A Laboratory Manual for

Kinematics and Theory of Machines (BE04000171)

B.E. Semester 4 (Mechanical)

Lukhdhirji Engineering College, Morbi
Department of Mechanical Engineering

Directorate of Technical Education, Gandhinagar, Gujarat

LUKHDHIRJI ENGINEERING COLLEGE-MORBI

Vision of the Institute

To provide quality engineering education and transforming students into professionally competent and socially responsible human beings.

Mission of the Institute

- To provide a platform for basic and advanced engineering knowledge to meet global challenges
- To impart state-of-art know- how with managerial and technical skills
- To create a sustainable society through ethical and accountable engineering practices

MECHANICAL ENGINEERING DEPARTMENT

Vision of the Department

To deliver quality engineering education for Mechanical Engineers with Professional competency, Human values and Acceptability in the society.

Mission of the Department

- To nurture engineers with basic and advance mechanical engineering concepts
- To impart Techno-Managerial skill in students to meet global engineering challenges
- To create ethical engineers who can contribute for sustainable development of society

Program Educational Objectives (PEOs)

Program Educational Objectives of the Department are,

1. Apply their knowledge of basic science and engineering to analyze and solve problems related to mechanical engineering.
2. Able to design and develop the new system/process using advanced technologies and tools.
3. Enhance professional practice to meet global challenges with their ethical and social responsibility.

Program Specific Outcomes (PSOs)

1. Students will be able to apply the knowledge of computer aided tools for design and development of products based on engineering principles.
2. Students will be able to manage production of components/systems using conventional and advanced manufacturing methods.

Lukhdhirji Engineering College, Morbi

Department of Mechanical Engineering

Certificate

This is to certify that Mr./Miss _____ is the student of 4TH Semester Mechanical Engineering Enrollment No._____ has satisfactorily completed the Practical/Tutorial work in "**Kinematics and Theory of Machines** (BE04000171)" within four walls of Lukhdhirji Engineering College, Morbi in academic year of 2025-26.

Date of Submission_____

_____ _____

Faculty Incharge **Head of Department**

Practical – Course Outcome matrix

Course Outcomes (COs):

CO1: Classify kinematic pairs, mechanisms and perform mobility analysis of various mechanisms.

CO2: Perform velocity and acceleration analysis of planar mechanisms using analytical, graphical, and numerical (software) approaches.

CO3: Synthesize mechanisms for function generation with precision points.

CO4: Develop Cam profiles for different types of followers and related motion characteristics.

CO5: Develop the concepts of basic power transmission devices for the given field/industrial application.

Sr. No.	Objective(s) of Experiment	CO1	CO2	CO3	CO4	CO5
1.	Study & demonstration of different types of mechanisms and their inversions.	√				
2.	Velocity and acceleration analysis of a four-bar and Slider crank mechanism using graphical & analytical method.		√			
3.	Synthesis of Four bar and Slider Crank Mechanism using C/C++/MATLAB/Python or any other suitable programming language.			√		
4.	Study and demonstration of Belts, Brakes and Clutches.					√
5.	Determination of Gear train ratios for different types of gear trains.					√
6.	Cam profile generation and follower motion analysis using analytical methods and develop a computer program using C/C++/MATLAB/Python or any other suitable programming language.				√	

Lukhdhirji Engineering College, Morbi

Department of Mechanical Engineering
B.E. Semester – IV
Kinematics and Theory of Machines (BE04000171)

Index

Experiment No: 1

Study & demonstration of different types of mechanisms and their inversions.

Date:

Relevant CO: Classify kinematic pairs, mechanisms and perform mobility analysis of various mechanisms.

INTRODUCTION:

THEORY OF MACHINE:

The engineering science that deals with the study of the relative motion between the various parts of a machine and various forces acting on them

KINEMATICS:

It is the branch of theory of machines that deals with the study of relatives motion between the various parts of a machine, thus it is the study, from a geometric point of view, to know the displacement, velocity and acceleration of a parts of a mechanism.

DEFINATIONS AND BASIC CONCEPTS:

MECHANISM:

If a number of bodies are assembled in such a way that the motion of one causes constrained and predictable motions to the others, it is known as a mechanism. Thus, mechanism transmits and modifies a motion. When one of the links of a kinematics chain is fixed, the chain is known as mechanism

MACHINE:

A machine is a mechanism or a combination of mechanisms which apart from imparting define motions to the parts, also transmits and modifies the available mechanical energy into some kind of desired work

STRUCTURE:

If one of the links of a redundant chain is fixed. It is known as a structure. The degree of freedom of a structure is zero. A structure with negative degree of freedom is known as a superstructure.

RIGID BODY:

A body is said to be rigid if under the action of forces, it does not suffer and distortion or the distance between any two points on it remains constant.

RESISTANT BODY:

Resistant bodies are those, which are rigid for the purposes they have to serve. A belt is rigid when subjected to tensile forces. Therefore, the bolt in a belt-drive acts as a resistant body.

LINK:

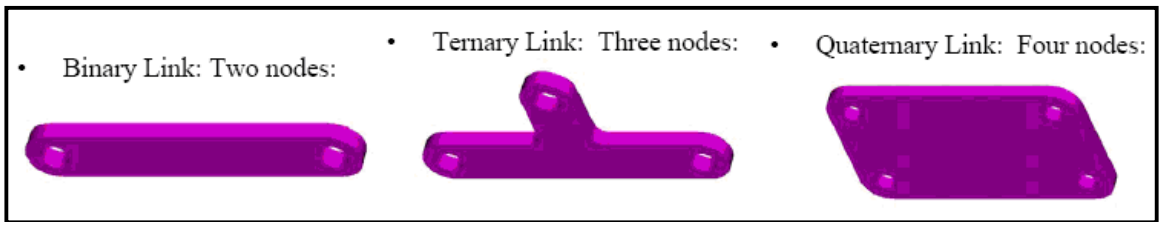


Figure: 1

A link may be defined as a single part or assembly of rigidly connected parts of 3 machines, which is a resistant body and which has a motion relative to other parts of machine. A link is also known as kinematics link or Element, Even if two or more connected parts are manufactured separately, they cannot be treated as different links unless; there is a relative motion between them. For instance, piston, piston rod and crosshead of a steam engine constitute a single link, as there is no relative motion between them. An element may be defined as a geometrical form provided on a link on a link so as to machine a working surface that permit relative motion between connected links constrained motion of the kind of relative motion between its link to controlled by the form of the contacting surfaces of the adjacent or connected links. For instance the connection between a lathe carriage and its bed id through contacting working surfaces, which are so shaped that only motion of translation, is possible.

KINEMATIC PAIR:

The two contacting element of a connection constitute a kinematics pair. A pair may also be defined as a connection between two adjacent links 5 that permits a definite relative motion between them. Cylindrical contacting surfaces between I. C. engine cylinder and piston constitute a pair. Similarly, cylindrical contacting surfaces of a rotating shaft and a journal bearing also constitute a pair

TYPES OF KINEMATIC PAIRS:

Kinematics pair is classified on the basis of the following characteristics.

(A) The types of relative motion between contacting elements.
(B) The types of contact between contacting elements.
(C) The number of degrees of freedom
(D) The types of closure / Type of mechanical constraint

(A) According to the types of relative motion between contacting elements.

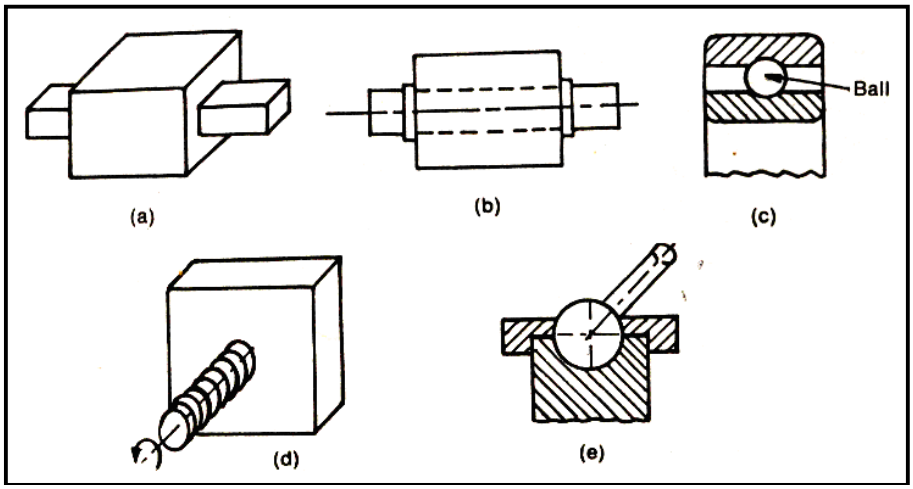


Figure 2 Types of pairs

The relative motion of a point on one element relative to the other machine element can be that of turning, sliding, screw (helical direction) planar, cylindrical of spherical, The controlling factor that determines the relative motions allowed by given joints is the shapes for the elements, and each permits a particular types of motion. Which is determined by the possible ways in which these elemental surfaces can move with respect to each other?

SLINDING PAIR (Prismatic pair):Fig-(2a)
If two links have a sliding, motion relative to each other they form a sliding pair. This type of pair permits relative motion of sliding only in one direction (along a line) and as such, has only one degree of freedom pairs between piston and cylinders cross head and guide die block and slot of slotted lever are all the examples of sliding pair.

TURNING PAIR: Fig-(2b)
When one link has a turning or revolving motion to the other they consult turning or revolving pair. The pair of piston pin, the pair of crank pin and the pair formed by rotating crank shaft in bearing are all the example of turning pair

ROLLING PAIR: Fig-(2c)
When the links of pair have a rolling motion relative to each other they form a rolling pair. Castor wheels of trolley ball and roller bearing wheel of locomotive. Wagon and rail are a few examples of this type.

SCREW PAIR (HELICAL PAIR): Fig-(2d)
If two mating links have a turning as well as sliding motion between them, they form a screw pair. This is achieved by cutting mating threads on the two links. A lead screw and nuts of a lathe is a screw pair.

SPHERICAL PAIR OR GOBULAR PAIR: Fig-(2e)
When one link is in form of a sphere turns inside a fix link it is a spherical pair. The ball and socket joint is a spherical pair.

CYLINDRICAL PAIR:
A cylindrical pair permits a relative motion, which is a combination of rotation and translation parallel to the axis of rotation between the contacting elements. The pair has two degree of freedom.

FLAT OR PLANER PAIR:
A flat or planer pair is sold on. If ever, found in mechanisms. The pair permits a planer relative motion between contacting elements. It has three degrees of freedom.

(B) Classification of pair according to the type of contract between contacting elements:
The kinematics pairs in this category are (I) Lower pair and (II) Higher pair
LOWER PAIR: A pair of links having a surface of area contact between the members is known as lower pair. The contact surfaces of the two links are similar.
EXAMPLES: Nut turning on a screw, shaft rotating in a bearing, all pair of slider crank mechanism, universal joint etc.
HIGHER PAIR: When a pair has a point of a line contact between the links it is known as a higher pair
EXAMPLES: Wheel rolling on a surface cam & a follower pair. Tooth gears, ball & roller bearings, etc.

(C) Classification of pairs based on degrees of freedom:

Degree of freedom of a pair is defined is defined as number of independent relative motions, both transnational and rotational.

A free-body in space has six degrees of freedom. In forming a kinematics pair one or more degrees of freedom are lost. The remaining degrees of freedom of pair can then be used to classify pairs.

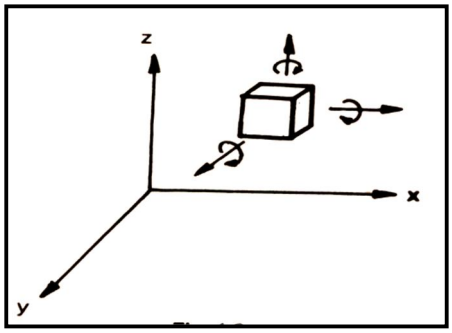


Figure: 3 Degree of Freedom

An unconstrained rigid body moving in a space can describe the following independent motions.

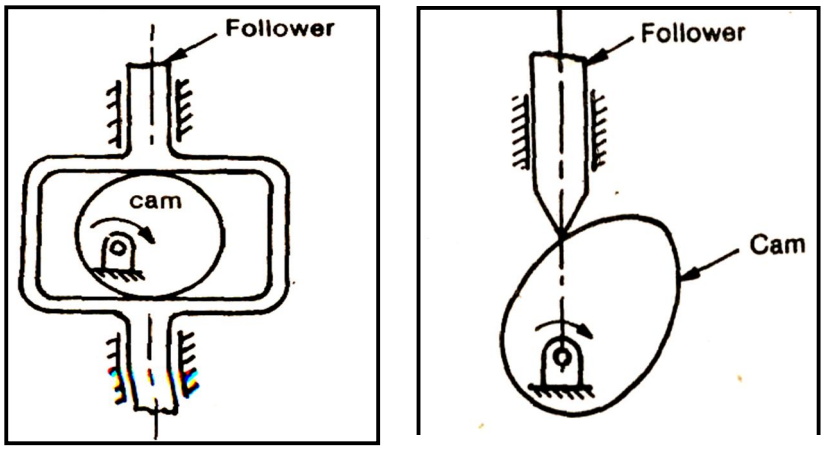
(1) Transnational motions along any three mutually perpendicular axis x, y, & z, and
(2) Three rotational motions about these axis

Degrees of freedom of a pair = 6 – Number of restrains

A kinematics pair can therefore be classified in line basis of member of restraints imposed on the relative motion of connected links. The classification is given in different forms of pairing elements are shown in fig.2.

