WHAT IS A MECHANICAL ACTUATING SYSTEM?

- Devices which can be considered to be motion converters that is, they transform motion from one form to some other required form
  - Eg: Transform linear motion into rotational motion and vice versa.
- Mechanical elements can include the use of linkages, cams, gears, rack-and-pinion, chains, belt drives, etc.
  - Eg: rack-and-pinion can be used to convert rotational motion to linear motion.
  - Force amplification – given by levers
  - Change of speed – given by gears
  - Transfer of rotation about one axis to rotation about another – timing belt

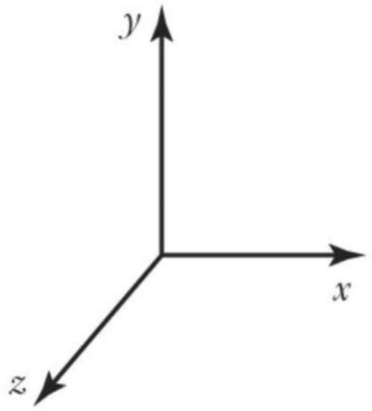
TYPES OF MOTION

Translation motion

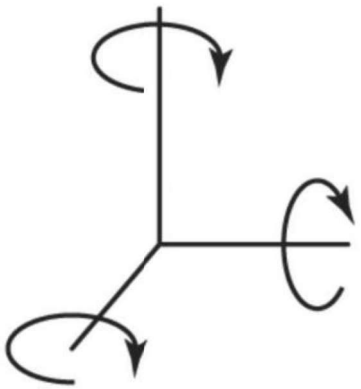
- Movement which can be resolved into components along one or more of the 3 axes.

Rotational motion

- Rotation which has components rotating about one or more of the axes.



Translation motion

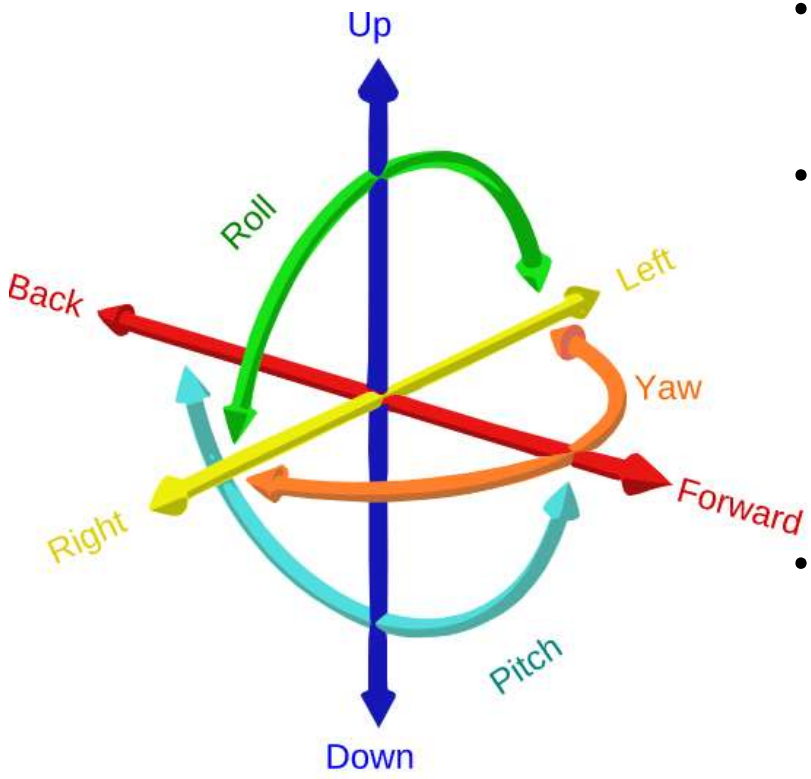


Rotational motion

DESIGN OF MECHANICAL ELEMENTS - DOF

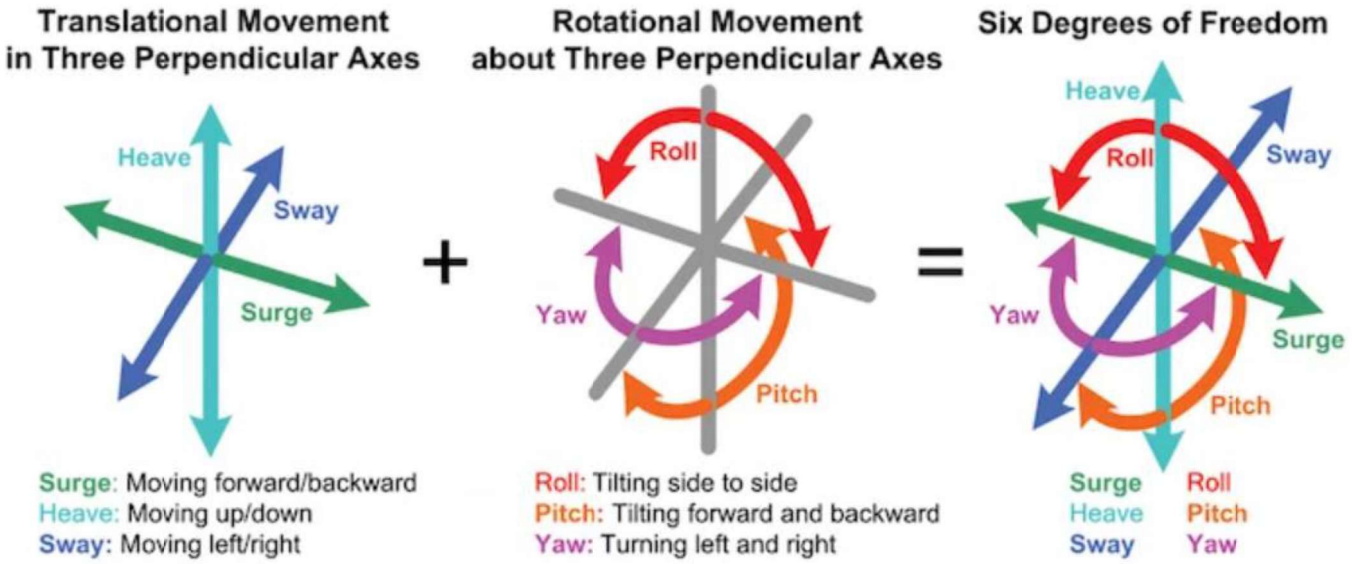
- An importance aspect in the design of mechanical elements is the orientation and arrangement of the elements and parts
- the design of a system to transmit power requires attention to the design and selection of individual components (e.g., gears, bearings, shaft)
- A body that is free in space can move in three, independent, mutually perpendicular directions and rotate in three ways about those directions.
- It is said to have six degrees of freedom (DOF).
- The number of degree of freedom is the number of components of motion that are required in order to generate the motion

WHAT ARE THE 6 DEGREES OF FREEDOM?



Translation in XYZ, and rotation in XYZ

- A point in space requires 6 independent quantities (DOF) to define its position and orientation.
- **Translational envelopes :**
  - Moving forward and backward on the X-axis. (Surge)
  - Moving left and right on the Y-axis. (Sway)
  - Moving up and down on the Z-axis. (Heave)
- **Rotational envelopes :**
  - Tilting side to side on the X-axis. (Roll)
  - Tilting forward and backward on the Y-axis. (Pitch)
  - Turning left and right on the Z-axis. (Yaw)



The translational and rotational movements that combine to form the six degrees of freedom. Image used courtesy of Honeywell

KINEMATIC CHAIN

Prerequisites

- Links
- Joints

WHAT IS A KINEMATIC CHAIN?

Kinematic chain is one in which number of links are so connected that relative motion of any point on a link with respect to any other point on the other link follows a governing law

$$L = 2/3(J+2)$$

$$J = 3/2(L)-2$$

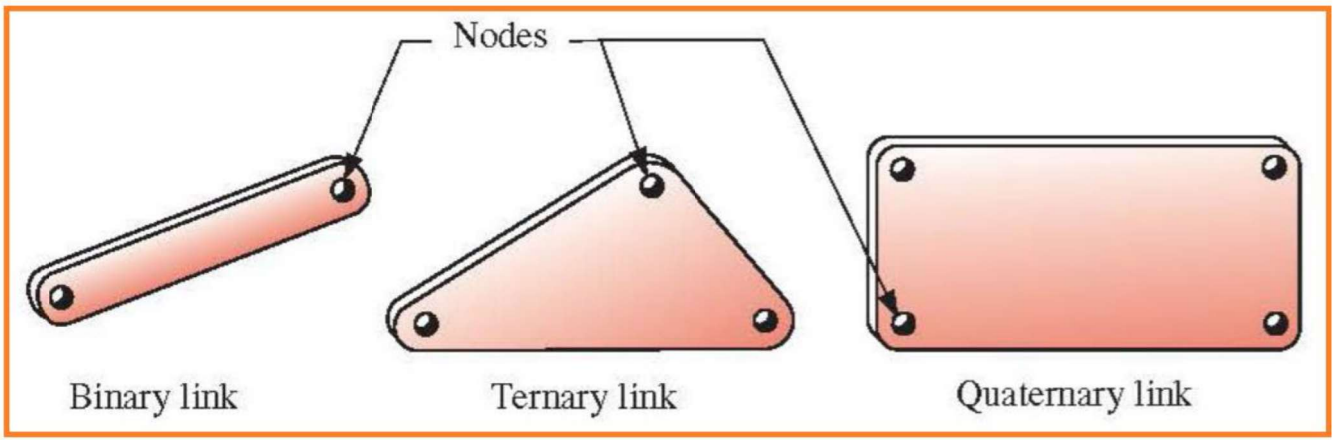
Where,

L = Number of links,

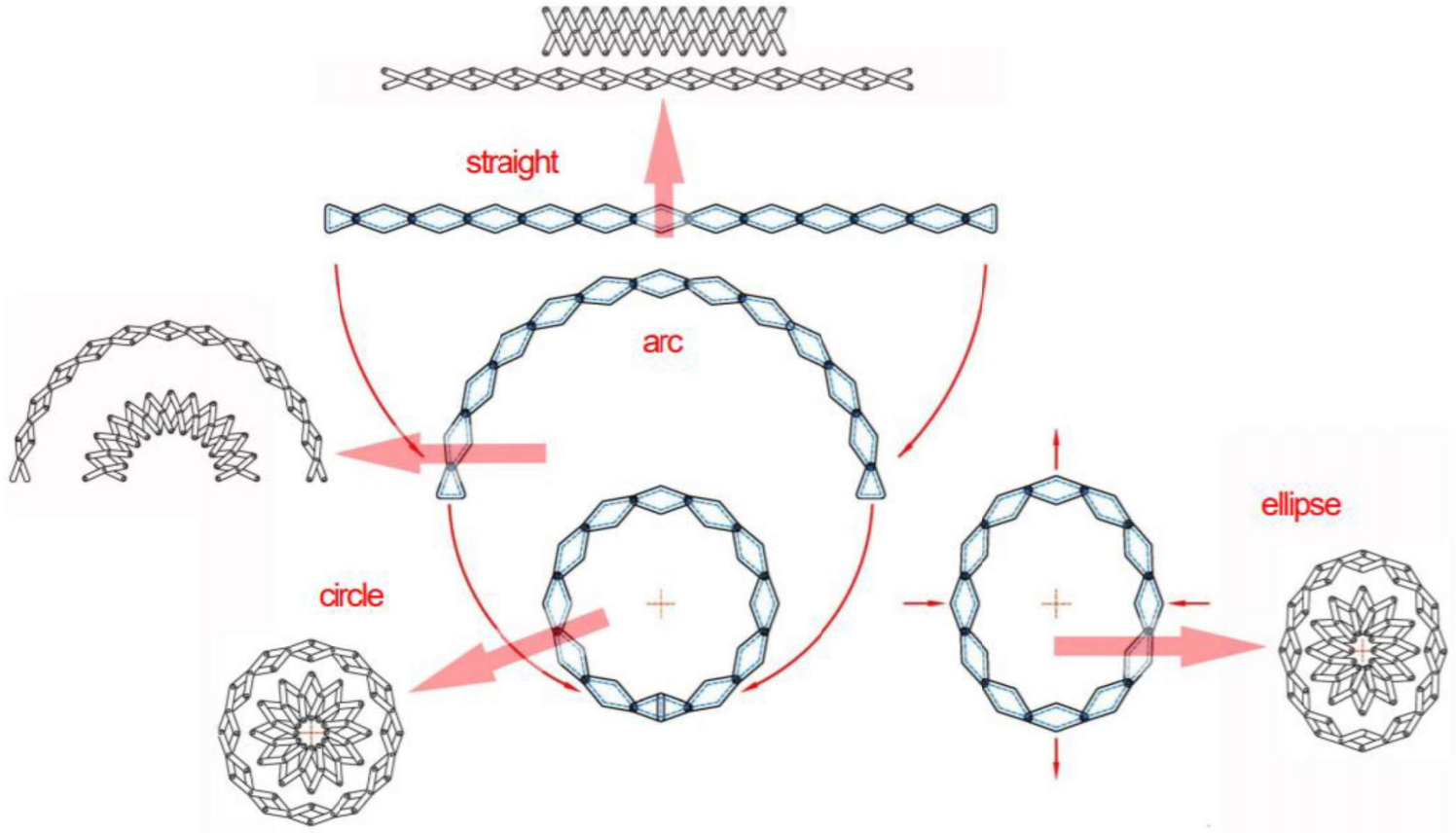
J = Number of Joints

WHAT IS A LINK?

