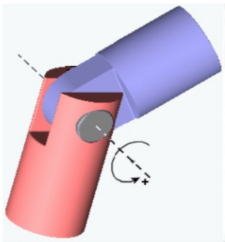
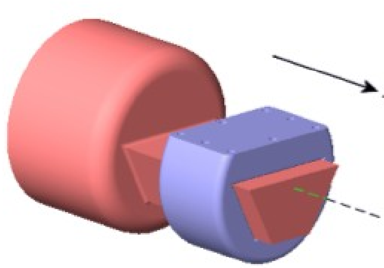
A revolute allows only a relative rotation between elements 1 and 2, which can be expressed by a single coordinate angle 'theta' .Thus a revolute pair has a single degree of freedom.



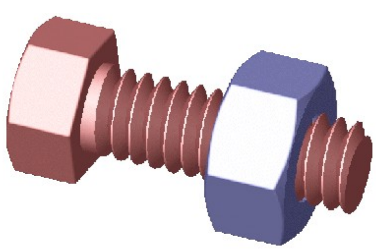

Prismatic Pair

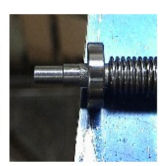
A prismatic pair allows only a relative translation between elements 1 and 2, which can be expressed by a single coordinate 'S'.Thus a prismatic pair has a single degree of freedom.




Screw Pair

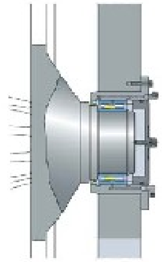
A screw pair allows only a relative movement between elements 1 and 2, which can be expressed by a single coordinate angle 'theta' or 'S' .Thus a screw pair has a single degree of freedom.These two coordinates are related as : 'theta/2'pi'=S/L



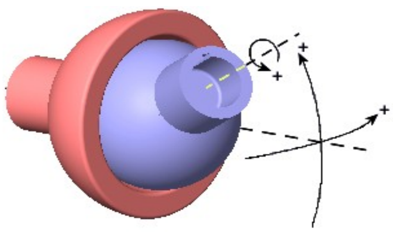
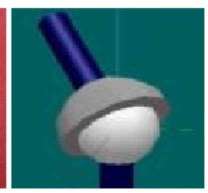
Cylindrical Pair

A cylindrical pair allows both rotation and translation between elements 1 and 2, which can be expressed as two independent coordinates angle 'theta' and 'S' .Thus a cylinderical pair has two degrees of freedom.

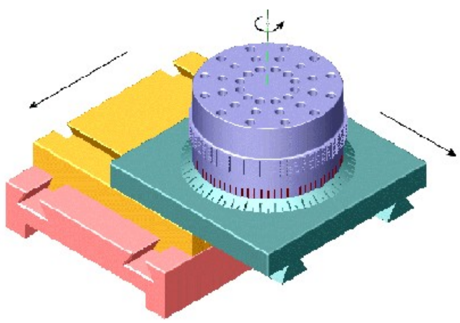
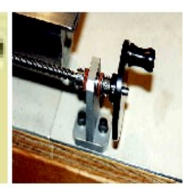
Spherical Pair

A spherical pair allows three degrees of freedom since the complete description of relative movement between the connected elements needs three independent cooordinates.Two of the coordinates 'alpha' and 'beta' are required to specify the position of the axis OA and the third coordinate 'theta' describes the rotatio about the axis OA.

Planar Pair

A planar pair allows three degrees of freedom.Two coordinates x and y describe the relative translation in the xy-plane and the third 'theta' describes the relative rotation about the z-axis.

To define a mechanism we define the basic elements as follows :

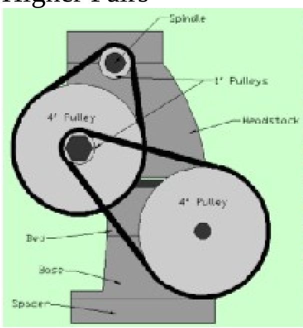
Link

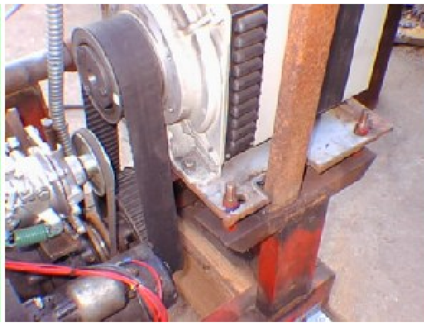
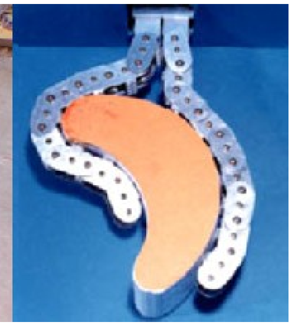
A material body which is common to two or more kinematic pairs is called a link.