(D) Classification of pair according to nature of mechanical constraint (type of closure):

CLOSED PAIR:



(a) (b)

Figure: 4 (a) Closed Pairs (b) Unclosed pair

When the elements of a pair are hold together mechanically. It is known as a closed pair. The two elements are geometrically full and the other is hollow or open. All the lower pairs and some of the higher pairs are closed pairs. A cam & follower mechanism and a screw pair belong to this category.

UNCLOSED PAIR: When two links of a pair are in contact either due to force of gravity or some spring action, they constitute an unclosed pair. In this the links are not hold together

mechanically, e.g. – cam & follower pair mechanism. Hold in contact due to spring force is this type.

KINEMATIC CHAIN:

A kinematics chain is assembly of links in which the relative motions of the links is possible and the motion of each relative to the others is definite.

In case, the motion of a link results in indefinite motion of a links, it is a non-kinematics chain.

A redundant chain does not allow any motion of a link relative to the other.

LINKAGE:

A linkage is obtained if one of the links of a kinematics chain is fixed to the ground. Many kinematicians of repute prefer to reverse the form linkage to describe mechanisms consisting of lower pairs only.

TYPE OF CONSTRAINED MOTIONS:

1. Completely constrained motion: When the motion between a pair is limited to a definite direction irrespective of the direction of force applied then the motion is said to be a completely constrained motion.
2. Incompletely constrained motion: When the motion between a pair can take place in more than one direction, then the motion is called an incompletely constrained motion.
3. Successfully constrained motion: When the motion between the elements, forming a pair is such that the constrained motion is not completed by it self, but by same other means then the motion is said to be successfully constrained motion.

INVERSIONS:

A mechanism is formed by fixing one of the links of a chain clearly, when different links of the same chain are chosen to become frame-link, different mechanisms will result. The process of choosing different link of a kinematics chain for properties of inversions.

1. Number of inversions, possible for a kinematics chain, equals number of links in the parent kinematics chain
2. Relative motion between any two links does not change with inversion.
3. Absolute motion of points on various links (measured with respect to the frame link), However, may change drastically from one inversion to the other, even in direct inversion.

INVERSIONS OF FOUR BAR CHAIN MECHANISM:

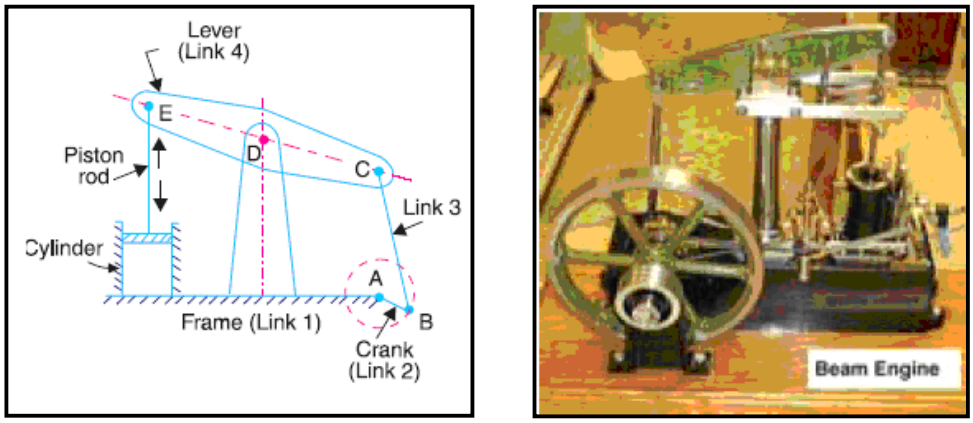


Figure: 5 Beam Engine

1. ENGINE (CRANK AND LEAVER BEAM MECHANISM):

Beam engine mechanism, is used for converting rotary motion of crank in to reciprocating

motion of piston

2. COUPLING ROD OF A LOCOMOTIVE:

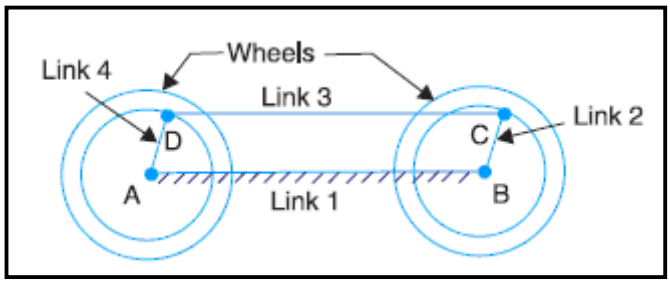


Figure: 6 Coupling rod of Locomotive

It is also known as parallel crank tour-bar. It in a four bar chain two opposite links are parallel and equal in length, then any of the links can be made fix, the two links adjacent to the fixed links always act as two cranks, provided the cranks, provided the cranks rotates in the same sense.

3. WATT'S INDICATOR MECHANISM:

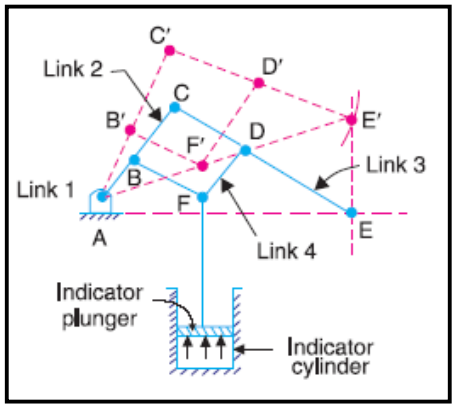


Figure: 7 Watt's Indicator Mechanism

It is also called as double lever mechanism or straight- line mechanism.

INVERSION OF SINGLE SLIDER CRANK CHAIN:

1.FIRST INVERSION:

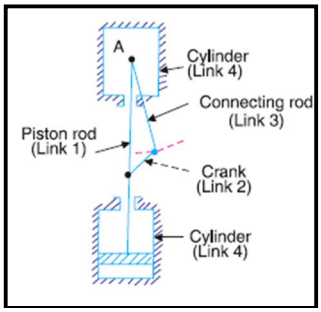


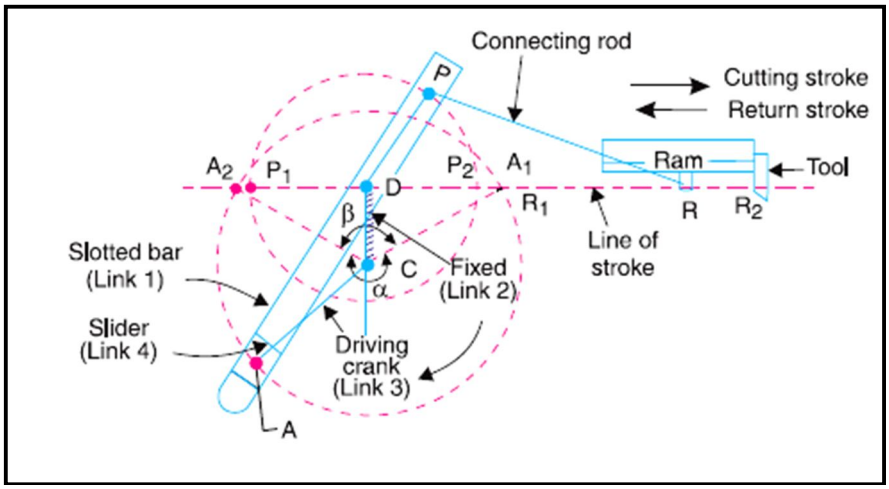
Figure: 8 Reciprocating engine

It is obtained by fixing link (1) of four bar crank chain other. Links being as crank, (2) as slider (4) and as a connecting link (3).

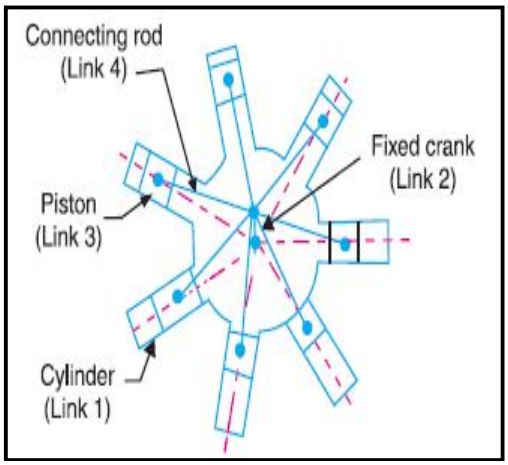
APPLICATION: Reciprocating engine, reciprocating compressor

2. SECOND INVERSION:

Here crank (2) is fixed, Remaining two links and slider link (1,3,4) are free to move



(a) Whit worth quick-return mechanism

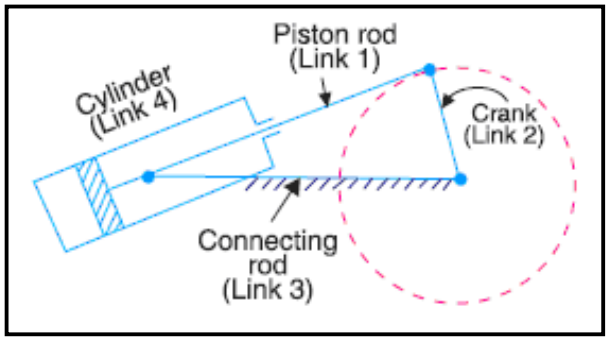


(b) Rotary engine

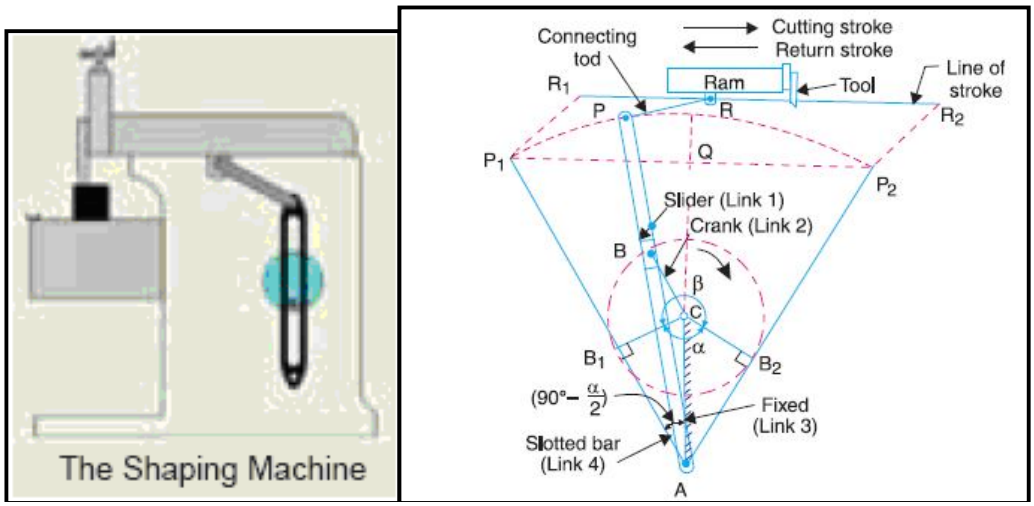
Figure: 9 Second inversions

APPLICATION: Whit worth quick-return mechanism (Fig.9 a), Rotary engine (Fig.9 b)

3. THIRD INVERSION: In this mechanism, connecting link (3) is fixed & other links move relatively.



(a) Oscillating cylinder engine crank



(b) Shaper machine and slotted-lever mechanism

Figure: 10 Third Inversions

APPLICATION: oscillating cylinder engine crank (fig10. a) and slotted- lever mechanism (fig10b).

4. FOURTH INVERSION: If slider (4) is fixed then this type of inversion will be obtained, in this link (1) is reciprocating and connecting link (3) is oscillating about the fixed pivot.

APPLICATION**:** Hand pump.

INVERSIONS OF DOUBLE SLIDER-CRANK CHAIN:

A four bar chain having two turning and two sliding pair such that two pairs of the same kind are adjacent is known as a double-slider-crank chain.

1. **FIRST INVERSION**: This inversion is obtained when one link is fixed and two adjacent pairs are turning pairs and two pairs are sliding pairs.