A rigid body which possesses at least two nodes which are points of attachments to other links



‘SHAPING’ TECHNIQUE TO CREATE EXPANDING LINKAGES



WHAT IS A JOINT?

A connection between two or more links which allows some motion.

Revolute Joint allows relative rotational motion but constrains relative translation

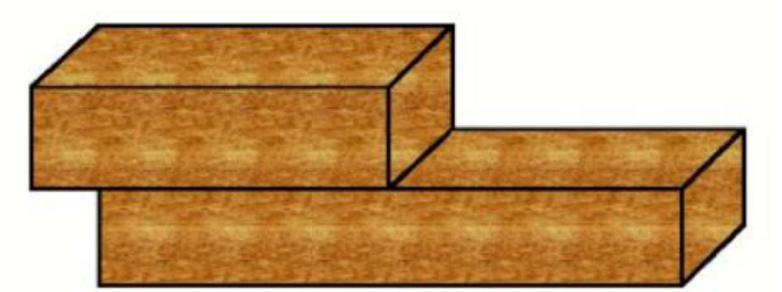
Prismatic Joint allows relative translation in one direction, but constrains relative rotation and translation in the other direction

WHAT IS A LOWER PAIR JOINT?

Lower Pair It is a pair of link which has surface to surface or area contact between members

Eg: Nut and Screw Assembly, Slider and Slotted Link

Where motion is transmitted over a surface or area

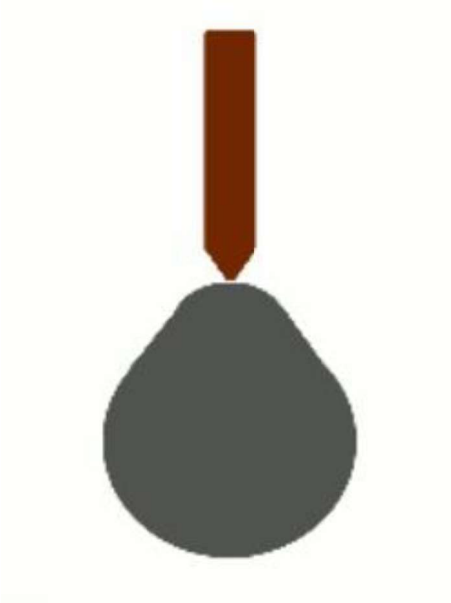


WHAT IS A HIGHER PAIR JOINT?

If a pair has point or line contact between links or member

Eg: Cam And Follower, Ball Bearing

Where motion is transmitted over a line or point



Cam & Follower

KUTZBACH CRITERIA

Kutzbach Criteria is for determining Degree of Freedom of body in Planar Mechanism (2D)

$$DOF = 3(L-1) - 2J - H$$

Here:

L = Number of Link

J = Number Of Lower Pair

H = Number Of Higher Pair

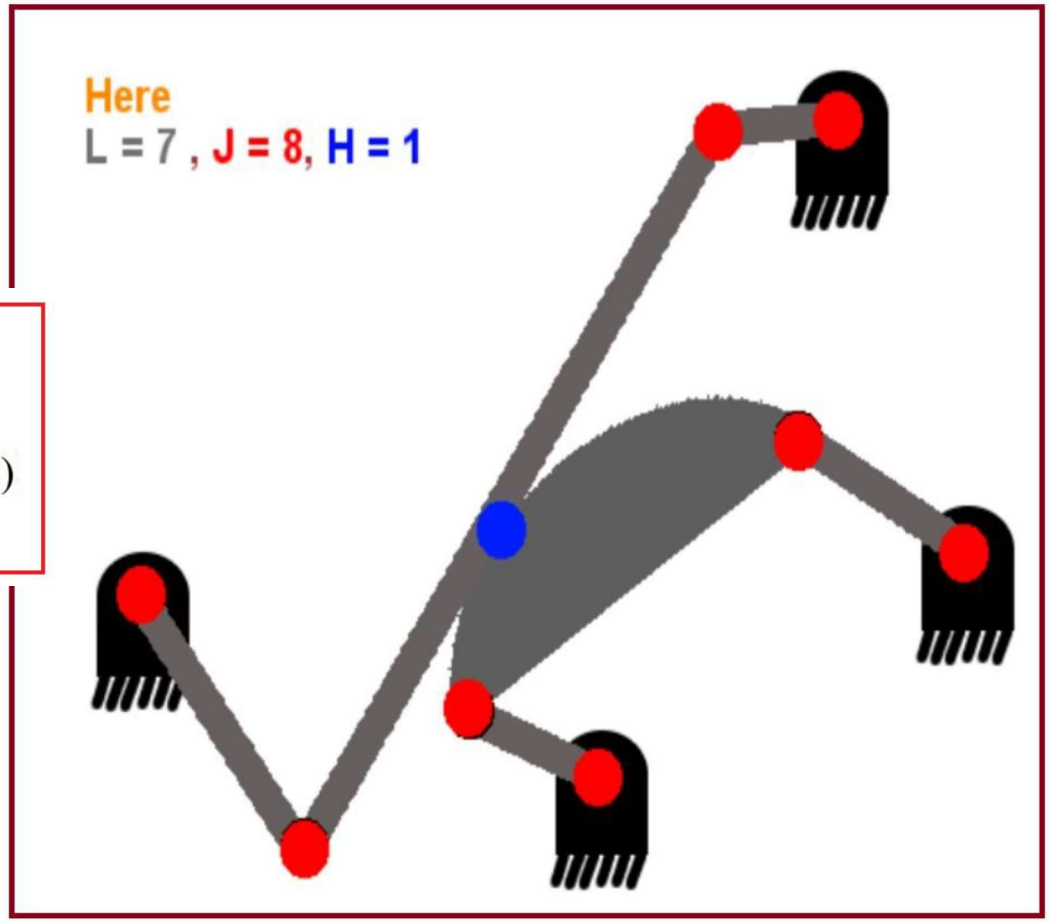
EXAMPLE

Formula

DOF = 3 (L-1) – 2 J – H

= 3 (7-1) – 2 (8) – (1)

= 1



GRUBLER'S CRITERIA

When Higher Pair (H) = 0 in Kutzbach Criteria then the Equation procured is Grubler's Criteria

$$DOF = 3(L-1) - 2J$$

Here:

L = Number of Link

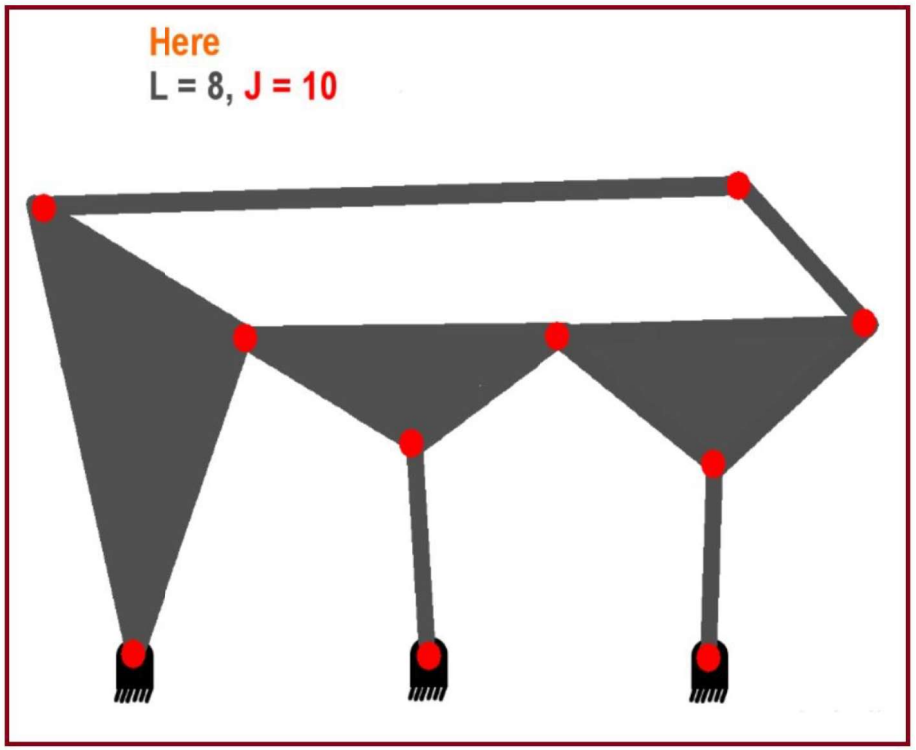
J = Number Of Lower Pair

Formula

DOF = 3 (L-1) – 2 J

= 3 (8-1) – 2 (10)

= 1



CONT...

It is possible to obtain from one kinematic chain a number of different mechanisms by having a different link as the fixed one.

The design of many mechanisms are based on two basic forms of kinematic chains

- the four-bar chain
- the slider-crank chain

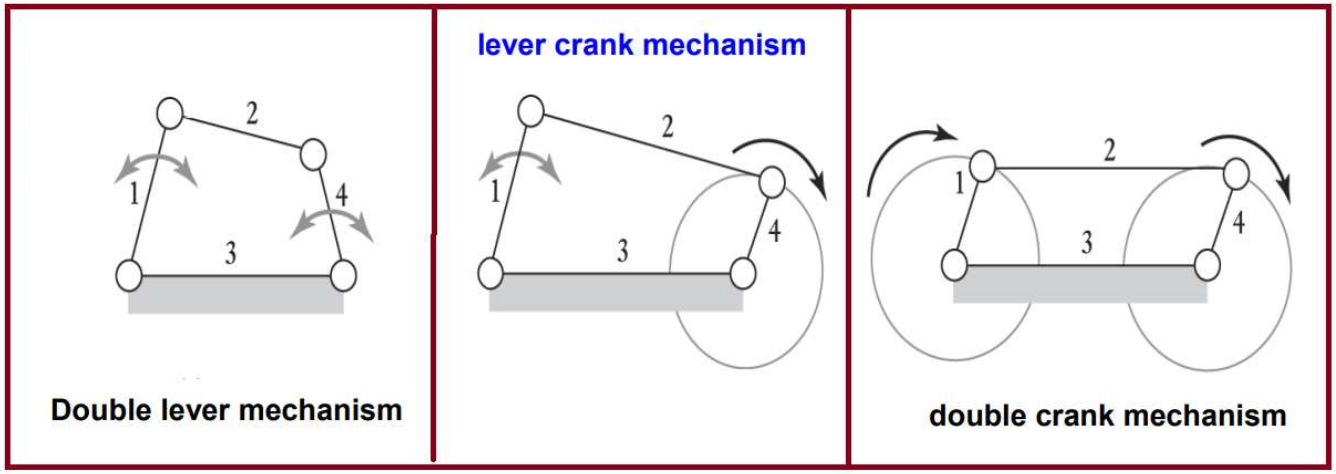
WHAT IS A 4 BAR CHAIN?

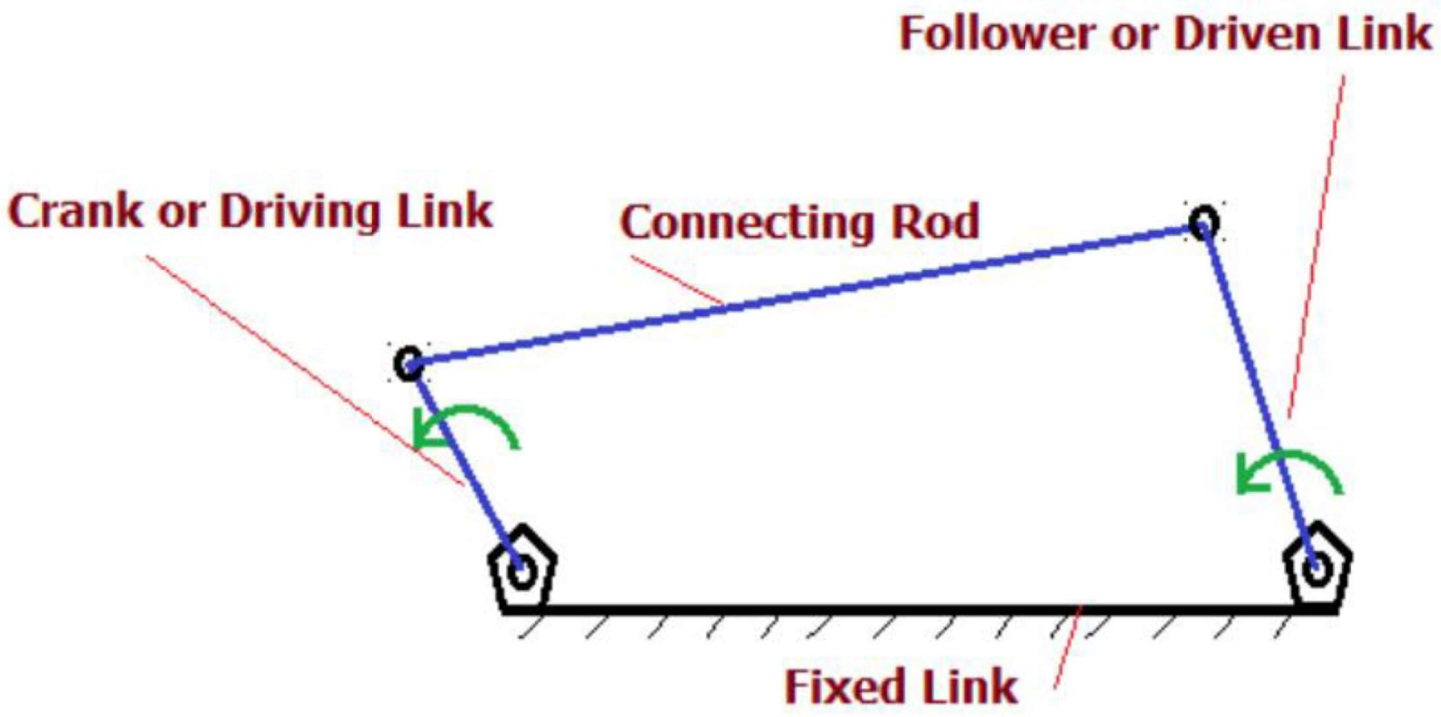
Consists of 4 links and 4 joints with two grounded points, about which turning can occur

Crank-rocker mechanism: In a four bar linkage, if the shorter side link revolves and the other one rocks (*i*.e., oscillates), it is called a *crank-rocker mechanism*.