Kinematic Chain

A kinematic chain is a series of links connected by kinematic pairs. The chain is said to be closed chain if every u link is connected to atleast two other links, otherwise it is calledan open chain. A link which is connected to only one other link is known as singular link.If it is connected to two other links, it is called binary link.If it is connected to three other links, it is called ternary link, and so on. A chain which consists of only binary links is called simple chain. A type of kinematic chain is one with constrained motion, which means that a definite motion of any link produces unique motion of all other links. Thus motion of any point on one link defines the relative position of any point on any other link.So it has one degree of freedom.

Higher Pairs



A higher pair is defined as one in which the connection between two elements has only a point or line of contact. A cylinder and a hole of equal radius and with axis parallel make contact along a surface. Two cylinders with unequal radius and with axis parallel make contact along a line. A point contact takes place when spheres rest on plane or curved surfaces (ball bearings) or between teeth of a skew-helical gears. in roller bearings, between teeth of most of the gears and in cam-follower motion. The degree of freedom of a kinetic pair is given by the number independent coordinates required to completely specify the relative movement.

Wrapping Pairs

Wrapping Pairs comprise belts, chains, and other such devices.

Let n be the no. of links in a mechanism out of which, one is fixed, and let j be the no. of simple hinges(ie, those connect two links.) Now, as the (n-1) links move in a plane, in the absence of any connections, each has 3 degree of freedom; 2 coordinates are required to specify the location of any reference point on the link and 1 to specify the orientation of the link. Once we connect the linmks there cannot be anyrelative translation betweenthem and only one coordinate is necessary to specify their relative orientation.Thus, 2 degrees of freedom (translation) are lost, and only one degree of freedom (rotational) is left. So, no. of degrees of freedom is: $F=3(n-1)-2j$

Most mechanisms are constrained, ie $F=1$. Therefore the above relation becomes, $2j-3n+4=0$, this is called Grubler's Criterion. Failure of Grubler's criterion

A higher pair has 2 degrees of freedom .Following the same argument as before, The degrees of freedom of a mechanism having higher pairs can be written as, $F=3(n-1)-2j-h$

Often some mechanisms have a redundant degree of freedom. If a link can move without causing any movement in the rest of the mechanism, then the link is said to have a redundant degree of freedom. Example of redundant degree of freedom

Grashofs criterion states that for a basic four bar mechanism if the sum of lengths of the shortest and the longest link is less than the sum of the other two link lengths then all types of inversions are possible. The different inversions may be obtained by fixing the different links of the mechanism. The mechanism satisfying the Grashof�s criterion is called Grashof�s linkage. For a non-Grashof�s linkage only Rocker-Rocker mechanism occurs.

UNIT 2: BELT DRIVE

1. A belt is a looped strip of flexible material, used to mechanically link two or more rotating shafts.
2. They may be used as a source of motion, to efficiently transmit power, or to track relative movement. Belts are looped over pulleys.
3. In a two pulley system, the belt can either drive the pulleys in the same direction, or the belt may be crossed, so that the direction of the shafts is opposite.

Types of belt drive

- Light drive - Up to 10 m/s
- Medium drive - over 10 but up to 22m/s
- Heavy drive - Above 22m/s

Types of belts

- Flat belt
- V – belt
- Circular belt (or) rope

Flat Belts

- Rectangular in cross section mounted on pulleys
- Crowning on the pulley to prevent the belt from running off the pulley

Types

Based on Materials

- Leather
- Rubber
- Canvas

Based on Layers

- Single-ply
- Double-ply
- Triple-ply

V-belts

Most popular.

