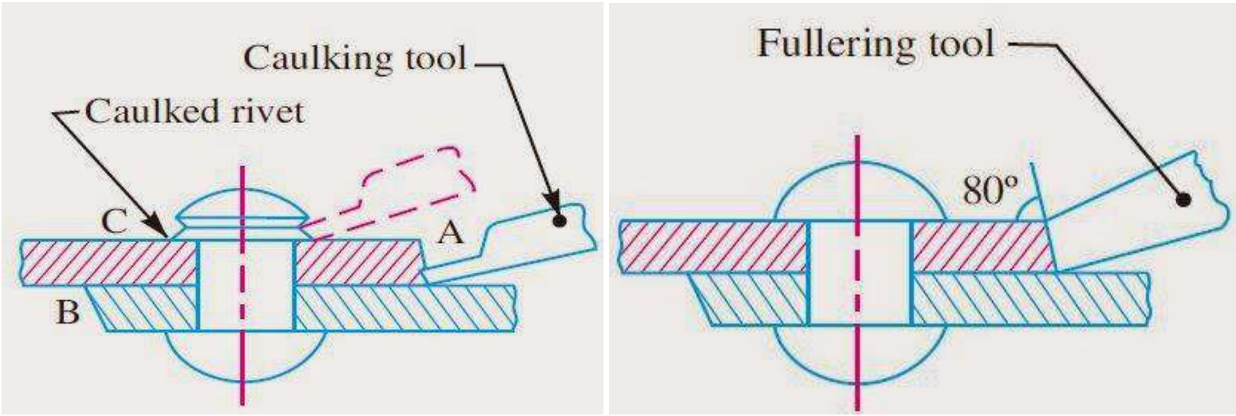
i. Boiler rivets: 10 to 60 mm diameters with 60 degree chamfer.
ii. Structural rivets: 10 to 50 mm diameter.
iii. General purpose rivets: below 10 mm diameter.

Caulking and Fullering

In order to make the joints leak proof or fluid tight in pressure vessels like steam boilers, air receivers and tanks etc. a process known as caulking is employed.

In this process, a narrow blunt tool called caulking tool, about 5 mm thick and 38 mm in breadth, is used. The edge of the tool is ground to an angle of 80°. The tool is moved after each blow along the edge of the plate, which is planed to a bevel of 75° to 80° to facilitate the forcing down of edge.

In actual practice, both the edges at A and B are caulked. The head of the rivets as shown at C are also turned down with a caulking tool to make a joint steam tight. A great care is taken to prevent injury to the plate below the tool. A more satisfactory way of making the joints staunch is known as Fullering which has largely superseded caulking. In this case, a Fullering tool with a thickness at the end equal to that of the plate is used in such a way that the greatest pressure due to the blows occur near the joint, giving a clean finish, with less risk of damaging the plate.



Terminology used in Riveted Joints

The following terms in connection with the riveted joints are important from the subject point of view: shown in figure given below.

1. Pitch:

It is the distance from the centre of one rivet to the centre of the next rivet measured parallel to the seam as shown in Fig. It is usually denoted by p.

$$p=3d$$

2. Back pitch:

It is the perpendicular distance between the centre lines of the successive rows as shown in Fig. It is usually denoted by pb.

$$pb= 2d+6 \text{ (for chain type riveting)}$$

$$=2d \text{ (for Zig-Zag riveting)}$$

3. Diagonal pitch:

It is the distance between the centers of the rivets in adjacent rows of Zig-Zag riveted joint as shown in Fig. It is usually denoted by pd.

$$pd=\frac{2p+d}{3}$$

4. Margin or marginal pitch:

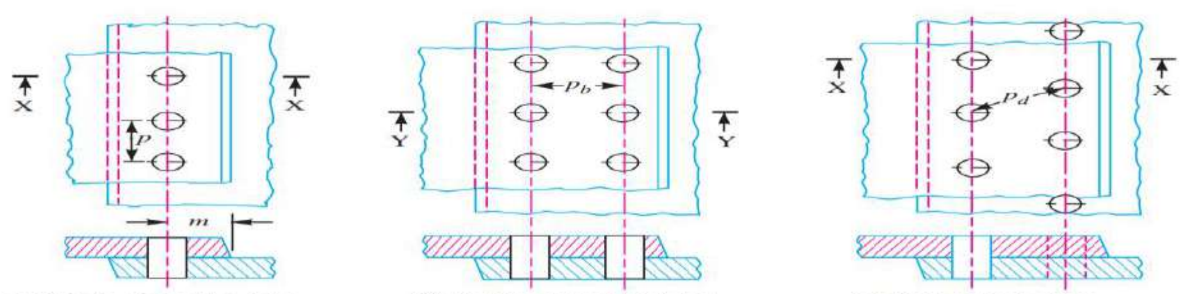
It is the distance between the centres of rivet hole to the nearest edge of the plate as shown in Fig. It is usually denoted by m.

$$m=1.5d$$

5. Diameter of rivet: -

$$d=\sqrt[6]{t}$$

t= thickness of the plate in mm.



(a) Single riveted lap joint. (b) Double riveted lap joint (Chain riveting). (c) Double riveted lap joint (Zig-zag riveting).

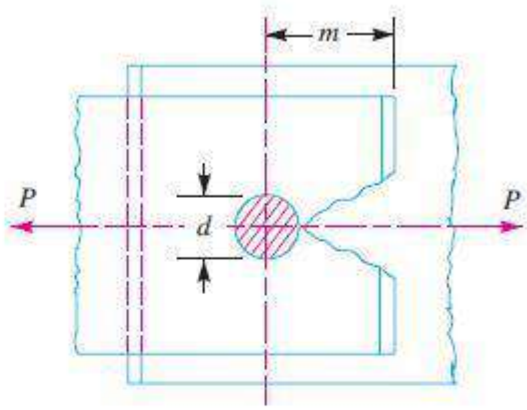
Fig. 9.6. Single and double riveted lap joints.

Failure of riveted joint

A riveted joint may fail in the following ways:

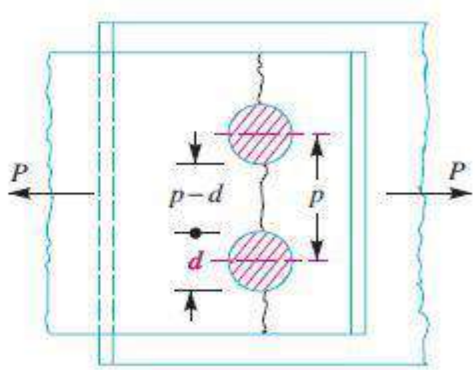
1. **Tearing of the plate at an edge**: -

A joint may fail due to tearing of the plate at an edge as shown in Fig. This can be avoided by keeping the margin, m = 1.5d, where d is the diameter of the rivet hole.



2. **Tearing of the plate across a row of rivets**:

Due to the tensile stresses in the main plates, the main plate or cover plates may tear off across a row of rivets as shown in Fig. In such cases, we consider only one pitch length of the plate, since every rivet is responsible for that much length of the plate only.



The resistance offered by the plate against tearing is known as tearing resistance or tearing strength or tearing value of the plate.

Let,

p = Pitch of the rivets,

d = Diameter of the rivet hole,

t = Thickness of the plate, and

σ_t = Permissible tensile stress for the plate material.

We know that tearing area per pitch length,

$A_t = (p - d)\,t$

∴ Tearing resistance or pull required to tear off the plate per pitch length,

$P_t = A_t.\sigma_t = (p - d)t.\sigma_t$

When the tearing resistance (P_t) is greater than the applied load (P) per pitch length, then this type of failure will not occur.

3. **Shearing of the rivets:** The plates which are connected by the rivets exert tensile stress on the rivets, and if the rivets are unable to resist the stress, they are sheared off.

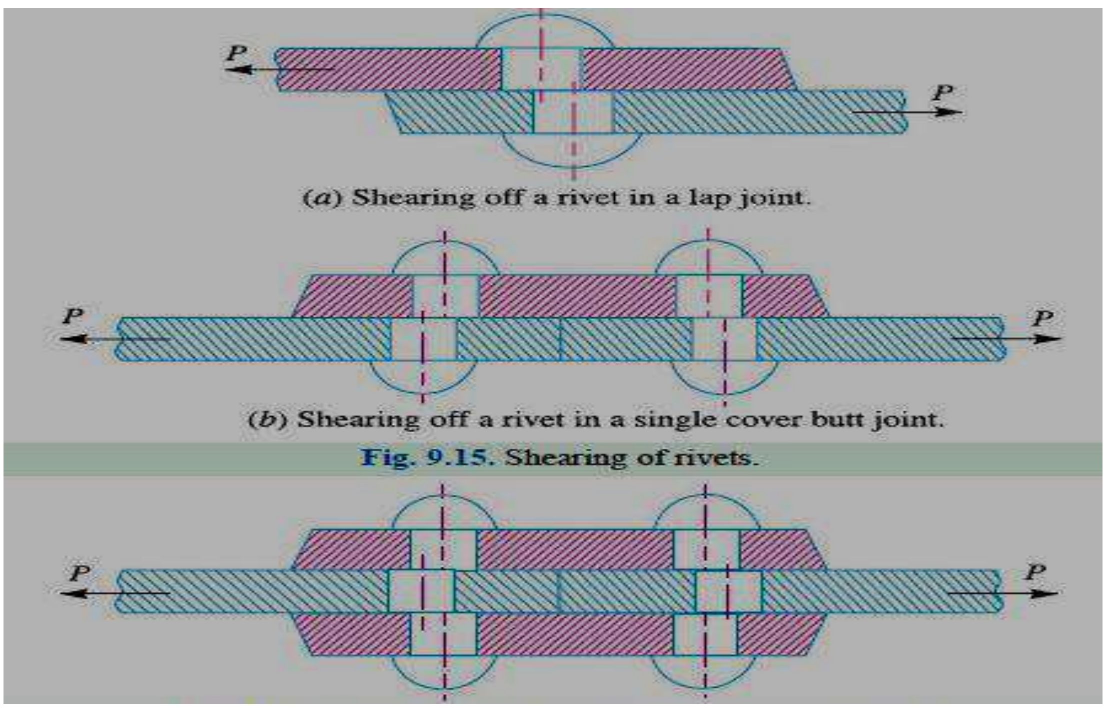


Fig. 9.15. Shearing of rivets.

Let d = Diameter of the rivet hole,

τ = Safe permissible shear stress for the rivet material, and

n = Number of rivets per pitch length.

$$A_s = \frac{\pi}{4} \times d^2 \quad \text{...(In single shear)}$$

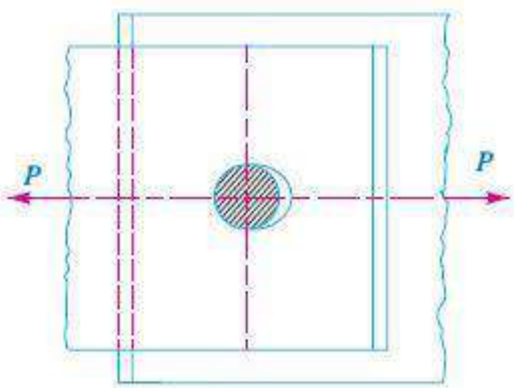
$$= 2 \times \frac{\pi}{4} \times d^2 \quad \text{...(Theoretically, in double shear)}$$

$$P_s = n \times \frac{\pi}{4} \times d^2 \times \tau \quad \text{...(In single shear)}$$

$$= n \times 2 \times \frac{\pi}{4} \times d^2 \times \tau \quad \text{...(Theoretically, in double shear)}$$

4. **Crushing of the plate or rivets:-**

Sometimes, the rivets do not actually shear off under the tensile stress, but are crushed. Due to this, the rivet hole becomes of an oval shape and hence the joint becomes loose. The failure of rivets in such a manner is also known as bearing failure. The area which resists this action is the projected area of the hole or rivet on diametral plane.



The resistance offered by a rivet to be crushed is known as crushing resistance or crushing strength or bearing value of the rivet.

Let, d = Diameter of the rivet hole,

t = Thickness of the plate,

σc = Safe permissible crushing stress for the rivet or plate material, and

n = Number of rivets per pitch length under crushing.

We know that crushing area per rivet (i.e. projected area per rivet),

Ac = d.t

∴ Total crushing area = n.d.t

and crushing resistance or pull required to crush the rivet per pitch length,

$P_c = n.d.t.\sigma_c$

When the crushing resistance (Pc) is greater than the applied load (P) per pitch length, then this type of failure will occur.

Strength of Riveted Joint

Strength of a Riveted Joint The strength of a joint may be defined as the maximum force, which it can transmit, without causing it to fail.

We have seen in Failure of riveted joint that Pt, Ps and Pc are the pulls required to tear off the plate, shearing off the rivet and crushing off the rivet. A little consideration will show that if we go on increasing the pull on a riveted joint, it will fail when the least of these three pulls is reached, because a higher value of the other pulls will never reach since the joint has failed, either by tearing off the plate, shearing off the rivet or crushing off the rivet.

If the joint is continuous as in case of boilers, the strength is calculated per pitch length. But if the joint is small, the strength is calculated for the whole length of the plate.

Efficiency of a Riveted Joint

The efficiency of a riveted joint is defined as the ratio of the strength of riveted joint to the strength of the un-riveted or solid plate.

We have already discussed that strength of the riveted joint = Least of Pt, Ps and Pc.

Strength of the un-riveted or solid plate per pitch length, $P = p \times t \times \sigma_t$

∴ Efficiency of the riveted joint, $\eta = \frac{least\ of\ P_t, P_s\ and\ P_c}{p \times t \times \sigma_t}$

Where,

p = Pitch of the rivets,

t = Thickness of the plate, and

σt = Permissible tensile stress of the plate material.

CHAPTER 8

DESIGN OF FLANGE COUPLING

COUPLING

A coupling is a component which joins two shafts and transfers torque from a driven shaft (driving force) to a driven shaft component.

Shafts are usually available up to 7 meters length due to inconvenience in transport. In order to have a greater length, it becomes necessary to join two or more pieces of the shaft by means of a coupling

Requirements of a Good Shaft Coupling

A good shaft coupling should have the following requirements:

1. It should be easy to connect or disconnect.
2. It should transmit the full power from one shaft to the other shaft without losses.
3. It should hold the shafts in perfect alignment.
4. It should reduce the transmission of shock loads from one shaft to another shaft.

5. It should have no projecting parts.

Types of Shafts Couplings

Shaft couplings are divided into two main groups as follows:

1. Rigid coupling.

2. Flexible coupling.

It is used to connect two shafts which are perfectly aligned.

Following types of **rigid coupling** are important from the subject point of view:

a) Sleeve or muff coupling.

b) Clamp or split-muff or compression coupling, and

c) Flange coupling.

Flexible coupling

It is used to connect two shafts having both lateral and angular misalignment. Following types of **flexible coupling** are important from the subject point of view:

a) Bushed pin type coupling,

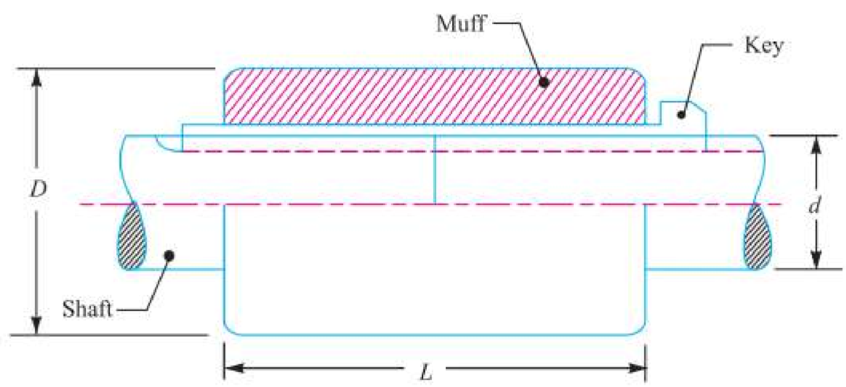
b) Universal coupling, and

c) Oldham coupling.

Sleeve or muff coupling

It is the simplest type of rigid coupling, made of cast iron. It consists of a hollow cylinder whose inner diameter is the same as that of the shaft. It is fitted over the ends of the two shafts by means of a Gib head key, as shown in Fig.

The power is transmitted from one shaft to the other shaft by means of a key and a sleeve. It is, therefore, necessary that all the elements must be strong enough to transmit the torque.



The usual proportions of a cast iron sleeve coupling are as follows:

Outer diameter of the sleeve, D = 2d + 13 mm

And length of the sleeve, L = 3.5 d

Where, d is the diameter of the shaft.

Design of Sleeve or muff coupling

In designing a sleeve or muff-coupling, the following procedure may be adopted.

1. Design for sleeve

The sleeve is designed by considering it as a hollow shaft and transmitting the same torque (T) as that of solid shaft.

Torque, $T = \frac{\pi}{16} \times \tau_C (\frac{D^4 - d^4}{D})$

The outer diameter of sleeve is taken as 2d+13 mm. The induced shear stress in the sleeve may be verified from the above relation. The length of sleeve (L) is generally taken as 3.5d.

2. Design for key

The key is designed with usual relations and it is checked for shear and crushing stresses. The material of key is generally mild steel.

Length of key is taken equal to the length of the sleeve. The key is usually made in two parts so that **length of key** in each shaft,

$$l = \frac{L}{2} = \frac{3.5d}{2}$$

NUMERICAL ON Sleeve or muff coupling

Design and make a neat dimensioned sketch of a muff coupling which is used to connect two steel shafts transmitting 40 kW at 350 r.p.m. The material for the shafts and key is plain carbon steel for which allowable shear and crushing stresses may be taken as 40 MPa and 80 MPa respectively. The material for the muff is cast iron for which the allowable shear stress may be assumed as 15 MPa.

Given: P = 40 kW =$40 \times 10^3 W$;

N = 350 r.p.m.;

τ_s = 40 MPa = 40 N/mm2;

σ_{cs} = 80 MPa = 80 N/mm2;

τ_c = 15 MPa = 15 N/mm2

The muff coupling is shown in Fig. above. It is designed as discussed below:

1. Design for shaft

Let d = Diameter of the shaft.

We know that the torque transmitted by the shaft, key and muff,

$$T = \frac{60P}{2\pi N}$$

$$= \frac{60 \times 40 \times 10^3}{2 \times \pi \times 350} = 1100Nm = 1100 \times 10^3 Nmm$$

We also know that the torque transmitted (T),

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3 = \frac{\pi}{16} \times 40 \times d^3 = 7.86d^3$$

$$d^3 = \frac{1100 \times 10^3}{7.86} = 140 \times 10^3 = or\ d = 52mm\ Ans$$

2. Design of Sleeve Design of Sleeve

We know that outer diameter of the muff,

D = 2d + 13 mm

= 2 × 52 + 13

= 117 say 125 mm Ans.

And length of the muff, L

= 3.5 d

= 3.5 × 55 = 192.5 say 195 mm Ans.

Let us now check the induced shear stress in the muff.

Let τ_c be the induced shear stress in the muff which is made of cast iron. Since the muff is considered to be a hollow shaft, therefore the torque transmitted (T),

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_C \left(\frac{D^4 - d^4}{D}\right)$$

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_C \left(\frac{(125)^4 - (55)^4}{125}\right)$$

$$1100 \times 10^3 = 370 \times 10^3 \tau_C$$

$$\tau_C = \frac{1100 \times 10^3}{370 \times 10^3}$$

$$= 2.97 Nmm^2$$

Since the induced shear stress in the muff (cast iron) is less than the permissible shear stress of 15 N/mm2, therefore the design of muff is safe.

3. **Design for key**

Since the crushing stress for the key material is twice the shearing stress, therefore a square key may be used.

Width of key w

$= \frac{d}{4} = \frac{52}{4} = 13\ mm$

∴ Thickness of key, t = w = 13 mm Ans.

We know that length of key in each shaft, $l = \frac{\mathrm{L}}{2}$

= 195 / 2

= 97.5 mm Ans

Let us now check the induced shear and crushing stresses in the key.

First of all, let us consider shearing of the key. We know that torque transmitted (T),

$$1100 \times 10^3 = l \times w \times \tau_s \times \frac{d}{2}$$

$$= 1100 \times 10^3 = 97.5 \times 13 \times \tau_s \times \frac{52}{2} =$$

$$= 1100 \times 10^3 = 32955\ \tau_s$$

$$\therefore\ \tau_s = \frac{1100 \times 10^3}{32955} = 33.37\mathrm{N/mm2}$$

Now, let us consider crushing of key.

We know that torque transmitted (T),

$$1100 \times 10^3 = l \times \frac{t}{2} \times \sigma_{cs} \times \frac{d}{2}$$

$$= 1100 \times 10^3 = 97.5 \times \frac{13}{2} \times \sigma_{cs} \times \frac{52}{2}$$

$$1100 \times 10^3 = 16477.5\sigma_{cs}$$

$$\sigma_{cs} = \frac{1100 \times 10^3}{16477.5}$$

=66.75 N/mm2

Since the induced shear and crushing stresses are less than the permissible stresses, therefore the design of key is safe.

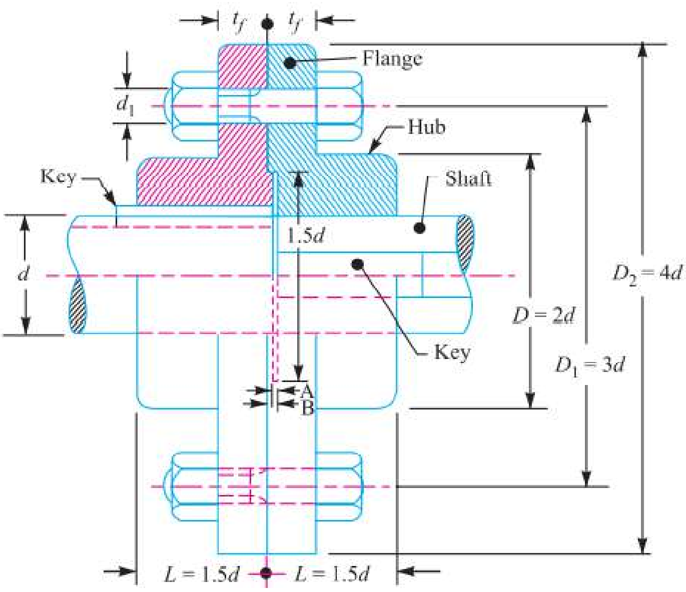
FLANGE COUPLING

Flange Couplings.