Double-crank mechanism: In a four bar linkage, if both of the side links revolve, it is called a *double-crank mechanism*.

Double-rocker mechanism: In a four bar linkage, if both of the side links rock, it is called a *double-rocker mechanism*.





Mechanism (one link is fixed for a chain)

GRASHOF'S LAW

Determines whether continuous rotation is possible

"The sum of lengths of shortest and longest link should not be greater than the sum of the remaining link lengths if there is to be continuous relative motion between the links"

Example, Linkage mechanism of excavator and its system

$$\Sigma(s+l) \leq \Sigma(p+q)$$

If this is true the mechanism will rotate continuously

s = length of shortest bar
l = length of longest bar
p, q = lengths of intermediate bar

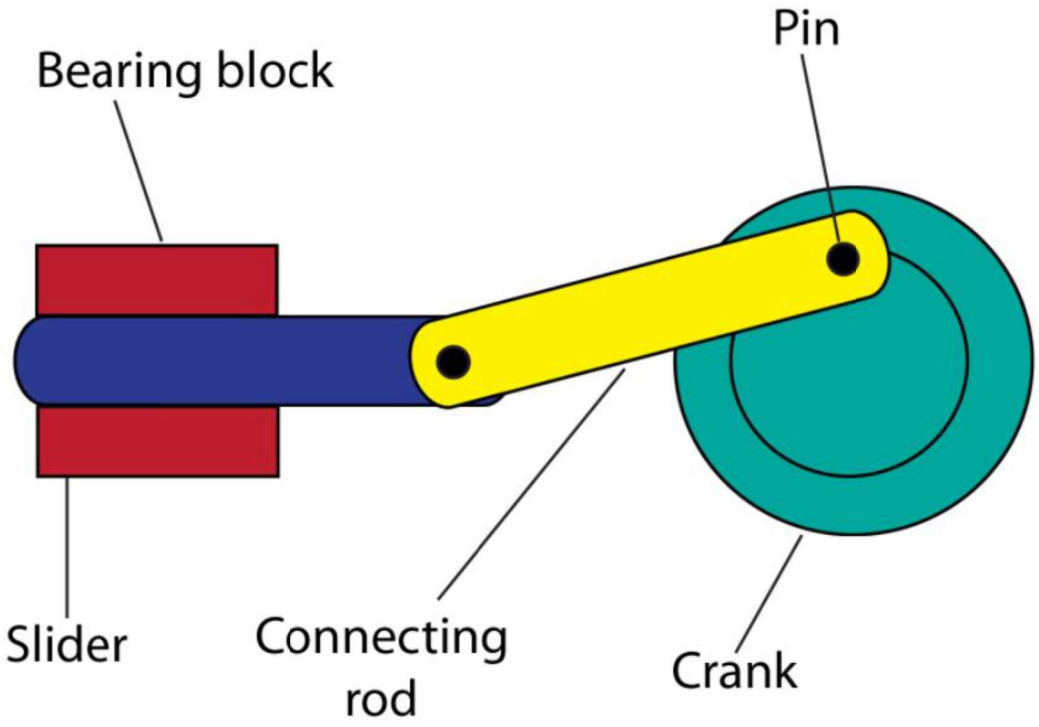
SLIDER–CRANK MECHANISM

- Converts the rotary motion of a crank to linear motion of a slider and vice versa based on application
- Circular wheel/Crank is free to rotate 360 degrees while connecting rod oscillates back and forth as one end of connecting rod attached with circular wheel/crank and another end connected to a slider which restricts it to linear motion
- Either crankshaft or slider can be the driver for this mechanism

crank -> the rotating disc

slider -> slides inside the tube

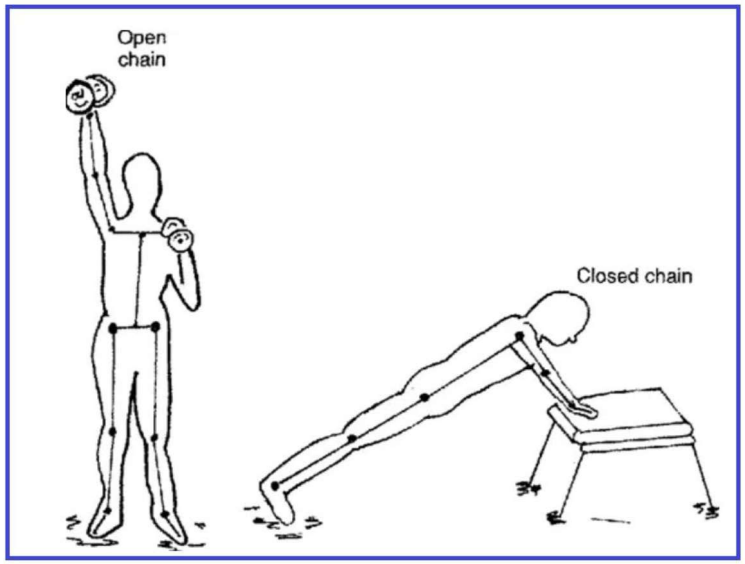
connecting rod -> joins the parts together



OPEN AND CLOSED KINEMATIC CHAIN?

Where an assembly of links and joins are connected in a way to provide a controlled output in response to an input

Closed kinematic chains restrict (or constrain) the motion of the system



THE CRITERION FOR A CHAIN TO BE CONSTRAINED:

$$J+H/2 = 3/2(L)-2,$$

Where,

H = Number of Higher pairs and

J =Number of binary joints in the chain
If R.H.S. = L.H.S.

Chain is said to be locked

VIDEOS

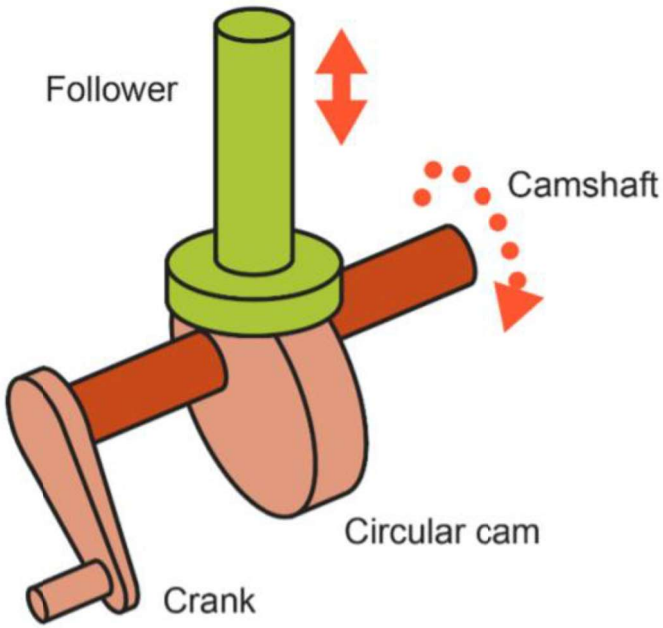
https://www.youtube.com/watch?v=3eVQA6AyE7A

https://www.youtube.com/watch?v=VHz155TZs-8

https://www.youtube.com/watch?v=3eVQA6AyE7A

CAMS AND GEARS

CAM & FOLLOWER



A cam is a mechanical device used to transmit motion to a follower by direct contact

The driver is called the cam and the driven member is called the follower

An axle or camshaft is rotated to provide movement.

Shaped pieces of material called cams are attached to the camshaft and rotated.

Followers are moved up and down along a straight path as the cam rises and falls.

WHAT IS A CAM?

A body which rotates or oscillates, and in doing so imparts a reciprocating motion to a second body - the follower.

What is the rise of a cam?

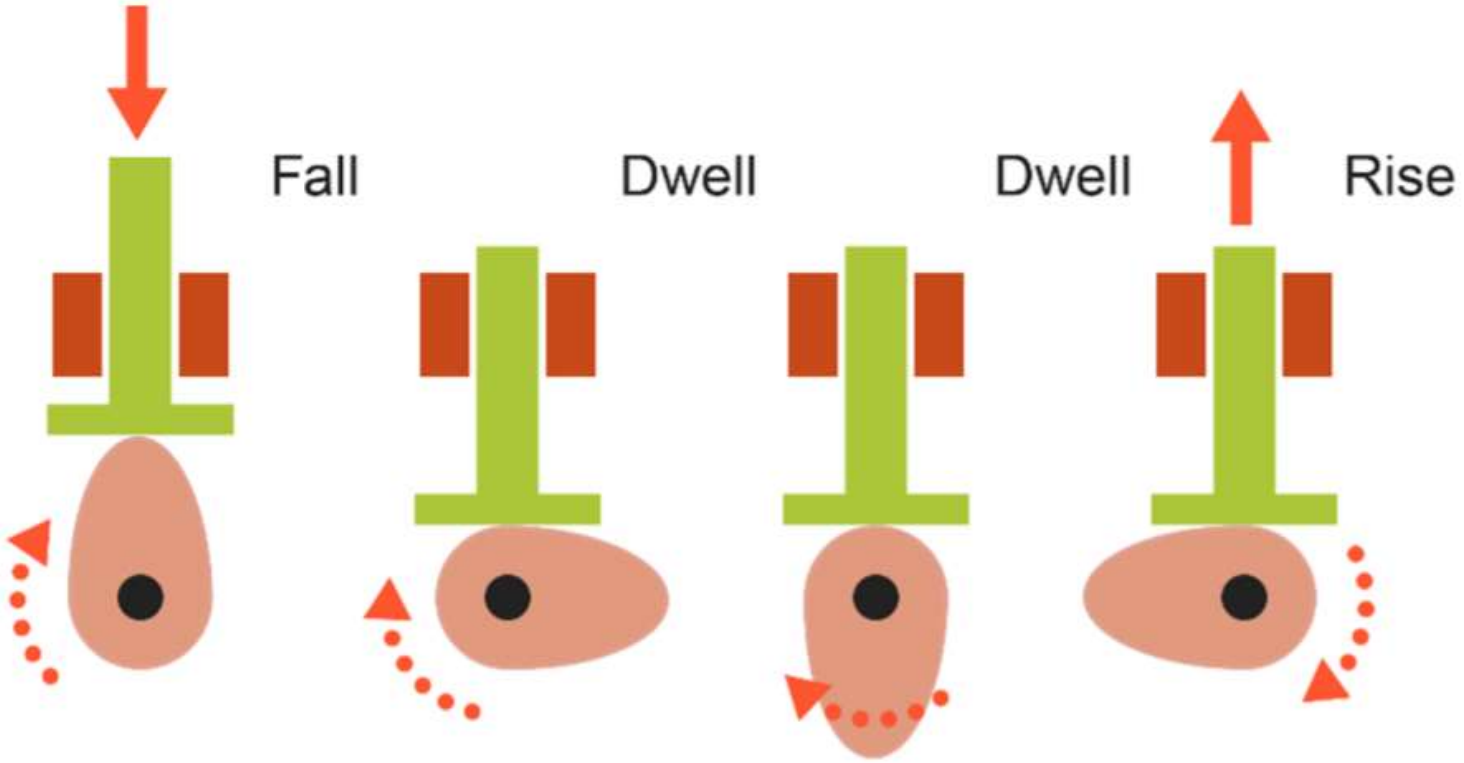
- The part that determines how quickly the follower will be lifted

What is the fall of the cam?

- The part that determines how quickly the follower will fall

What is the dwell of the cam?

- The part that allows the follower to remain at a certain height for a certain period of time



- Rise is when the follower goes up
- Fall is when the follower goes down
- Dwell is when the follower doesn't rise or fall

TYPES OF CAM (BASED OH SHAPE)

eccentric cam

- An eccentric cam is circular shaped with an off-centre hole. It has a steady rise and fall with little dwell.

snail cam

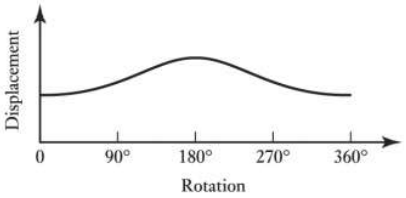
- A snail cam has a steady rise followed by a sudden fall. It has a long dwell and can only be used in one direction.