- V belt is designed to ride inside the groove of the pulley or sheave

Types of belt drive

- open belt drive
- crossed belt drive
- Quarter turn belt drive
- belt drive with idlers
- compound belt drive
- stepped pulley drive
- fast and loose pulley

Simple belt drive

The shafts are parallel, and the pulleys fastened to the shaft with set screws or keys. The central planes of the pulleys must obviously be coincident

Cross belt drive

Belt Drive with Idlers

Compound belt drive

Advantages of belt drive

- They are simple. They are economical.

- Parallel shafts are not required.
- Overload and jam protection are provided.
- Noise and vibration are damped out. Machinery life is prolonged because load fluctuations are cushioned (shock-absorbed).
- They are lubrication-free. They require only low maintenance.
- They are highly efficient (90–98%, usually 95%). Some misalignment is tolerable.
- They are very economical when shafts are separated by large distances.

Disadvantages of belt drive

- The angular-velocity ratio is not necessarily constant or equal to the ratio of pulley diameters, because of belt slip and stretch.
- Heat buildup occurs. Speed is limited to usually 7000 feet per minute (35 meters per second). Power transmission is limited to 370 kilowatts (500 horsepower).
- Operating temperatures are usually restricted to –31 to 185°F (–35 to 85°C).
- Some adjustment of center distance or use of an idler pulley is necessary for wear and stretch compensation.
- A means of disassembly must be provided to install endless belts.

UNIT III CHAIN DRIVE

Chain drive

- Chain drive is a way of transmitting mechanical power from one place to another.
- It is often used to convey power to the wheels of a vehicle, particularly bicycles and motorcycles.
- It is also used in a wide variety of machines besides vehicles.
- Most often, the power is conveyed by a roller chain, known as the drive chain, passing over a sprocket gear, with the teeth of the gear meshing with the holes in the links of the chain.
- The gear is turned, and this pulls the chain putting mechanical force into the system..

Chain drive

- Chain = sequence of inner link and pin link articulated to form a flexible device for power transmission

Classification of chains
Hoisting and hauling chains (or) crane chains
Conveyor chains
Power transmitting chains
Hoisting chain

- Chain with square link

    Manufacturing cost is less used in hoists, cranes Chain with oval link
    Joint is welded Used for slow speed

Conveyor chains
Detachable or hook joint type
Closed joint type
Power transmitting chains
Two types
Block chain
Bush roller chain
Made of malleable C.I
Run at speed of 3 to 12 KMPH
Do not run smoothly
Advantages of chain drive

- No slip takes place
- Occupy less space
- used when distance is low
- high transmission efficiency (98 %)

Disadvantages

- production cost is high
- need accurate mounting and careful maintenance
- has a velocity fluctuations when stretched

UNIT IV GEARS AND GEAR TRAINS

- A gear is a component within a transmission device that transmits rotational force to another gear or device

TYPES OF GEARS

According to the position of axes of the shafts.

Parallel

1.Spur Gear 2.Helical Gear 3.Rack and Pinion

b. Intersecting

Bevel Gear

c. Non-intersecting and Non-parallel

worm and worm gears

SPUR GEAR

- Teeth is parallel to axis of rotation
- Transmit power from one shaft to another parallel shaft
- Used in Electric screwdriver, oscillating sprinkler, windup alarm clock, washing machine and clothes dryer

Helical Gear

- The teeth on helical gears are cut at an angle to the face of the gear
- This gradual engagement makes helical gears operate much more smoothly and quietly than spur gears
- One interesting thing about helical gears is that if the angles of the gear teeth are correct, they can be mounted on perpendicular shafts, adjusting the rotation angle by 90 degrees

Herringbone gears

To avoid axial thrust, two helical gears of opposite hand can be mounted side by side, to cancel resulting thrust forces

Herringbone gears are mostly used on heavy machinery.

Rack and pinion

- **Rack and pinion gears** are used to convert rotation (From the pinion) into linear motion (of the rack)
- A perfect example of this is the steering system on many cars

Bevel gears

- **Bevel gears** are useful when the direction of a shaft's rotation needs to be changed
- They are usually mounted on shafts that are 90 degrees apart, but can be designed to work at other angles as well
- The teeth on bevel gears can be **straight**, **spiral** or **hypoid**

- locomotives, marine applications, automobiles, printing presses, cooling towers, power plants, steel plants, railway track inspection machines, etc.