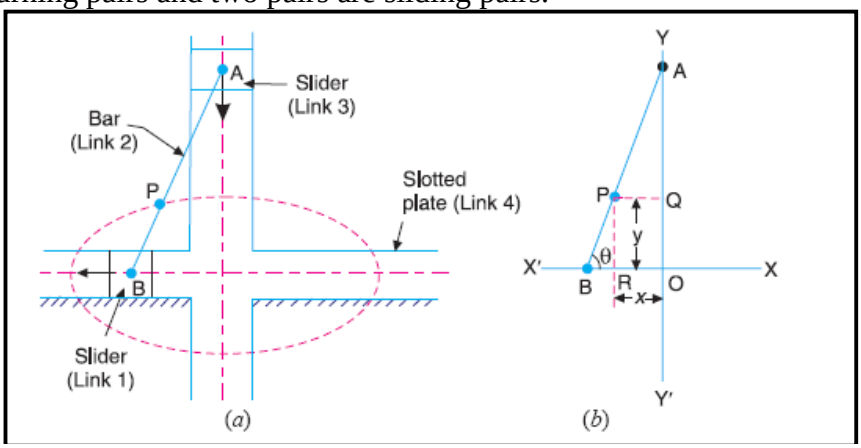


Figure: 11 first Inversion (Elliptical trammel)

APPLICATION**:** Elliptical trammel

2. **SECOND INVERSION**: If any of the slide-blocks of the first inversion is fixed, the second inversion of the double-slider-crank chain is obtained.

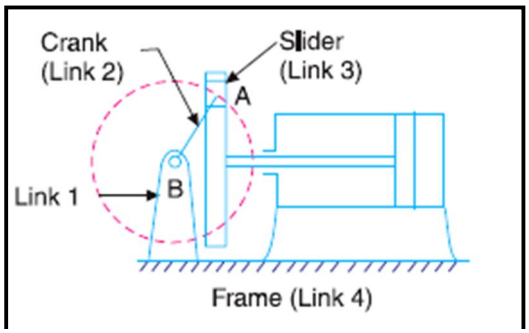


Figure: 12 Scotch viewed mechanism.

APPLICATION: Scotch viewed mechanism.

3. **THIRD INVERSION:** When connecting link of first inversion is fixed then this type of inversion will be obtained.

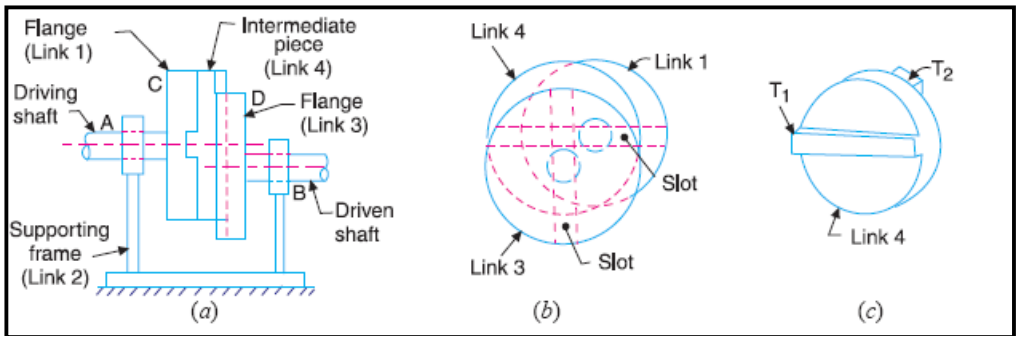


Figure: 13 Oldham's coupling

APPLICATION: Oldham's coupling.

Answer Type Questions:

1. What is a 'Resistant Body ' ?

2. What is a 'Kinematic Link' ?

3. What are the characteristics of a kinematic link ?

4. What is a'Structure'?

5. What is a 'Kinematic Pair'?

6. How are kinematic pairs classified ?

7. What are 'Lower and Higher' pairs ? Give two practical examples of each.

8. What are closed and unclosed or open pairs ? Give two practical examples of each.

9. What are different types of constraints in kinematic pairs ?

10. What is a 'kinematic chain' ?

11. How a kinematic chain is converted into a mechanism ?

12. What is an 'Inversion' ?

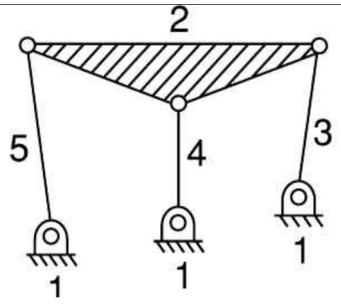
13. Name any four inversion applications of a slider crank chain.

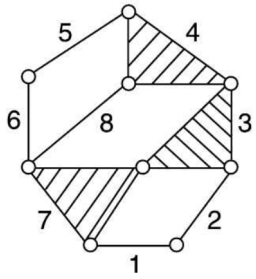
14. Which quick-return motion mechanism is used in shapers ?

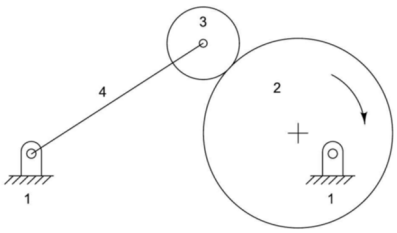
15. What is the special feature of quick-return motion mechanism?

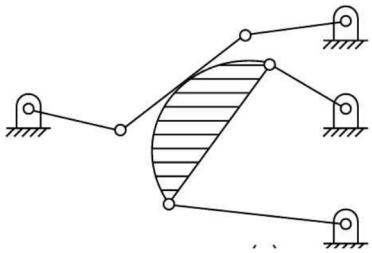
16. What are the special features of Oldham's coupling ?

17. Find degree of freedom of given mechanism using Kutzbach mobility criterion.









References:

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2. Theory of Machines and Mechanisms, Uicker J J Jr., Pennock G R, Shigley J E, Oxford Press.
3. Kinematics and Dynamics of Machinery, Norton R L, McGraw-Hill
4. Mechanism and Machine Theory, Ambekar, A G, Prentice Hall
5. Theory of Machines, Singh Sadhu, Pearson Education

References used by the students:

Rubric wise marks obtained:

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70- 89%.	Student give the correct answers between 50- 69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*_____		
			Total Marks		

Teacher Sign

Experiment No: 2
Velocity and acceleration analysis of a four-bar mechanism and Slider Crank mechanism using graphical & analytical method.

Date:

Relevant CO: Perform velocity and acceleration analysis of planar mechanisms using analytical, graphical, and numerical (software) approaches.

THEORY:

For proper study of the different parts of a mechanism one should know the velocities and accelerations at different moments. To facilitate such type of study, commonly configuration diagrams are used. The solution can be obtained either by analytically or graphical method.

VELOCITY ANALYSIS:

a) Analytical method:

The velocity is described in two different ways, one is absolute velocity and other is relative velocity. Here we will keep more stress on relative velocity method, which can be found as under:

$$V_{ab} = \omega * r$$

Where V_{ab} = velocity of any point 'a' on link with respect to reference point 'b'

ω = Angular velocity of link

r = radius of link AB

This velocity is always proportional to the line joining these points a & b on configuration or space diagrams.

The velocity of an intermediate point on any of the links can be found easily by dividing the corresponding velocity vector in the ratio as the point divides the link.

VELOCITY OF RUBBING:

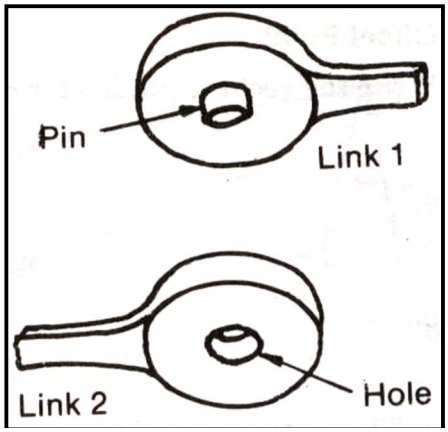


Figure 1

Figure 1 shows two ends of the two links of a turning pair. In turning pair, the pin is fixed to one of the link whereas a hole is provided in the other to fit the pin. When joined, the surface of the hole of one link will rub on the surface of other link. The velocity of rubbing of the two surfaces will depend upon the angular velocity of a link relative to the other. Which can be found by following way;

Velocity of rubbing = $r(\omega_1 \pm \omega_2)$

Where, r = radius of the pin

ω_1 &ω_2 = angular velocities of respective links

The angular velocity of the two links together are in the same direction, the velocity of rubbing will be the difference of the angular velocities and if it is in different directions than the sum of the angular velocities.

b) Graphical method:

In this method velocity diagrams, which can be constructed as under:

1. Take all the points, which are on fixed link as a single point because their velocity is zero.
2. Take the first vector as it is completely known from above point and perpendicular to respective link.
3. Similar way completes the polygon and measured the magnitude and direction of required velocity of point.

ACCELERATION ANALYSIS:

Velocity is a vector quantity having the magnitude and direction. A change in velocity required following condition

- A change in the magnitude only
- A change in the direction only
- A change in both

The rate of change of velocity with respect to time is known acceleration and acts in the direction of the change in velocity. Thus acceleration is also a vector quantity.

The rate of change of velocity in tangential direction of the motion is known as tangential acceleration, which can be found as follows;

$$f_t = \alpha * r$$

Where, α = angular acceleration and r = radius (length of link)

The rate of change of velocity along the link towards the center is called centripetal acceleration, which can be found as follows;

$$F_c = V^2 * r$$

The total acceleration = ft + f_c

1. If $\alpha = 0$ then $f_t = 0$ and total acceleration is f_c
2. If $\alpha = 0$ then $f_t = 0$ and total acceleration is f_t
3. When α negative, then tangential acceleration will be negative

The acceleration of intermediate points on the links can be obtained by dividing the acceleration vectors in the same ratio as the points divide the links.

CORIOLIS COMPONENT:

The tangential component of acceleration of the slider with respect to coincident point on the link, which is rotating

Section A) <u>Objective Type Questions</u>

1. The component of acceleration parallel to the link is called
   (a) Radial (b) Tangential (c) Coriolis (d) Absolute
2. Coriolis component of acceleration is considered in case of
   (a) quick return mechanism (b) Slider crank mechanism
   (c) four bar mechanism (d) none of the above
3. When crank rotates with uniform speed, it has
   (a) Only radial acceleration (b) only tangential acceleration
   (c) Only coriolis acceleration (d) none of the above
4. The total number of instantaneous centers for a mechanism containing n links is given by
   (a) n-1 / 2 (b) n (n-1) / 2 (c) n (d) n / 2
5. Klein's construction is helpful in determining
   (a) Acceleration of various parts (b) velocity of various parts
   (c) Displacement of various parts (d) none of the above
6. The direction of the coriolis component is the direction
   (a) Along the tangential acceleration (b) along radial acceleration
   (c) Of the relative velocity vector for the two coincident points rotated by 90° in the direction of the angular velocity of the link
   (d) None of the above
7. If three bodies move relatively to each other then according to Kennedy's theorem their instantaneous centers will lie on
   (a) Parabolic curve (b) ellipse (c) circle (d) straight line
8. A slider sliding at 10 cm/sec on a link which is rotating at 60 rpm is subjected to Coriolis acceleration of magnitude,
   (a) $40\pi^2$ cm/sec^2 (b) o.4π cm/sec^2 (c) 40π cm/sec^2 (d) 4π cm/sec^2

Examples

1. In slider – crank mechanism, the crank is 480 mm long and rotates at 20 rad/sec on counter clockwise direction. The length at connecting rod is 1600 mm. When the crank turns 60° from the inner – dead center, find
   (i) The velocity of slides
   (ii) The angular velocity of connecting rod.

2. In a pin jointed four bar mechanism ABCD, the length of various links are as follows: AB = 25 m, BC = 87.5 mm, CD = 50 mm and AD = 80 mm. The link AD is fixed and <BAD = 135°. If the velocity of B is 1.8 m/s in the clockwise direction, find by graphical method.
   (i) Velocity and acceleration of the mid point of BC
   (ii) Angular velocity and acceleration of link CB and CD

3. The length of crank and connecting rod of a crank slider mechanism are 100 mm and 400mm respectively. If the crank angle is 45 degree from inner dead centre, locate all the instantaneous centers of the mechanism and determine velocity of all links.

References:

1. Theory of Machines, Rattan S S, Tata McGraw-Hill
2. Theory of Machines and Mechanisms, Uicker J J Jr., Pennock G R, Shigley J E, Oxford Press.
3. Kinematics and Dynamics of Machinery, Norton R L, McGraw-Hill
4. Mechanism and Machine Theory, Ambekar, A G, Prentice Hall
5. Theory of Machines, Singh Sadhu, Pearson Education

References used by the students:

Rubric wise marks obtained:

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70- 89%.	Student give the correct answers between 50- 69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*_____		
			Total Marks		

Teacher Sign

Experiment No: 3
Synthesis of Four Bar Mechanism and Slider Crank Mechanism using C/C++/MATLAB/Python or any other suitable programming language.

Date:

Relevant CO: Synthesize mechanisms for function generation with precision points.