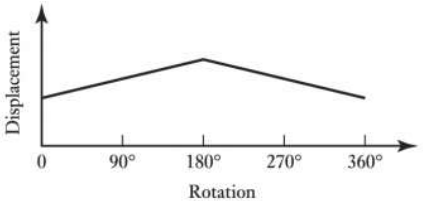
pear cam

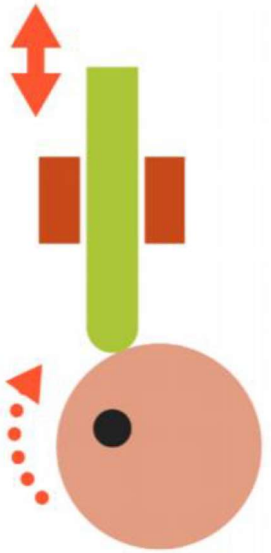
- A pear shaped cam has a rise and fall for half the rotation followed by a long dwell.

heart cam

- A heart shaped cam has smooth and gentle rise and fall. It has no dwell and is also known as a constant velocity cam.







Eccentric cam

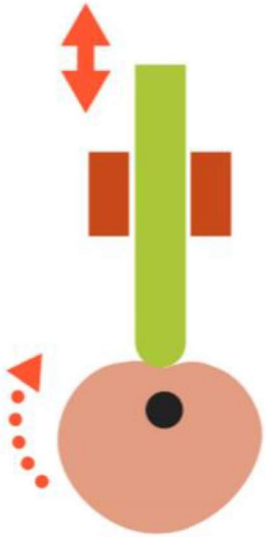
Has a steady rise and fall with little dwell.

Snail cam

Has a steady rise followed by a sudden fall. It has a long dwell. Can only be used in one direction.

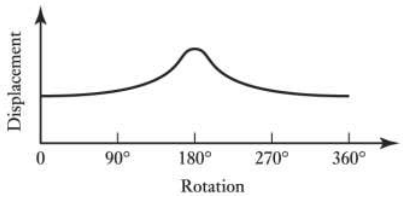
Pear cam

Has a rise and fall for half the rotation followed by a long dwell.

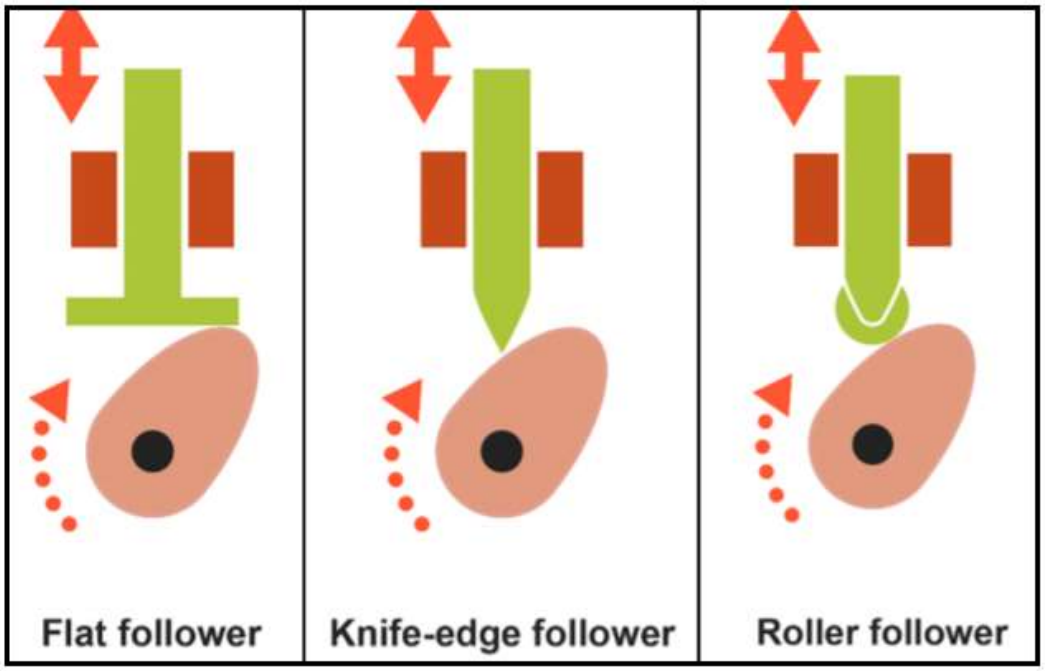


Heart cam

Has smooth and gentle rise and fall. Has no dwell. Also known as constant velocity cam.



COMMONLY USED CAM FOLLOWERS

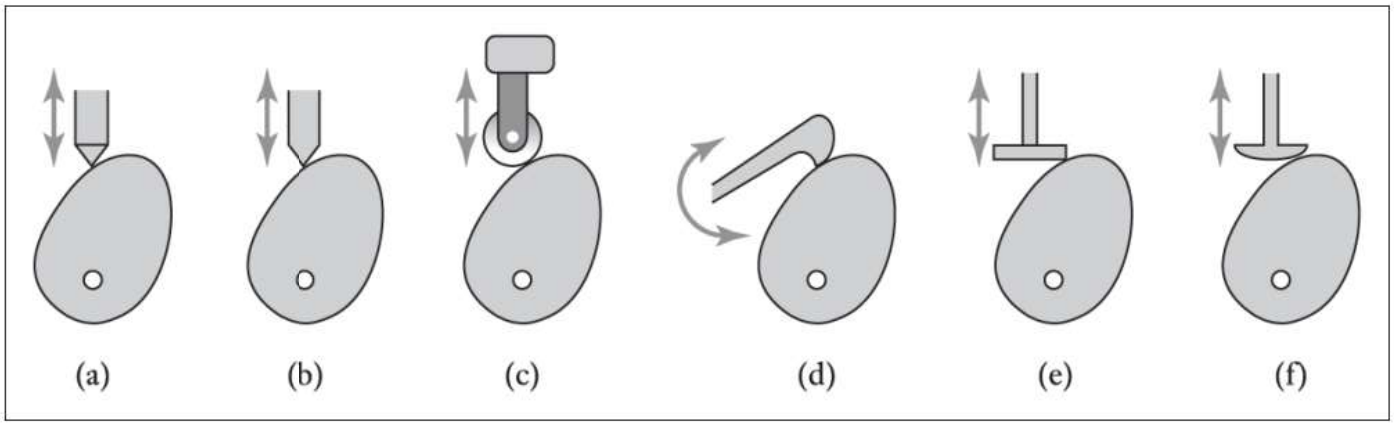


High levels of friction and are not very accurate but are good under load.

Accurately track cams and have low friction. Prone to wear on tip and not good with weight.

Track cams with some accuracy, have very low friction and are good under load. Use of bearings helps.

OTHER TYPES OF CAM FOLLOWERS



Cam followers: (a) point, (b) knife, (c) roller, (d) sliding and oscillating, (e) flat, (f) mushroom

VIDEOS

https://www.youtube.com/watch?v=Ibs10c9FX0M

https://www.youtube.com/watch?v=HsXWewecMLE

ANIMATIONS-CAM-USES

- https://technologystudent.com/cams/cam10.htm
- https://technologystudent.com/cams/snail1.htm
- https://technologystudent.com/cams/cam1.htm
- https://technologystudent.com/cams/swash1.htm

GEAR

- A circular toothed object used to transfer rotary motion and torque (a measure of how much a force acting on an object causes the object to rotate) through interlocking teeth.
- Transfer motion or power from one moving part to next
- Application - Anywhere there are engines and motors making rotational motion
- Purpose
  - Reverse direction of rotation
  - Increase or decrease speed rotation
  - Move rotational motion to a different axis
  - Keep rotation of two axis synchronized

FORMS OF GEARS

Spur Gear

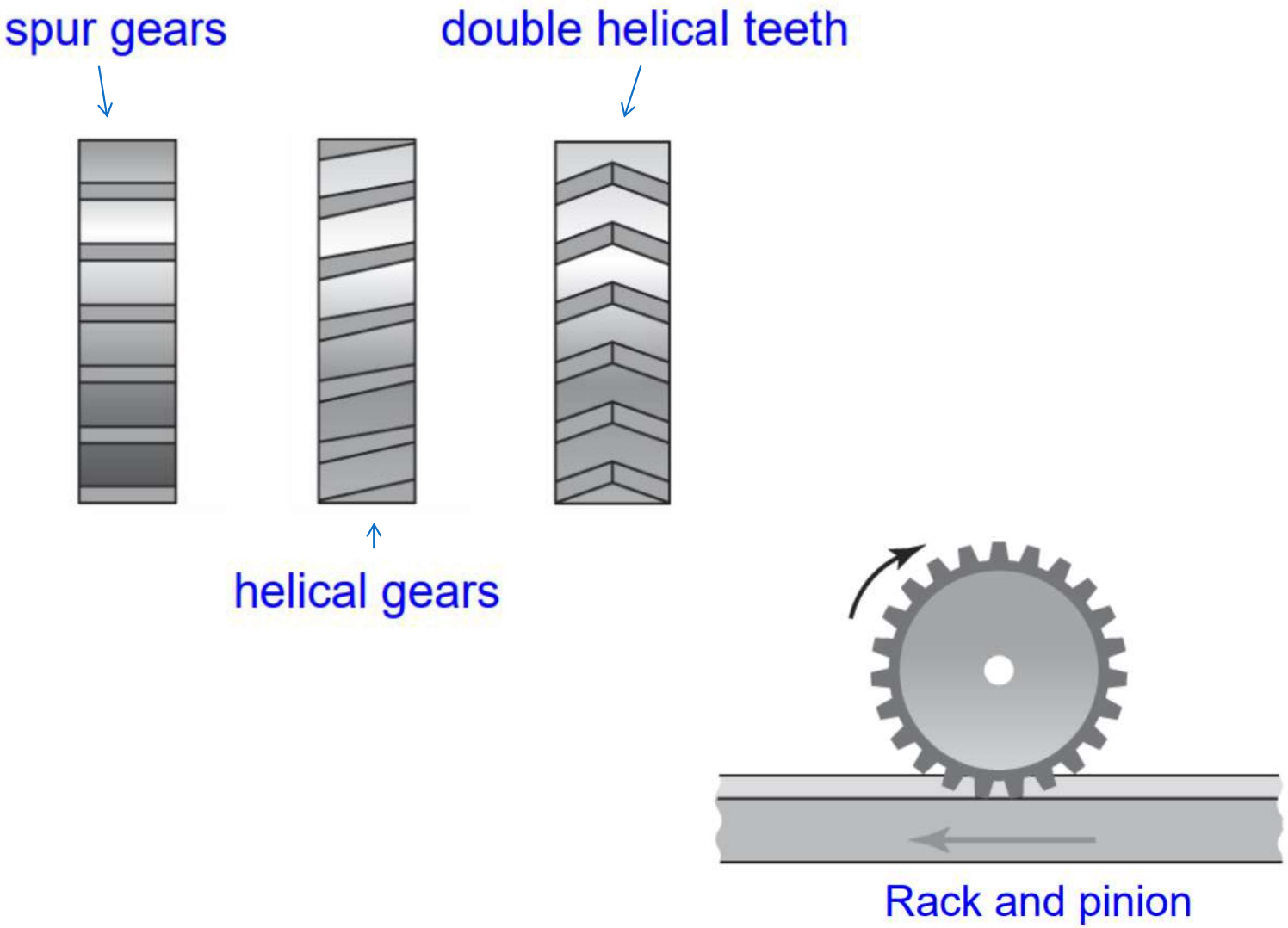
- a gearwheel with teeth projecting parallel to the wheel's axis

Helical gears

- helical teeth with teeth being cut on helix
- helical gears have the advantage of smoother drive and prolonged life of gears, however, the inclination of the teeth results in an axial force component on the shaft bearing which can be overcome by using double helical teeth.