A flange coupling usually applies to a coupling having two separate cast iron flanges. Each flange is mounted on the shaft end and keyed to it. The faces are turned up at right angle to the axis of the shaft. One of the flanges has a projected portion and the other flange has a corresponding recess. This helps to bring the shafts into line and to maintain alignment. The two flanges are coupled together by means of bolts and nuts. The flange coupling is adopted to heavy loads and hence it is used on large shafting.

The flange couplings are of the following three types:

1. **Unprotected type flange coupling**
2. **Protected type flange coupling**
3. **Marine type flange coupling**



In an **unprotected type flange coupling**, as shown in Fig., each shaft is keyed to the boss of a flange with a counter sunk key and the flanges are coupled together by means of bolts. Generally, three, four or six bolts are used. The keys are staggered at right angle along the circumference of the shafts in order to divide the weakening effect caused by keyways.

The usual proportions for an unprotected type cast iron flange couplings, as shown in Fig. are as follows:

If d is the diameter of the shaft or inner diameter of the hub,

Then Outside diameter of hub, D = 2 d,

Length of hub, L = 1.5 d

Pitch circle diameter of bolts, D_1 = 3d

Outside diameter of flange, D_2= 4 d

Thickness of flange, t_f = 0.5 d

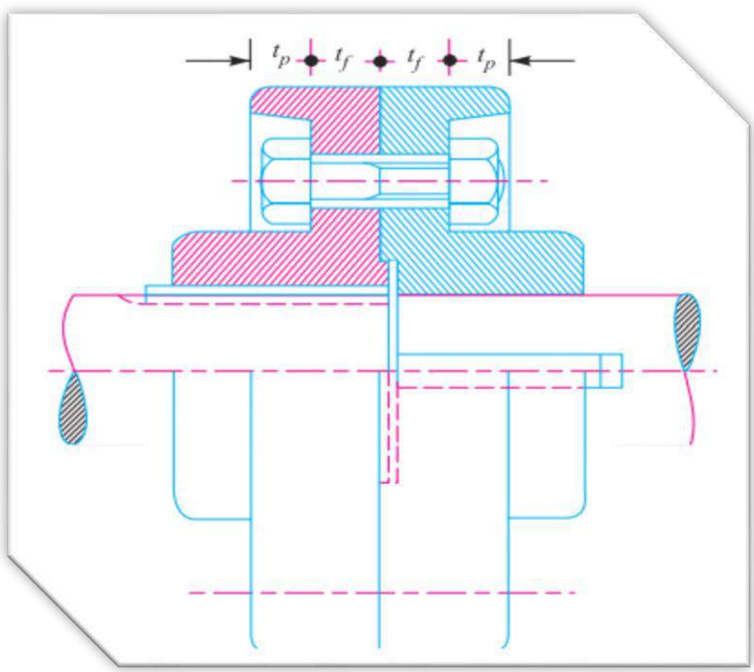
Number of bolts, n = 3, for d upto 40 mm

= 4, for d upto 100 mm

= 6, for d upto 180 mm

2. **Protected type flange coupling.** In a protected type flange coupling, as shown in Fig... The protruding bolts and nuts are protected by flanges on the two halves of the coupling, in order to avoid danger to the workman.

The thickness of the protective circumferential flange (t_p) is taken as 0.25 d. The other proportions of the coupling are same as for unprotected type flange coupling.



Design of Flange Coupling

Consider a flange coupling as shown in Fig.

Let d = Diameter of shaft or inner diameter of hub,

D = Outer diameter of hub,

d_1 = Nominal or outside diameter of bolt,

D_1 = Diameter of bolt circle,

n = Number of bolts,

t_f = Thickness of flange,

τ_s, τ_b, τ_k= Allowable shear stress for shaft, bolt and key material respectively

τ_c= Allowable shear stress for the flange material i.e. cast iron,

σ_{cb}, σ_{ck} = Allowable crushing stress for bolt and key material respectively. The flange coupling is designed as discussed below:

1. **Design for hub**

The hub is designed by considering it as a hollow shaft, transmitting the same torque (T) as that of a solid shaft.

$$\frac{\pi}{16} \times \tau_C \left(\frac{D^4 - d^4}{D}\right)$$

The outer diameter of hub is usually taken as twice the diameter of shaft. Therefore from the above relation, the induced shearing stress in the hub may be checked. The length of hub (L) is taken as 1.5 d.

2. **Design for key**

The key is designed with usual proportions and then checked for shearing and crushing stresses. The material of key is usually the same as that of shaft. The length of key is taken equal to the length of hub.

3. Design for flange

The flange at the junction of the hub is under shear while transmitting the torque. Therefore, the torque transmitted,

T = Circumference of hub × Thickness of flange × Shear stress of flange × Radius of hub

$$\pi D \times t_f \times \tau_c \times \frac{D}{2} = \frac{\pi D^2}{2} \times \tau_c \times t_f$$

The thickness of flange is usually taken as half the diameter of shaft. Therefore from the above relation, the induced shearing stress in the flange may be checked.

4. **Design for bolts**

The bolts are subjected to shear stress due to the torque transmitted. The number of bolts (n) depends upon the diameter of shaft and the pitch circle diameter of bolts (D1) is taken as 3 d.

We know that

Load on each bolt = $\frac{\pi}{4} d_1^2 \times \tau_b$

∴ Total load on all the bolts = $\frac{\pi}{4} d_1^2 \times \tau_b \times n$

And Torque transmitted, T = $\frac{\pi}{4} d_1^2 \times \tau_b \times n \times \frac{D_1}{2}$

From this equation, the diameter of bolt (d_1) may be obtained. Now the diameter of bolt may be checked in crushing.

We know that area resisting crushing of all the bolts = $n \times d_1 \times t_f$

And crushing strength of all the bolts = $n \times d_1 \times t_f \times \sigma_{cb}$

∴ Torque, T = $(n \times d_1 \times t_f \times \sigma_{cb}) \frac{D_1}{2}$

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

CHAPTER 9

DESIGN OF SCREWED JOINTS

Introduction

A screw thread is formed by cutting a continuous helical groove on a cylindrical surface. A screw made by cutting a single helical groove on the cylinder is known as single threaded (or single-start) screw and if a second thread is cut in the space between the grooves of the first, a double threaded (or double-start) screw is formed. Similarly, triple and quadruple (i.e. multiple-start) threads may be formed. The helical grooves may be cut either right hand or left hand.

A screwed joint is mainly composed of two elements i.e. a bolt and nut. The screwed joints are widely used where the machine parts are required to be readily connected or disconnected without damage to the machine or the fastening. This may be for the purpose of holding or adjustment in assembly or service inspection, repair, or replacement or it may be for the

manufacturing or assembly reasons.
The parts may be rigidly connected or provisions may be made for predetermined relative motion.

Advantages and Disadvantages of Screwed Joints

Following are the advantages and disadvantages of the screwed joints.

Advantages

1. Screwed joints are highly reliable in operation.
2. Screwed joints are convenient to assemble and disassemble.
3. A wide range of screwed joints may be adopted to various operating conditions.
4. Screws are relatively cheap to produce due to standardisation and highly efficient manufacturing processes.

Disadvantages

The main disadvantage of the screwed joints is the stress concentration in the threaded portions which are vulnerable points under variable load conditions.

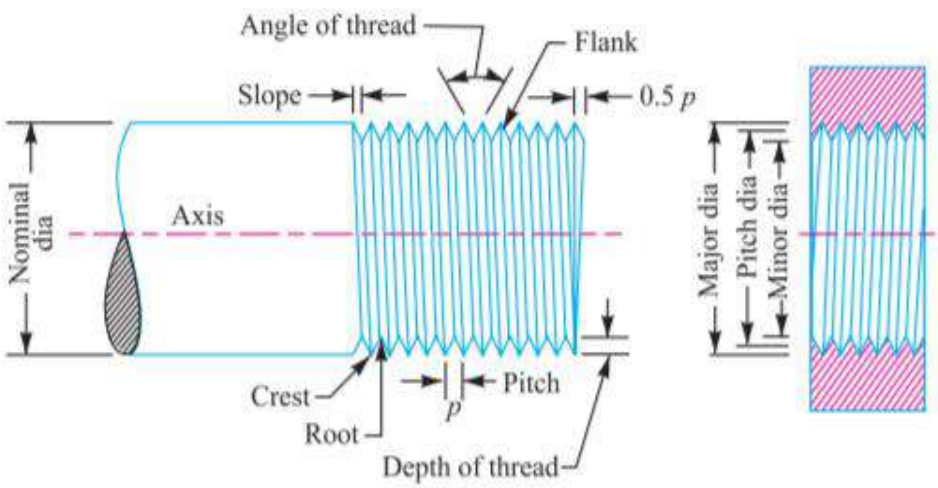
Note: The strength of the screwed joints is not comparable with that of riveted or welded joints.

Chapter9 lect2 MD

Design of screw joint

Important Terms Used in Screw Threads

The following terms used in screw threads, as shown in Fig. are important from the subject point of view:



1. **Major diameter**

It is the largest diameter of an external or internal screw thread. The screw is specified by this diameter. It is also known as outside or nominal diameter.

2. **Minor diameter**

It is the smallest diameter of an external or internal screw thread. It is also known as core or root diameter.

3. Pitch diameter

The mean of major and minor diameter is called pitch diameter.

4. Pitch

It is the distance from a point on one thread to the corresponding point on the next.

5. Lead

It is the distance between two corresponding points on the same helix. It may also be defined as the distance which a screw thread advances axially in one rotation of the nut.

6. **Crest**

It is the top surface of the thread.

7. Root

It is the bottom surface created by the two adjacent flanks of the thread.

8. Depth of thread

It is the perpendicular distance between the crest and root.

9. Flank

It is the surface joining the crest and root.

10. **Angle of thread**

It is the angle included by the flanks of the thread.

11. Slope

It is half the pitch of the thread.

E-NOTES OF

Refrigeration & Air Conditioning

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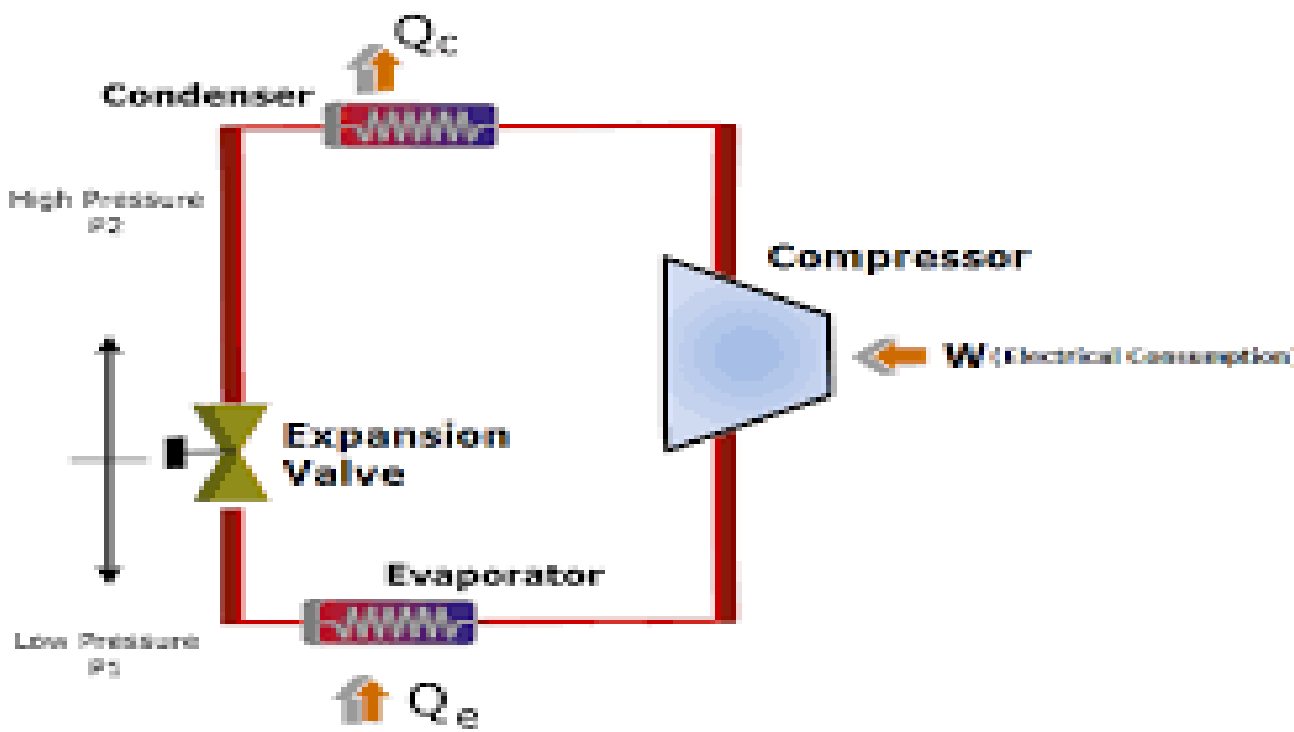
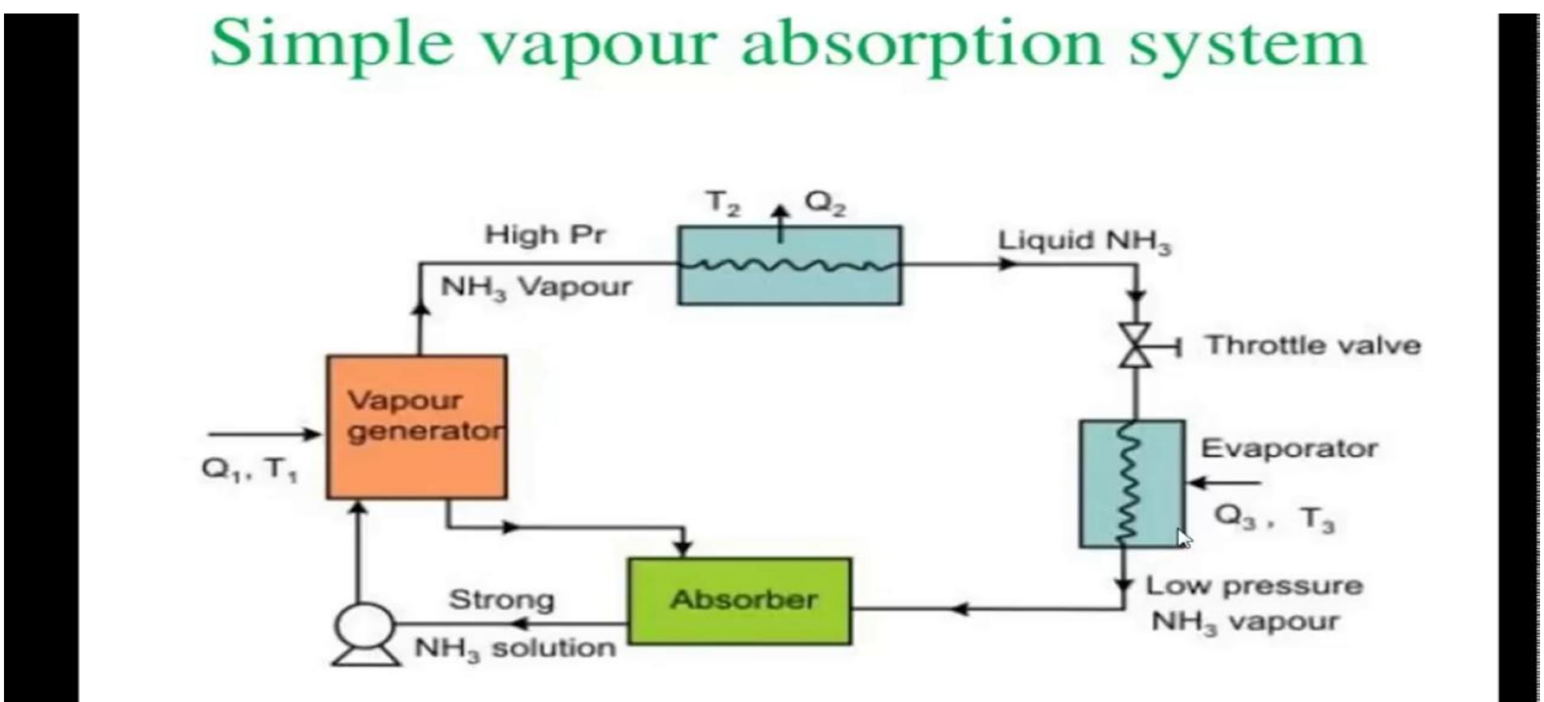
The term **refrigeration** means cooling a space, substance or system to lower and/or maintain its temperature below the ambient one (while the removed heat is rejected at a higher temperature). In other words, **refrigeration** is artificial (human-made) cooling.

Air conditioning (often referred to as AC, A/C, or **air** con) is the process of removing heat and moisture from the interior of an occupied space to improve the comfort of occupants. ... In construction, a complete system of heating, ventilation, and **air conditioning** is referred to as HVAC.

Vapour-compression refrigeration or **vapor-compression refrigeration system** (**VCRS**),[1] in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems. Cascade refrigeration systems may also be implemented using 2 compressors.



An **absorption refrigerator** is a refrigerator that uses a heat source (e.g., solar energy, a fossil-fueled flame, waste heat from factories, or district heating systems) to provide the energy needed to drive the cooling process. The system uses two coolants, the first of which performs evaporative cooling and is then absorbed into the second coolant; heat is needed to reset the two coolants to their initial states. The principle can also be used to air-condition buildings using the waste heat from a gas turbine or water heater. Using waste heat from a gas turbine makes the turbine very efficient because it first produces electricity, then hot water, and finally, air-conditioning—trigeneration. Absorption refrigerators are commonly used in recreational vehicles (RVs), campers, and caravans because they can be powered with propane fuel, rather than electricity. Unlike more common vapor-compression refrigeration systems, an absorption refrigerator can be produced with no moving parts other than the coolants.



Definition:

- Condenser is a device in which steam is condensed to water at a pressure less than atmosphere.
- Condensation can be done by removing heat from exhaust steam using circulating cooling water.
- During condensation, the working substance changes its phase from vapour to liquid and rejects latent heat.
- The exhaust pressure in the condenser is maintaned nearly 7 to 8 kpa which corresponds to condensate temperature of nearly 313 kelvin.

Functions of Condenser:

- To reduce the turbine exhaust pressure so as to increase the specific output and hence increase the plant efficiency and decrease the specific steam consumption.
- To condense the exhaust steam from the turbine and reuse it as pure feed water in the boiler. Thus only make up water is required to compensate loss of water
- Enables removal of air and other non condensable gases from steam. Hence improved heat transfer.

TYPES OF CONDENSER

AIR COOLED CONDENSER

- a. Natural convection air cooled condenser
- b. Forced convection air cooled condenser

WATER COOLED CONDENSER

- a. Tube in tube condenser
- b. Shell and coil condenser
- c. Shell and tube condenser

TYPES OF COMPRESSOR:

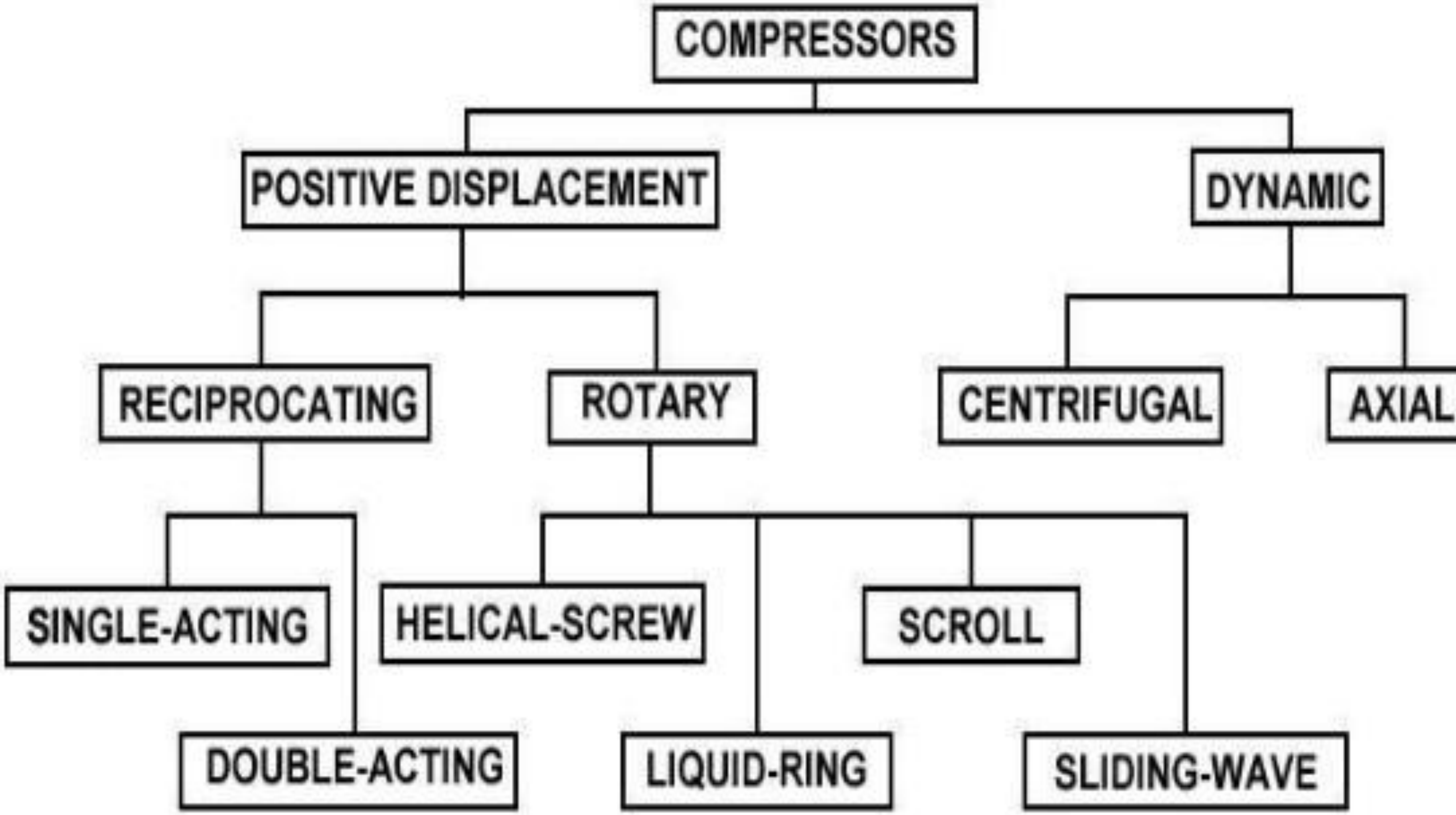


Figure 1-2, Compressor Family Tree

What is evaporators

Evaporators: - An evaporator is a device used to turn the liquid form of a chemical into its gaseous form. The liquid is evaporated, or vaporized, into a gas. Many types of evaporators and many variations in processing techniques have been developed to various products.