Introduction:

The synthesis of mechanism is the design or creation of a mechanism to produce a desired output motion for a given input motion. In other words, the synthesis of mechanism deals with the determination of proportions of a mechanism for the given input and output motion. In the application of synthesis, to the design of a mechanism, the problem divides itself into the following three parts:

1. Type synthesis, i.e. the type of mechanism to be used,
2. Number synthesis, i.e. the number of links and the number of joints needed to produce the required motion, and
3. Dimensional synthesis, i.e. the proportions or lengths of the links necessary to satisfy the required motion characteristics.

In designing a mechanism, one factor that must be kept in mind is that of the accuracy required of the mechanism. Sometimes, it is possible to design a mechanism that will theoretically generate a given motion. The difference between the desired motion and the actual motion produced is known as structural error. In addition to this, there are errors due to manufacture. The error resulting from tolerances in the length of links and bearing clearances is known as mechanical error.

Classifications of Synthesis Problem

The problems in synthesis can be placed in one of the following three categories:

1. Function generation; 2. Path generation; and 3. Body guidance.

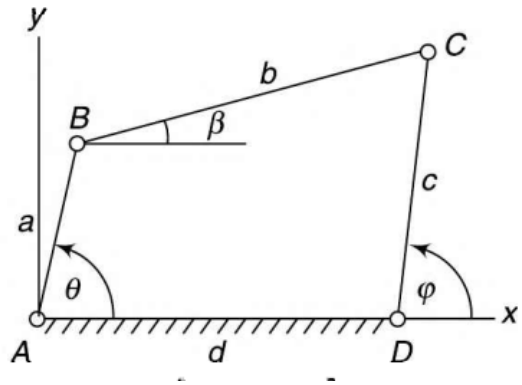
These are discussed as follows:

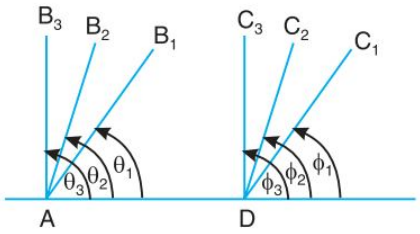
1. Function generation. The major classification of the synthesis problems that arises in the design of links in a mechanism is a function generation. In designing a mechanism, the frequent requirement is that the output link should either rotate, oscillate or reciprocate according to a specified function of time or function of the motion of input link. This is known as function generation. A simple example is that of designing a four bar mechanism to generate the function y = f (x). In this case, x represents the motion of the input link and the mechanism is to be designed so that the motion of the output link approximates the function y.

2. Path generation. In a path generation, the mechanism is required to guide a point (called a tracer point or coupler point) along a path having a prescribed shape. The common requirements are that a portion of the path be a circular arc, elliptical or a straight line.

3. **Body guidance**. In body guidance, both the position of a point within a moving body and the angular displacement of the body are specified. The problem may be a simple translation or a combination of translation and rotation.

Freudenstein's equation (Three position Function Generation)





Three positions of input and output link.

A four-link mechanism shown in Fig. 5.25 is in equilibrium. Let a, b, c and d be the magnitudes of the links AB, BC, CD and DA respectively. θ, β and φ are the angles of AB, BC and DC respectively with the X-axis (taken along AD). AD is the fixed link. AB and DC are the input and output links respectively of the mechanism.

Considering the links to be vectors, displacement along the X-axis

$a \cos \theta + b \cos \beta = d + c \cos \phi$ (The equation is valid for $< \phi$ more than 90° also.)

or $\quad b \cos \beta = c \cos \varphi - a \cos \theta + d$

or $\quad (b \cos \beta)^2 = (c \cos \varphi - a \cos \theta + d)^2$

$$= c^2 \cos^2 \varphi + a^2 \cos^2 \theta + d^2 - 2ac \cos \theta \cos \varphi - 2ad \cos \theta + 2cd \cos \varphi \qquad \text{(i)}$$

Displacement along Y-axis

$$a \sin \theta + b \sin \beta = c \sin \phi$$

or $\quad b \sin \beta = c \sin \varphi - a \sin \theta$

or $\quad (b \sin \beta)^2 = (c \sin \varphi - a \sin \theta)^2$

$$= c^2 \sin^2 \varphi + a^2 \sin^2 \theta - 2ac \sin \theta \sin \varphi \qquad \text{(ii)}$$

Adding (i) and (ii),

$$b^2 = c^2 + a^2 + d^2 - 2ac \cos \theta \cos \varphi - 2ad \cos \theta + 2cd \cos \varphi - 2ac \sin \theta \sin \varphi$$

or $\quad 2cd \cos\varphi - 2ad \cos\theta + a^2 - b^2 + c^2 + d^2 = 2ac(\cos\theta \cos \varphi + \sin\theta \sin \varphi)$

Dividing throughout by $2ac$,

$$\frac{d}{a}\cos \varphi - \frac{d}{c}\cos \theta + \frac{a^2 - b^2 + c^2 + d^2}{2ac} = \cos(\theta - \varphi) = \cos(\varphi - \theta)$$

This is known as *Freudenstein's* equation and can be written as,

$$k_1 \cos\varphi + k_2 \cos\theta + k_3 = \cos(\theta - \varphi)$$

where

$$k_1 = \frac{d}{a}; k_2 = -\frac{d}{c}; \quad \text{and} \quad k_3 = \frac{a^2 - b^2 + c^2 + d^2}{2ac}$$

Let the input and the output are related by some function such as $y = f(x)$ and for the specified positions

$\theta_1, \theta_2, \theta_3$ = three positions of input link (given)

and $\varphi_1, \varphi_2, \varphi_3$ = three positions of output link (given)

It is required to find the values of a, b, c and d to form a four-link mechanism giving the prescribed motions of the input and the output links.

Equation (5.1) can be written as,

$$k_1\cos\varphi_1 + k_2\cos\theta_1 + k_3 = \cos(\theta_1 - \varphi_1)$$
$$k_1\cos\varphi_2 + k_2\cos\theta_2 + k_3 = \cos(\theta_2 - \varphi_2)$$
$$k_1\cos\varphi_3 + k_2\cos\theta_3 + k_3 = \cos(\theta_3 - \varphi_3)$$

k_1, k_2, and k_3 can be evaluated by Gaussian elimination method or by the Cramer's rule.

$$\Delta = \begin{vmatrix} \cos\varphi_1 & \cos\theta_1 & 1 \\ \cos\varphi_2 & \cos\theta_2 & 1 \\ \cos\varphi_3 & \cos\theta_3 & 1 \end{vmatrix}$$

$$\Delta_1 = \begin{vmatrix} \cos(\theta_1 - \varphi_1) & \cos\theta_1 & 1 \\ \cos(\theta_2 - \varphi_2) & \cos\theta_2 & 1 \\ \cos(\theta_3 - \varphi_3) & \cos\theta_3 & 1 \end{vmatrix}$$

$$\Delta_2 = \begin{vmatrix} \cos\varphi_1 & \cos(\theta_1 - \varphi_1) & 1 \\ \cos\varphi_2 & \cos(\theta_2 - \varphi_2) & 1 \\ \cos\varphi_3 & \cos(\theta_3 - \varphi_3) & 1 \end{vmatrix}$$

$$\Delta_3 = \begin{vmatrix} \cos\varphi_1 & \cos\theta_1 & \cos(\theta_1 - \varphi_1) \\ \cos\varphi_2 & \cos\theta_2 & \cos(\theta_2 - \varphi_2) \\ \cos\varphi_3 & \cos\theta_3 & \cos(\theta_3 - \varphi_3) \end{vmatrix}$$

k_1, k_2 and k_3 are given by,

$$k_1 = \frac{\Delta_1}{\Delta}; \quad k_2 = \frac{\Delta_2}{\Delta}; \quad k_3 = \frac{\Delta_3}{\Delta}$$

Knowing k_1, k_2 and k_3, the values of a, b, c and d can be computed from the relations

$$k_1 = \frac{d}{a}; \quad k_2 = -\frac{d}{c}; \quad k_3 = \frac{a^2 - b^2 + c^2 + d^2}{2ac}$$

Value of either a or d can be assumed to be unity to get the proportionate values of other parameters.

Precision Points for Function Generation (Chebyshev's spacing):

In designing a mechanism to generate a particular function, it is usually impossible to accurately produce the function at more than a few points. The points at which the generated and desired functions agree are known as precision points or accuracy points and must be located so as to minimize the error generated between these points.

According to Freudenstein and Sandor, the Chebychev spacing for n points in the range $x_S \le x \le x_F$ (*i.e.* when x varies between x_S and x_F) is given by

$$x_j = \frac{1}{2}(x_S + x_F) - \frac{1}{2}(x_F - x_S)\cos\left[\frac{\pi(2j-1)}{2n}\right]$$
$$= \frac{1}{2}(x_S + x_F) - \frac{1}{2}\times\Delta x\times\cos\left[\frac{\pi(2j-1)}{2n}\right]$$

where x_j = Precision points

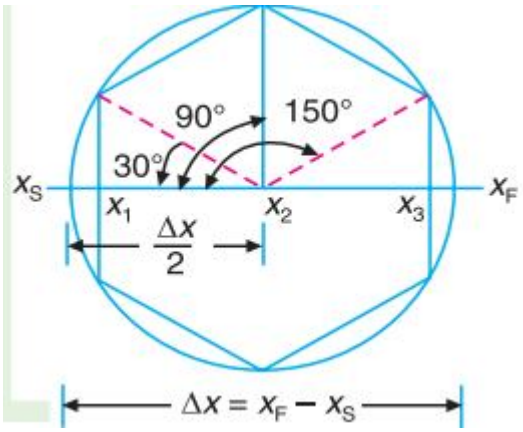
Δx = Range in $x = x_F - x_S$, and

j = 1, 2, ... n

The subscripts $_S$ and $_F$ indicate start and finish positions respectively.

The precision or accuracy points may be easily obtained by using the graphical method as discussed below.

1. Draw a circle of diameter equal to the range $\Delta x = x_F - x_S$
2. Inscribe a regular polygon having the number of sides equal to twice the number of precision points required, i.e. for three precision points, draw a regular hexagon inside the circle, as shown in Fig.
3. Draw perpendiculars from each corner which intersect the diagonal of a circle at precision points x1, x2, x3.



Now for the range $1 \le x \le 3$, $x_S = 1$; $x_F = 3$, and

$$\therefore \quad \Delta x = x_F - x_S = 3 - 1 = 2$$

or radius of circle, $$r = \Delta x / 2 = 2/2 = 1$$

$$\therefore \quad x_2 = x_S + r = x_S + \frac{\Delta x}{2} = 1 + \frac{2}{2} = 2$$

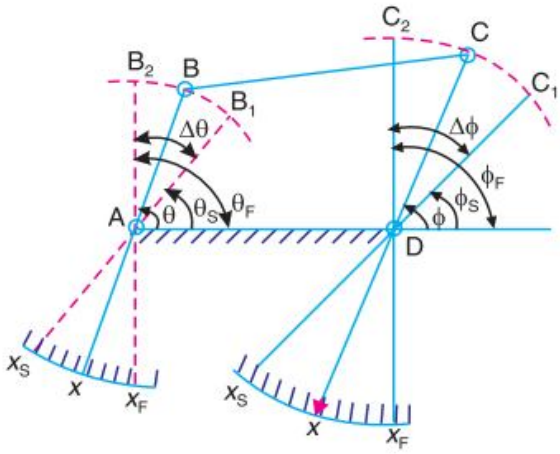
$$x_1 = x_2 - r\cos 30° = x_2 - \frac{\Delta x}{2}\cos 30°$$

$$= 2 - \frac{2}{2}\cos 30° = 1.134$$

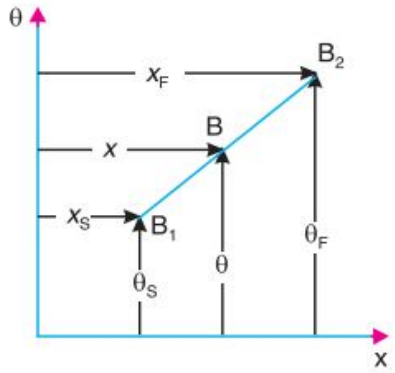
and $$x_3 = x_2 + r\cos 30° = x_2 + \frac{\Delta x}{2}\cos 30°$$

$$= 2 + \frac{2}{2}\cos 30° = 2.866$$

Angle Relationships for Function Generation:



(*a*) Four bar mechanism.



(*b*) Linear relationship between x and θ.