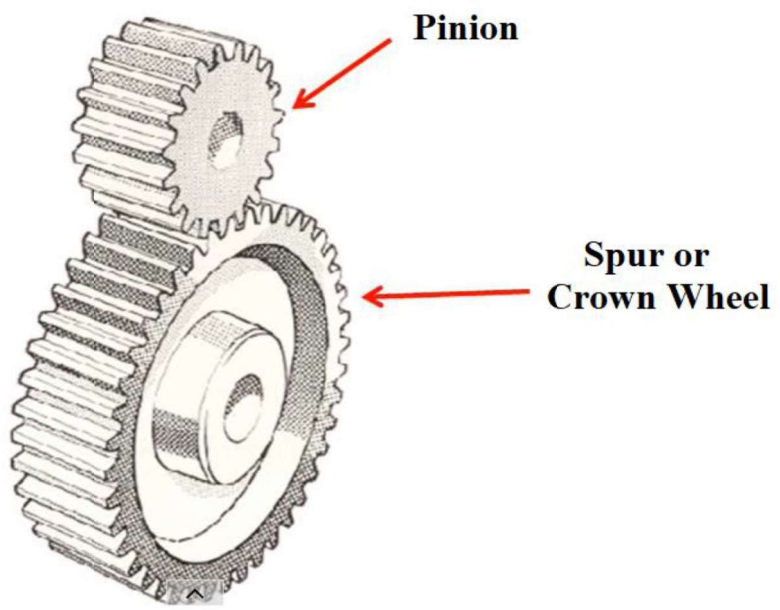
Rack and Pinion

- A rotating gear that meshes with a bar that has gear teeth along its length.
- Changes rotating motion into linear motion.
- Used for big increase in torque.


spur gears
double helical teeth
helical gears
Rack and pinion

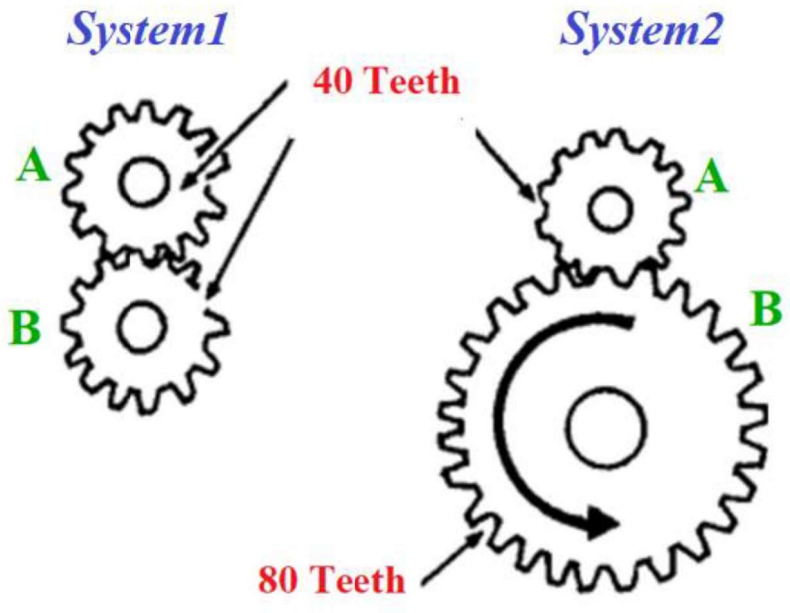
TWO MESHED GEARS

When two gears in mesh; the larger gear wheel is called the **spur** (or crown wheel), the smaller is called the **pinion**



GEARS RATIO

- Difference of speed between motor and endpoint
- Example: Consider meshed wheels A & B .
  - System1 -> A with 40 teeth and B with 40 teeth
  - System2 -> A with 40 teeth and B with 80 teeth
- Wheel B must have twice the diameter of wheel A.



- The **gear ratio** is calculated by dividing the output speed by the input speed (i= Ws/ We) or by dividing the number of teeth of the driving **gear** by the number of teeth of the driven **gear** (i= Ze/ Zs)

System1

$$\frac{\omega_A}{\omega_B} = \frac{No\ of\ teeth\ on\ B}{No\ of\ teeth\ on\ A} = \frac{40}{40}$$

$$\omega_A = \omega_B$$

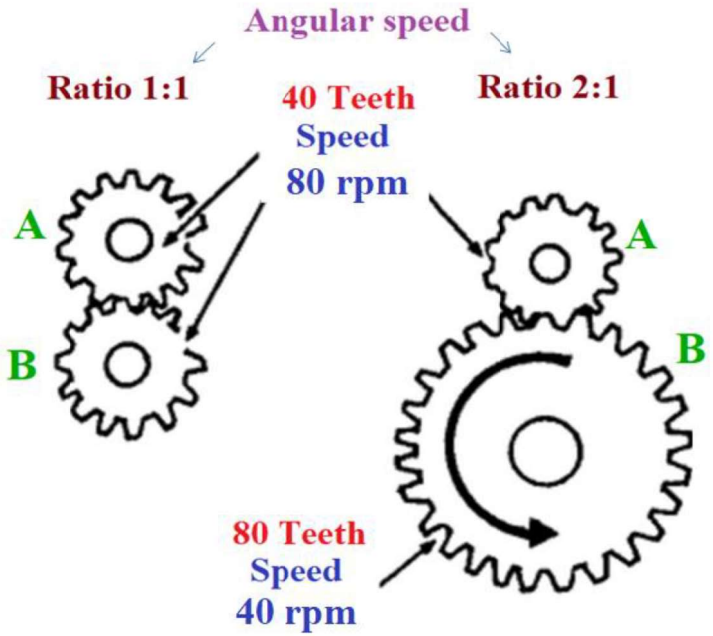
$$G = \frac{\omega_A}{\omega_B} = \frac{d_B}{d_A} = gear\ ratio = 1$$

System2

$$\frac{\omega_A}{\omega_B} = \frac{No\ of\ teeth\ on\ B}{No\ of\ teeth\ on\ A} = \frac{80}{40} = 2$$

$$\omega_A = 2\omega_B$$

$$G = \frac{\omega_A}{\omega_B} = \frac{d_B}{d_A} = gear\ ratio = 2$$



Number of teeth /Diameter -> gives gear ratio

GEAR TRAIN

A connected set of rotating gears that transmits power from an input to an output

A group of 2 or more gears meshed together to transfer power

Two attributes that can be controlled by gear train

- Speed
- Torque

SIMPLE GEAR TRAIN

Driving gear

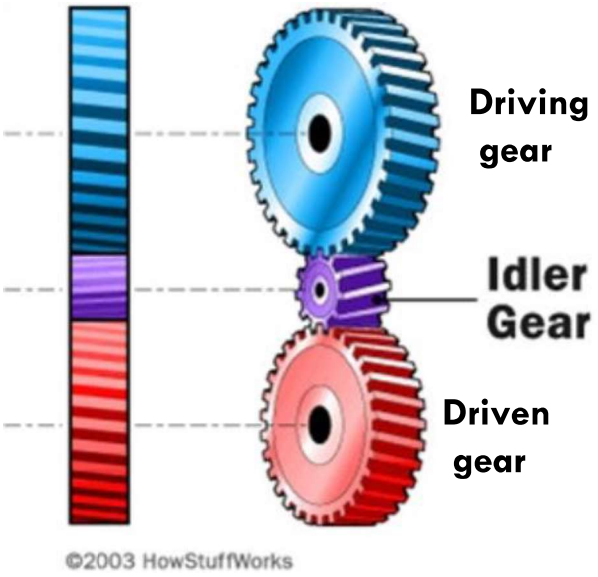
- input gear
- The gear that supplies force to another gear/connected to input

Driven Gear

- output gear / Follower gear
- The member of a pair of gears to which motion and power are transmitted by the other. The output gear

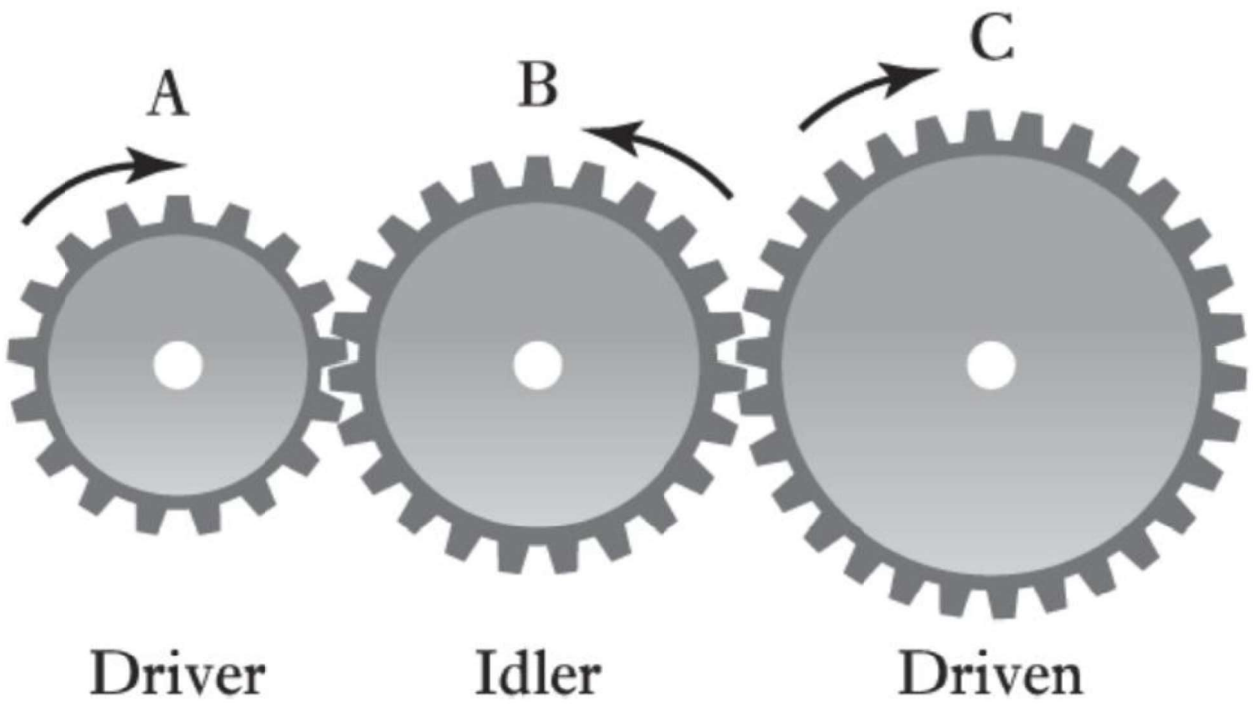
Idler gear

- A gear between the driver and the driven gear used to change rotational direction



Formula

$$\text{Gear ratio} = \frac{\text{Driven teeth}}{\text{Driver teeth}}$$



$$G = \frac{\omega_A}{\omega_C} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C}$$

COMPOUND GEAR TRAIN

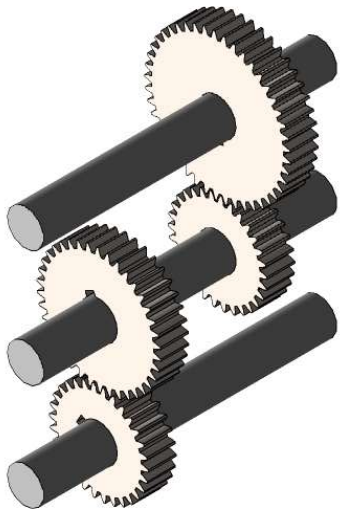
This term is used to describe a gear train when two (or more) wheels are mounted on a common shaft.

(or)

An assembly of two gears of different sizes, fixed to a single axle.

Also called a stacked gear.

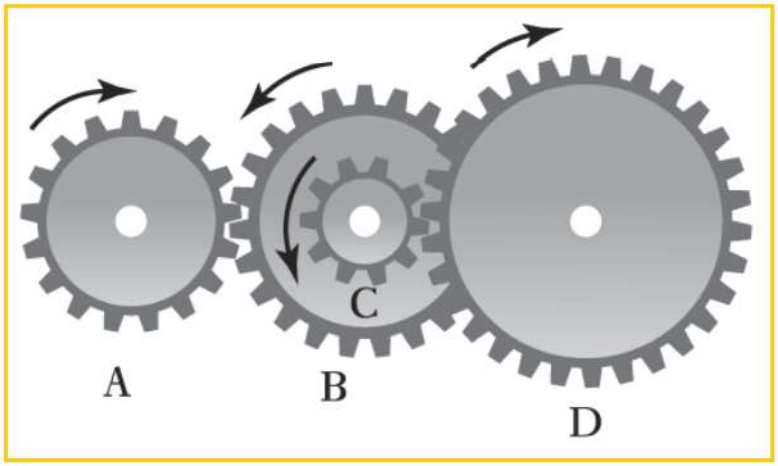
When two wheels are mounted on the same shaft, they have the same angular velocity.