Types Of Evaporators

Based on their construction the various types of evaporators are:

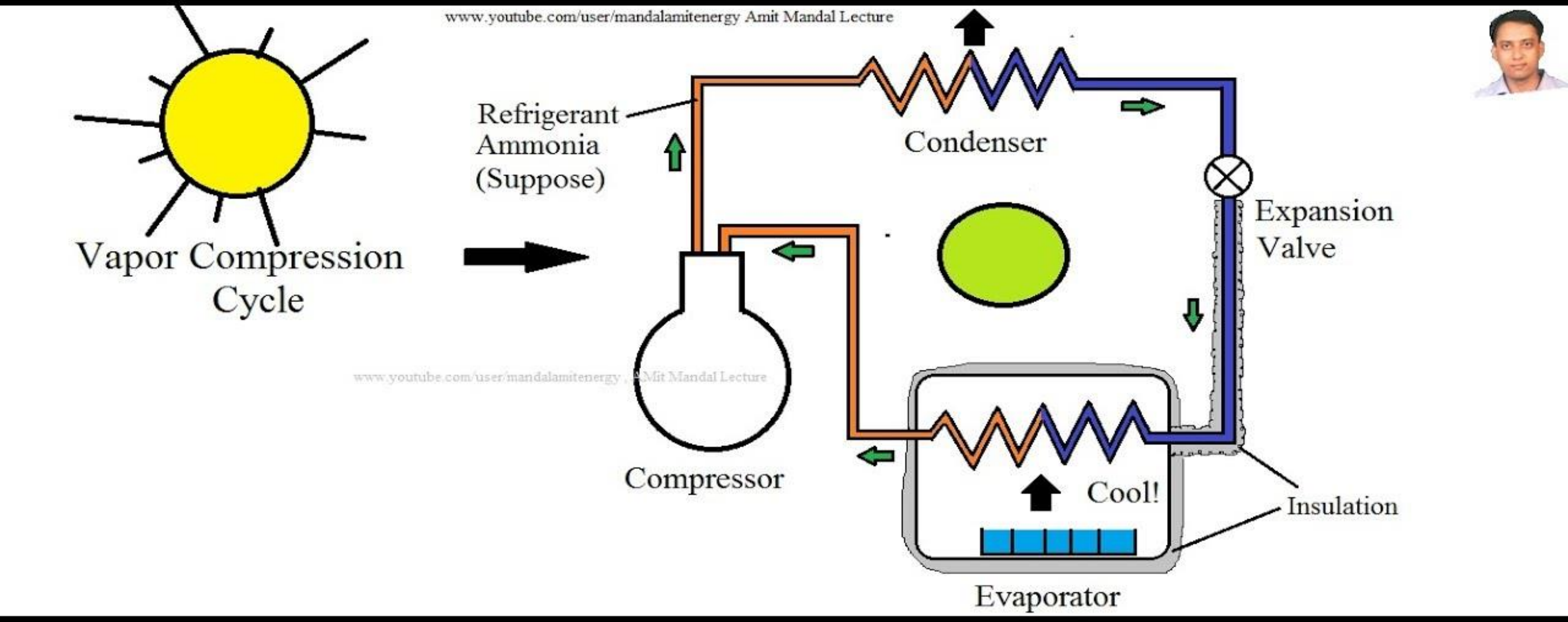
1. Bare Tube Evaporators :

a) The bare tube evaporators are made up of copper tubing or steel pipes
b) The copper tubing is used for small evaporators where the refrigerant other than ammonia is used
c) the steel pipes are used with the large evaporators where ammonia is used as the refrigerant.
d) the atmospheric air flows over the bare tube evaporator and the chilled air leaving it used for the cooling purposes..
e) The bare tube evaporators are usually used for liquid chilling

solar-powered refrigerator is a refrigerator which runs on energy directly provided by sun, and may include photovoltaic or solar thermal energy.

Solar-powered refrigerators are able to keep perishable goods such as meat and dairy cool in hot climates, and are used to keep much needed vaccines at their appropriate temperature to avoid spoilage.

Solar-powered refrigerators are typically used in off-the-grid locations where utility provided AC power is not available.



Types of Refrigerants

Refrigerants used in industrial spaces

Here we bring you a list of refrigerants that are majorly adopted for industrial refrigeration plants.

Water

Water is one of the substances filled with perfect chemical and thermodynamic properties. It has been used as a type of refrigerant for decades due to its easy availability. Well, it can't be considered to be a refrigerant alone, but when chilled in cooling plants, it is put to use in the circuits for lowering the temperatures.

For using water as a refrigerant, there is a need for ambient temperature that is higher than 100° C.

HFC R134A

This refrigerant is used in air-conditioned cars but also put to use in commercial refrigerant spaces in refrigerant piping. While talking about its features, it is enriched with minimal toxicity, non-combustibility, flawless thermal stability, and non-corrosiveness.

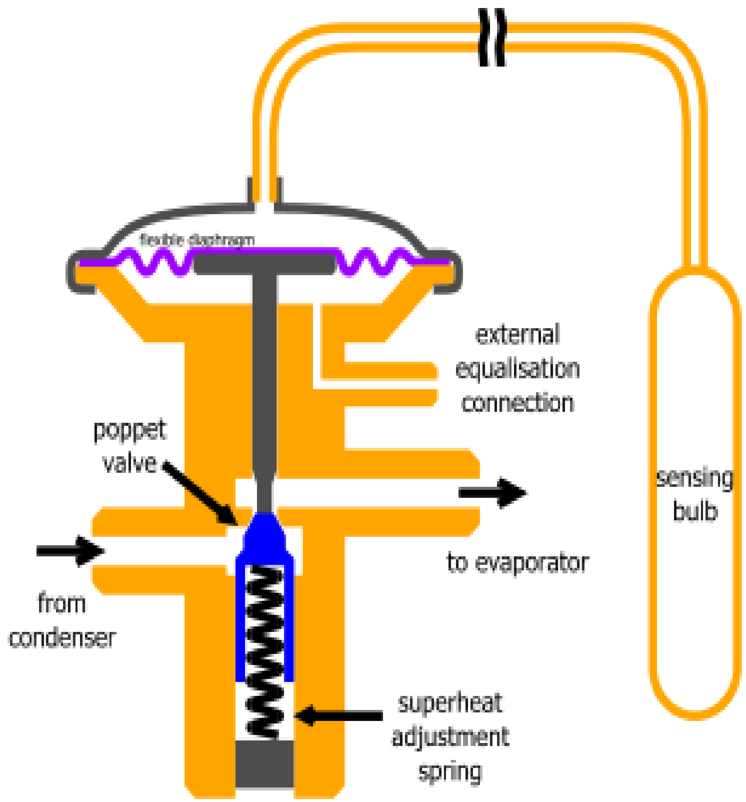
Hydrocarbons (HCS)

This refrigerant is filled with chemicals that are used in commercial refrigeration systems, air conditioning systems, and domestic refrigeration systems. This refrigerant is apt for industrial cooling as it has propane with zero ODP (Ozone depletion potential). But it needs specific safety installations.

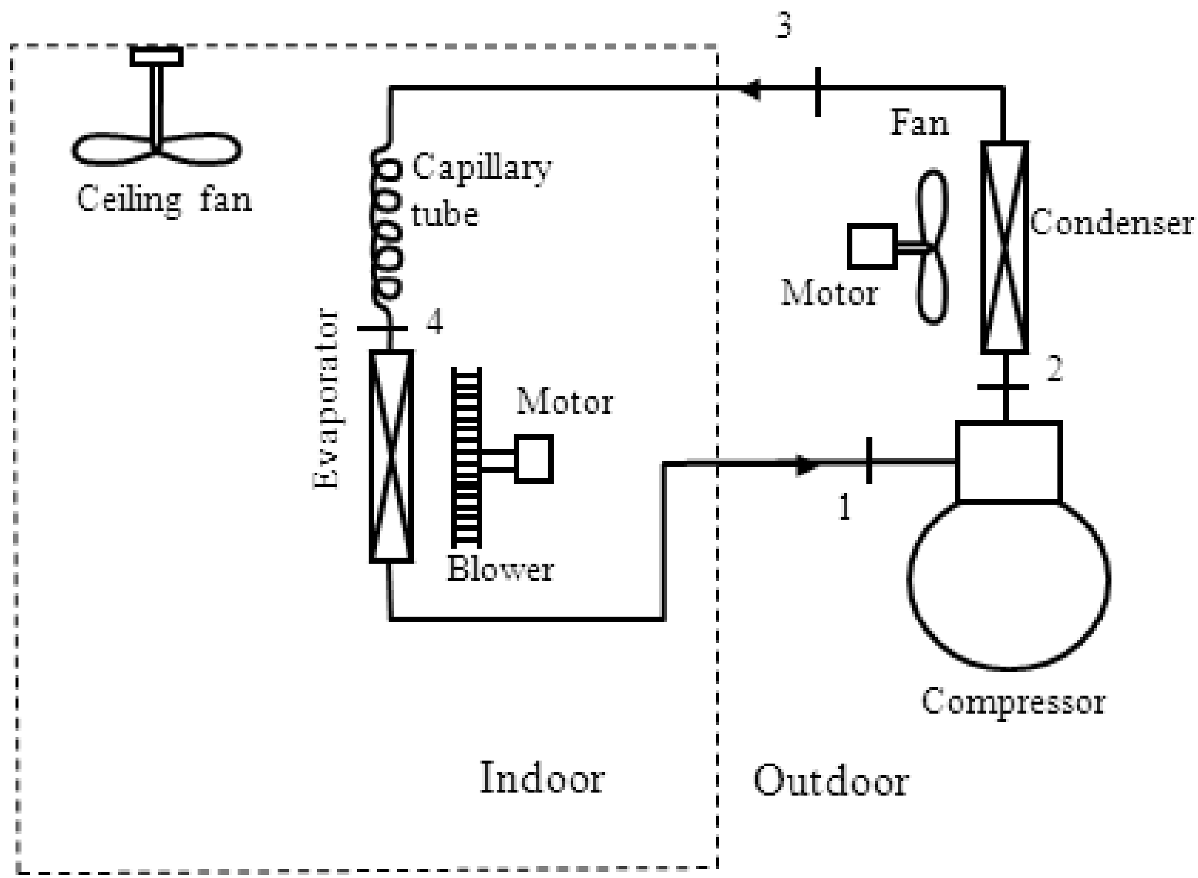
While working with Hydrocarbons, keep certain things in mind for better operation such as avoiding welding in the same area, and staying away from sparks and wire.

Ammonia (R717)
Ammonia is considered to be the oldest and most commonly used refrigerant in industrial cooling plants. It is power-packed with halogen-free chemicals. Here, the application process is in smaller components thereafter eradicating the need for big cooling plants.
Besides, it has a lower molecular weight, high critical points, and a high coefficient of performance, but with this comes the damaging effects.
CO2 R744
This refrigerant has to be handled with care due to its heavyweight, while in a situation of leakage it might replace oxygen. On the brighter side, CO2 R744 has a minimum impact on the environment as it is non-toxic and non-flammable.

A **thermal expansion valve** or **thermostatic expansion valve** (often abbreviated as **TEV**, **TXV**, or **TX valve**) is a component in refrigeration and air conditioning systems that controls the amount of refrigerant released into the evaporator and is intended to regulate the superheat of the vapor leaving the evaporator. Although often described as a "thermostatic" valve, an expansion valve does not regulate temperature, the temperature of the evaporator will vary with the evaporation pressure.



A split air conditioner consists of two main parts – a compressor located outside and an inside air outlet unit. Unlike a system that requires a series of ductwork networked throughout the ceiling, split air conditioners rely on a set of pipes to connect the outdoor to the inside air unit which is why there are referred to as a ductless mini-split air conditioner installation. Refrigerant is dispersed through the copper pipes that cycle through the system to generate either heated or cold air.



Theory of Machine

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Narnaul

Inversion of Mechanism

Absolute motion is measured with respect to a stationary frame. Relative motion is measured for one point or link with respect to another link.

We have already stated that when one of links is fixed in a kinematic chain, it is called a mechanism. So we can obtain as many mechanisms as the number of links in a kinematic chain by fixing, in turn, different links in a kinematic chain. This method of obtaining different mechanisms by fixing different links in a kinematic chain, is known as **inversion of the mechanism.**

1.16. Inversion of Mechanism

It may be noted that the relative motions between the various links is not changed in any manner through the process of inversion, but their absolute motions (those measured with respect to the fixed link) may be changed drastically.

1.16. Inversion of Mechanism

Note:

The part of a mechanism which initially moves with respect to the frame or fixed link is called **driver** and that part of the mechanism to which motion is transmitted is called **follower.**

Most of the mechanisms are reversible, so that same link can play the role of a driver and follower at different times. For example, in a reciprocating steam engine, the piston is the driver and flywheel is a follower while in a reciprocating air compressor, the flywheel is a driver.

1.16. Inversion of Mechanism

The most important kinematic chains are those which consist of four lower pairs, each pair being a sliding pair or a turning pair. The following three types of kinematic chains with four lower pairs are important from the subject point of view :

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

These kinematic chains are discussed, in detail, in the following articles.

1.16. Inversion of Mechanism

1. Four Bar Chain or Quadric Cycle Chain

We have already discussed that the kinematic chain is a combination of four or more kinematic pairs, such that the relative motion between the links or elements is completely constrained.

The simplest and the basic kinematic chain is a four-bar chain or quadric cycle chain, as shown in Fig. 1. 32.

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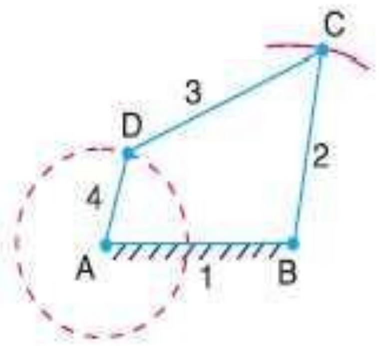


Fig. 1.32 Four bar chain

It consists of four links, each of them forms a turning pair at A, B, C and D. The four links may be of different lengths.

1.16. Inversion of Mechanism

In a four bar chain, one of the links, in particular the shortest link, will make a complete revolution relative to the other three links, if it satisfies the Grashof's law. Such a link is known as **crank or driver.**

In **Fig. 1.32**, AD (link 4) is a crank. The link BC (link 2) which makes a partial rotation or oscillates is known as **lever or rocker or follower** and the link CD (link 3) which connects the crank and lever is called **connecting rod or coupler.** The fixed link AB (link 1) is known as **frame** of the mechanism.

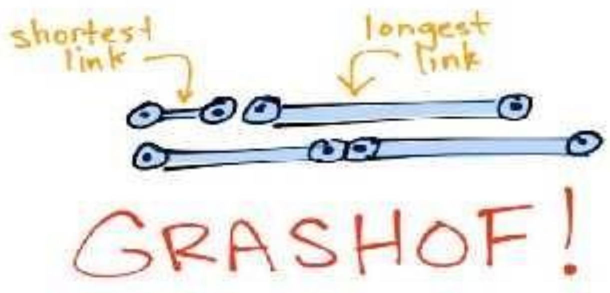
When the crank (link 4) is the driver, the mechanism is transforming rotary motion into oscillating motion.

1.16. Inversion of Mechanism

A very important consideration in designing a mechanism is to ensure that the input crank makes a complete revolution relative to the other links. The mechanism in which no link makes a complete revolution will not be useful in such applications. For the four-bar linkage there is a very simple test of whether this is the case.

Grashof's law for four-bar mechanism.

If one of the links can perform a full rotation relative to another link, the linkage is called a **Grashof mechanism. Grashof's law** states that for a planar four-bar mechanism (linkage), the sum of the shortest and longest link lengths can not be greather than the sum of the other two link lengths if there is to be continuous relative motion between two members.



1.16. Inversion of Mechanism

This is illustrated in Fig. 1.33, where the longest link has length l, the shortest link has length s , and the other two links have lengths p and q. Grashof's law states that one of the links , in particular the shortest link, will rotate continuously relative to the other three links if only if

$$s + l \leq p + q$$

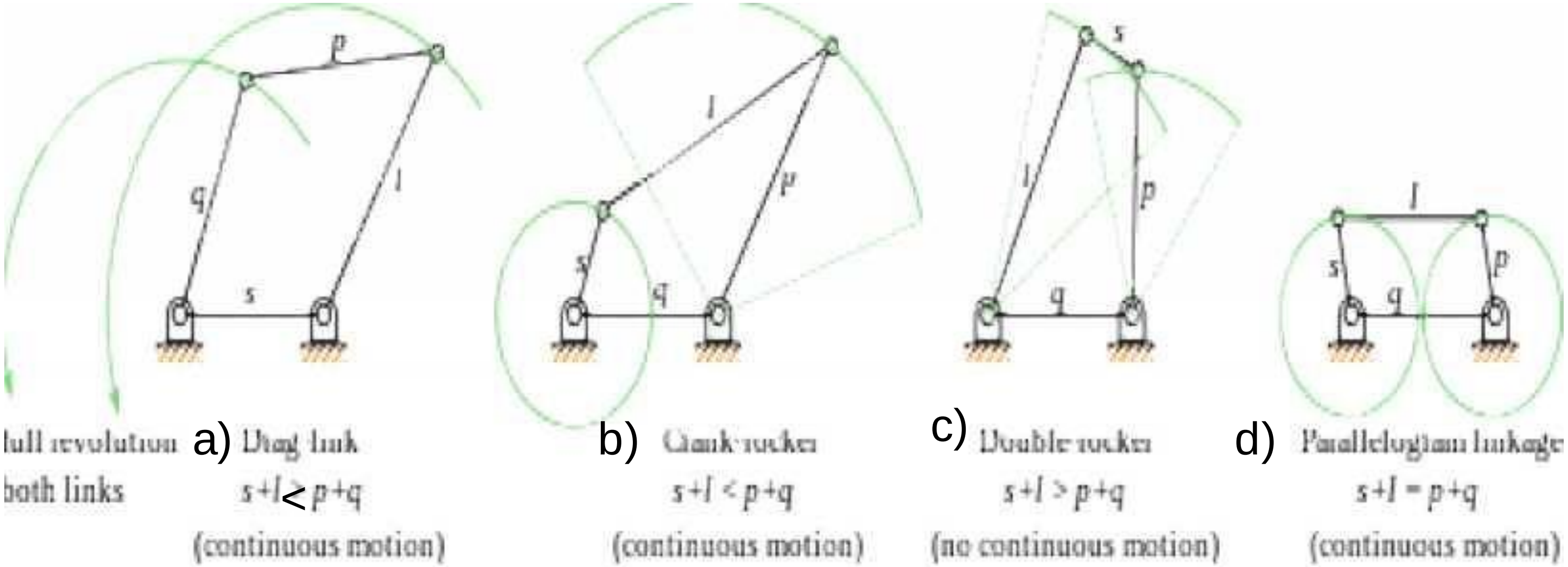
or

$$L_{max} + L_{min} < L_a + L_b$$

where L_{max} and L_{min} are the longest and shortest links, L_a and L_b are each links of intermediate length. If this inequality is not satisfied no link will make a complete revolution relative to another.

1.16. Inversion of Mechanism

Fig. 1.33. Four inversions of the Grashof chain



https://youtu.be/mwPIB89V-L8 https://youtu.be/9D0IBiM4_1M

https://youtu.be/Tjr2c4d09wQ https://youtu.be/eojqAbhdg_w

1.16. Inversion of Mechanism

It should be notted that nothing in Grashof's law specifies the order in which the links are connected or which link of the four –bar chain is fixed. Hence, by fixing any of the four links, we create four inversions of the four –bar mechanism shown in Fig.1.33.

The drag-link mechanism is obtained by fixing the shortest link s as the frame, as shown in Fig. 1.33a. In this inversion, both links adjacent to s can rotate continously, and both are properly described as cranks: the shortest of the two is generally used as the input

If the shortest links is adjacent to the fixed link, as shown in Figs.1.33b, a crank-rocker mechanism is obtained. Link s, the crank, since it is able to rotate continously , and link p, which can only oscilate between limits, is the rocker.

1.16. Inversion of Mechanism

By fixing the link opposite to s we obtain the the third inversion, the double-rocker mechanism of Fig. 1.33c. Note that although link s is able to make a complete revolution , neither link adjacent to the frame can do so; both must oscilate between limits and are therefore rockers.

If $L_{max} + L_{min} < Lp + Lq$ i.e. or s=p and l=q then, the forth inversion, the parallelogram or change-point or crossover-position mechanism is optained as shown in Fig.1.33d.

In each of these inversions , the shortest link s is adjacent to the longest link l . However, exactly the same types of linkages inversions will occur if the longest link l is opposite the shortest links.

1.16. Inversion of Mechanism

AI-Inversions of Four Bar Chain

Though there are many inversions of the four bar chain, yet the following are important from the subject point of view :

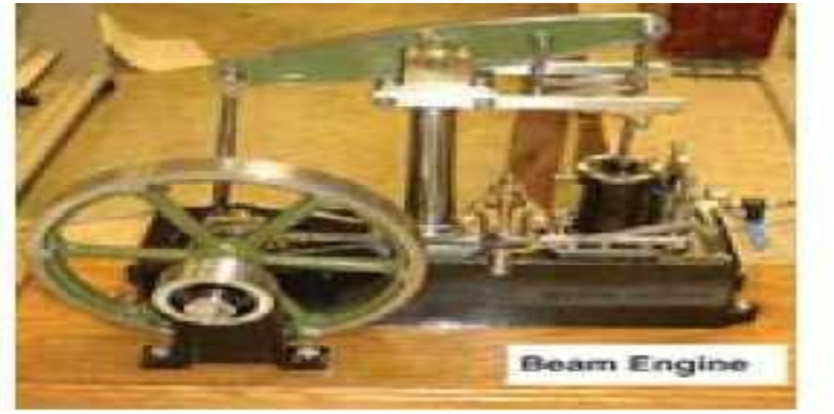
1. **Beam engine (crank and lever(rocker) mechanism).**
2. **Coupling rod of a locomotive (Double crank mechanism).**
3. **Watt's indicator mechanism (Double lever(rocker) mechanism).**

1.16. Inversion of Mechanism

1. Beam engine (crank and lever (rocker) mechanism

https://youtu.be/1e8ZWsOzun4 https://youtu.be/bmh0a2OI0u8

A part of the mechanism of a beam engine (also known as crank and lever mechanism) which consists of four links, is shown in Figs. 1.34 and 1.35.