Consider a four bar mechanism, as shown in Fig. 25.6 (*a*) arranged to generate a function $y = f(x)$ over a limited range. Let the range in x is $(x_F - x_S)$ and the corresponding range in θ is $(\theta_F - \theta_S)$. Similarly, let the range in y is $(y_F - y_S)$ and the corresponding range in ϕ is $(\phi_F - \phi_S)$.

$$\theta = \theta_S + \frac{\theta_F - \theta_S}{x_F - x_S}(x - x_S)$$

Similarly, the linear relationship between y and ϕ may be written as

$$\phi = \phi_S + \frac{\phi_F - \phi_S}{y_F - y_S}(y - y_S)$$

For n points in range

$$\theta_j = \theta_S + \frac{\theta_F - \theta_S}{x_F - x_S}(x_j - x_S) = \theta_S + \frac{\Delta\theta}{\Delta x}(x_j - x_S)$$

and

$$\phi_j = \phi_S + \frac{\phi_F - \phi_S}{y_F - y_S}(y_j - y_S) = \phi_S + \frac{\Delta\phi}{\Delta y}(y_j - y_S)$$

where $j = 1, 2, \ldots n$,

$\Delta x = x_F - x_S$; $\Delta\theta = \theta_F - \theta_S$,

$\Delta y = y_F - y_S$; and $\Delta\phi = \phi_F - \phi_S$

Problems

1. Design a four link mechanism when the motion of the input and output links are governed by a function $y = x^2$ and x varies from 0 to 2 with an interval of 1. Assume input angles to vary from 50^0 to 150^0 and output angles to vary from 80^0 to 160^0.

2. Design a four link mechanism to coordinate three positions of the input and output links as follows

$$\theta_1 = 20°,\ \varphi_1 = 35°$$
$$\theta_2 = 35°,\ \varphi_2 = 45°$$
$$\theta_3 = 50°,\ \varphi_3 = 60°$$

3. Determine the proportions of four bar mechanism, by using three precision points, to generate $y = x^{1.5}$, where x varies between 1 and 4. Assume $\theta_s = 30^0$; $\Delta\theta = 90°$; $\varphi_s = 90°$; and $\Delta\varphi = 90°$. Take length of the fixed link AD as 25 mm.

4. Develop C/C++/MATLAB/Python program to solve problem 1 to 3.

References:

1. Theory of Machines, Rattan S S, Tata McGraw-Hill
2. Theory of Machines and Mechanisms, Uicker J J Jr., Pennock G R, Shigley J E, Oxford Press.
3. Kinematics and Dynamics of Machinery, Norton R L, McGraw-Hill
4. Mechanism and Machine Theory, Ambekar, A G, Prentice Hall
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References used by the students:

Rubric wise marks obtained:

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70- 89%.	Student give the correct answers between 50- 69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*_____		
			Total Marks		

Teacher Sign

Experiment No: 4
Study and demonstration of Belts, Brakes and Clutches.

Date:

Relevant CO: Develop the concepts of basic power transmission devices for the given field/industrial application.

INTRODUCTION

Power is transmitted from one shaft to another by means of Belt, rope, chain and gears.

Salient Features:

- Belt, rope and chain are used where the distance between the shaft is large. For small distance, gears are preferred.
- Belt, rope and chain are the flexible types of connectors, i.e., they are bent easily.
- The flexibility of belt and rope is due to the property of their materials whereas chains have a number of small rigid elements having relative motion between the two elements.
- Belt and rope transmit power due to friction between them and the pulley. If the power transmitted exceeds the force of friction, the belt or rope slips over the pulley.
- Belts and ropes are strained during motion as tensions are developed in them.
- Owing to slipping and straining action belts and ropes are not positive drive, i.e., velocity ratio are not constant. Chain and gears have a constant velocity ratio.

SELECTION OF BELT DRIVE

Following are the factors which affect the selection of belt drive:

- Speed of driving and driven shafts.
- Power to be transmitted.
- Space available.
- Service conditions.
- Centre distance between the shafts.
- Speed reduction ratio.

TYPES OF BELT DRIVES

a) Light drives
   - Small power.
   - $V \leq 10$ m/s Agricultural machine, Small machine.

b) Medium drives
   - Medium power
   - $22 < V > 10$ m/s, Machine tool.

c) Heavy drives
   - Large power
   - $V > 22$ m/s Compressor, generator.

BELT DRIVES & ITS MATERIALS

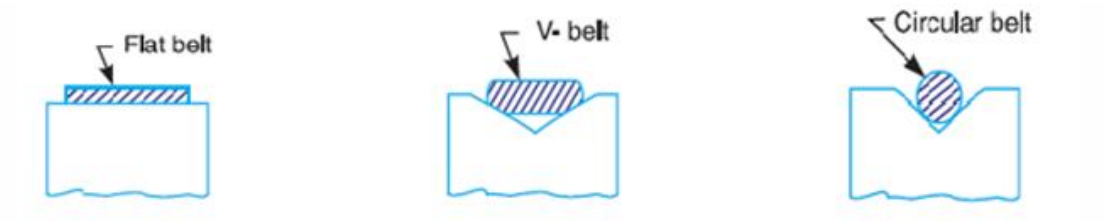

Fig.1.Types of Belt

Flat Belt

- Used in the industry where a moderate amount of power is transmitted.
- Dist. x ≤ 8m or 10m apart with 22 m/sec.
- Materials are leather, rubber, canvas, cotton & rubber Balata (higher strength than rubber belt).

V- Belt

- Used in the industry where a moderate amount of power to be transmitted.
- Connect the shaft up to 4m.
- Speed ratio can be up to 7 to 1 and belt speed 24 m/sec.
- Made of rubber impregnated fabric with the angle of V between 30° to 40°.

Note: In multiple V – belt drive all the belt should be stretch at the same rate so that load is equally divided. When one of the selves of belt break, the entire set should be replaced at the same drive. If one belt is replaced the new unworn and unstressed will be more tightly stretched and will more with different velocity.

Ropes

- Used where a higher amount of power to be transmitted distance up to 30m apart.
- Operating speed is less than 3 m/sec.
- Materials for rope are cotton, hemp, manila or wire.

Types of Flat Belt Drives

Open Belt Drive

- An open belt drive is used when the driven pulley is desired to rotate in the same direction.

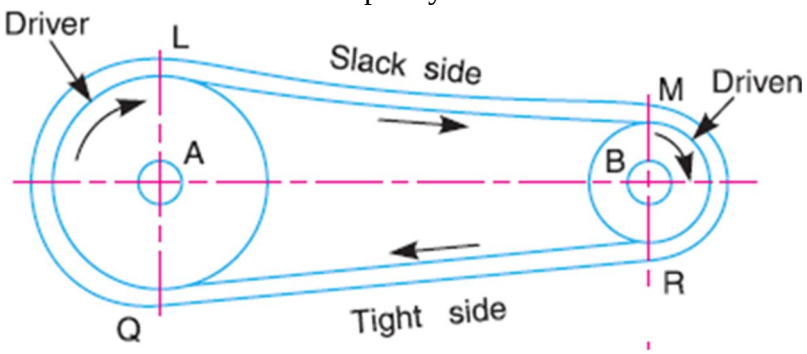

Fig.2 Open belt Drive

- Generally, the centre distance for open belt drive is 14 – 16 m. if the distance is too large, the belt whips i.e. vibrate in a direction perpendicular to the direction of motion.
- For very shorter distance, the belt slips increase.
- While transmitting power, one side of the belt is more tightened (known as a tight side) as compared to other (known as a slack side).
- In the case of horizontal drives, it is always desired that the tight side is at the lower side of

two pulleys. This is because the sag of the belt will be more on the upper side than the lower side. This slightly increases the angle of wrap of the belts on the two pulleys than if the belt had been perfectly straight between the pulleys.

- In case the tight side of the belt is on the upper side, the sag will be greater at the lower side, reducing the angle of wrap and slip could occur earlier. This ultimately affects the power to be transmitted.

Crossed Belt Drive

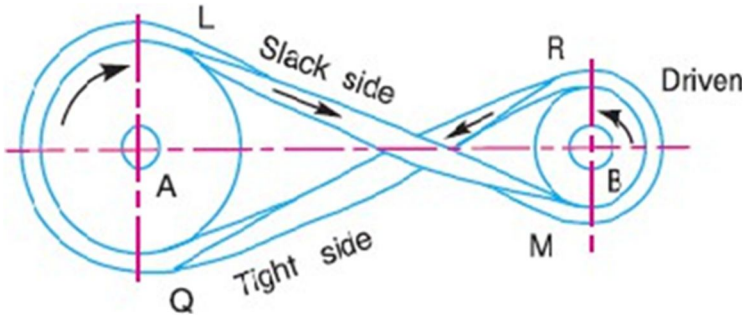

Fig. 3 Crossed Belt Drive

- A crossed belt drive is used when the driven pulley is to be rotated in the opposite direction to that of the driving pulley.
- A crossed belt drive can transmit more power than an open belt drive as the angle of wrap is more.
- However, the belt has to bend in two different planes and it wears out more. To avoid this the shaft should be placed at a max dist. 20 b where b = width of belt and speed should be less than 15 m /sec.

Quarter Turn Belt Drive / Right Angle Belt Drive

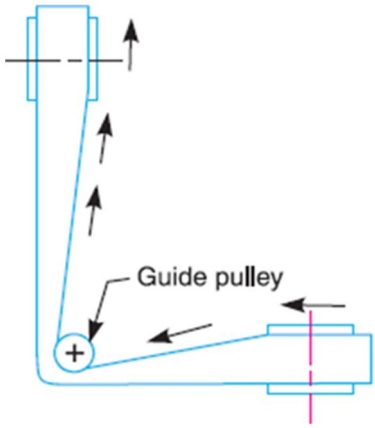

Fig. 4 Quarter Turn Belt Drive

- A guide pulley is used to connect two non-parallel shafts in such a way that they may run in either direction and still making the pulley to deliver the belt properly in accordance with the law of belting.
- A guide pulley can also be used to connect even intersecting shaft also.

Belt Drive with Idler Pulley

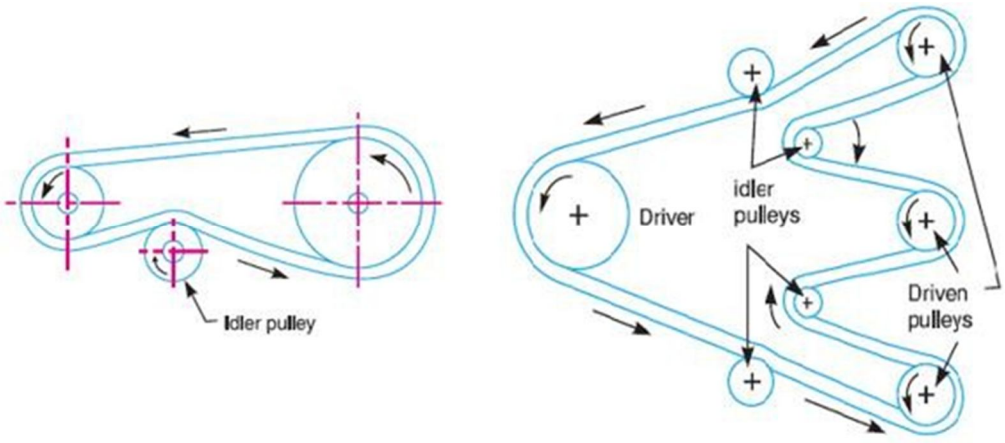

Fig.5 BeltdrivewithIdlerpulley

- With constant use, the belt is permanently stretched in a little longer. This reduces the initial tension in the belt leading to lower power transmission capacity. However, the tension in the belt can be restored to the original value.
- A bell – crank lever, hinged on the axis of the smaller pulley, supports adjustable weights on its one arm and the axis of a pulley on the other. The pulley is free to rotate on its axis and is known as an idler pulley. Owing to weights on one arm of the lever, the pulley exerts pressure on the belt increasing the tension and the angle of contact. Thus, the life of the belt is increased and the power capacity is restored to the original value.
- The motion of one shaft can be transmitted to two or more than two shafts by using a number of the idler pulley.

Compound Belt Drive / Intermediate Pulley

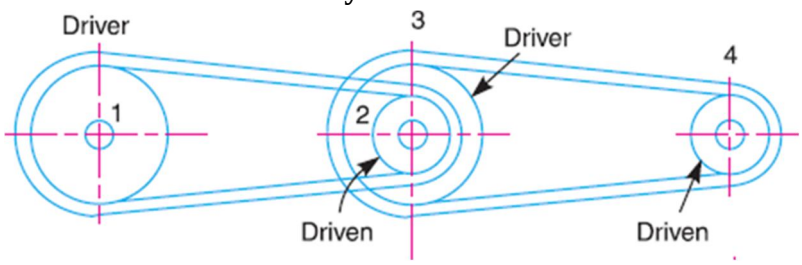

Fig.6 Compound Belt Drive

- When it is required to have large velocity ratios, ordinarily the size of the larger pulley will be quite big. However, by using an intermediate (counter-shaft) pulley, the size can be reduced.