WORM AND WORM GEAR

- **Worm gears** are used when large gear reductions are needed. It is common for worm gears to have reductions of 20:1, and even up to 300:1 or greater
- Many worm gears have an interesting property that no other gear set has: the worm can easily turn the gear, but the gear cannot turn the worm
- Worm gears are used widely in material handling and transportation machinery, machine tools, automobiles etc

NOMENCLATURE of GEAR

- **Pitch surface**: The surface of the imaginary rolling cylinder (cone, etc.) that the toothed gear may be considered to replace.
- **Pitch circle**: A right section of the pitch surface.
- **Addendum circle**: A circle bounding the ends of the teeth, in a right section of the gear.
- **Root (or dedendum) circle**: The circle bounding the spaces between the teeth, in a right section of the gear.
- **Addendum**: The radial distance between the pitch circle and the addendum circle.
- **Dedendum**: The radial distance between the pitch circle and the root circle.
- **Clearance**: The difference between the dedendum of one gear and the addendum of the mating gear.
- **Face of a tooth**: That part of the tooth surface lying outside the pitch surface.
- **Flank of a tooth**: The part of the tooth surface lying inside the pitch surface.
- **Circular thickness** (also called the **tooth thickness**): The thickness of the tooth measured on the pitch circle. It is the length of an arc and not the length of a straight line.
- **Tooth space**: pitch diameter The distance between adjacent teeth measured on the pitch circle.
- **Backlash**: The difference between the circle thickness of one gear and the tooth space of the mating gear.

- **Circular pitch** (Pc) : The width of a tooth and a space, measured on the pitch circle.

GEAR TRAINS

- A gear train is two or more gear working together by meshing their teeth and turning each other in a system to generate power and speed
- It reduces speed and increases torque
- Electric motors are used with the gear systems to reduce the speed and increase the torque

Types of Gear Trains

- Simple gear train Compound gear train Planetary gear train Reverted gear train

Simple Gear Train

- The most common of the gear train is the gear pair connecting parallel shafts. The teeth of this type can be spur, helical or herringbone.
- Only one gear may rotate about a single axis

Compound Gear Train

- For large velocities, compound arrangement is preferred
- Two or more gears may rotate about a single axis

Planetary Gear Train…

- They have higher gear ratios.
- They are popular for automatic transmissions in automobiles.
- They are also used in bicycles for controlling power of pedaling automatically or manually.
- They are also used for power train between internal combustion engine and an electric motor

Reverted gear train

Advantages

- It transmits exact velocity ratio
- Used for transmitting large power
- High efficiency
- Reliable service
- Compact layout

Disadvantages

- Manufacturing of gears requires special tools
- Error in cutting teeth may cause noise and vibration.

UNIT V CAM

Cams come under higher pair mechanisms. As we already know that in higher pair the contact between the two elements is either point or line contact, instead of area in the case of lower pairs.

In CAMs, the driving member is called the cam and the driven member is referred to as the *follower*. CAM is used to impart desired motion to the follower by direct contact. Generally the CAM is a rotating or reciprocating element, where as the follower may de rotating, reciprocating or oscillating element. Using CAMs we can generate complex, coordinate movements that are very difficult with other mechanisms. And also CAM mechanisms are relatively compact and easy it design. Cams are widely used in automatic machines, internal combustion engines, machine tools, printing control mechanisms and so on. Along with *cam* and *follower* one *frame* also will be there with will supports the *cam* and guides the follower.

A follower can be classified in three ways

1. According to the motion of the follower.
2. According to the nature of contact.
3. According to the path of motion of the follower

According to the motion of the follower

1. Reciprocating or Translating follower

   : When the follower reciprocates in guides as the can rotates uniformly, it is known as reciprocating or translating follower.
2. Oscillating or Rotating follower

: When the uniform rotary motion of the cam is converted into predetermined oscillatory motion of the follower, it is called oscillating or rotating follower

According to the nature of contact:

1. The Knife-Edge follower

   : When contacting end of the follower has a sharp knife edge, it is called a knife edge follower. This cam follower mechanism is rarely used because of excessive wear due to small area of contact. In this follower a considerable thrust exists between the follower and guide.
2. The Flat-Face follower