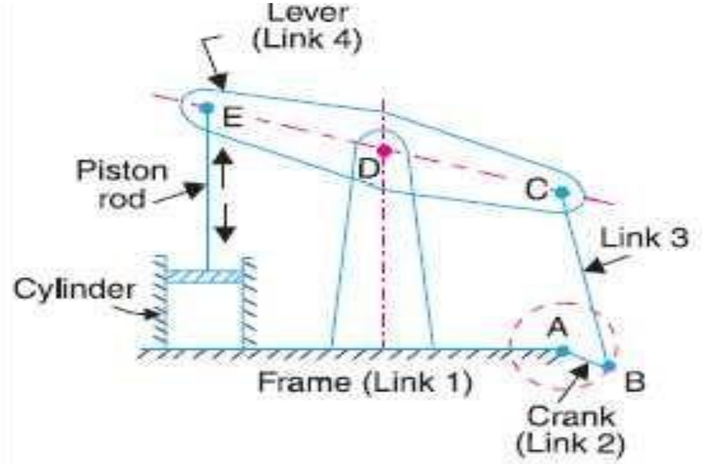


Fig. 1.34 Beam engine **Fig.1.35 Beam engine mechanism**

In this mechanism, when the crank rotates about the fixed centre A, the lever oscillates about a fixed centre D. The end E of the lever CDE is connected to a piston rod which reciprocates due to the rotation of the crank. In other words, the purpose of this mechanism is to convert rotary motion into reciprocating motion.

1.16. Inversion of Mechanism

2. Coupling rod of a locomotive (Double crank mechanism).

The mechanism of a coupling rod of a locomotive (also known as double crank mechanism) which consists of four links, is shown in Fig. 1.36.

https://youtu.be/gYmT1M4NyyM

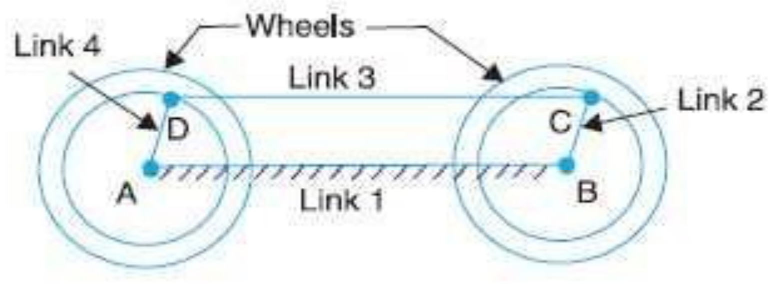


Fig. 1.36. Coupling rod of a locomotive

In this mechanism, the links AD and BC (having equal length) act as cranks and are connected to the respective wheels. The link CD acts as a coupling rod and the link AB is fixed in order to maintain a constant centre to centre distance between them.

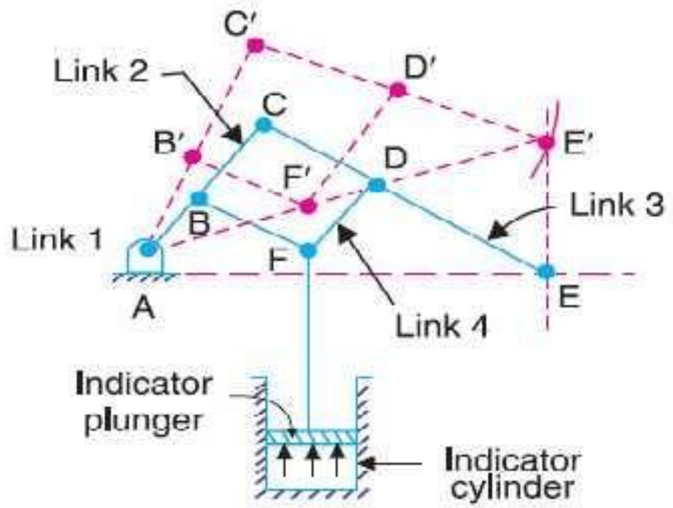
This mechanism is used for transmitting rotary motion from one wheel to the other wheel.

1.16. Inversion of Mechanism

3. Watt's indicator (Double rocker) mechanism.

A Watt's indicator mechanism (also known as Watt's straight line mechanism or double lever mechanism) which consists of four links, is shown in Fig. 1.37.

Fig.1.37. Watt's indicator mechanism



The four links are : fixed link at A, link AC, link CE and link BFD. It may be noted that BF and FD form one link because these two parts have no relative motion between them. The links CE and BFD act as levers. The displacement of the link BFD is directly proportional to the pressure of gas or steam which acts on the indicator plunger. On any small displacement of the mechanism, the tracing point E at the end of the link CE traces out approximately a straight line.

The initial position of the mechanism is shown in Fig. 1.37 by full lines whereas the dotted lines show the position of the mechanism when the gas or steam pressure acts on the indicator plunger.

1.16. Inversion of Mechanism

B. Single Slider Crank Chain

A single slider crank chain is a modification of the basic four bar chain. It consist of one sliding pair and three turning pairs. It is, usually, found in reciprocating steam engine mechanism. This type of mechanism converts rotary motion into reciprocating motion and vice versa.

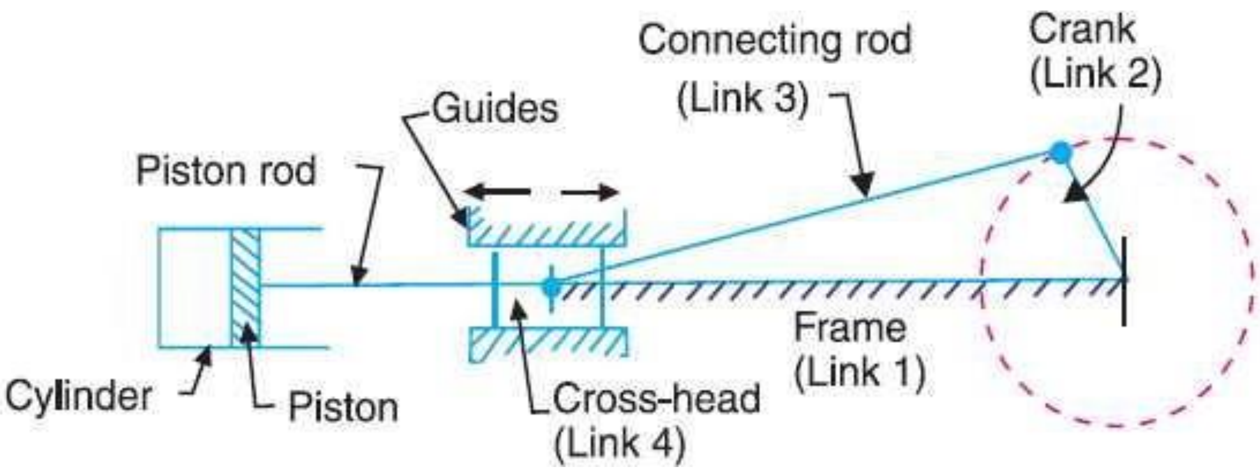


Fig. 1.38. Single slider crank chain

1.16. Inversion of Mechanism

In a single slider crank chain, as shown in Fig. 1.38, the links 1 and 2, links 2 and 3, and links 3 and 4 form three turning pairs while the links 4 and 1 form a sliding pair.

The link 1 corresponds to the frame of the engine, which is fixed. The link 2 corresponds to the crank ; link 3 corresponds to the connecting rod and link 4 corresponds to cross-head. As the crank rotates, the cross-head reciprocates in the guides and thus the piston reciprocates in the cylinder.

1.16. Inversion of Mechanism

BI: Inversions of Single Slider Crank Chain

We have seen in the previous article that a single slider crank chain is a four-link mechanism. We know that by fixing, in turn, different links in a kinematic chain, an inversion is obtained and we can obtain as many mechanisms as the links in a kinematic chain. It is thus obvious, that four inversions of a single slider crank chain are possible. These inversions are found in the following mechanisms.

1.16. Inversion of Mechanism

1. Pendulum pump or Bull engine.

In this mechanism, the inversion is obtained by fixing the cylinder or link 4 (i.e. sliding pair), as shown in Fig.
1.39. In this case, when the crank (link 2) rotates, the
connecting rod (link 3) oscillates about a pin pivoted to the fixed link 4 at A and the piston attached to the piston rod (link 1) reciprocates. The duplex pump which is used to supply feed water to boilers have two pistons attached to link 1, as shown in Fig.

1.16. Inversion of Mechanism

1.39.

1.16. Inversion of Mechanism

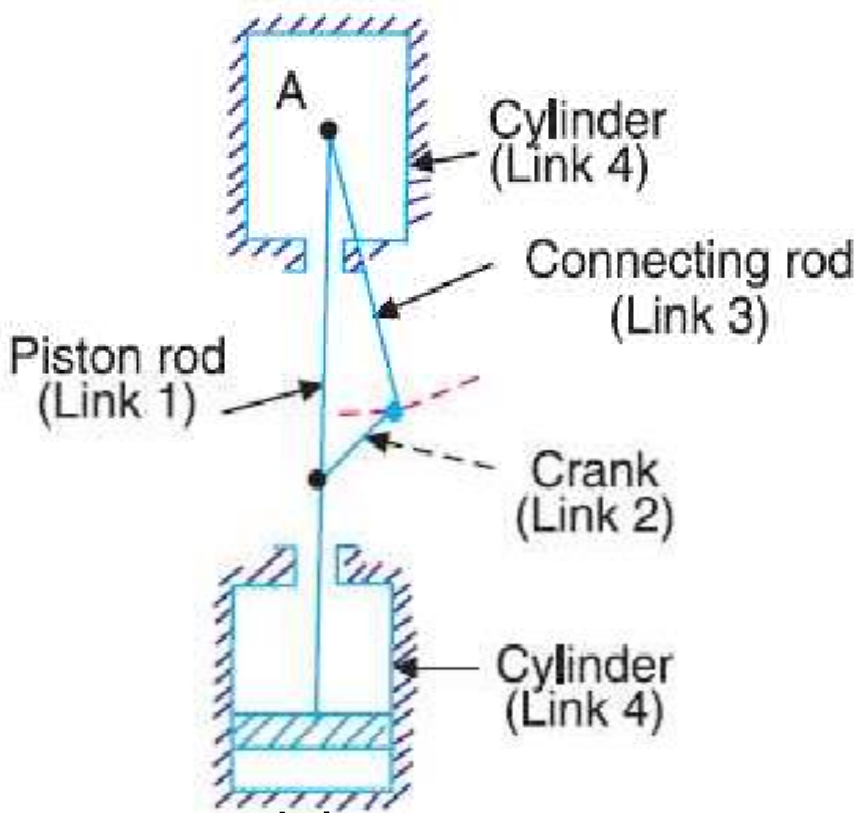


Fig. 1.39 Pendulum pump

https://youtu.be/mxgPTsXpB6k

1.16. Inversion of Mechanism

2. **Oscillating cylinder engine.** The arrangement of oscillating cylinder engine mechanism, as shown in Fig. 1.40, is used to convert reciprocating motion into rotary motion. In this mechanism, the link 3 forming the turning pair is fixed. The link 3 corresponds to the connecting rod of a reciprocating steam engine mechanism. When the crank (link 2) rotates, the piston attached to piston rod (link 1) reciprocates and the cylinder (link 4) oscillates about a pin pivoted to the fixed link at A.

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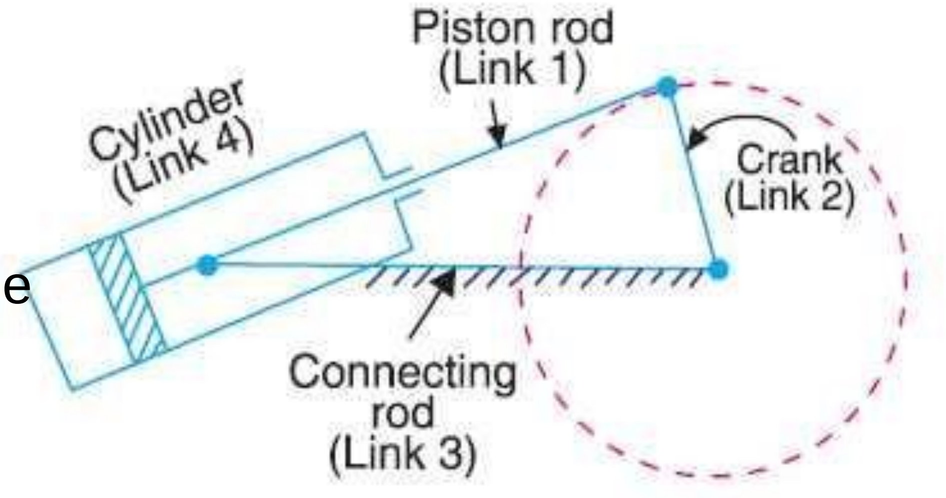


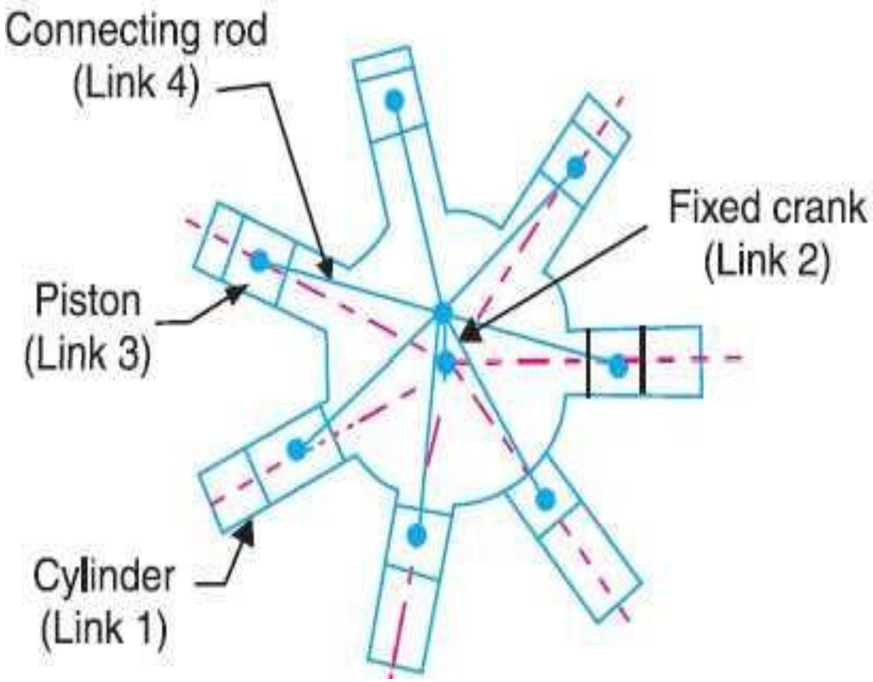
Fig.1.40 Oscilating cylinder engine

1.16. Inversion of Mechanism

3. Rotary internal combustion engine or Gnome engine.

Sometimes back, rotary internal combustion engines were used in aviation. But presently gas turbines are used in its place. It consists of seven cylinders in one plane and all revolves about fixed centre D, as shown in Fig. 1.41, while the crank (link 2) is fixed. In this mechanism, when the connecting rod (link 4) rotates, the piston (link 3) reciprocates inside the cylinders forming link 1.

1.16. Inversion of Mechanism



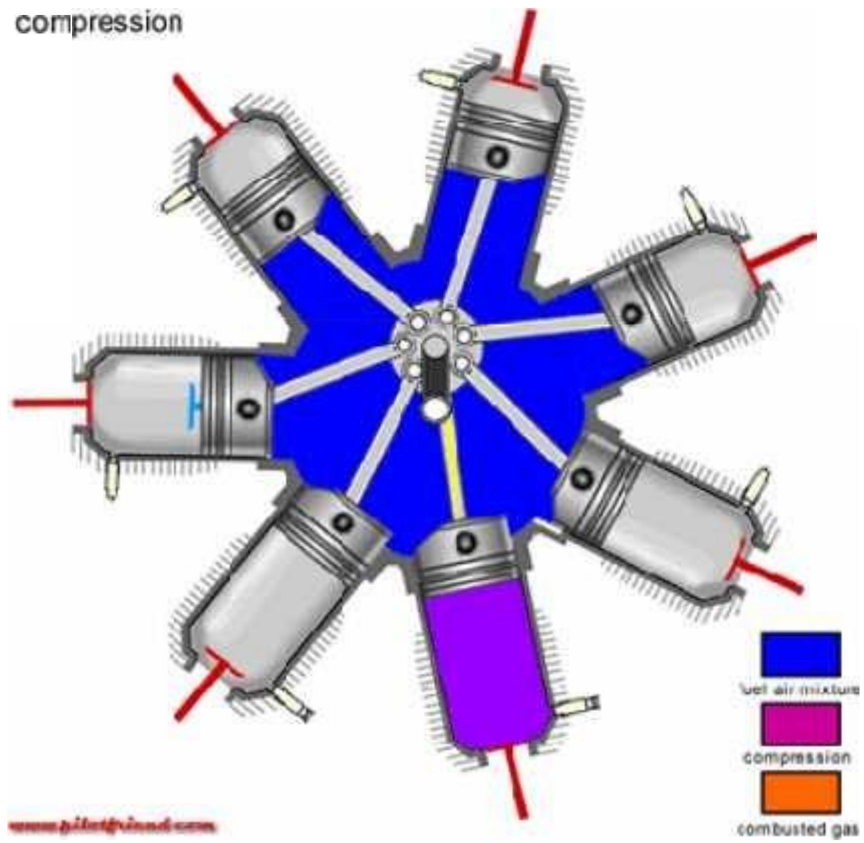


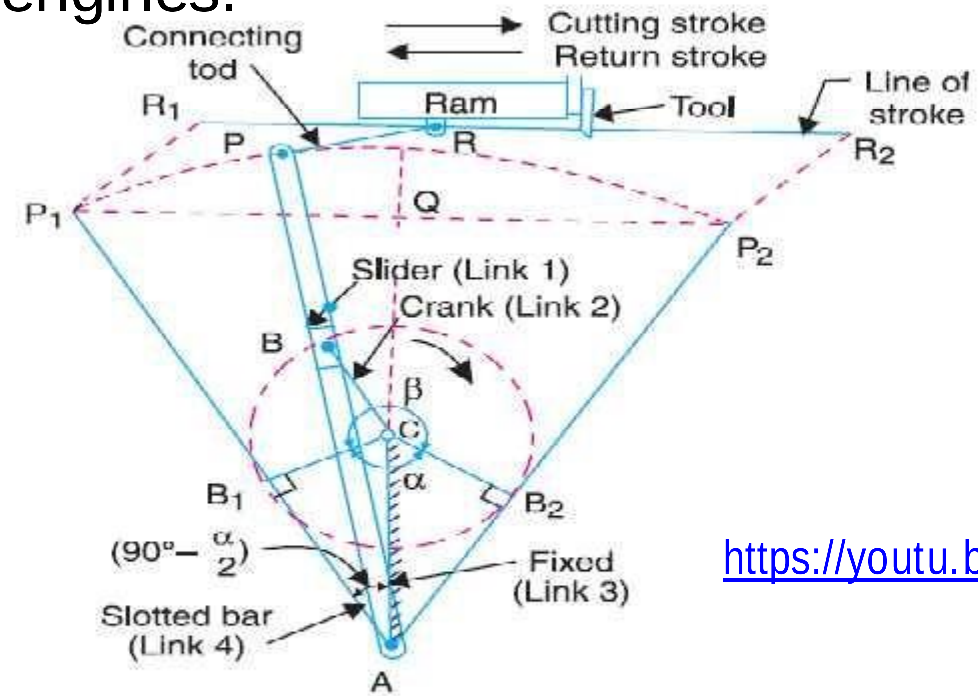
Fig. 1.41

https://youtu.be/W3elogQimk4 https://youtu.be/0jHRuEkvO8E

1.16. Inversion of Mechanism

4. Crank and slotted lever quick return motion mechanism. *This mechanism is mostly used* in shaping machines, slotting machines and in rotary internal combustion engines.

Fig.1.42



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https://youtu.be/s3TiMedJKds

1.16. Inversion of Mechanism

In this mechanism, the link AC (i.e. link 3) forming the turning pair is fixed, as shown in Fig. 1.42. The link 3 corresponds to the connecting rod of a reciprocating steam engine. The driving crank CB revolves with uniform angular speed about the fixed centre C. A sliding block attached to the crank pin at B slides along the slotted bar AP and thus causes AP to oscillate about the pivoted point A. A short link PR transmits the motion from AP to the ram which carries the tool and reciprocates along the line of stroke R1R2. The line of stroke of the ram (i.e. R1R2) is perpendicular to AC produced.