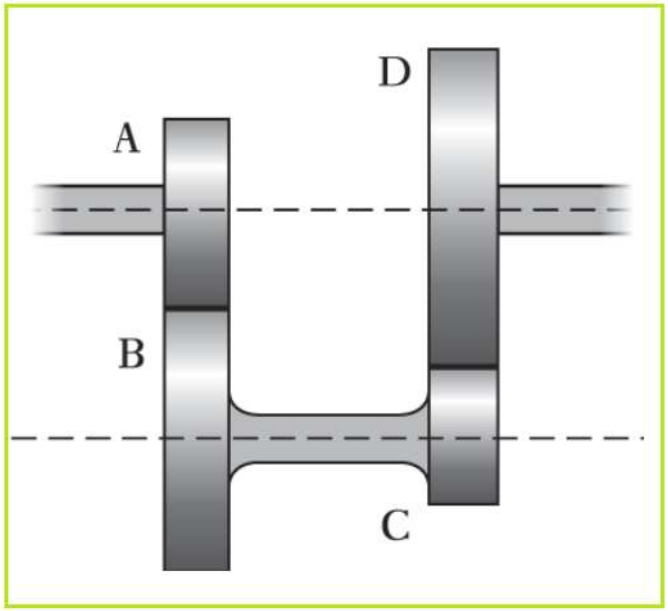


$$\omega_B = \omega_C$$

The over all gear ratio

$$G = \frac{\omega_A}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C} \times \frac{\omega_C}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_C}{\omega_D}$$





For the input and output shafts to be in line

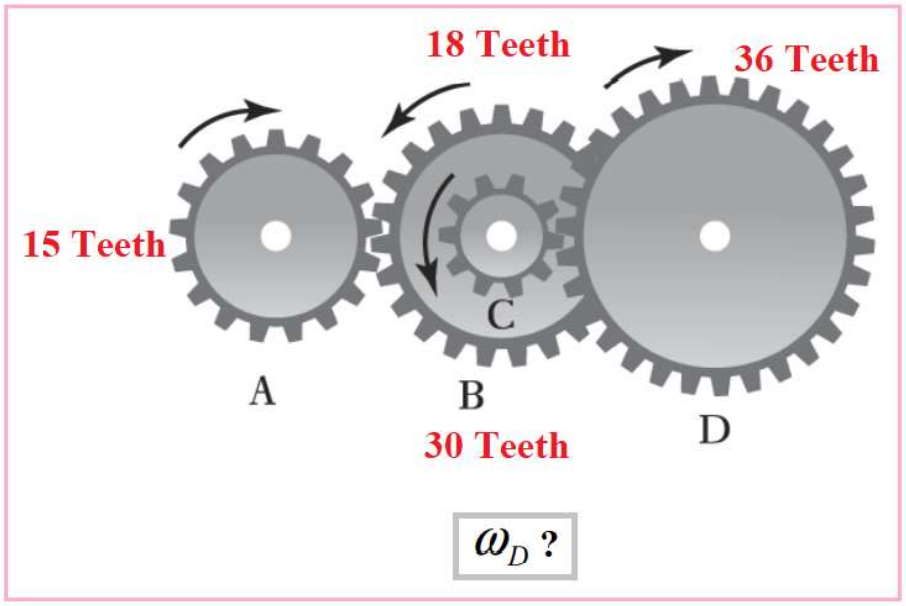
$$d_A + d_B = d_C + d_D$$

Example:

If A has 15 teeth, B 30 teeth, C 18 teeth and D 36 Teeth. Find the angular speed of D if A speed is 160 rpm

Sol:

Since the angular speed of a wheel is inversely proportional to the number of teeth on the wheel, the overall gear ratio is



$$G = \frac{30}{15} \times \frac{36}{18} = 4 = \frac{\omega_A}{\omega_D}$$

$$\omega_D = \frac{\omega_A}{4} = 160/4 = 40 \ \ rpm$$

VIDEO

https://www.youtube.com/watch?v=ihGFUAAwj7g

https://www.youtube.com/watch?v=BKjo8Usp21k

PNEUMATIC AND HYDRAULIC ACTUATING SYSTEMS

INTRODUCTION

- Use pressurized fluid to transmit power

What are the 2 fluids?

- liquids (hydraulics)
- gas (pneumatics)

- The Hydraulic fluid power system is usually selected when an application requires a high operating pressure.

- The Pneumatic fluid power system can usually provide the best solution where lightweight and easily handled tools are a requirement.

- Hydraulic/Pneumatic Amplifying Elements employing various types of valves or constrictions, to get significant variation in pressure with small variation in the input parameters

COMPARISON

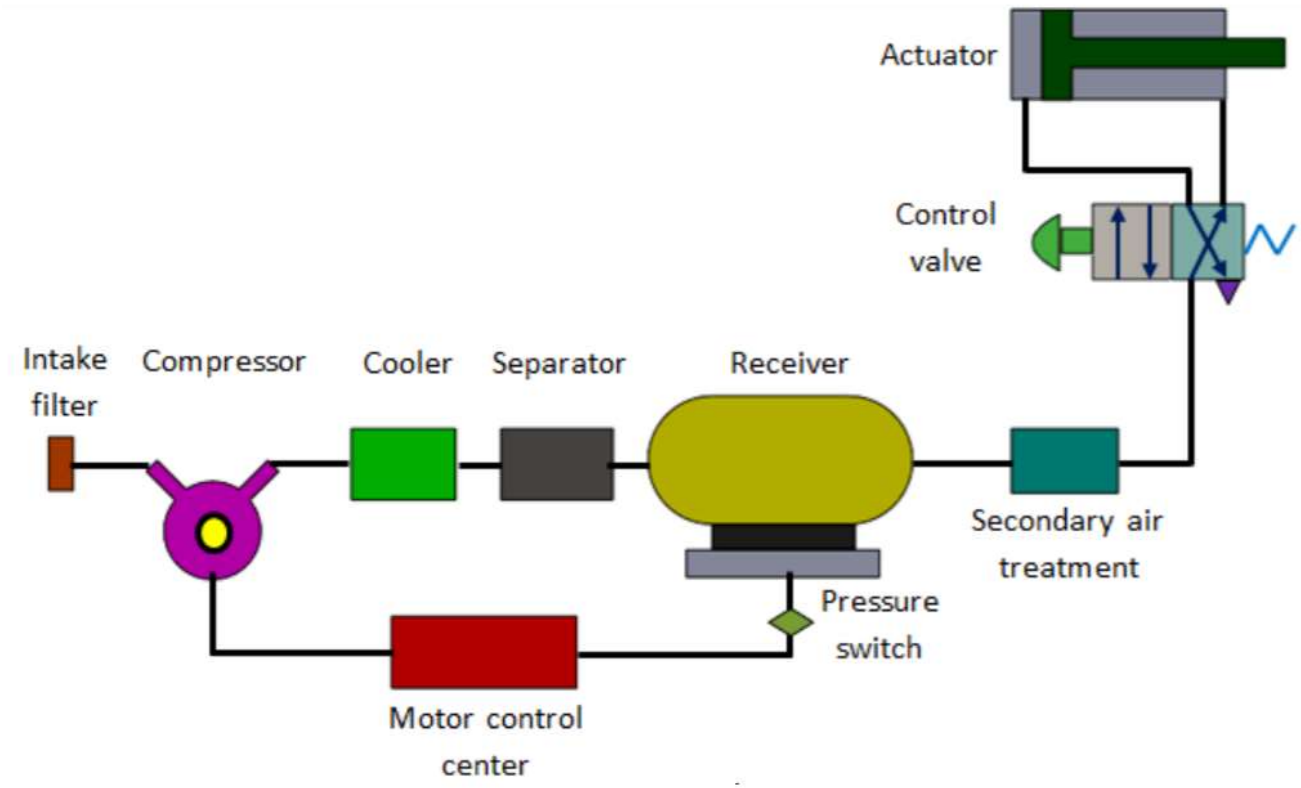
S. No.	Hydraulic System	Pneumatic System
1.	It employs a pressurized liquid as a fluid	It employs a compressed gas, usually air, as a fluid
2.	An oil hydraulic system operates at pressures up to 700 bar	A pneumatic system usually operates at 5–10 bar
3.	Generally designed as closed system	Usually designed as open system
4.	The system slows down when leakage occurs	Leakage does not affect the system much
5.	Valve operations are difficult	Valve operations are easy
6.	Heavier in weight	Lighter in weight
7.	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gases
8.	The system is unsafe to fire hazards	The system is free from fire hazards
9.	Automatic lubrication is provided	Special arrangements for lubrication are needed

PNEUMATIC ACTUATORS

- It converts energy, in the form of compressed air into mechanical motion
- Consists of a piston on a diaphragm
- Main principle – Has a cylinder, keeps the air in the upper portion, allowing air pressure to force the diaphragm/piston to create the mechanical movement. (usually opening/closing of a valve)

1. CYLINDER

- Double acting (air actuation of movement in both directions) or spring return
- In either case, the valve controlling the cylinder must provide an exhaust route for air trapped within the cylinder, to be released in the atmosphere.
- Force F exerted by the air is $F = p \times A$.
- Friction must be subtracted from this
- The typical max operating speed of a cylinder for pneumatic actuation is 2 m/s


Actuator
Control valve
Intake filter
Compressor
Cooler
Separator
Receiver
Secondary air treatment
Pressure switch
Motor control center

COMPONENTS OF A PNEUMATIC SYSTEM

Air filters: filter out the contaminants from the air

Compressor: generates Compressed air. Air compressors are either diesel or electrically operated.

Air cooler: Reduces air temperature which was increased during compression operation

Dryer: water vapor or moisture in the air is separated from the air

CONTD...

Control Valves: used to regulate, control and monitor for control of direction flow, pressure etc.

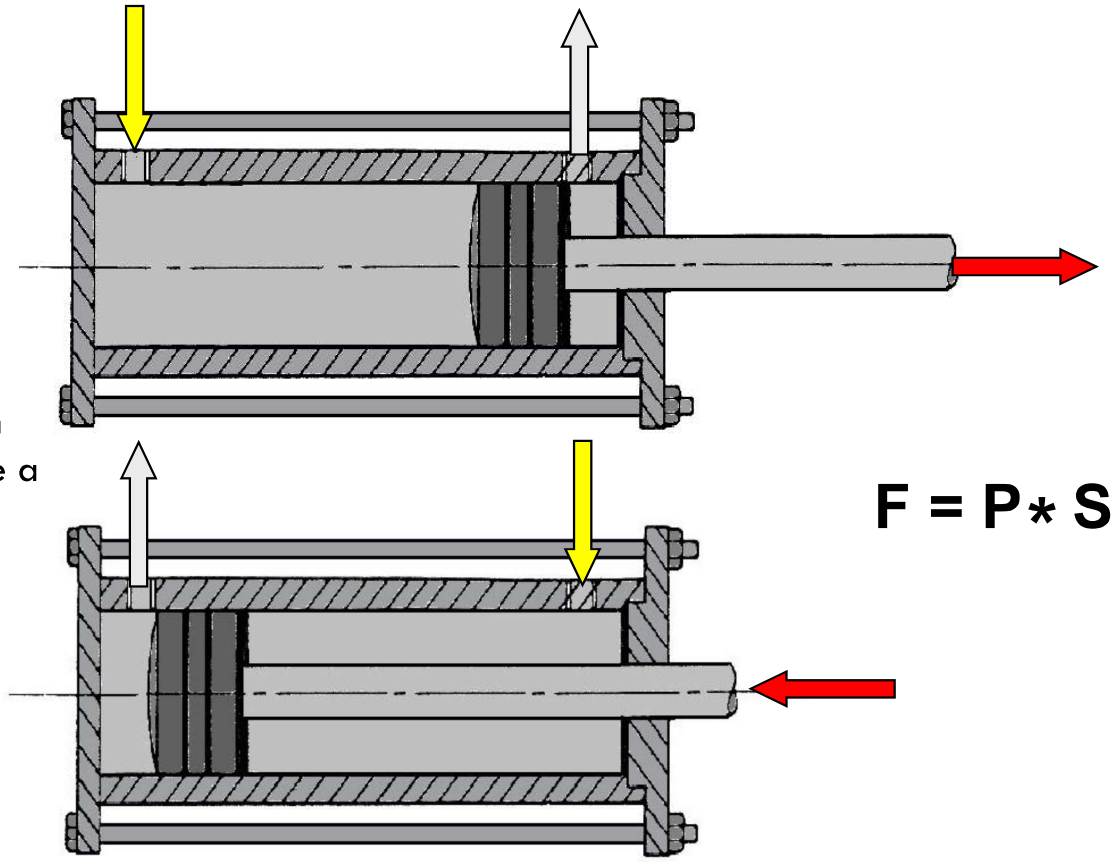
Air Actuator: Air cylinders and motors are used to obtain the required movements of mechanical elements of pneumatic system.

Electric Motor: Transforms electrical energy into mechanical energy. It is used to drive the compressor.