Stepped / Cone Pulley Drive

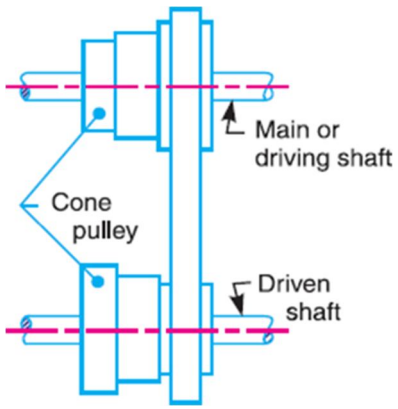

Fig.7 Stepped / Cone Pulley Drive

- A stepped cone pulley drive is used for changing the speed of the driven shaft while the main

or driving shaft runs at a constant speed.

- This is done by shifting the belt from one part of the step to the other.

Fast and Loose Pulley drive

- Many times, it is required to drive several machines from a single main shaft. In such a case, some arrangement to link or delink a machine to or from the main shaft has to be incorporated as all the machines may not be operating simultaneously. The arrangement usually provided is that of using a loose pulley along with a fast pulley.
- A fast pulley is keyed to the shaft and rotates with it at the same speed and thus transmits power.
- A loose pulley is not keyed to the shaft and thus is unable to transmit any power.
- Whenever a machine is to be driven, the belt is mounted on the fast pulley and when it is not required to transmit any power, the belt is pushed to the loose pulley placed adjacent to the fast pulley.

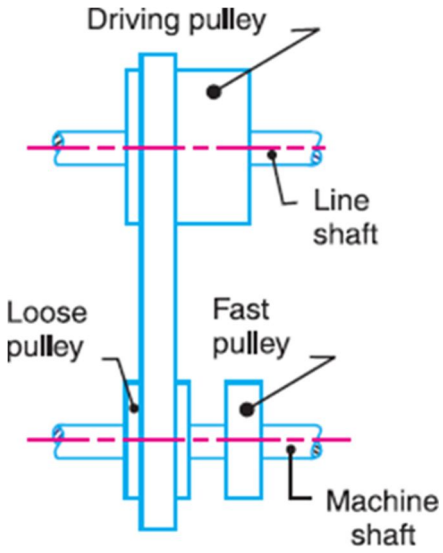

Fig.8 Fast and Loose Pulley drive

FRICTIONCLUTCHES

Aclutchisadeviceusedtotransmittherotarymotion ofoneshafttoanotherwhendesired.Theaxesof the two shafts are coincident.

Disc clutch

A disc clutch consists of a clutch plate attached to a splined hub that is free to slide axially on splines cut on the driven shaft. The clutch plate is made of steel and has a ring of friction lining on each side. The engine shaft supports a rigidly fixed flywheel.

A spring-loaded pressure plate presses the clutch plate firmly against the flywheel when the clutch is engaged.

When disengaged, the springs press against a cover attached to the flywheel. Thus, both the flywheel and the pressure plate rotate with the input shaft. The movement of the clutch pedal is transferred to the pressure plate through a thrust bearing.

Fig. 9 shows the pressure plate pulled back by the release levers and the friction linings on the clutch plate are no longer in contact with the pressure plate or the flywheel. The flywheel rotates without driving the clutch plate and thus, the driven shaft.

When the foot is taken off the clutch pedal, the pressure on the thrust bearing is released. As a result, the springs become free to move the pressure plate to bring it in contact with the clutch plate. The clutch plate slides on the splined hub and is tightly gripped between the pressure plate and the flywheel. The frictionbetween the linings on the clutch plate, and the flywheel on one side and the pressure plate on the other, cause the

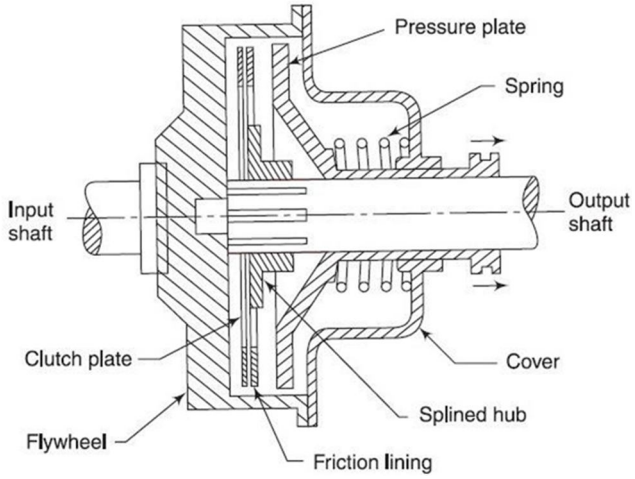

Fig.9Discclutch

Multi-plate clutch

Inamulti-plateclutch,thenumberoffrictionallinings andthemetalplatesis increasedwhichincreases thecapacityoftheclutchtotransmittorque.*Fig.10*showsasimplifieddiagramofamulti-plateclutch.

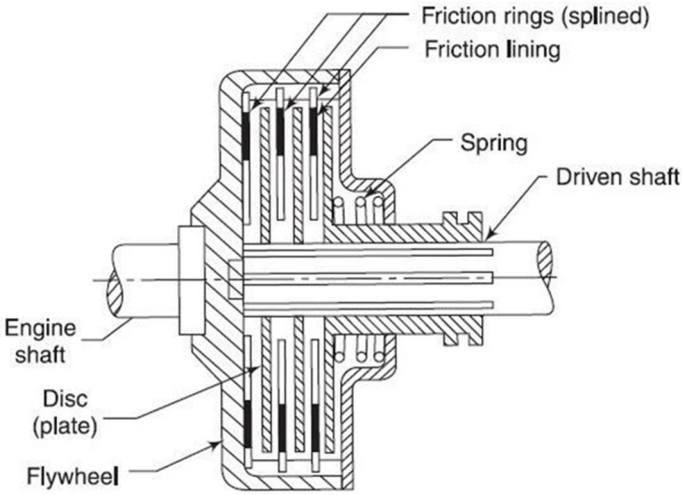

Fig.10 Multi-plate clutch

The friction rings are splined on their outer circumference and engage with corresponding splines on the flywheel. They are free to slide axially. The friction material thus rotates with the flywheel and the engine shaft. The number of friction rings depends upon the torque to be transmitted.

The driven shaft also supports discs on the splines which rotate with the driven shaft and can slide axially. If the actuating force on the pedal is removed, a spring presses the discs into contact with the friction rings and the torque is transmitted between the engine shaft and the driven shaft.

If n is the total number of plates both on the driving and the driven members, the number of active surfaces will be n – 1.

Coneclutch

In a cone clutch (Fig.11), the contact surfaces are in the form of cones. In the engaged position, the

friction surfaces of the two cones A and B are in complete contact due to spring pressure that keeps one cone pressed against the other all the time.

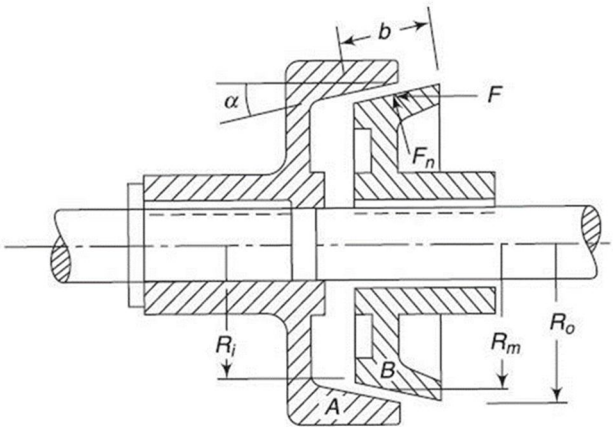

Fig.11-Coneclutch

When the clutch is engaged, the torque is transmitted from the driving shaft to the driven shaft through the flywheel and the friction cones. For disengaging the clutch, the cone B is pulled back through a lever system against the force of the spring. The advantage of a cone clutch is that the normal force on the contact surfaces is increased.

Centrifugal clutch

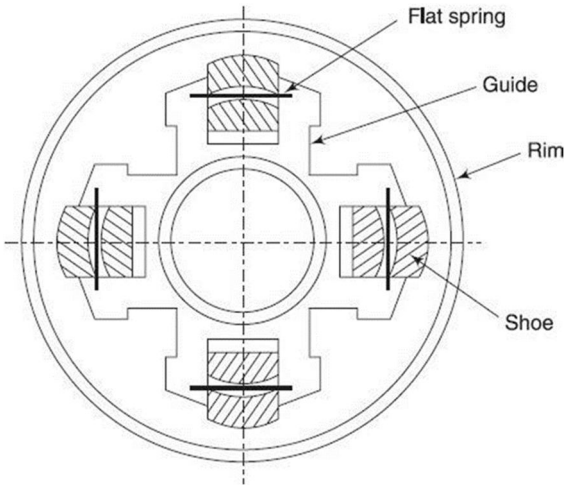

Fig.12-Centrifugalclutch

Centrifugal clutches are being increasingly used in automobiles and machines. A centrifugal clutch has a driving member consisting of four sliding blocks (Fig.12).

These blocks are kept in position by means of flat springs provided for the purpose. As the speed of the shaft increases, the centrifugal force on the shoe increases.

When the centrifugal force exceeds the resisting force of the springs, the shoes move forward and press against the inside of the rim and thus, torque is transmitted to the rim.

In this way, the clutch is engaged only when the motor gains sufficient speed to take up the load in an effective manner. The outer surfaces of the shoes are lined with some friction material.

BRAKES:

A brake is an appliance used to apply frictional resistance to a moving body to stop or retard it by absorbing its kinetic energy. By providing brakes, the external resistance is considerably increased and the period of retardation shortened.

TYPES OF BRAKES:

The following are the main types of mechanical brakes.

(i) Block or shoe brake
(ii) Band brake
(iii) Band and Block brake
(iv) Internal expanding shoe brake

RATIO OF FRICTION TENSIONS:

1). Flat Belts

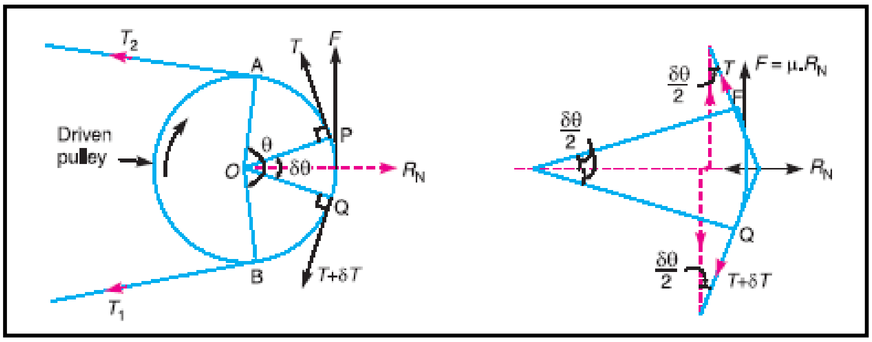

Figure: 13

Let, T_1 = Tension on the tight side.
T_2 = Tension on the slide side.
= Angle of lap of the belt over pulley
= Co- efficient of friction between the belt and the pulley
Consider a short length of belt subtending an angle so at the center of the pulley.
Let, R = Normal reaction between the belt and the pulley
T = Tension on the slack side.
δT = Increase in tension on the tight side than on slack side.
T + δT = Tension on tight side of the element.

Tension T and (T+δT) alt in a direction perpendicular to the radius drawn at the ends of the element. The friction force will at tangentially to the pulley rim resisting the slipping of the belt on the pulley.