1.16. Inversion of Mechanism

Whitworth quick return motion mechanism

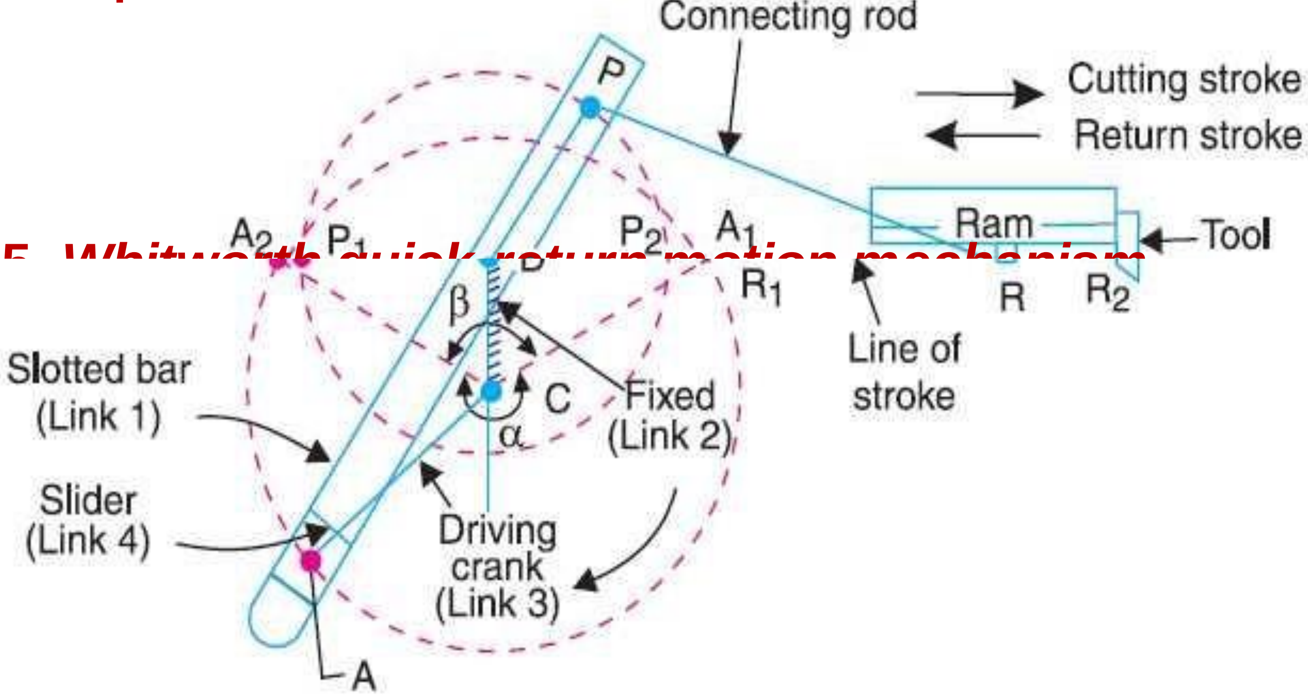
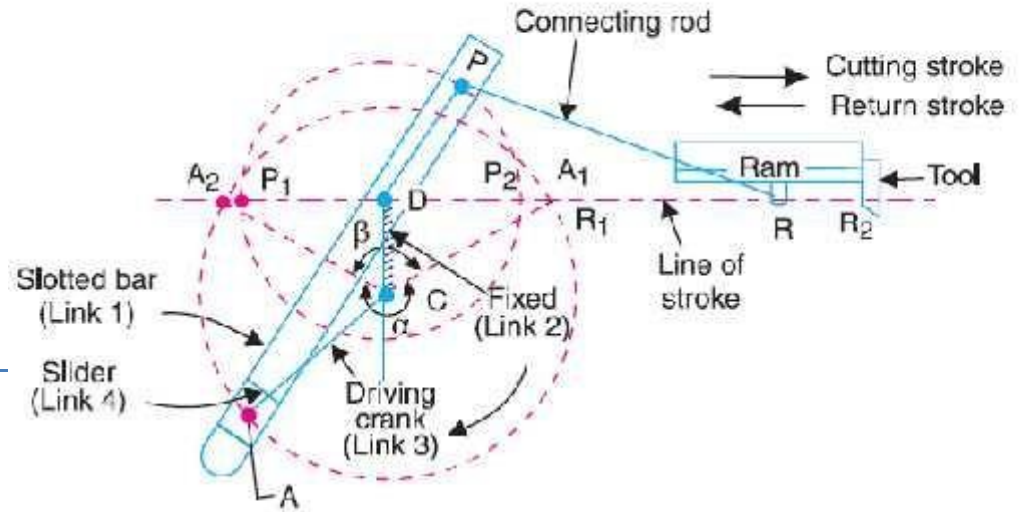


Fig. 1.43

https://youtu.be/UuTNtg7-Bwg

1.16. Inversion of Mechanism

This mechanism is mostly used in shaping and slotting machines. In this mechanism, the link CD (link 2) forming the turning pair is fixed, as shown in Fig. 1.43. The link 2 corresponds to a crank in a reciprocating steam engine. The driving crank CA (link 3) rotates at a uniform angular speed. The slider (link 4) attached to the crank pin at A slides along the slotted bar PA (link 1) which oscillates at a pivoted point D. The connecting rod PR carries the ram at R to which a cutting tool is fixed. The motion of the tool is constrained along the line RD produced, i.e. along a line passing through D and perpendicular to CD.



1.16. Inversion of Mechanism

When the driving crank CA moves from the position CA1 to CA2 (or the link DP from the position DP1 to DP2) through an angle α in the clockwise direction, the tool moves from the left hand end of its stroke to the right hand end through a distance 2 PD. Now when the driving crank moves from the position CA2 to CA1 (or the link DP from DP2 to DP1) through an angle β in the clockwise direction, the tool moves back from right hand end of its stroke to the left hand end.

A little consideration will show that the time taken during the left to right movement of the ram (i.e. during forward or cutting stroke) will be equal to the time taken by the driving crank to move from CA1 to CA2. Similarly, the time taken during the right to left movement of the ram (or during the idle or return stroke) will be equal to the time taken by the driving crank to move from CA2 to CA1.

1.16. Inversion of Mechanism

Since the crank link CA rotates at uniform angular velocity therefore time taken during the cutting stroke (or forward stroke) is more than the time taken during the return stroke. In other words, the mean speed of the ram during cutting stroke is less than the mean speed during the return stroke. The ratio between the time taken during the cutting and return strokes is given by

Time of cutting stroke/ Time of return stroke

$= \alpha / \beta = \alpha / (360° - \alpha)$ or $= (360° - \beta) / \beta$

Note. In order to find the length of effective stroke R1 R2, mark P1 R1 = P2 R2 = PR. The length of effective stroke is also equal to 2 PD.

1.16. Inversion of Mechanism

C-Double Slider Crank Chain

A kinematic chain which consists of two turning pairs and two sliding pairs is known as double slider crank chain, as shown in Fig. 1.44. We see that the link 2 and link 1 form one turning pair and link 2 and link 3 form the second turning pair. The link 3 and link 4 form one sliding pair and link 1 and link 4 form the second sliding pair.

https://youtu.be/iMYiM8I__vE

1.16. Inversion of Mechanism

C. Inversions of Double Slider Crank Chain

The following three inversions of a double slider crank chain
Are important from the subject point of view:

1. **Elliptical trammels.** It is an instrument used for drawing ellipses. This inversion is obtained by fixing the slotted plate (link 4), as shown in Fig. 1.44. The fixed plate or link 4 has two straight grooves cut in it, at right angles to each other. The link 1 and link 3, are known as sliders and form sliding pairs with link 4. The link AB (link 2) is a bar which forms turning pairs with links 1 and 3.

https://youtu.be/dilOGtjHvCE

1.16. Inversion of Mechanism

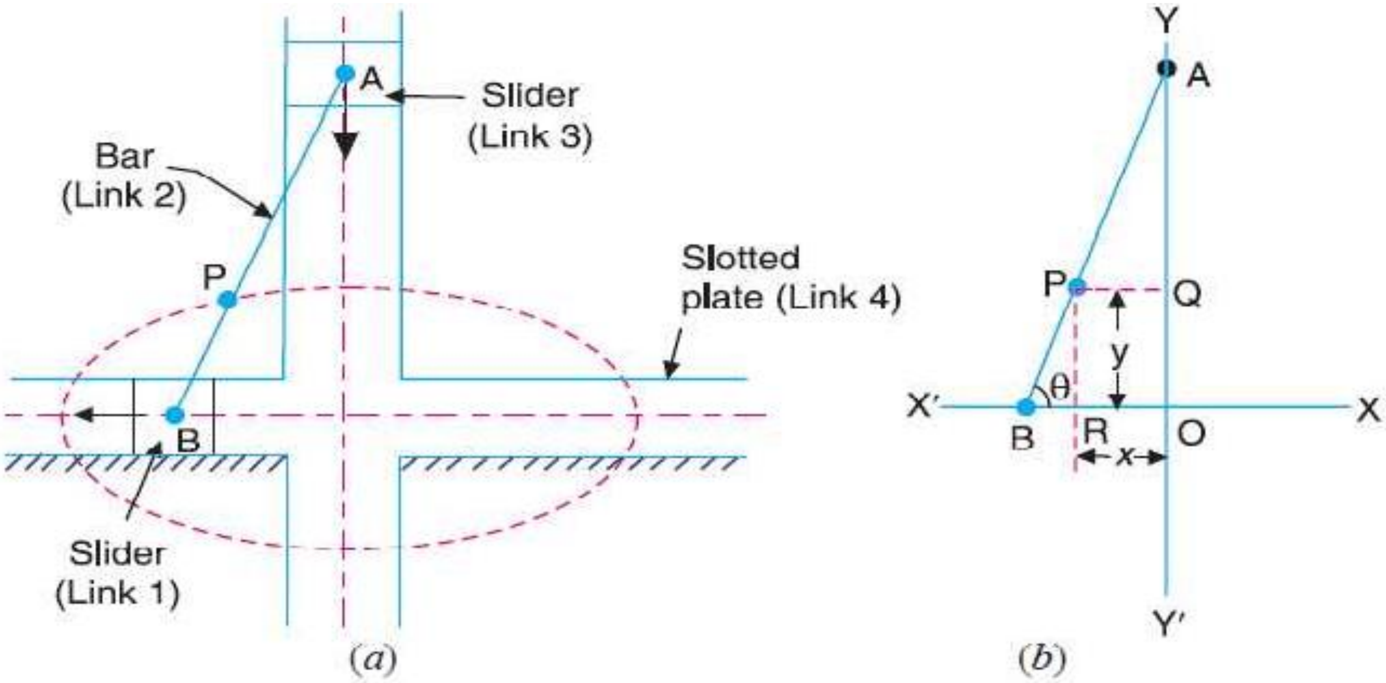


Fig.1.44 Eliptical trammels

1.16. Inversion of Mechanism

When the links 1 and 3 slide along their respective grooves, any point on the link 2 such as P traces out an ellipse on the surface of link 4, as shown in Fig. 1.44 (a). A little consideration will show that AP and BP are the semi-major axis and semi-minor axis of the ellipse respectively.

1.16. Inversion of Mechanism

2. Scotch yoke mechanism.

https://youtu.be/hsaoTo1vuY4

https://youtu.be/HhX-8RyP214

This mechanism is used for converting rotary motion into a reciprocating motion. The inversion is obtained by fixing either the link 1 or link 3. In Fig. 1.45, link 1 is fixed. In this mechanism, when the link 2 (which corresponds to crank) rotates about B as centre, the link 4 (which corresponds to a frame) reciprocates. The fixed link 1 guides the frame.

1.16. Inversion of Mechanism

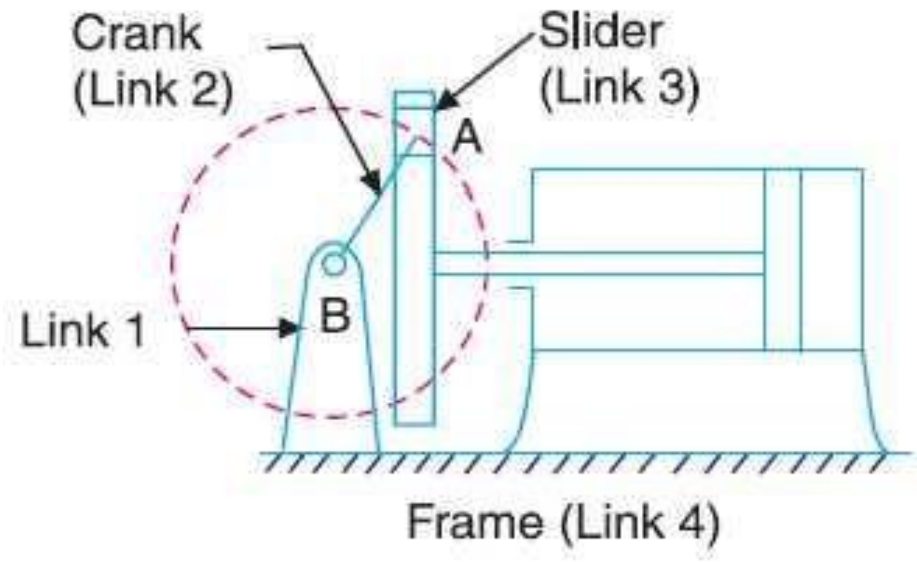


Fig 1.45 Scotch yoke mechanism.

1.16. Inversion of Mechanism

3. Oldham's coupling. https://youtu.be/XvaDAbdZCyU

An Oldham's coupling is used for connecting two parallel shafts whose axes are at a small distance apart. The shafts are coupled in such a way that if one shaft rotates, the other shaft also rotates at the same speed. This inversion is obtained by fixing the link 2, as shown in Fig. 1.46 (a). The shafts to be connected have two flanges (link 1 and link 3) rigidly fastened at their ends by forging.

The link 1 and link 3 form turning pairs with link 2. These flanges have diametrical slots cut in their inner faces, as shown in Fig. 1.46 (b). The intermediate piece (link 4) which is a circular disc, have two tongues (i.e. diametrical projections) T1 and T2 on each face at right angles to each other, as shown in Fig. 1.46 (c). The tongues on the link 4 closely fit into the slots in the two flanges (link 1 and link 3). The link 4 can slide or reciprocate in the slots in the flanges.

1.16. Inversion of Mechanism

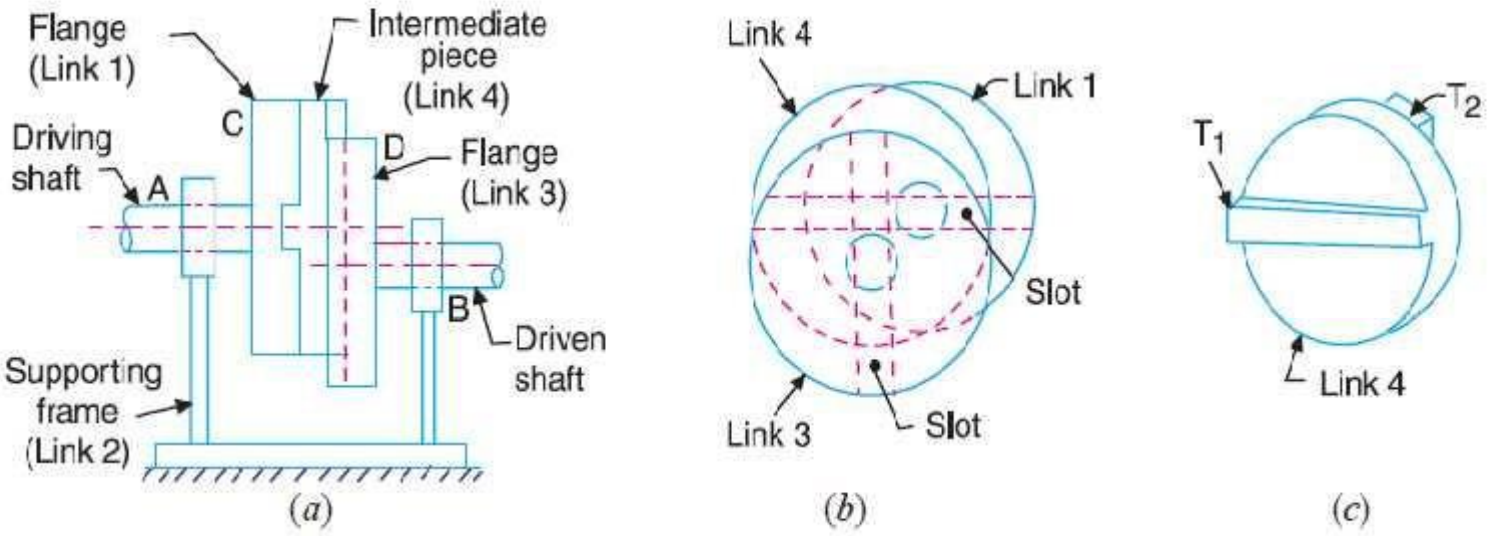


Fig. 1.46 Oldham'scoupling.

1.16. Inversion of Mechanism

When the driving shaft A is rotated, the flange C (link 1) causes the intermediate piece (link 4) to rotate at the same angle through which the flange has rotated, and it further rotates the flange D (link 3) at the same angle and thus the shaft B rotates. Hence links 1, 3 and 4 have the same angular velocity at every instant. A little consideration will show, that there is a sliding motion between the link 4 and each of the other links 1 and 3.

1.16. Inversion of Mechanism

If the distance between the axes of the shafts is constant, the centre of intermediate piece will describe a circle of radius equal to the distance between the axes of the two shafts. Therefore, the maximum sliding speed of each tongue along its slot is equal to the peripheral velocity of the centre of the disc along its circular path.

Let ω = Angular velocity of each shaft in rad/s, and

r = Distance between the axes of the shafts in metres.

∴ Maximum sliding speed of each tongue (in m/s),

$v = \omega . r$

1.16. Inversion of Mechanism

Non Grashof mechanisms

Four bar linkages that do not satisfy the Grashof criterion are called double rocker mechanisms of the second kind or triple-rocker mechanisms. If $L_{max} + L_{min} > L_p + L_q$ no link can rotate through 360°. A computer program based on the flowchart of Figure 1.47 may be used to classify four-bar linkages by characteristics of their motion.

1.16. Inversion of Mechanism

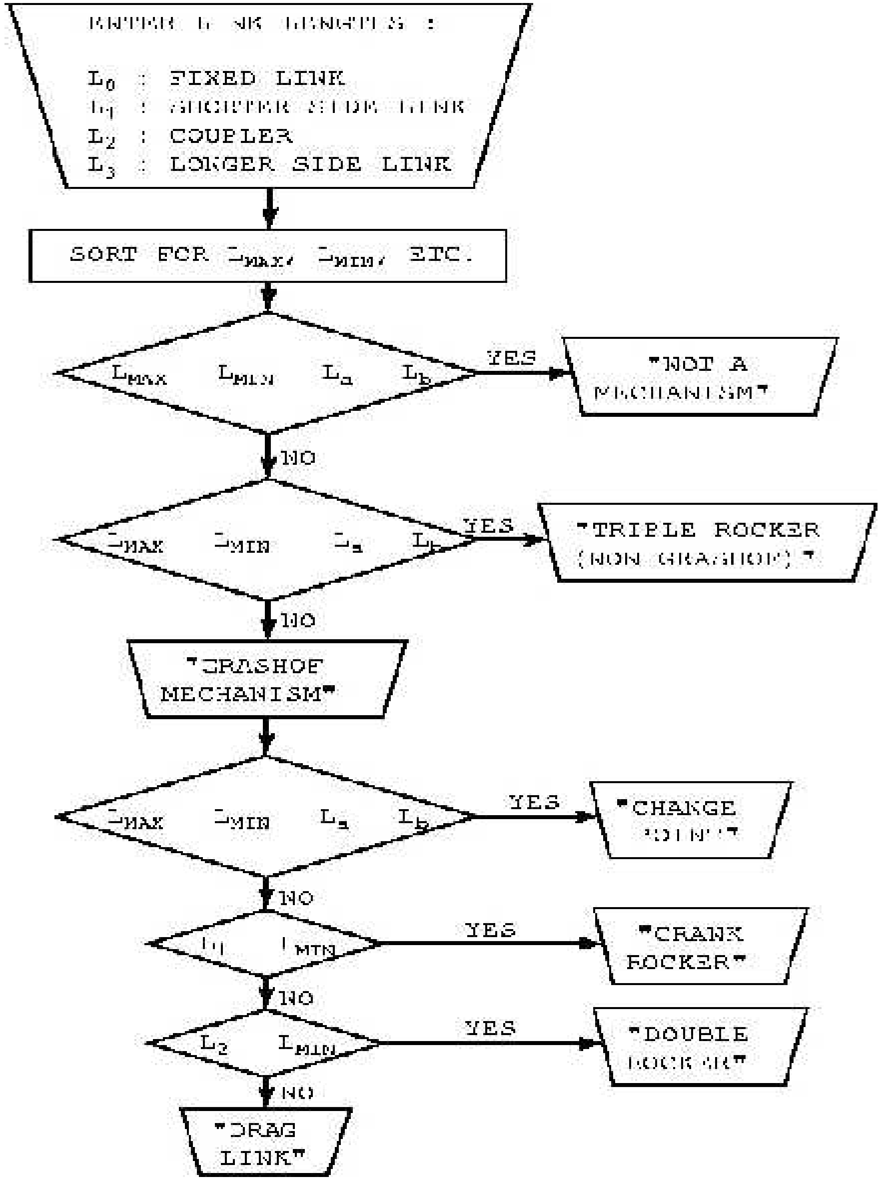


FIGURE 1. 47 Flowchat for classifying four-bar linkages according to the characteristics of theirmotion.

HOMEWORK PROBLEM 1

The Grashof Criterion

This problem concerns the classification of four-bar linkages. Link lengths: L_0, fixed link; L_1, dri-ver crank; L_2, coupler; L_3, follower crank; $L_1 = 100$ mm, $L_2 = 200$ mm, $L_3 = 300$ mm. Find the ranges of values for L_0, if the linkage can be classified as follows:

a. Grashof mechanism
b. Crank-rocker mechanism
c. Drag link mechanism
d. Double-rocker mechanism
e. Change –point mechanism
f. Triple-rocker mechanism

1.17. Mechanical Advantage

Mechanical advantage:- Mechanical advantage of a linkage is the ratio of output torque exerted by the driven link to the necessary input torque required at the driver. The mechanical advantage of the four-bar linkage shown in Fig. 1. 48 is directly proportional to the sine of the angle γ between the coupler and the follower and inversely proportional to the sine of the angle β between the coupler and the driver. When the sign of the angle β becomes zero, the mechanical advantage becomes infinite; thus, at such a position, only a small input torque is necessary to overcome a large output torque load. This is the case when the driver AB of Fig. 1.48 is directly in line with the coupler BC; it occurs when the crank is in position AB_1 and again when the crank is in position AB_4. Note that these also define extreme positions of travel of the rocker DC_1 and DC_4.When the four-bar linkage is in either of these positions, mechanical advantage is infinite and the linkage is said to be in a **toggle position**.