   : When contacting end of the follower is perfectly flat faced, it is called a flat faced follower. The thrust at the bearing exerted is less as compared to other followers. The only side thrust is due to friction between the contact surfaces of the follower and the cam. The thrust can be further reduced by properly offsetting the follower from the axis of rotation of cam so that when the cam rotates, the follower also rotates about its axis. These are commonly used in automobiles.
3. The Roller follower

   : When contacting end of the follower is a roller, it is called a roller follower. Wear rate is greatly reduced because of rolling motion between contacting surfaces. In roller followers also there is side thrust present between follower and the guide. Roller followers are commonly used where more space is available such as large stationary gas or oil engines and aircraft engines.
4. The Spherical-Faced follower

   : When contacting end of the follower is of spherical shape, it is called a spherical faced follower. In flat faced follower�s high surface stress are produced. To minimize these stresses the follower is machined to spherical shape.

According to the path of motion of the follower:

1. Radial follower

   : When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial follower.
2. Off-set follower

   : When the motion of the follower is along an axis away from the axis of the cam centre, it is called off-set follower.

A Cam can be classified in two ways:

1. Radial or Disc cam

   : In radial cams, the follower reciprocates or oscillates in a direction perpendicular to the cam axis.
2. Cylindrical cam

: In cylindrical cams, the follower reciprocates or oscillates in a direction parallel to the cam axis. The follower rides in a groove at its cylindrical surface.

CAM NOMENCLATURE

The various terms we will very frequently use to describe the geometry of a radial *cam* are defined as fallows.

1. Base Circle

   : It is the smallest circle, keeping the center at the *cam*center, drawn tangential to *cam* profile. The base circle decides the overall size of the *cam* and thus is fundamental feature.

2. Trace Point

   : It is a point on the follower, and it is used to generate the pitch curve. Its motion describing the movement of the follower. For a knife-edge follower, the trace point is at knife-edge. For a roller follower the trace point is at the roller center, and for a flat-face follower, it is a t the point of contact between the follower and the *cam* surface when the contact is along the base circle of the cam. It should be note that the trace point is not necessarily the point of contact for all other positions of the *cam*

The various terms we will very frequently use to describe the geometry of a radial *cam* are defined as fallows.

3. Pitch Curve

   : It is the curve drawn by the trace point assuming that the *cam* is fixed, and the trace point of the follower rotates around the cam, i.e. if we hold the *cam* fixed and rotate the follower in a direction opposite to that of the cam, then the curve generated by the locus of the trace point is called *pitch curve*.
   For a knife-edge follower, the pitch curve and the *cam* profile are same where as for a roller follower they are separated by the radius of the roller.

4. Pressure Angle

   : It is the measure of steepness of the *cam* profile. The angle between the direction of the follower movement and the normal to the pitch curve at any point is called *pressure angle*. Pressure angle varies from maximum to minimum during complete rotation. Higher the pressure angle higher is side thrust and higher the chances of jamming the translating follower in its guide ways. The pressure angle should be as small as possible within the limits of design. The pressure angle should be less than 450 for low speed *cam* mechanisms with oscillating followers, whereas it should not exceed 300 in case of cams with translating followers. The pressure angle can be reduced by increasing the *cam* size or by adjusting the offset.

5. Pitch Point

   : The point corresponds to the point of maximum pressure angle is called *pitch point*, and a circle drawn with its centre at the *cam* centre, to pass through the pitch point, is known as the *pitch circle*.

6. Prime Circle

   : The *prime circle* is the smallest circle that can be drawn so as to be tangential to the pitch curve, with its centre at the *cam* centre. For a roller follower, the radius of the prime circle will be equal to the radius of the base circle plus that of the roller where as for knife-edge follower the prime circle will coincides with the base circle.

DESCRIPTION OF THE FOLLOWER MOTION

The *cam* is assumed to rotate at a constant speed and the follower rotates over it. A complete revolution of *cam* is described by displacement diagram, in which follower displacement i.e. the movement of the trace point, is along y axis and is plotted against the *cam* rotation �. The maximum follower displacement is referred to as the lift L of the follower. The inflexion points on the displacement diagram i.e., the points corresponding to the maximum and minimum velocities of the follower correspond to the pitch points. In general the displacement diagram consists of four parts namely.