Resolving the force in tangential direction.

$$2\,\mu R + T\cos\frac{\delta\theta}{2} - (T+\delta T)\cos\frac{\delta\theta}{2} = 0$$

As $\frac{\delta\theta}{2}$ is small,

$$\cos\frac{\delta\theta}{2} \sim 1$$

$\therefore \delta T = 2\mu R$……………………………………………………… (1)

Resolving the forces in the radial direction

$$R - T\sin\frac{\delta\theta}{2} - (T+\delta\theta)\sin\frac{\delta\theta}{2} = 0$$

As $\frac{\delta\theta}{2}$ is small $\sin\frac{\delta\theta}{2} \approx \frac{\delta\theta}{2}$

$$\therefore R - T\frac{\delta\theta}{2} - T\frac{\delta\theta}{2} - \frac{\delta T.\delta\theta}{2} = 0$$

Neglecting product by two small quantities

$\therefore$R = Tδθ…………………………………………..…… (2)

From (1) and (2)

δT = μ.Tδθ

$\therefore$δT / T = μδθ

Integrating proper limits,

$$\int_{T2}^{T1} \frac{\delta T}{T} = \int_{0}^{\theta} \mu\delta\theta \qquad \therefore \log_e\left(\frac{T1}{T2}\right) = \mu\theta$$

$$\therefore \frac{T1}{T2} = e^{\mu\theta}$$

2). For V – Belts

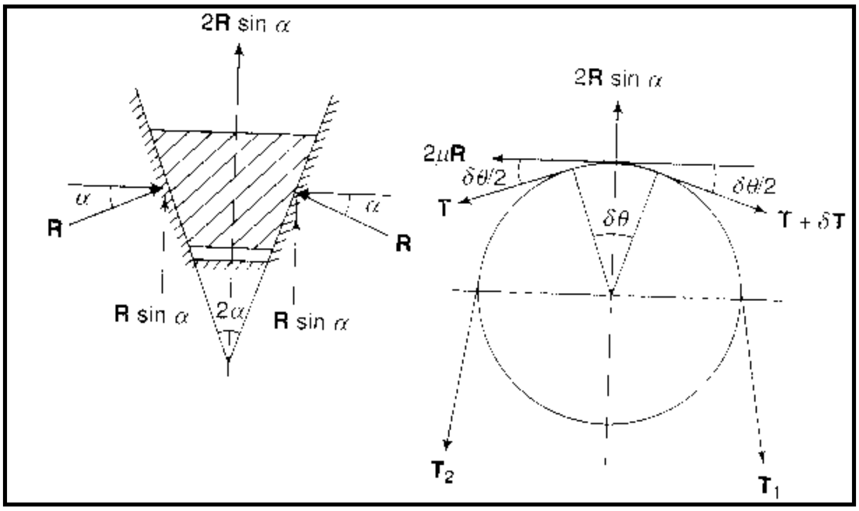

Figure: 14

Resolving forces radially

$$2R\sin\alpha - T\sin\frac{\delta\theta}{2} - (T + \delta T)\sin\frac{\delta\theta}{2} = 0$$

As δθ is small, $\sin\frac{\delta\theta}{2} \approx \frac{\delta\theta}{2}$

$$\therefore 2R\sin\alpha - T\frac{\delta\theta}{2} - T\frac{\delta\theta}{2} = 0$$

$\therefore$R = $\frac{T\delta\theta}{2\sin\alpha}$ ……………….(3)

From eq. (1) and (3)

$$\delta T = 2\mu \frac{T\delta\theta}{2\sin\alpha}$$

$$\therefore \frac{\delta T}{T} = \frac{\mu\delta\theta}{\sin\alpha}$$

Integrating proper limits,

T1 θ

$$\int \frac{\delta T}{T} = \int \frac{\mu\delta\theta}{\sin\alpha} \qquad \therefore \log_e\left(\frac{T1}{T2}\right) = \frac{\mu\theta}{\sin\alpha}$$

$$\therefore \frac{T1}{T2} = e^{\frac{\mu\theta}{\sin\alpha}}$$

Block or Shoe Brake:

A block or shoe brake consists of a block shoe, which is passed against rotating drum. The force on the drum is increased by using a lever, If only one block is used for the purpose, a side thrust on the bearing of the shaft supporting the drum will at. This can be prevented by using two blocks on the two sides of the drum. This also doubles the braking torque.

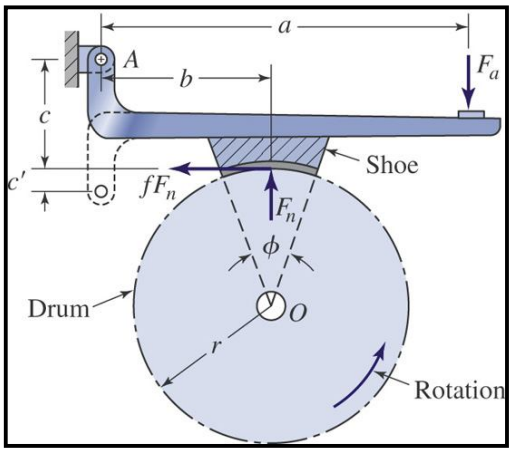

Figure: 15 Block or Shoe brake

A material shorter than that of the drum or the rim of the wheel is used to make the blocks so that there can be replaced easily on wearing. Wood and rubber are used for light vehicles and cast steel for heavy vehicles.

Let, r = radius of the drum

μ = Coefficient of friction

Fr = radial force applied on the drum

Rn = normal reaction on the block

F = force applied at the lever

Ff = frictional force = μRn

Assuming that the normal reaction Rn and the frictional force if act at the mid point of the block.

Braking torque = friction force x radius on the drum

T_B = μRn X r

To obtain Rn consider the equilibrium of the block as follows the direction of the frictional force on the drum is to be opposite to that of its rotation while on the block it is in the same direction taking moments about the pivot o.

$$F \times a - Rn \times b + \mu Rn \times c = 0$$

$$\therefore Rn = \frac{Fa}{b - \mu c}$$

$$\therefore F = Rn \left(\frac{b - \mu c}{a}\right)$$

When b= μc, F= 0 which implies that the force needed to apply the brake is naturally zero on that once the contact the block and the drum, the block is applied itself, such a brake is known as a self locking brake.

As the moment of the force Ef about o is in the same direction as that of the applied force F, Ef, aids in applying the brake. Such a brake is known as a self-align brake.

If the rotation of the drum is reversed i.e. it is made clockwise $F = Rn \left(\frac{b + \mu c}{a}\right)$

Which shows that the required force F will be for greater than what it would be when the drum rotates counter clockwise. If the pivot lies on the line of action of Ff i.e. at O', c = 0 and F = Rn(a/b). Which is valid for both clockwise and counter clockwise direction.

If the pivot is made at o" i.e. C is made negative then.

$$F = Rn\left(\frac{b + \mu c}{a}\right) \text{ for counter clockwise}$$

$$F = Rn\left(\frac{b - \mu c}{a}\right) \text{ for clockwise}$$

In case the pivot is provided on the same side of the applied force and the block, the equilibrium conditions can be considered accordingly.

In the above case, it is assumed that the normal reaction and the frictional force act at the midpoint of the block. However this is true for only small angle of contact of more than 40', it has to be replaced by an equivalent coefficient of friction μ given

Band brake:

It consists of a rope, belt or flexible steel band lined with friction material which is pressed against the external surface of a cylindrical drum when the brake is applied. The force is applied at the free end of the lever.

Brake torque on the drum = (T1-T2), where r is the effective radius of the drum.

The ratio of the light and the slack side tensions is given by integrating between proper limits,

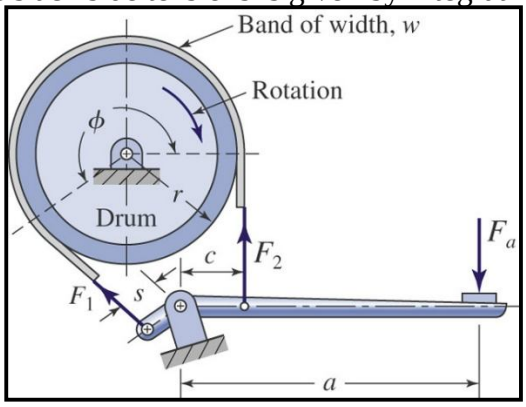

Figure: 16 Band brake

It is noted that this equation is valid only when the belt is on the point of slipping on the pulleys.

V-belt or rope:

In case of v-belt or rope, Considering the forces acting on the ever and talking moments about the pivot,
As T1>T2 and a>b under all conditions, the effectiveness of the brake will depend upon the force F.

Rotation Clockwise

In this case, the light and the slack slides reversed i.e. T2 becomes greater than T1.
Then T1>T2 and a>b
The brake will be effective as long as T1a is greater than T2b.
i.e. as long as the ratio of T2 to T1 is less than the ratio a/b.
i.e. the brake becomes self-locking as no force is needed to apply the brake once the brake has been engaged, no further force is required to stop the rotation of the drum.

Rotation Counter Clockwise

Tight slides and the slack side will be the same as in the above case of counter clockwise rotation.

Internal Expanding Shoe Brake:

The internal expanding shoe brake consists of two semi-circle shoes, which are lined with a friction material. The shoes press against the inner flange of the drum when the brakes are applied under normal conditions; the drum rotates fully as the outer diameter of the shoes is a little less than the internal diameter of the drum.

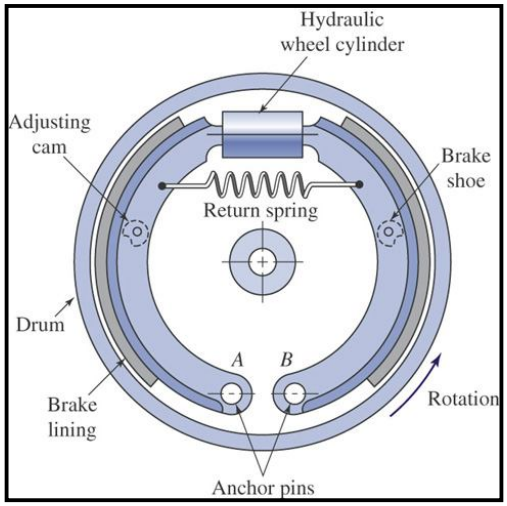

Figure: 17 Internal expanding shoe brake

The actuating force F is usually applied by two equal diameter pistons in a common hydraulic cylinder and is applied equally in magnitude to each shoe. The left shoe is known as the forward shoe or the right shoe is known as the raising or rear shoe.

Assuming that each shoe is rigid as compared to the friction surface, the pressure p at any point A on the contact surface will be proportional to its distance l from the pivots.

Considering the breaking shoe,

Consider a small element of brake lining on the loading shoe that makes an angle so at the centre.
Also note that the leading shoe is self-energizing whereas the reversing shoe is not this is because the friction force acting on the leading shoe help the applied force F, and that on the leading shoe oppose it on reversing shoe oppose it. On reversing the direction of drum rotation, the right shoe will become self-energizing whereas the left will not be so any longer.

A brake should be self-energizing but not self-locking.

(1) Find the power transmitted by a belt running over a pulley of 600 mm diameter at 200 RPM. The co-efficient of friction between the belt and the pulley is 0.25 and angle of lap160° and maximum tension in the belt is 2500 N

(2) What is centrifugal tension? Discuss the effect of it on power transmitted by a belt drive.

(3) Define pitch circle diameter of the chain sprocket

(4) List advantages and disadvantages of chain drive over other power drives.

(5) Distinguish between brakes and clutch.

(6) A single plate clutch, effective on both sides, is required to transmit 25 kW at 3000 rpm. Determine the outer and inner radii of frictional surface if the coefficient of friction is 0.255, the ratio of radii is 1.25 and the maximum pressure is not to exceed 0.1 N/mm^2. Also determine the axial thrust to be provided by springs. Assume the theory of uniform wear.

(7) A differential band brake acting on the 3/4th of the circumference of a drum of 450 mm diameter is to provide a braking torque of 225 N-m. One end of the band is attached to a pin 100 mm from the fulcrum of the lever and the other end to another pin 25 mm from the fulcrum on the other side of it where the operating force is also acting. If the operating force is applied at 500 mm from the fulcrum and the co-efficient of friction is 0.25 find the two tensions and operating force for clockwise rotation of brake dru

References:

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2. Theory of Machines and Mechanisms, Uicker J J Jr., Pennock G R, Shigley J E, Oxford Press.
3. Kinematics and Dynamics of Machinery, Norton R L, McGraw-Hill
4. Mechanism and Machine Theory, Ambekar, A G, Prentice Hall
5. Theory of Machines, Singh Sadhu, Pearson Education

References used by the students:

Rubric wise marks obtained:

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70- 89%.	Student give the correct answers between 50- 69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*_____		
			Total Marks		

Teacher Sign

Experiment No: 5

Determination of Gear train ratios for different types of gear trains.

Date:

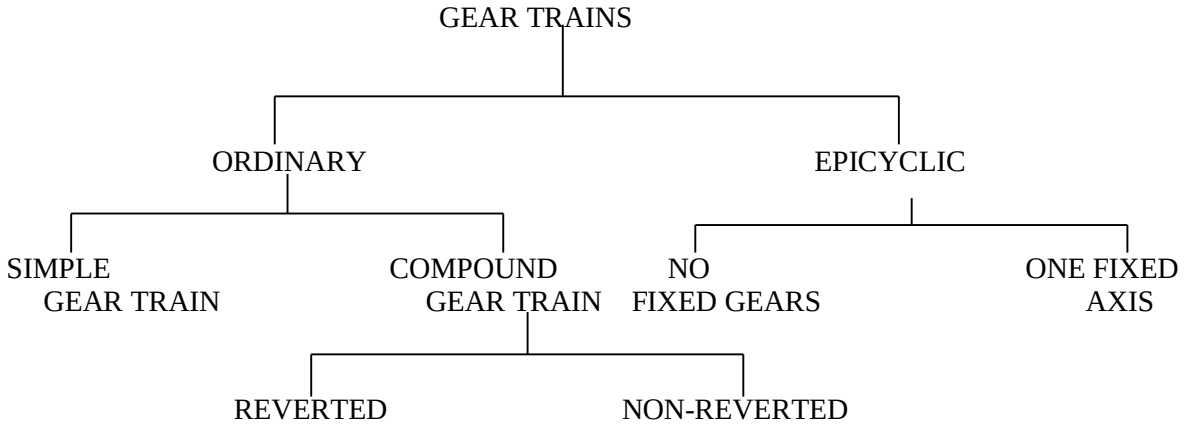
Relevant CO: Develop the concepts of basic power transmission devices for the given field/industrial application.