1.17. Mechanical Advantage

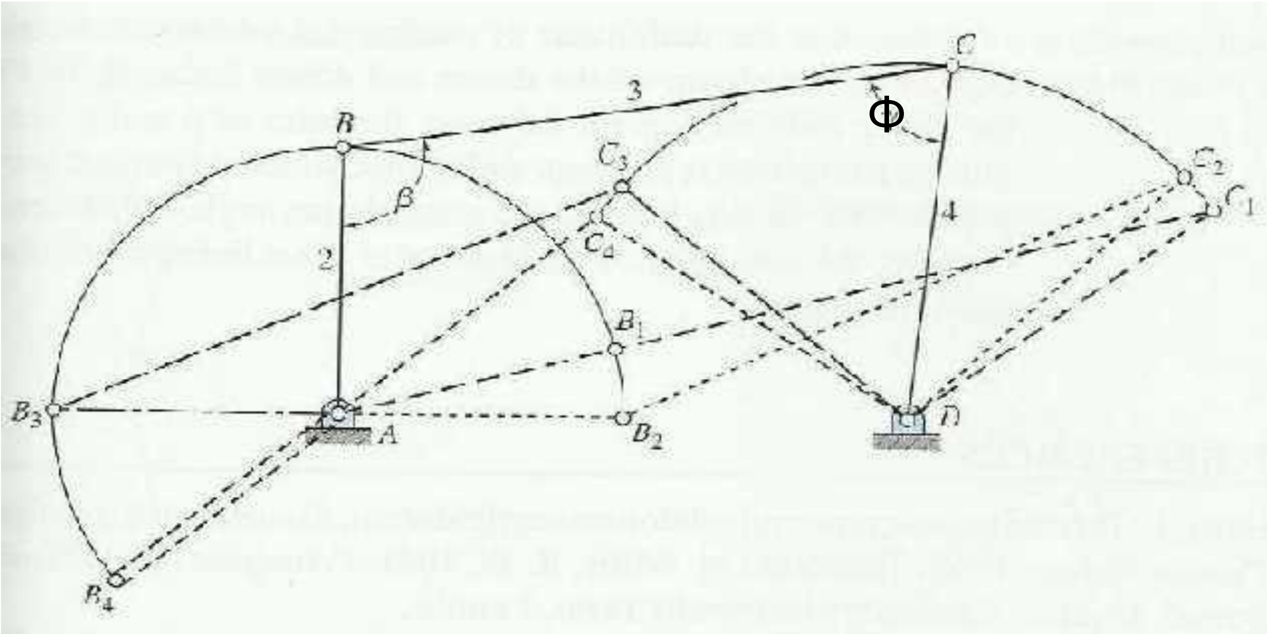


Fig.1.48 Toggle positions

1.17. Mechanical Advantage

Transmission angle : The angle γ between the coupler and the follower is called **transmission angle**. As this angle becomes small, the mechanical advantage decreases and even a small amount of friction will cause the mechanism to lock or jam. A common rule of thumb is that a four- bar linkage should not be used in the rigion where the transmission angle is less than 40^o or 45^o and no great than 135^o or 140^o is usually satisfactory. The extreme values of the transmission angle occur when the crank AB lies along the line of the frame AD. In Fig.1.47 the transmission angle is minimum when the crank is position AB_2 and maximum when the crank has position AB_3.

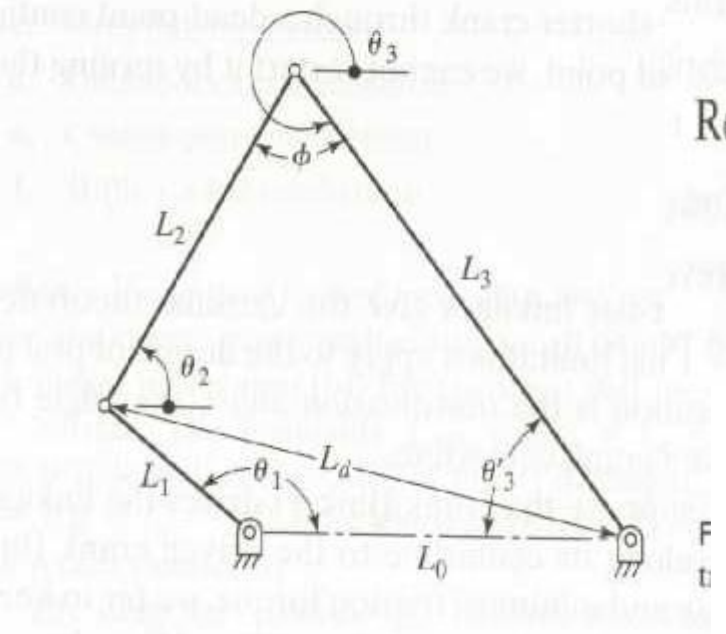
1.17. Mechanical Advantage

Consider the four-bar linkage whose links form a quadrilateral, as in Figure 1.49. For crank angle

$$L_d^2 = L_0^2 + L_1^2 - 2\,L_0\,L_1 \cos\theta_1$$

Using the law of cosines for the triangle formed by the diagonal and links 2 and 3

$$L_d^2 = L_2^2 + L_3^2 - 2\,L_2\,L_3 \cos\phi$$



Rearranging the cosine law equation:

$$\cos\phi = \frac{L_2^2 + L_3^2 - L_d^2}{2L_2L_3}.$$

FIGURE 1.49 Determination of transmission angle.

HOMEWORK PROBLEM 2

Given the driver crank length L_1 = 100mm, coupler length L_2 = 200 mm, and follower length L_3 = 300 mm, and considering the transmission angle, find the range of values for the fixed link L_0 if the linkage is to be a crank rocker. Make the design decision to limit the transmission angle to $45° \leq \phi \leq 135°$.

1.18. Actuators and Drivers

In order to operate a mechanism, an actuator, or driver device, is required to provide the input motion and energy. To precisely operate a mechanism, one driver is required for each degree of freedom exhibited. Many different actuators are used in industrial and commercial machines and mechanisms. Some of the more common ones are given in the following section.

1.18. Actuators and Drivers

Electric motors (DC) produce continuous rotary motion. The speed and direction of the motion can be readily altered, but they require power from a generator or a battery. DC motors can achieve extremely high speeds––up to 30,000 rpm. These motors are most often used in vehicles, cordless devices, or in applications where multiple speeds and directional control are required.

1.18. Actuators and Drivers

Engines also generate continuous rotary motion. The speed of an engine can be throttled within a range of approximately 1000 to 8000 rpm. They are a popular and highly portable driver for high-power applications. Because they rely on the combustion of fuel, engines are used to drive machines that operate outdoors.

1.18. Actuators and Drivers

Servomotors are motors that are coupled with a controller to produce a programmed motion or hold a fixed position. The controller requires sensors on the link being moved to provide feedback information on its position, velocity, and acceleration. These motors have lower power capacity than non-servomotors and are significantly more expensive, but they can be used for machines demanding precisely guided motion, such as robots.

1.18. Actuators and Drivers

Electric motors (AC) provide the least expensive way to generate continuous rotary motion. However, they are limited to a few standard speeds that are a function of the electric line frequency. Single-phase motors are used in residential applications and are available from. Three-phase motors are more efficient, but mostly limited to industrial applications because they require three-phase power service.

1.18. Actuators and Drivers

Air or hydraulic motors also produce continuous rotary motion and are similar to electric motors, but have more limited applications. This is due to the need for compressed air or a hydraulic source. These drive devices are mostly used within machines, such as construction equipment and aircraft, where high pressure hydraulic fluid is available.

1.18. Actuators and Drivers

Hydraulic or pneumatic cylinders are common components used to drive a mechanism with a limited linear stroke. Figure 1.50a illustrates a hydraulic cylinder. Figure 1.50b shows the common kinematic representation for the cylinder unit. The cylinder unit contains a rod and piston assembly that slides relative to a cylinder. For kinematic purposes, these are two links (piston/rod and cylinder), connected with a sliding joint. In addition, the cylinder and rod end usually have provisions for pin joints.

1.18. Actuators and Drivers

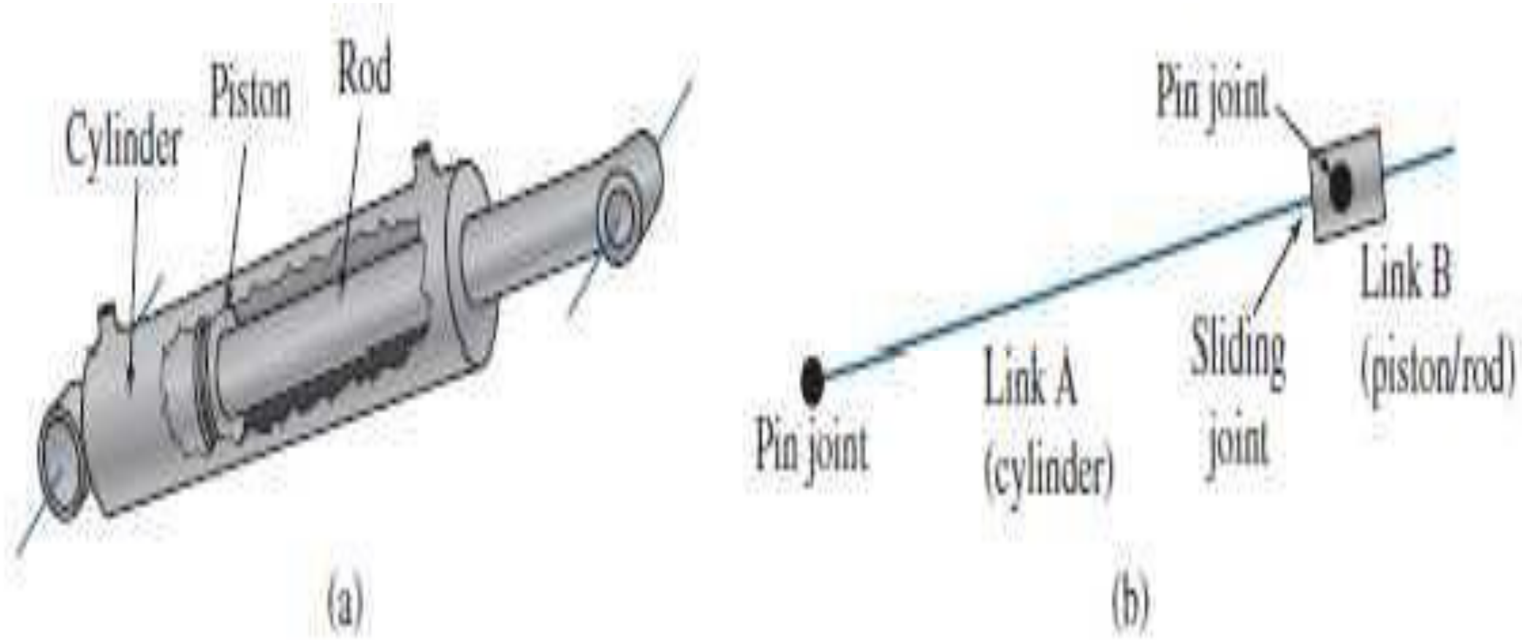


Fig. 1.50 Hydrolic cylinder

1.18. Actuators and Drivers

Screw actuators also produce a limited linear stroke**.** These actuators consist of a motor, rotating a screw. A mating nut provides the linear motion. Screw actuators can be accurately controlled and can directly replace cylinders. However, they are considerably more expensive than cylinders if air or hydraulic sources are available. Similar to cylinders, screw actuators also have provisions for pin joints at the two ends. Therefore, the kinematic diagram is identical to Figure 1.50b.

1.18. Actuators and Drivers

Manual, or hand-operated, mechanisms comprise a large number of machines, or hand tools. The motions expected from human “actuators” can be quite complex. However, if the expected motions are repetitive, caution should be taken against possible fatigue and stain injuries

1.18. Actuators and Drivers

Example 1.10: Figure 1.51 shows an outrigger foot to stabilize a utility truck. Draw a kinematic diagram, using the bottom of the stabilizing foot as a point of interest. Also compute the degrees of freedom.

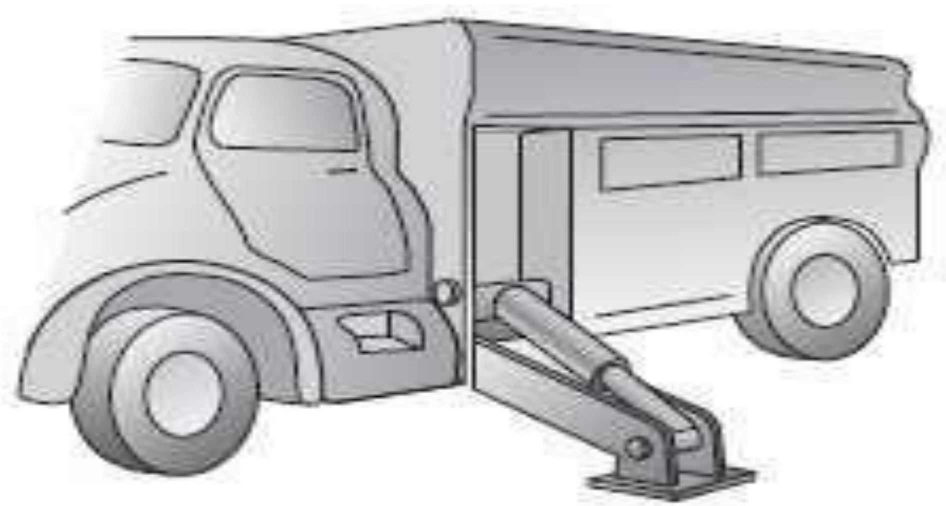


Fig. 1.51 Outrigger foot

1.18. Actuators and Drivers

SOLUTION:

1. Identify the Frame

During operation of the outriggers, the utility truck is stationary. Therefore, the truck is designated as the frame. The motion of all other links is determined relative to the truck. The frame is numbered as link 1.

2. Identify All Other Links

Careful observation reveals three other moving parts:

Link 2: Outrigger leg

Link 3: Cylinder

Link 4: Piston/rod

1.18. Actuators and Drivers

3. Identify the Joints

Three pin joints are used to connect these different parts. One connects the outrigger leg with the truck frame. This is labeled as joint A. Another connects the outrigger leg with the cylinder rod and is labeled as joint B. The last pin joint connects the cylinder to the truck frame and is labeled as joint C. One sliding joint is present in the cylinder unit. This connects the piston/rod with the cylinder. It is labeled as joint D.

1.18. Actuators and Drivers

4. Identify Any Points of Interest

The stabilizer foot is part of link 2, and a point of interest located on the bottom of the foot is labeled as point of interest X.

5. Draw the Kinematic Diagram

The resulting kinematic diagram is given in Figure 1.52.

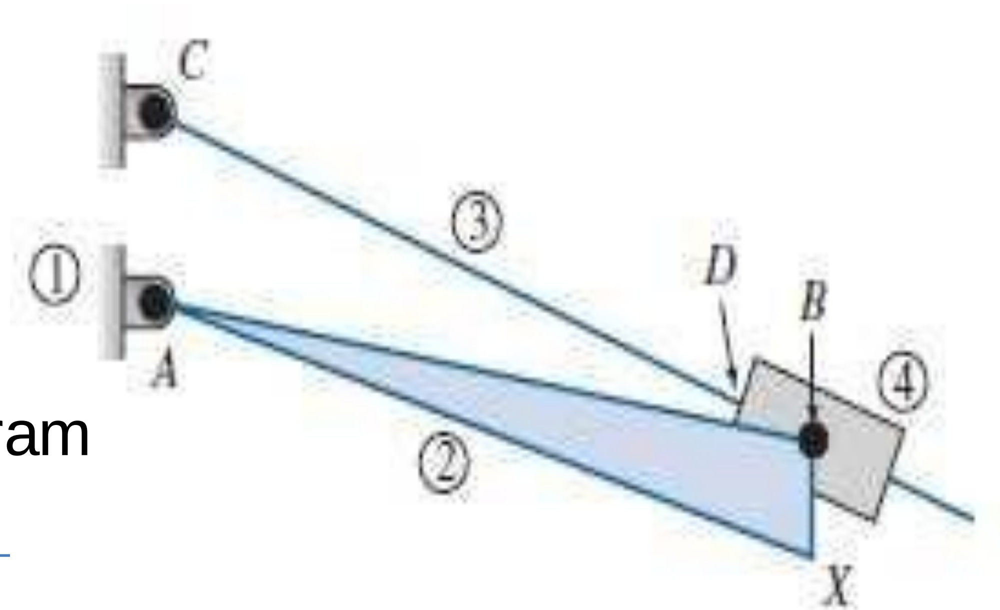


Fig. 1.52 Kinematic Diagram

1.18. Actuators and Drivers

6. Calculate Mobility

To calculate the mobility, it was determined that there are four links in this mechanism, as well as three pin joints and one slider joint. Therefore,

l = 4, jp = (3 pins + 1 slider) = 4, jh = 0

and

n = 3(n - 1) - 2jp - jh = 3(4 - 1) - 2(4) - 0 = 1

With one degree of freedom, the outrigger mechanism is constrained. Moving only one link, the piston, precisely positions all other links in the outrigger, placing the stabilizing foot on the ground.

1.19. Commonly Used Lınks and Joınts

1. Eccentric Crank

On many mechanisms, the required length of a crank is so short that it is not feasible to fit suitably sized bearings at the two pin joints. A common solution is to design the link as an eccentric crankshaft, as shown in Fig. 1.53a. This is the design used in most engines and compressors. The pin, on the moving end of the link, is enlarged such that it contains the entire link. The outside circumference of the circular lobe on the crankshaft becomes the moving pin joint, as shown in Figure 1.53b. The location of the fixed bearing, or bearings, is offset from the eccentric lobe. This eccentricity of the crankshaft, , is the effective length of the crank. Fig. 1.53c illustrates a kinematic model of the eccentric crank. The advantage of the eccentric crank is the large surface area of the moving pin, which reduces wear.

1.19. Commonly Used Links and Joints

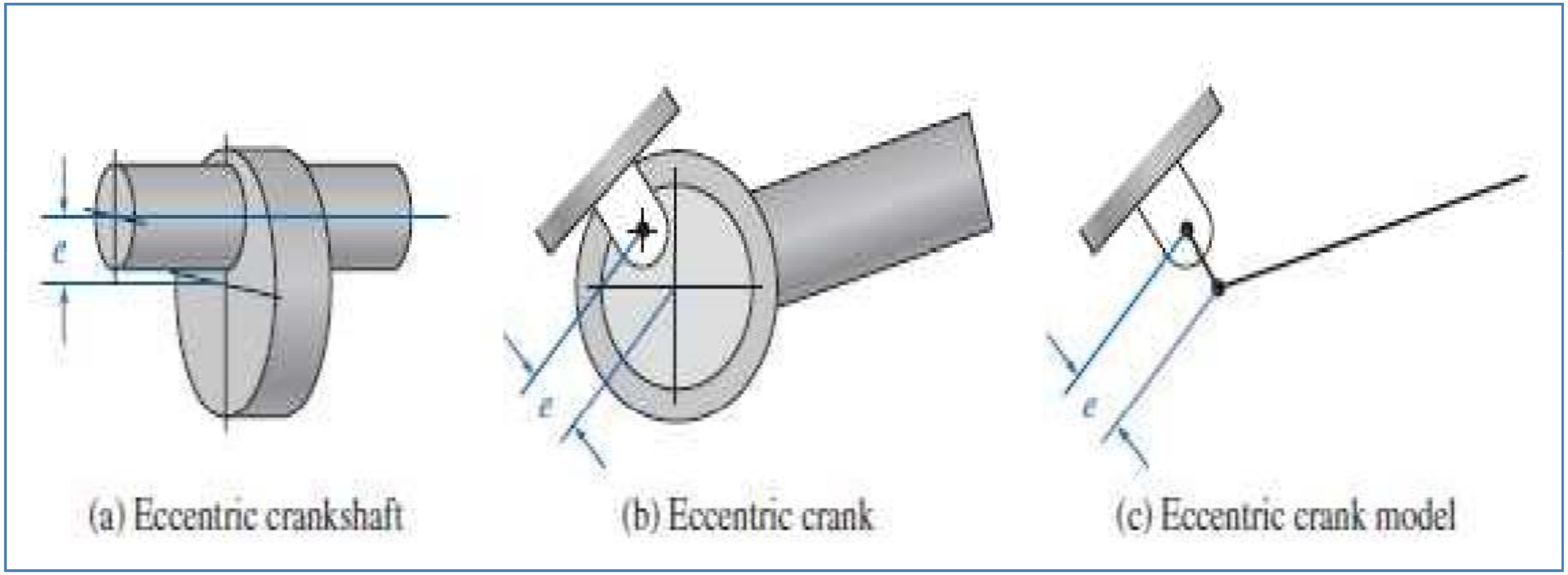


Fig.1.53 Eccentric crank.

1.19. Commonly Used Lınks and Joınts

2. Pin-in-a-Slot Joint

A common connection between links is a pin-in-a-slot joint, as shown in Figure 1.54a. This is a higher-order joint because it permits the two links to rotate and slide relative to each other. To simplify the kinematic analysis, primary joints can be used to model this higher-order joint. The pin-in-a-slot joint becomes a combination of a pin joint and a sliding joint, as in Figure 1.54b. Note that this involves adding an extra link to the mechanism. In both cases, the relative motion between the links is the same. However, using a kinematic model with primary joints facilitates the analysis.