1. Rise

   : The movement of the follower away from the centre of the *cam*. The follower rises upwards in this motion.
2. Dwell

   : In this phase there is no movement of the follower. In this dwell, the distance between the centre of the *cam* and the contact point is maximum.
3. Return

   : The movement of the follower towards the *cam* centre.
4. Dwell

   : The movement of the follower is not present in this phase. In this dwell, the distance between the centre of the *cam* and the contact point is minimum.

Construction of Displacement Diagrams

Though the follower can be made to have any type of desired motion, we are going to discus the construction of the displacement diagrams for the basic follower movements as mentioned below.

1. Uniform motion and its modifications.
2. Simple harmonic motion.
3. Uniform acceleration motion i.e. parabolic motion.
4. Cycloidal motion.

In uniform motion the velocity of the followers is constant. As the displacement is from $y = 0$ to $y = L$ then the cam rotates from $\theta = 0$ to $\theta = \theta ri$, and thus the straight line joining the two points ($\theta = 0$, $y = 0$) and ($\theta = \theta ri$, $y = L$) represents the displacement diagram for uniform motion.

Uniform motion and its modifications

As there is an instantaneous change from zero velocity at the beginning of the rise and a change to zero velocity at the end of the rise, the accelerations at this instance attain a very high value. To avoid this, the straight line of the displacement diagram is connected tangentially to the dwell at both ends of the rise by means of smooth curves of any convenient radius and the bulk of the displacements take place at uniform velocity, whish is represented as straight line as shown in the diagram. So, most part of the time the velocity of the follower is uniform.

SIMPLE HARMONIC MOTION.

The displacement diagram for simple harmonic motion can be obtained as shown in figure.5. The line representing angle �ri is divided into a convenient number of equal lengths. A semicircle of diameter L is drawn as shown and divided into same number of circular arcs of equal length. Horizontal lines are drawn from the points so obtained on the semicircle, to meet the corresponding vertical lines through the points on the length �ri. For SHM we always have finite velocity, acceleration, jerk, and higher order derivatives of displacements.

UNIFORM ACCELERATION MOTION

In such cam and followers, there is acceleration in the first half of the follower motion whereas it is deceleration during the later half. With dwell at the beginning and at the end of the rise, when lift of the follower has to take place in a given time, it is easy to show that the maximum acceleration will be the least if the first half of the rise takes place at a constant acceleration and the remaining displacement is at a constant deceleration of same magnitude. For this reason the parabolic motion is very suitable for high speed cams as it minimizes inertia force.
While locating the vertical divisions in the displacement diagram, the fact used is that at constant acceleration the displacement is proportional to the square of the time i.e. it is proportional to the square of the cam rotation as the cam rotates at constant speed. The displacement diagram for such cam and followers is shown in figure 6.(a). This is also applicable for deceleration.

MODIFIED UNIFORM ACCELERATION MOTION

For *cam* operating valves of internal combustion engines, the modified uniform acceleration motion is used for the follower. It is desired that the valves should open and close quickly, at the same time maintain the aforementioned advantage of parabolic motion. In modified parabolic motion, the acceleration f_1 during the first part of the rise is more than the deceleration f_2 during the rest of the rise as shown in fig.6(b).

Let

Then it is easy to prove that,

Where,
= angle of cam rotation when the acceleration is f_1,
$K\ \theta_a$ = angle of cam rotation when the deceleration f_2.
The lift L is given by,

Where
L_1 = rise with acceleration , and
$K\ L_1$= rise with deceleration f_2.
.

CYCLOIDAL MOTION

Cycloidal motion is obtained by rolling a circle of radius L/(2п) on the ordinate of the displacement diagram. A point P rolling on the ordinate describes a cycloid. A circle of radius L/(2п) is drawn with centre at the end A of the displacement diagram. This circle is divided into equal number of divisions as the abscissa of the diagram representing the cam rotation θri. The projections of the on the circumference are taken on the vertical diameter, represented by 1', 2',…6'. The displacement diagram is obtained from the intersection of the vertical lines through the points on the abscissa and the corresponding lines parallel to OA. The following figure will show the displacement diagram for Cycloidal motion with construction details.