Receiver tank: The compressed air coming from the compressor is stored in the air receiver

Double effect pneumatic cylinders

double acting-air actuation of movement in both directions or have a spring return



$$F = P * S$$

Double-acting cylinders are able to produce force in both directions by applying pneumatic fluid pressure to either side of the piston

WHAT ARE DIFFERENT TYPES OF DOUBLE-ACTING CYLINDERS?

double-rod cylinders

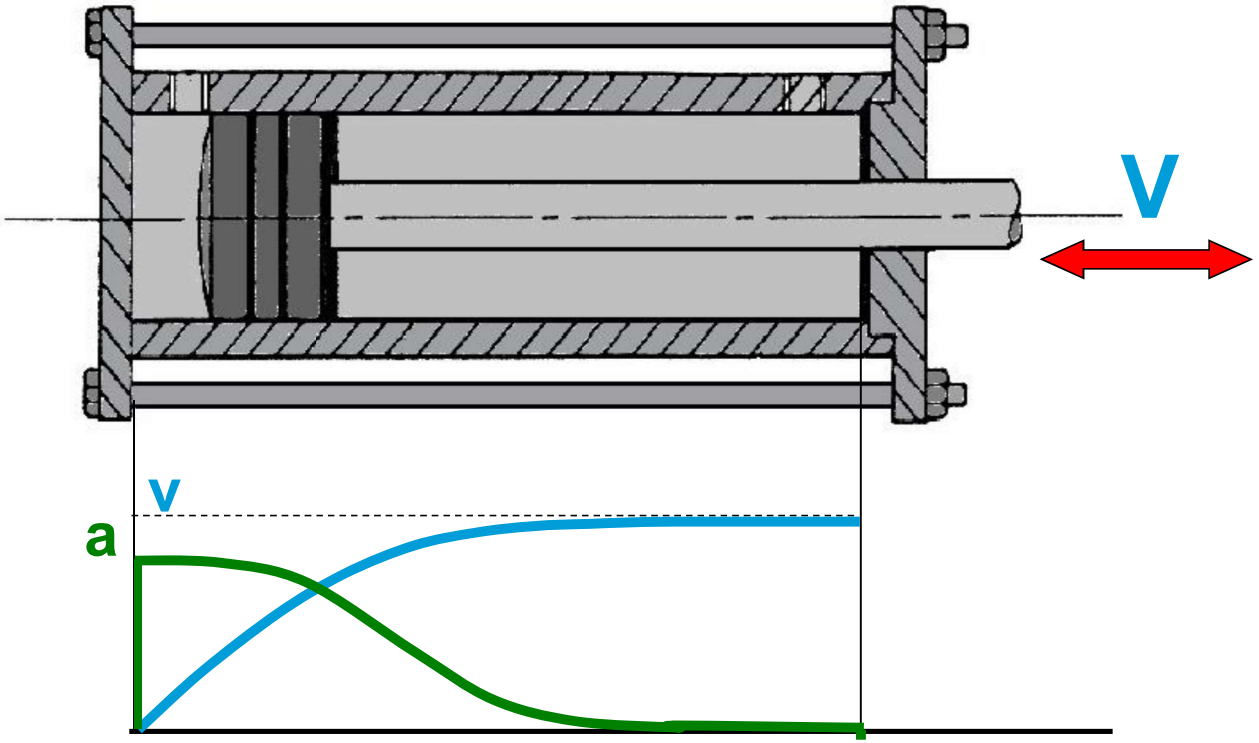
- a hydraulic cylinder that has a single piston and rod that protrudes from both end caps of the cylinder

tandem cylinders

- a hydraulic cylinder that consists of two or more in-line cylinders with their rods connected to form a common rod

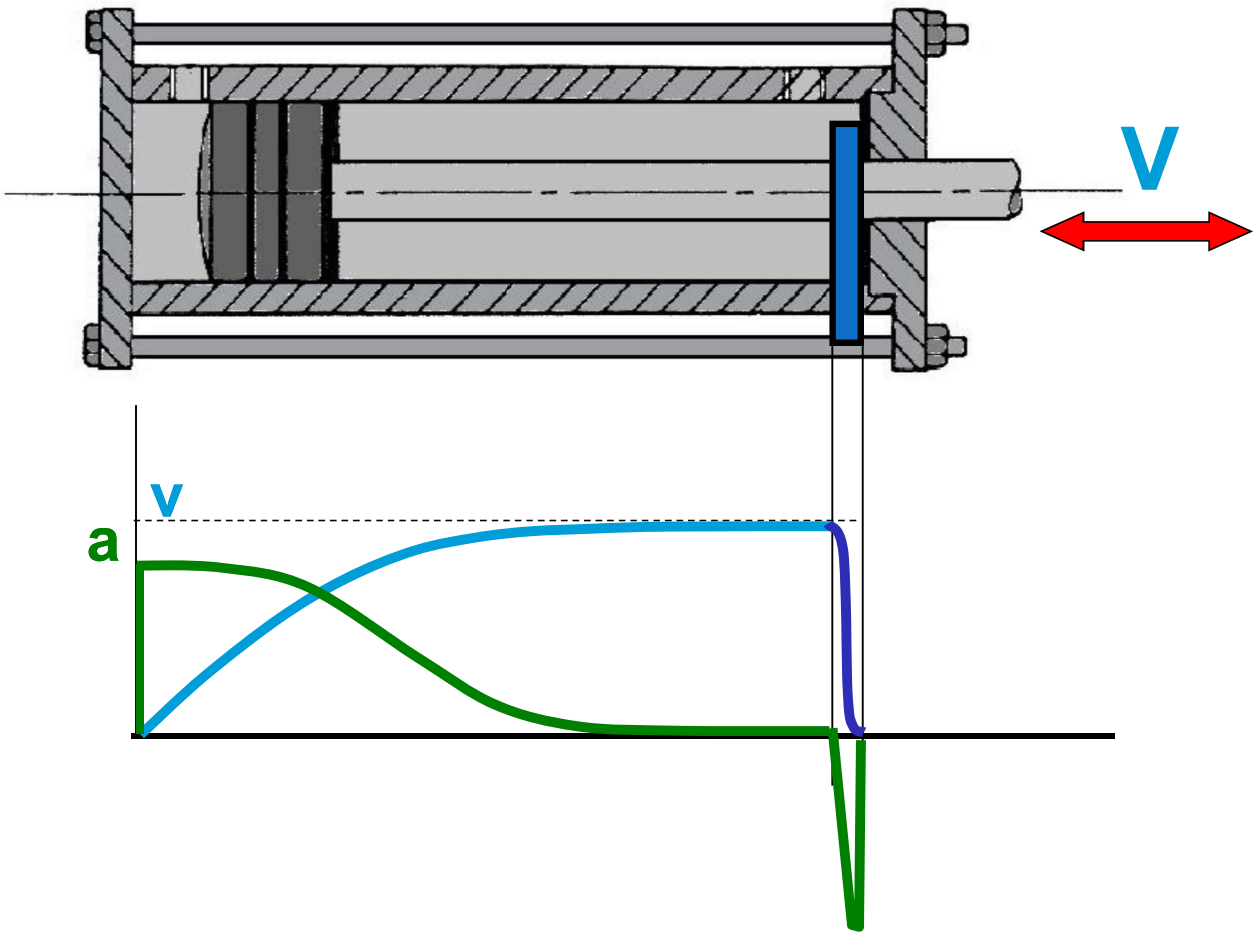
duplex cylinders

- a hydraulic cylinder that consists of two or more in-line cylinders that do not have their rods connected to form two or more cylinders in one housing



$$\left.\begin{aligned} F &= P * S \\ F - F_f &= M * a \\ F_f &= k * v^2 \end{aligned}\right\} \Rightarrow \quad a = \frac{P * S - k * v^2}{M}$$

Speed is not controllable. The cylinder maximum speed is achieved when friction forces (kv^2) equal those that produce the advancing movement (F = P.S), and a = 0.



- The impact produced when reaching the end of the run is reduced using a shock absorber.

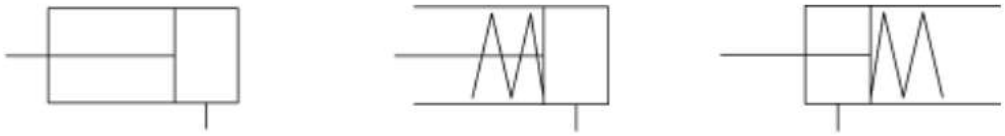
TYPES OF DOUBLE-ACTING CYLINDERS?

❖spring return (common type)

- In the spring return cylinder, the spring is located between the front end of the cylinder and the piston (around the piston rod)
- the piston rod extends when compressed air is supplied to the cylinder.
- As soon as the air supply is cut off, the piston rod retracts by spring force.

❖spring extended

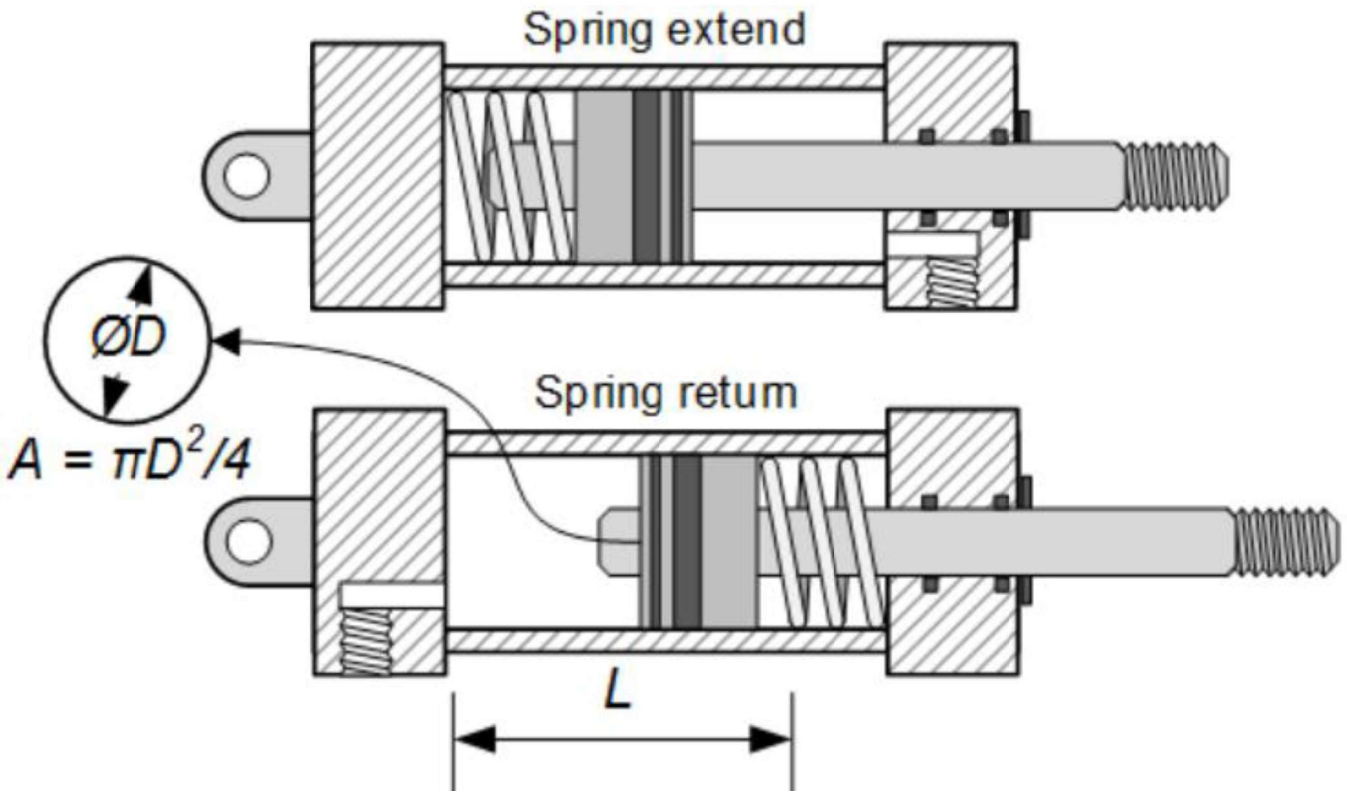
- the spring is located between the piston and the rear end of the cylinder
- piston retracts when compressed air is supplied
- When the air supply is switched off, the spring pushes the rod out



external force return (e.g. gravity)