1.19. Commonly Used Lınks and Joınts

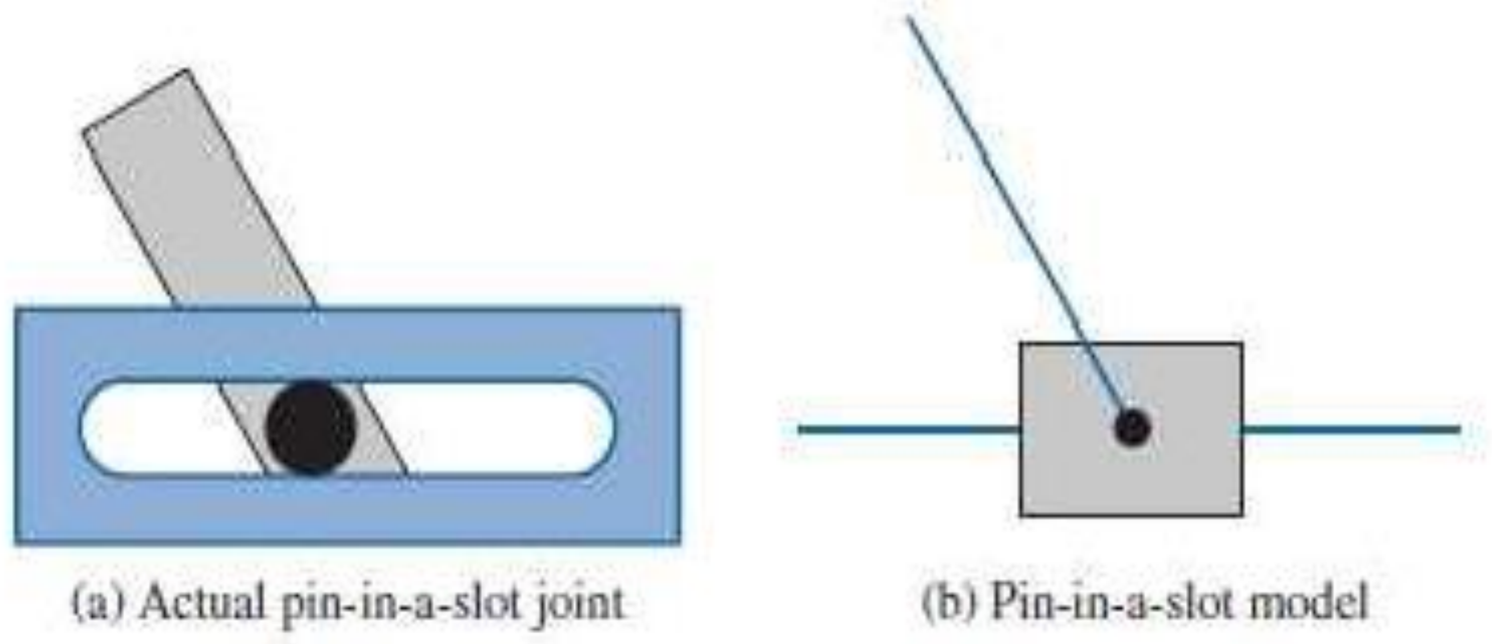


Fig.1.54 Pin-in-a-slot joint.

1.19. Commonly Used Lınks and Joınts

3. Screw Joint

A screw joint, as shown in Figure 1.55a, is another common connection between links. To start with, a screw joint permits two relative, but dependent, motions between the links being joined. A specific rotation of one link will cause an associated relative translation between the two links. For example, turning the screw one revolution may move the nut along the screw threads a distance of 0.1 in. Thus, only one independent motion is introduced. A screw joint is typically modeled with a sliding joint, as shown in Figure 1.55b. It must be understood that out-of plane rotation occurs. However, only the relative translation between the screw and nut is considered in planar kinematic analysis.

1.19. Commonly Used Lınks and Joınts

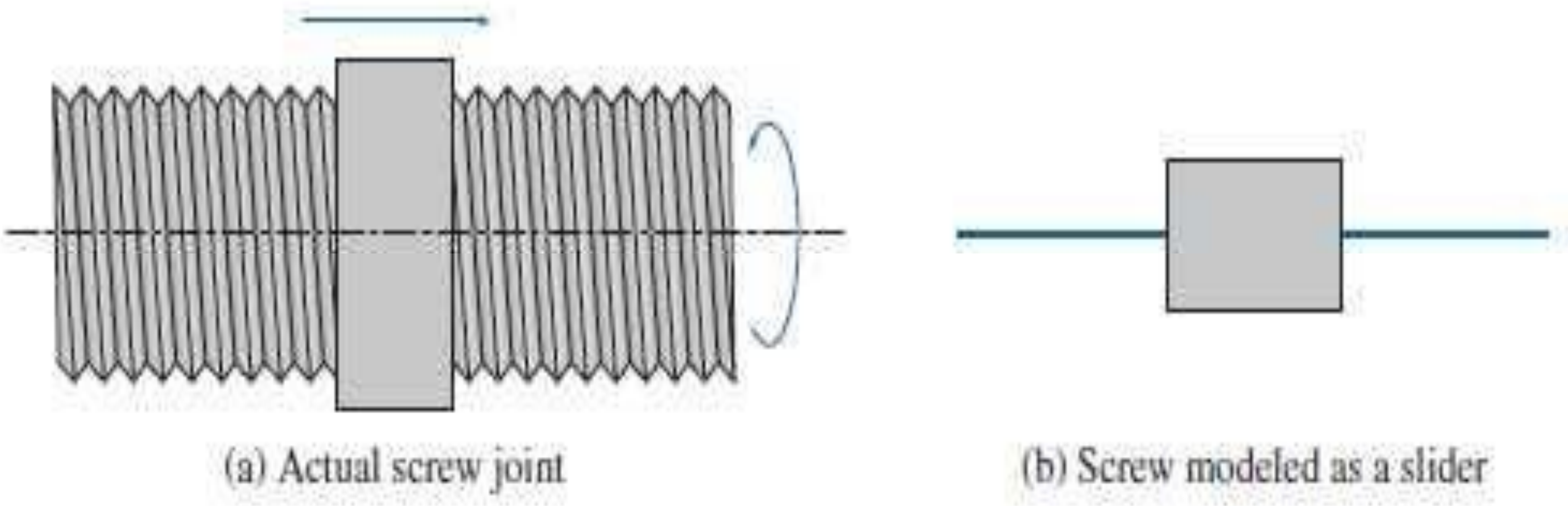


Fig.1.55 Screwjoint.

1.19. Commonly Used Lınks and Joınts

Example 1. Figure 1.56 presents a lift table used to adjust the working height of different objects. Draw a kinematic diagram and compute the degrees of freedom.

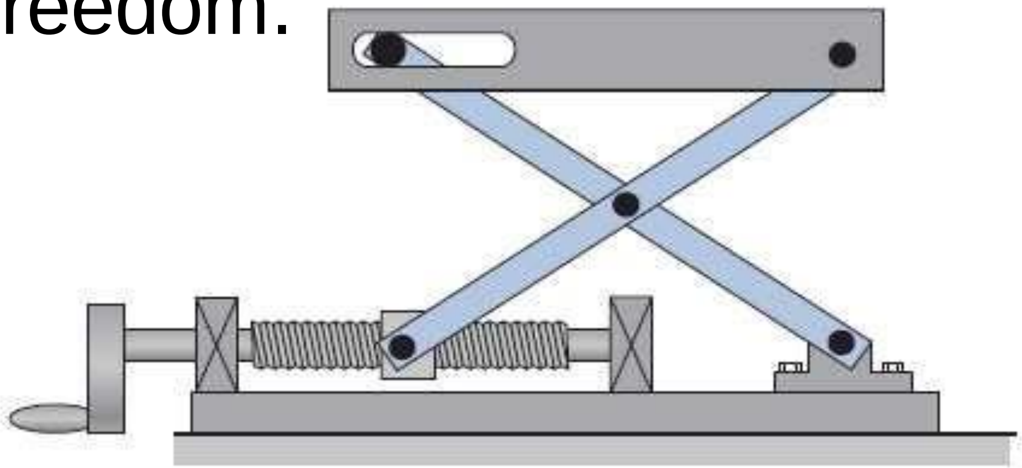


Fig.1. 56 Lift table

1.19. Commonly Used Lınks and Joınts

Solution:

1. **Identify the Frame:**

The bottom base plate rests on a fixed surface. Thus, the base plate will be designated as the frame. The bearing at the bottom right of Figure 1.56 is bolted to the base plate. Likewise, the two bearings that support the screw on the left are bolted to the base plate.

From the discussion in the previous section, the out-of-plane rotation of the screw will not be considered. Only the relative translation of the nut will be included in the kinematic model. Therefore, the screw will also be considered as part of the frame. The motion of all other links will be determined relative to this bottom base plate, which will be numbered as link 1.

1.19. Commonly Used Lınks and Joınts

_2._ Identify All Other Links

Careful observation reveals five other moving parts:

Link 2: Nut

Link 3: Support arm that ties the nut to the table

Link 4: Support arm that ties the fixed bearing to the slot in the table

Link 5: Table

Link 6: Extra link used to model the pin in slot joint with separate pin and slider joints

1.19. Commonly Used Lınks and Joınts

_3._ Identify the Joints

A sliding joint is used to model the motion between the screw and the nut. A pin joint, designated as point A, connects the nut to the support arm identified as link 3. A pin joint, designated as point B, connects the two support arms—link 3 and link 4. Another pin joint, designated as point C, connects link 4 to link 6. A sliding joint joins link 6 to the table, link 5. A pin, designated as point D, connects the table to the support arm, link 3. Lastly, a pin joint, designated as point E, is used to connect the base to the support arm, link 4.

1.19. Commonly Used Lınks and Joınts

5. ***Draw the Kinematic Diagram***
The kinematic diagram is given in Figure 1.57.

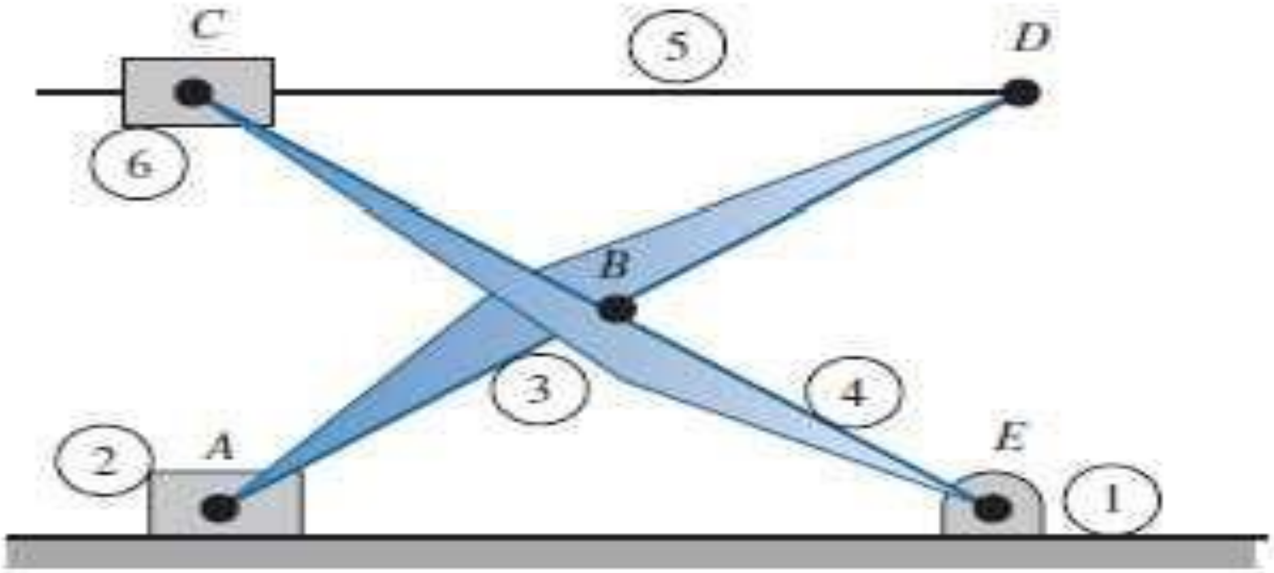


Fig.1.57 Kinematic diagram

1.19. Commonly Used Lınks and Joınts

5. **Calculate Mobility**

To calculate the mobility, it was determined that there are six links in this mechanism. There are also five pin joints and two slider joints. Therefore,

$l = 6$, $j_p = (5 \text{ pins} + 2 \text{ sliders}) = 7$, $j_h = 0$

and

$n = 3(l - 1) - 2j_p - j_h = 3(6 - 1) - 2(7) - 0 = 15 - 14 = 1$

With one degree of freedom, the lift table has constrained motion. Moving one link, the handle that rotates the screw, will precisely position all other links in the device, raising or lowering the table.

1.20. Analysis and Syntesis

There are two different aspects of the study of mechanical systems: **design** and **analysis.**

The concept embodied in the word “ design” might be more properly termed **syntesis,** the process of contriving a scheme or a method of accomplishing a given purpose.

Design is the process of prescribing the sizes, shapes material compositions, and arrangements of parts so that the resulting machine will perform the prescribed task. It calls for imagination, intuition, creativity, judgments and experience.

Design process is by its very nature as much an art as a science. The role of science in the design process is merely to provide tools to be used by the designers as that practise their art.

1.20. Analysis and Syntesis

The process of evaluating the various interacting alternatives that designers find usually requires a large collection of mathematical and scientific tools. These tools , when applied properly , can provide more accurate and more reliable information for use in judging a design than one can achive through intuition or estimation. Thus, they can provide tremendous help in deciding among alternatives.

Hovever, scientific tools can not make decisions for designer.

Designers have every right to exert their imaginations and creative abilities.

1.20. Analysis and Syntesis

The largest collection of scientific methods at the designer’s disposal fall into the category called **analysis.** These are the techniques which allow the designer to critically examine an already existing or proposed design in order to judge its suitability and rating of things already conceived.

We should always bear in mind that although most of our effort may be spent on analysis, real goal is synthesis, design of a machine or system. Analysis is simply a tool. It is, however a vital tool and will inevitable be used as one step in the design process.

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5. Internet based resources(Because of the shortage of space, the list is not given).

E-NOTES OF

Workshop Technology-III

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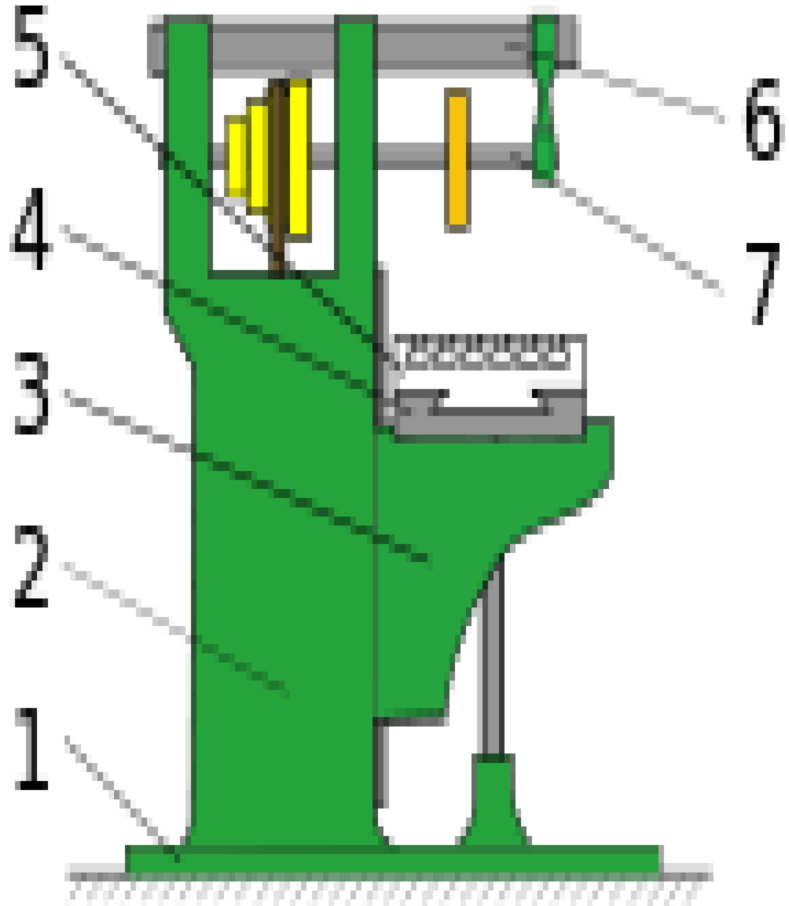
Milling:- is the process of machining using rotary cutters to remove material by advancing a cutter into a work piece. This may be done varying direction[on one or several axes, cutter head speed, and pressure. Milling covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes for machining custom parts to precise tolerances.

Milling can be done with a wide range of machine tools. The original class of machine tools for milling was the milling machine (often called a mill). After the advent of computer numerical control (CNC) in the 1960s, milling machines evolved into *machining centers*: milling machines augmented by automatic tool changers, tool magazines or carousels, CNC capability, coolant systems, and enclosures. Milling centers are generally classified as vertical machining centers (VMCs) or horizontal machining centers (HMCs).

The integration of milling into turning environments, and vice versa, began with live tooling for lathes and the occasional use of mills for turning operations. This led to a new class of machine tools, multitasking machines (MTMs), which are purpose-built to facilitate milling and turning within the same work envelope.

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 but the cutters are mounted on a horizontal spindle (see Arbor milling) across 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*. While endmills and the other types of tools available to a vertical mill may be used in a horizontal mill, their real advantage lies in arbor-mounted cutters, called side and face mills, which have a cross section rather like a circular saw, but are generally wider and smaller in diameter. Because the cutters have good support from the arbor and have a larger cross-sectional area than an end mill, quite heavy cuts can be taken enabling rapid material removal rates. These are used to mill grooves and slots. Plain mills are used to shape flat surfaces. Several cutters may be ganged together on the arbor to mill a complex shape of slots and planes. Special cutters can also cut grooves, bevels, radii, or indeed any section desired. These specialty cutters tend to be expensive. Simplex mills have one spindle, and duplex mills have two. It is also easier to cut gears on a horizontal mill. Some horizontal milling machines are equipped with a power-take-off provision on the table. This allows the table feed to be synchronized to a rotary fixture, enabling the milling of spiral features such as hypoid gears.



Horizontal milling machine. 1: base 2: column 3: knee 4 & 5: table (x-axis slide is integral) 6: overarm 7: arbor (attached to spindle)

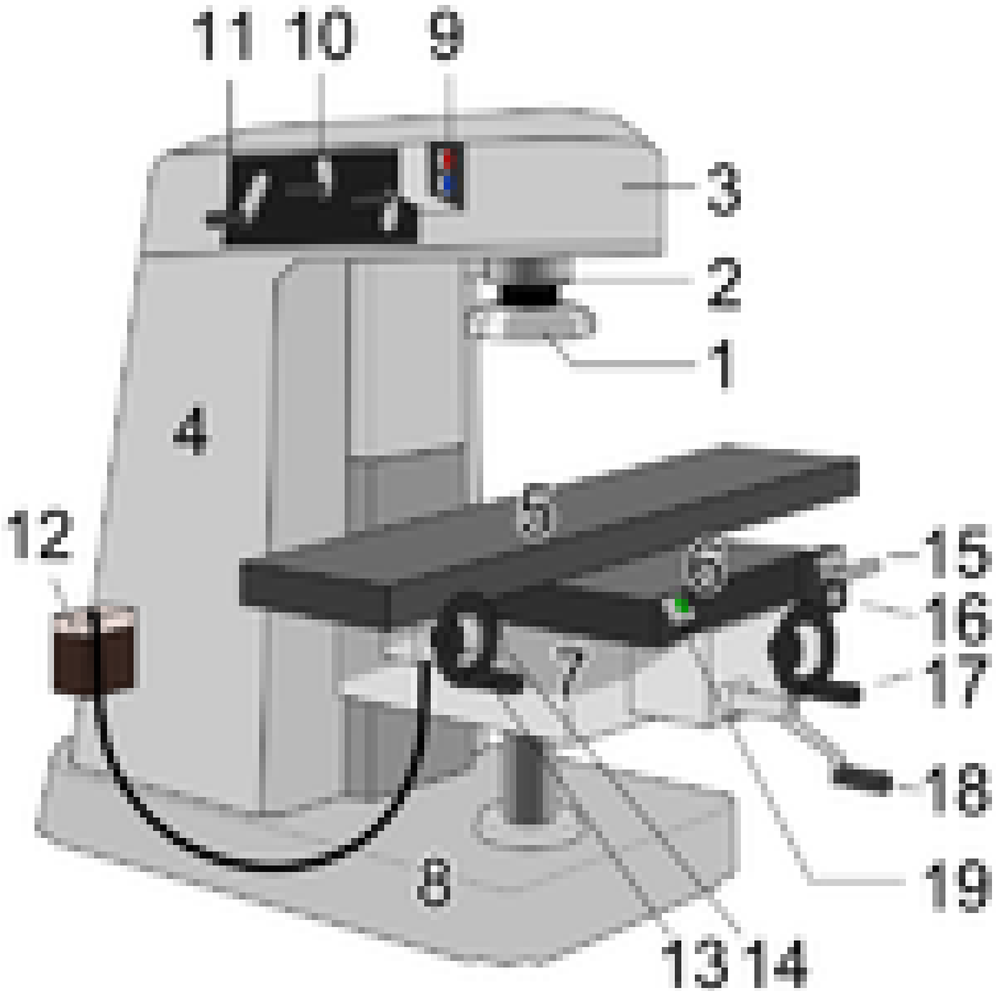
Vertical milling machine:-

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 milling machine** the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be lowered (or the table can be raised, giving the same relative effect of bringing the cutter closer or deeper into the work), allowing plunge cuts and drilling. There are two subcategories of vertical mills: the bed mill and the turret mill.

A **turret mill** has a fixed spindle and the table is moved both perpendicular and parallel to the spindle axis to accomplish cutting. Some turret mills have a quill which allows the milling cutter (or a drill) to be raised and lowered in a manner similar to a drill press. This provides two methods of cutting in the vertical (Z) direction: by raising or lowering the quill, and by moving the knee.

In the **bed mill**, however, the table moves only perpendicular to the spindle's axis, while the spindle itself moves parallel to its own axis.



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

Classification of Milling Operations

Milling operations may be classified under four general heading as follows:

Face Milling, machining flat surfaces which are at right angle to the axis of the cutter.

Plain or Snab Milling, machining flat surfaces which are parallel to the axis of the cutter.

Angular Milling, machining flat surfaces which are at an inclination to the axis of the cutter.