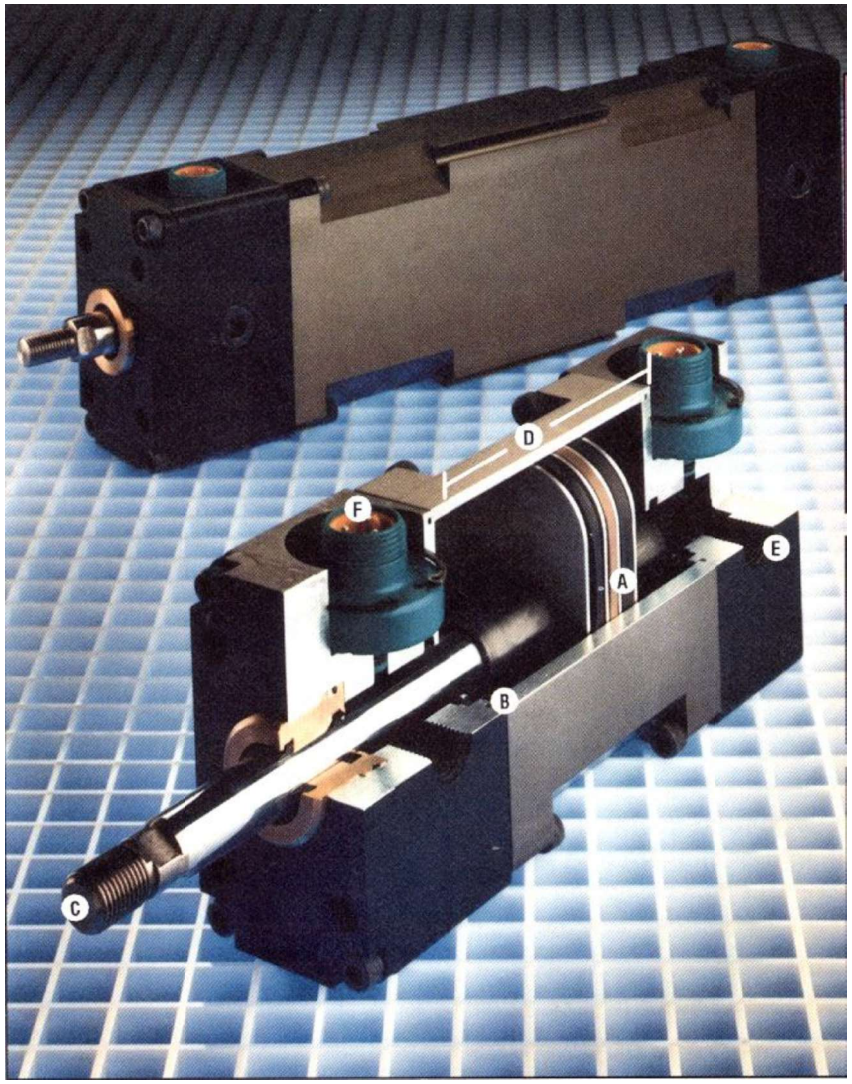
spring return

spring extended

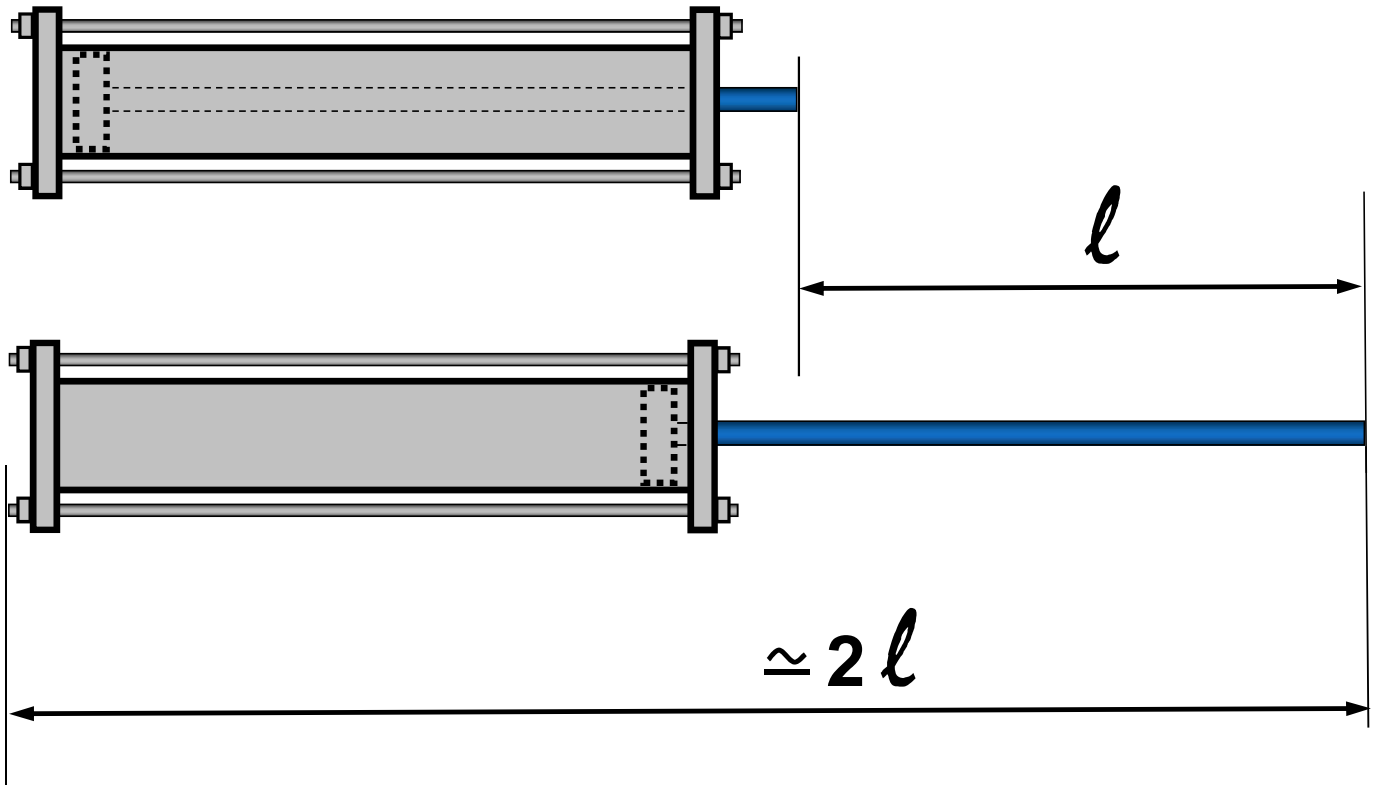

Spring extend
ØD
$A = \pi D^2/4$
Spring retum
L

Example of commercial pneumatic cylinders

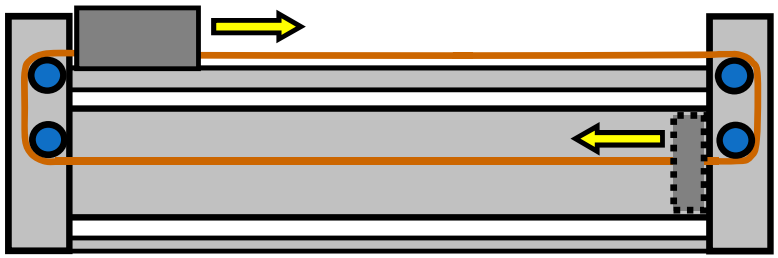
(Lateral guides to prevent axial rotation)

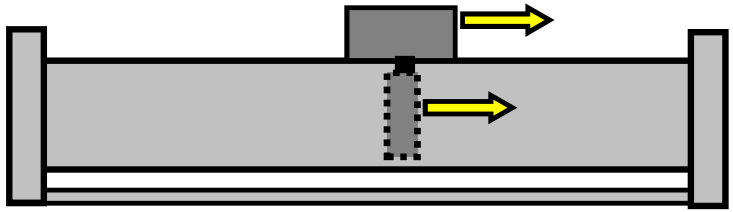


Oval pistons to prevent the rotation of the axis avoiding the need of auxiliary guides



Classical cylinders drawbacks: a displacement of length ℓ requires an additional length ℓ.





$$\Delta \ell \simeq \ell$$

Solutions to reduce the occupied space

PROS OF PNEUMATIC ACTUATORS

Explosion proofing relatively simple

Relatively insensitive to corroding environments if control air is used

Unsophisticated design

Use of control gas possible

Logic interlocking of signals can be realized easily Relatively low cost

High stroking velocities can be realized

“Fail safe outages of the auxiliary energy do not prevent reaching of safe position (spring loaded actuator)”

CONS OF PNEUMATIC ACTUATORS

Distance to the source of energy is limited (dead time problems)

Actuating force of spring loaded units is limited

Auxiliary energy must be generated and made available (cost implications)

Auxiliary energy system requires considerable maintenance

Small systems are normally not economical

Sensitive to changing process pressure

Summary Pneumatic actuators (cylinders)

- Economic
- Reliable
- High operation speed
- Operation at constant force
- Resistant to overloads

- No speed control
- Poor position speed
- Noisy operation

Applications of Pneumatic systems:

- Guided Missiles
- Aircraft systems
- Automation of production machines
- Automatic controllers
- Many more……

HYDRAULIC ACTUATORS

Purpose of the actuator

- to convert hydraulic energy to mechanical energy to preform work

Hydraulic Cylinders are used to create linear motion

Three common types of cylinders

- single acting
- double acting
- telescoping

SINGLE ACTING CYLINDERS

Single acting cylinders are hydraulically actuated

- in one direction only

Two types of forces used to retract single acting cylinders are

- Spring force
- gravity

Two main types of single acting cylinders are

- piston type
- ram type

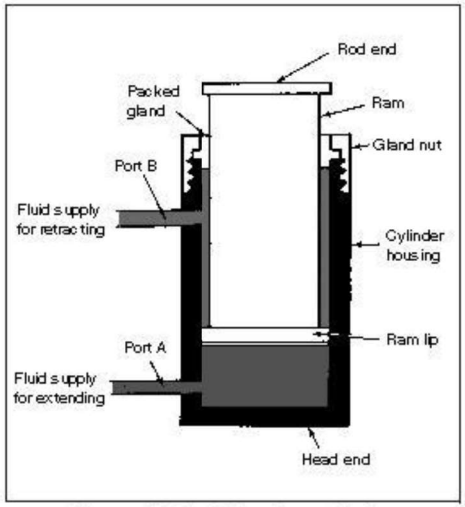


Figure 4-2. Double-acting cylinder

DOUBLE ACTING CYLINDERS

Double acting cylinders are

- hydraulically extended
- hydraulically retracted

Double acting single rod cylinders are referred to as differential cylinders because of

- the difference between extension and retraction speed and the forces they produce due to this

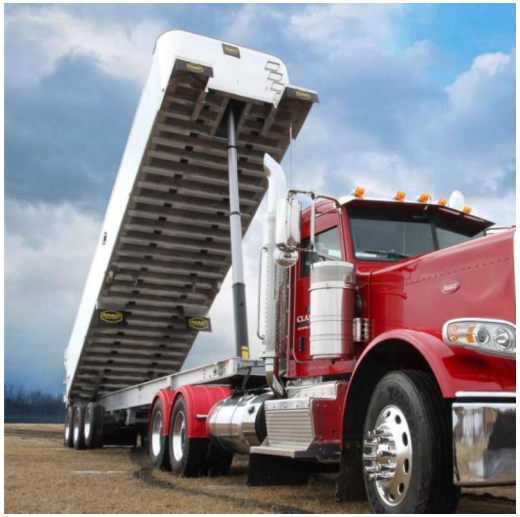
TELESCOPIC CYLINDERS

Why are single acting telescoping cylinders often used on heavy mobile machinery

- to obtain additional stroke length from a relatively compact retracted package

Telescoping single acting cylinders are commonly used on

- Haul truck's dump box where the dump box does not tilt over center.



BELLOWS

An expandable and retractable protective cover that is attached to the rod

used in actuator assemblies to transfer pressure or temperature into a linear motion.

Bellows actuators can be used in valve applications, where pressure is internal or external to the bellows.

With sizes less than half an inch in diameter, bellows actuators can reduce the size of traditional actuators in hydraulic and pneumatic systems.

Often known as pneumatic bellows and hydraulic bellows, edge welded bellows in these applications can save space and improve performance.

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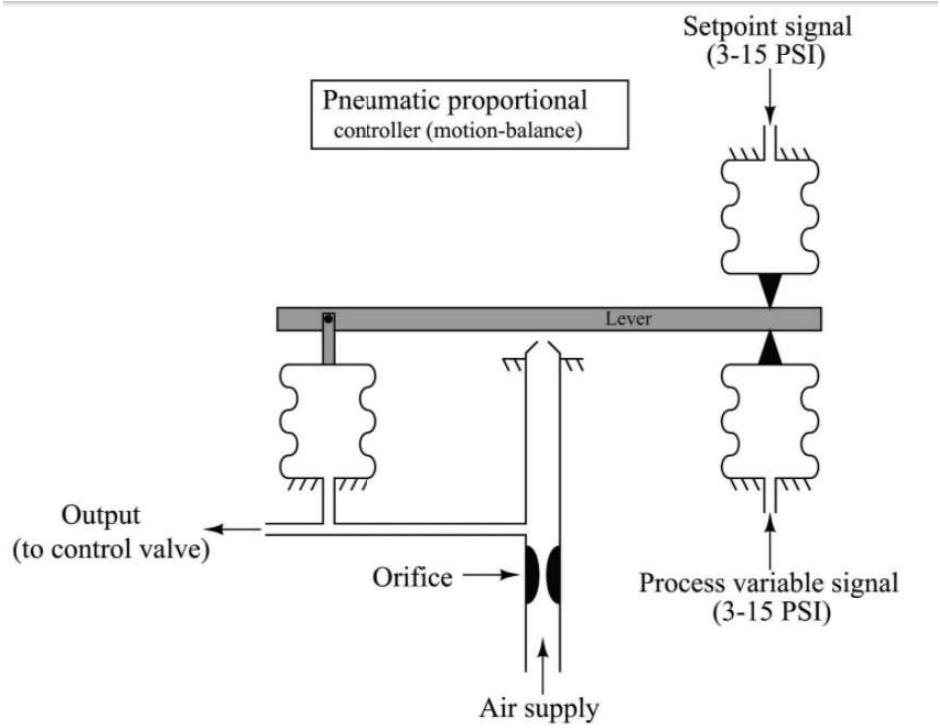
CONTD...



https://control.com/textbook/closed-loop-control/pneumatic-pid-controllers/

PROS OF HYDRAULIC ACTUATORS

High actuating forces

High stroking velocities are possible

High stability

CONS OF HYDRAULIC ACTUATORS

Distance/the source of energy is limited

Tubing is required for transmission of the actuating power, implying additional leakage risks

Costly control

Considerable maintenance requirements

	Hydraulic	Pneumatics	Electrical
Working Fluid	Mineral Oil	Air	Voltage-Current
Working Pressure	500 Bar (maximum	6-7 Bar	Up to 11kV
Available Force	100MN	10kN	100kN
Speed	Low	High	Very High
Conversion Efficiency	Over 70%	Under 20%	Over 80%
Capital Costs	High	Low	Intermediate
Proportional Control	Easy	Difficult	Easy
Hold Load Power-Off/ Stability	Possible	No (air is compressible)	Possible
Precise Positioning	Easy	Difficult	Easy
Environmental Influences	Sensitive in case of temperature fluctuation, risk of fire in case of leakage	Explosion proof, Insensitive to temperature	Risk of explosion in certain areas, insensitive to temperature
Energy storage	Limited with the help of compressed gases	Easy	Difficult, only in small quantities using batteries
Linear Motion	Simple using cylinders	Simple using cylinders	Difficult and expensive – with motion converter
Rotary Motion	Simple	Simple	Simple