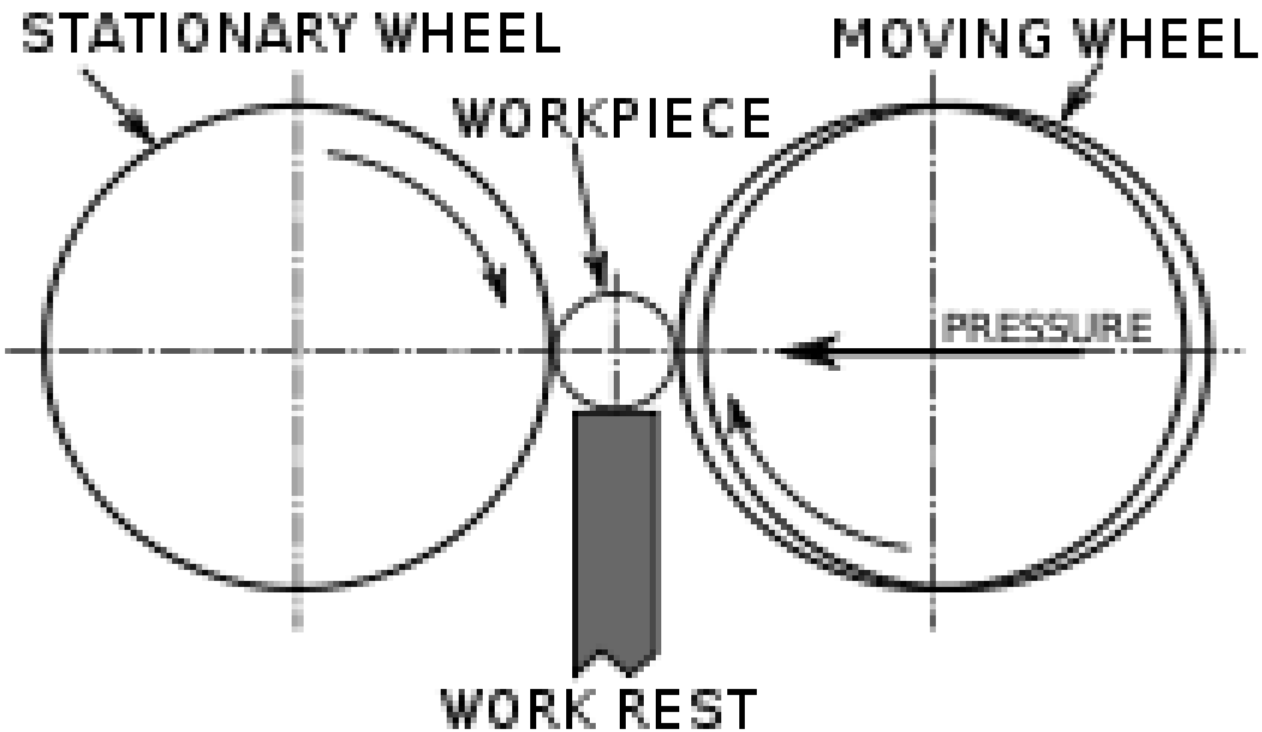
Form Milling, machining surfaces having an irregular outline.

Following are the types of milling cutters that we use in different milling machines:

Roughing end mill
Slab mill
End mill cutter
Hollow mill
Ball mill cutter
Involute gear cutter
Face mill cutter
Wood ruff cutter
Thread mill cutter
Fly cutter
Slide and face cutter
Hobbing cutter
Dovetail cutter

Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool.

Centerless grinding is a machining process that uses abrasive cutting to remove material from a workpiece. Centerless grinding differs from centered grinding operations in that no spindle or fixture is used to locate and secure the workpiece;the workpiece is secured between two rotary grinding wheels, and the speed of their rotation relative to each other determines the rate at which material is removed from the workpiece.
Centerless grinding is typically used in preference to other grinding processes for operations where many parts must be processed in a short time.



Floor or bench grinder:

Floor or bench grinder is a small type of machine used in the labs where a small workpiece has to grind. For example, when we manufacture a single-point cutting tool for a lathe machine we use to manufacture by floor or bench grinder.

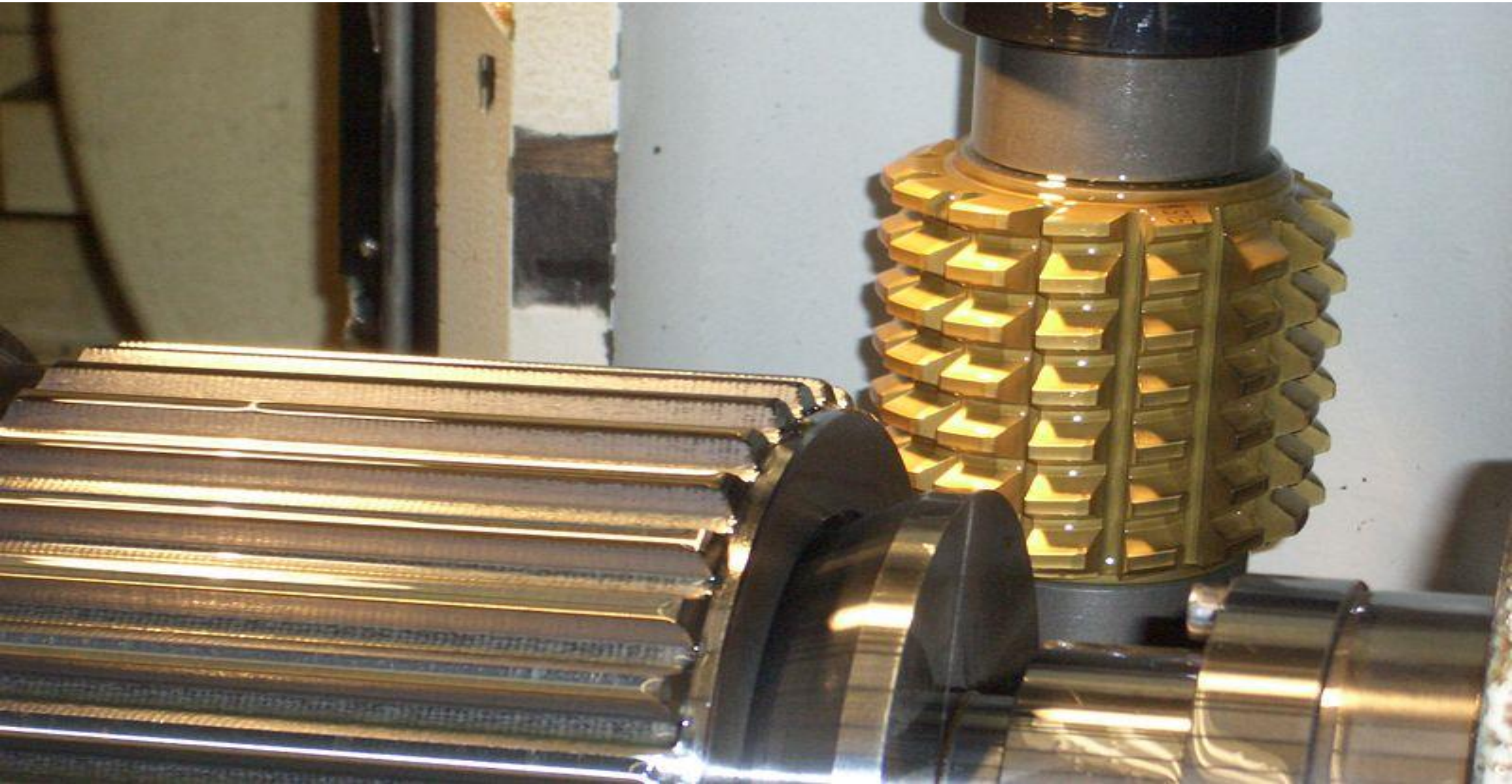
Abrasive grinder:

The **abrasive grinder** is a similar type of these grinders but the main difference is here abrasive is used while cutting and finishing the job. This is more costly than the floor and portable grinder.

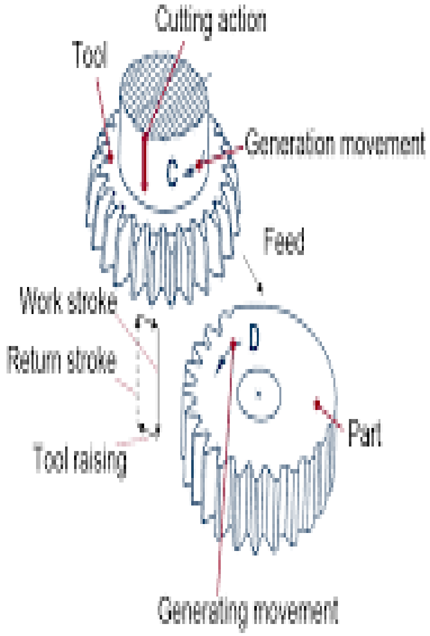
Surface Grinder:

A **surface grinder** consists of an **abrasive wheel, a chuck (a workpiece holding device), and a rotary tabl**e. The chuck is used to hold the material in place while the wheel and object are rotated to produce a smooth finish.

Hobbing is a machining process for gear cutting, cutting splines, and cutting sprockets on a **hobbing machine**, which is a special type of milling machine. The teeth or splines of the gear are progressively cut into the material (a flat, cylindrical piece of metal) by a series of cuts made by a cutting tool called a **hob**. Compared to other gear forming processes it is relatively inexpensive but still quite accurate, thus it is used for a broad range of parts and quantities.[1] It is the most widely used gear cutting process for creating spur and helical gears[2] and more gears are cut by hobbing than any other process as it is relatively quick and inexpensive.[3]



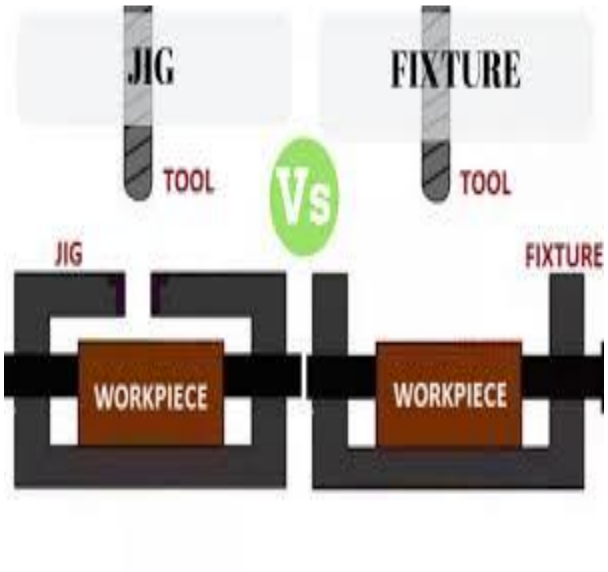
Gear shaping is a machining process for creating teeth on a **gear** using a cutter. **Gear shaping** is a convenient and versatile method of **gear** cutting. It involves continuous, same-plane rotational cutting of **gear**.

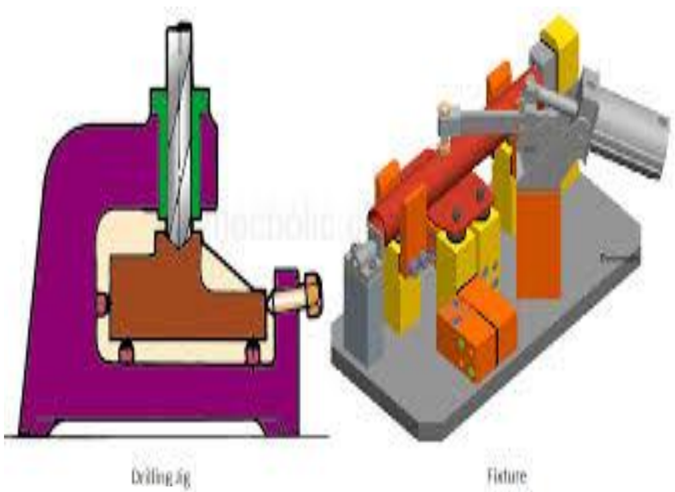


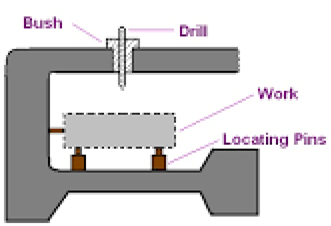
Jig and fixture

Featured snippet from the web

A **jig's** primary purpose is to provide repeatability, accuracy, and interchangeability in the manufacturing of products. A **jig** is often confused with a **fixture**; a **fixture** holds the work in a fixed location. A device that does both functions (holding the work and guiding a tool) is called a **jig**.







-: Jig :-

Principle of Location:-

The 3-2-1 **principle of location** (six point **location principle**) is used to constrain the movement of workpiece along the three axes XX, YY, and ZZ. This is achieved by providing six locating points, 3 pins in base plate, 2 pins in vertical plane and 1 pin in a plane which is perpendicular to first two planes.

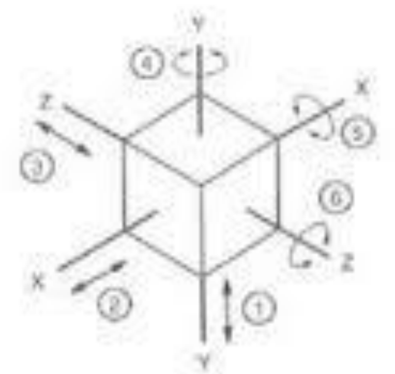
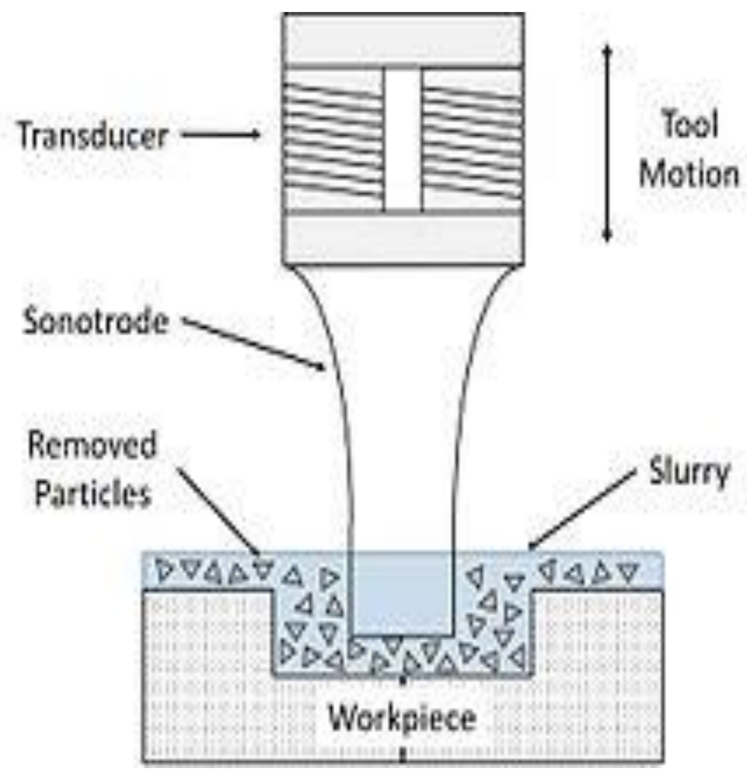
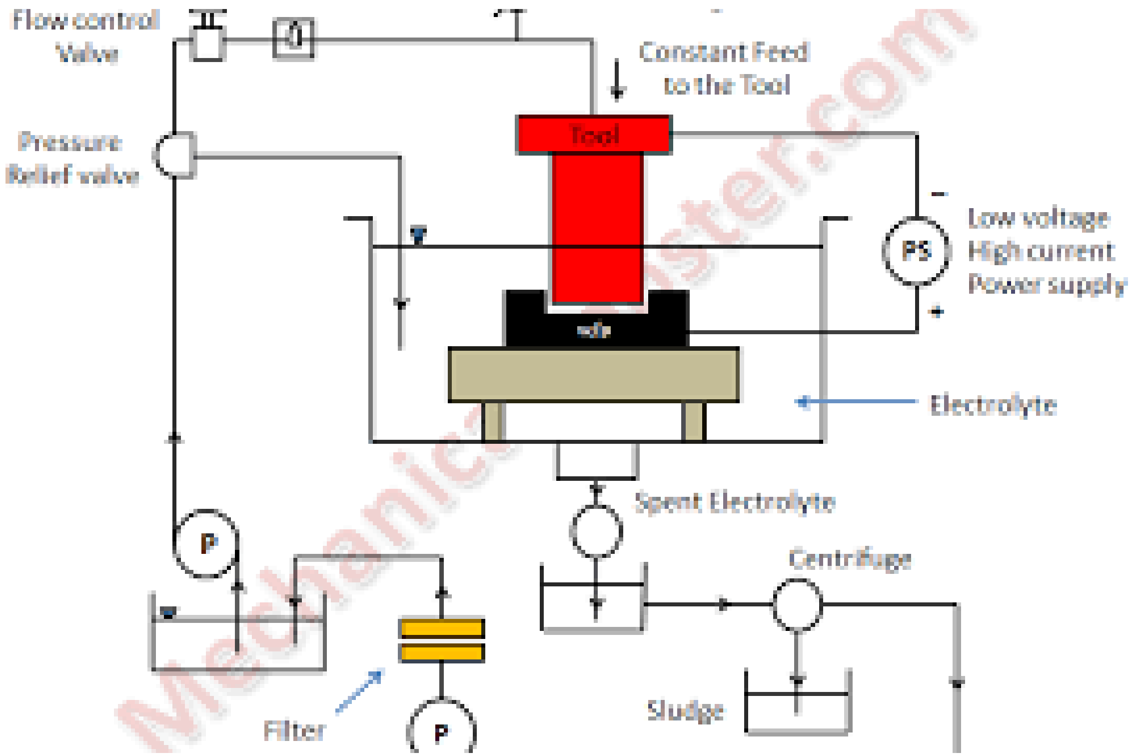


Figure 1.1 Six degrees of freedom

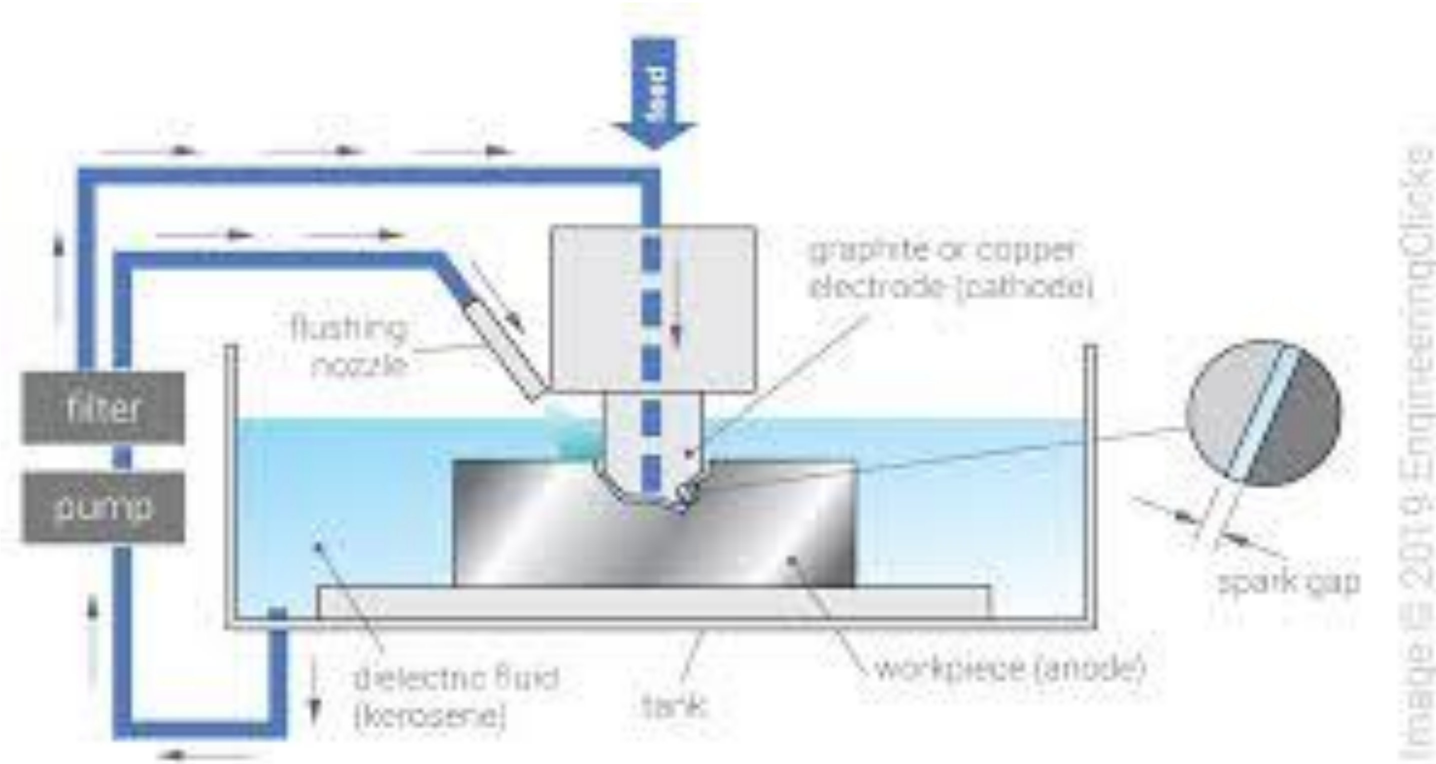
Ultrasonic machining, or strictly speaking the "[1]", is a subtraction manufacturing process that removes material from the surface of a part through high frequency, low amplitude vibrations of a tool against the material surface in the presence of fine abrasive particles. The tool travels vertically or orthogonal to the surface of the part at amplitudes of 0.05 to 0.125 mm (0.002 to 0.005 in.).[2] The fine abrasive grains are mixed with water to form a slurry that is distributed across the part and the tip of the tool. Typical grain sizes of the abrasive material range from 100 to 1000, where smaller grains (higher grain number) produce smoother surface finishes.[2] Ultrasonic vibration machining [3]is typically used on brittle materials as well as materials with a high hardness due to the microcracking mechanics.



Electrochemical machining (**ECM**) is a method of removing metal by an electrochemical process. It is normally used for mass production and is used for working extremely hard materials or materials that are difficult to machine using conventional methods.[1] Its use is limited to electrically conductive materials. ECM can cut small or odd-shaped angles, intricate contours or cavities in hard and exotic metals, such as titanium aluminides, Inconel, Waspaloy, and high nickel, cobalt, and rhenium alloys.[2] Both external and internal geometries can be machined.



Electrical discharge machining (**EDM**), also known as **spark machining**, **spark eroding**, **die sinking**, **wire burning** or **wire erosion**, is a metal fabrication process whereby a desired shape is obtained by using electrical discharges (sparks).[1] Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the *tool* or *electrode*, while the other is called the workpiece-electrode, or *work piece*. The process depends upon the tool and work piece not making physical contact.



Electron Beam Machining (EBM) – Introduction

Electron beam machining is a thermal process used for metal removal during the machining process. In the electrical beam machining, electrical energy is used to generate the electrons with high energy. In the Electron Beam Machining process, a high velocity focused beam of electrons are used to remove the metal from the workpiece. These electrons are traveling at half the velocity of light i.e., 1.6 x 10^8 m / s. This process is best suited for the micro-cutting of materials.