GEAR TRAINS:

When two or more gears are made to mesh with each other to transmit power irons one shaft to another the mechanism so formed is termed as Gear train of toothed wheels. The nature of the train used depends upon the train used depends upon the velocity ratio required and the relative position of the axes of shafts. A gear train may consist of spur bevel or spiral gears.
Most electric motors, I.C. engines, and turbines operate efficiently and produce maximum power at high rotating speeds-speeds much higher than the optimum speeds for operating machinery. In such cases it is advisable to go for using trains and other speed reducers for domestic engines and industrial engines as well.
Some gear trains permit us to change output speed even though the input speed remains constant. A pair of gears may be removed from the train and replaced by a pair having a different speed ratio. For rapid or frequent speed ratio changes, pairs of gears having different ratios are engaged by shifting the location of the gears themselves (as in sliding type gear box of an automobile) and by employing bands and clutches within the transmission.

NECESSITY OF GEAR TRAINS:

- When a large velocity reduction or mechanical advantage is desired.
- When the distance between two shafts is not too great and at the same time is not short enough to permit use of a single large gear.
- When certain velocity ratio is desired.



From subject point of view we will study following types of gear trains
(1) Simple gear train (2) Compound gear train (3) Reverted gear train &
(4) Planetary

SIMPLE GEAR TRAIN:

As the name implies, this is the simplest type of gear train for transmitting motion from one shaft to the other in which (I) all the gear axes remain fixed with respect to frame and (II) each gear is mounted on separate shaft.

Features of Simple Gear Train:

-A pair of external gears meshing always move in opposite direction.
-All odd numbered gears move in one direction and all even numbered gears in the opposite direction.
-The ratio of the driving to that of the driven shaft (i.e. Speed ratio) is negative when the input and output gears rotate in the opposite direction and it is positive when the two rotate in the same direction
-Train value is the reciprocal of speed ratio.

Speed Ratio = $N_1/N_2 = T_2/T_1$
Train value = $N_2/N_1 = T_1/T_2$
Where, N_1 = Speed of gear-1, in R.P.M.
N_2 = Sped of gear-2, in R.P.M.
AND T_1 = No. of teeth on gear-1 & T_2 = No. of teeth on gear-2

When the distance between two shafts is large then the motion may be transmitted either by providing the large size gear or by providing one or more intermediate gears.
Large size gears are inconvenient and become uneconomical. Therefore the choice should be to use intermediate gears for such criteria.

For this case, let us take
N_1& N_3 = Speed of driver & driven responsively &
N_2 = speed of an intermediate gear.
T_1, T_2, & T_3 = Corresponding values of No. of teeth on the gear-1 intermediate gear-2 & gerar-3 resp.
Speed ratio for gear – 1 & 2 will be
$N_1/N_2 = T_2/T_1$
Similarly, for gear 2 & 3
$N_2/N_3 – T_3/T_2$
Speed ratio of the gear train will be
$N_1/N_3 = T_3/T_1$, i.e. Speed ratio = Speed of driver/ Speed of driven
It is obvious from the derivation that the intermediate gears have no effect on the speed ratio, hence they are known as idlers.

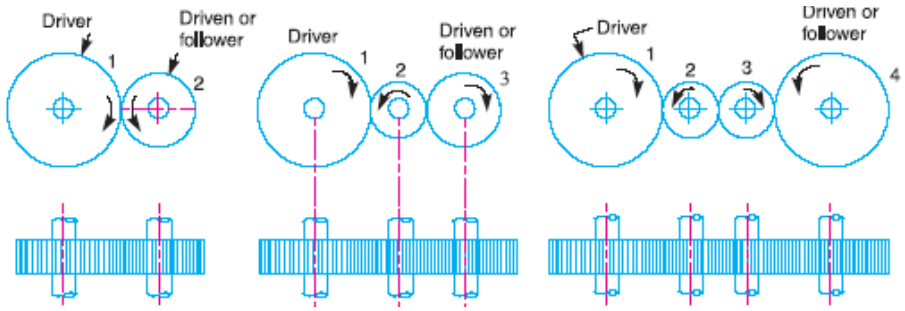


Figure: 1 Simple gear train

COMPOUND GEAR TRAINS:

An alternative way of transmitting motion from one shaft to another shaft using gear train is to compound one or more pair of gears. A gear pair is compounded if they are mounted on the same shaft and are made into and integral part in some way and total

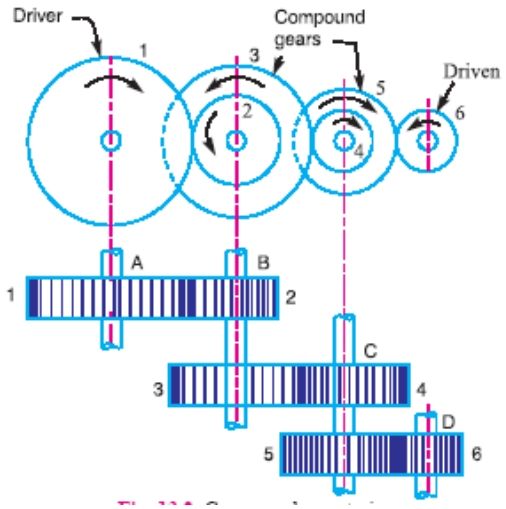


Figure: 2 Compound gear train

About an axis with the same angular velocity. A compound gear train is one, which consists of one or more compound gears.

There are many applications in which power is supplied through high-speed motor of prime mover. Such motors or prime movers are smaller size and are usually chapter than their low speed counterparts. Moreover, such applications involve large sped reductions. Simple gear trains in which input and output gear alone decide the reduction ratio is of little use in such applications. A compound gear train in which each shaft except the first and last carries two wheels is more useful in such cases. A higher speed there are two intermediate shafts.

REVERTED GEAR TRAINS: When the axes of the first gear i.e. first driver and the last gear (i.e.- Last driven or follower) are co-axial, the gear train is known as Reverted gear train as shown in fig. 3. It is a compound type gear train.

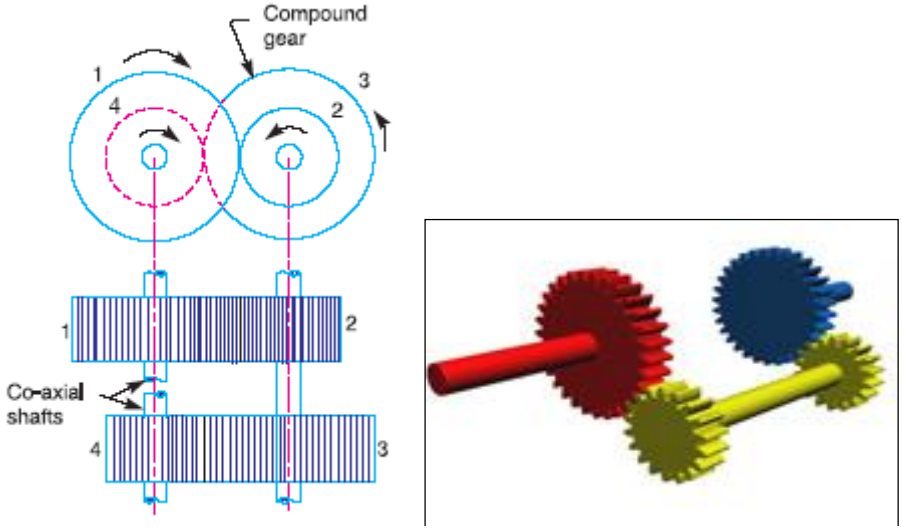


Figure: 3 Reverted gear trains

Reverted gear trains find applications in clocks and in simple lathes where back gear is used to impart slow speed to the chuck.

Any compound gear train in which first and last gears are not co-axial are called Non-Reverted type gear train.

PLANETARY OR EPICYCLIC GEAR TRAIN:
If axis of rotation of one or more gears is allowed to rotate about axis the gear train is known as planetary or epicyclic gear train

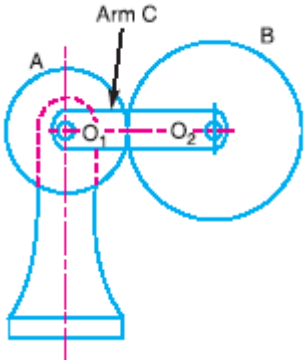
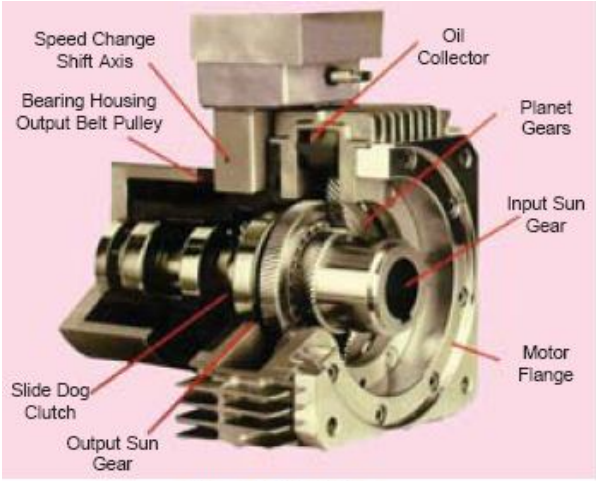


Figure: 4 Epicyclic gear trains

PLANET WHEEL: A gear whose axis is permitted to move in an arc of a circle about the fixed axis is called a planet wheel.

SUN WHEEL: A gear whose axis is fixed in position, and about which axis of planet wheel revolves is called a sun wheel.



Sun and Planet gears.

The planet wheel is carried by an arm, which is free to revolve about the fixed axis, and revolves with the input shaft. Sun wheel is also free to revolve about this fixed axis and is mounted on the driven shaft. The planet gear is free to revolve with respect to arm on a pin attached to it. A simple epicylic gear train is shown in fig3. The sun & planet wheels are shown meshing each other.

If the arm shown in fig.3 is held stationary, the inversion gives a simple gear train. In some applications, the fixed sun wheel is annular (i.e. an internal gear also called as annulus) wheel and another (planet) wheel rolls on the inside of it. In such a case meshing point on planet wheel traces Hypocycloid path. Customarily all such type of arrangements are categorized in an Epicyclic gear train.

Solve the given problems.

Example.1 The annulus A in the gear shown in Fig. a rotates at 300 rpm about the axis of the fixed wheel S which has 80 teeth. The three-armed spider (only one arm a is shown in Fig. a) is driven at 180 rpm. Determine the number of teeth required on the wheel *P*.

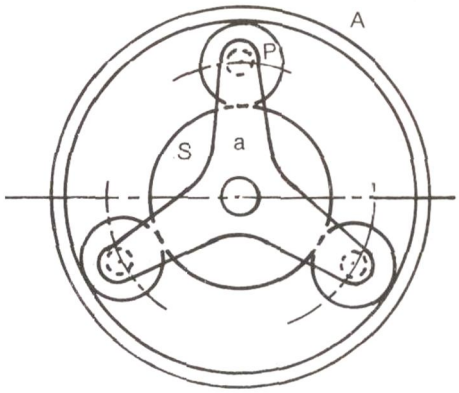


Figure. (a)

Example.2 In a reduction gear shown in Fig. (b), the input S has 24 teeth. *P* and *C* constitute a compound planet having 30 and 18 teeth respectively. If all the gears are of the same pitch, find the ratio of the reduction gear. Assume A to be fixed.

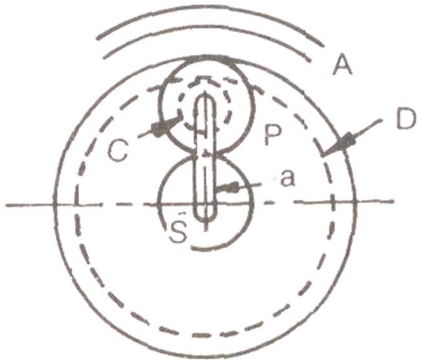


Figure. (b)

References:

1. Theory of Machines, Rattan S S, Tata McGraw-Hill
2. Theory of Machines and Mechanisms, Uicker J J Jr., Pennock G R, Shigley J E, Oxford Press.
3. Kinematics and Dynamics of Machinery, Norton R L, McGraw-Hill
4. Mechanism and Machine Theory, Ambekar, A G, Prentice Hall
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Rubric wise marks obtained:

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70- 89%.	Student give the correct answers between 50- 69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*_____		
			Total Marks		

Teacher Sign

Experiment No: 6

Cam profile generation and follower motion analysis using analytical methods and develop a computer program using C/C++/MATLAB/Python or any other suitable programming language.

Date:

Relevant CO: Develop the concepts of basic power transmission devices for the given field/industrial application.

THEORY:

The simplest method by which a body can be given a certain prescribed motion accomplished by making use of a cam and a follower. A cam is a mechanical component (i.e. driver) that causes another body known as the follower. The cam and follower have a line contact and constitute a higher pair. The cam may be rotating or reciprocating whereas the follower may be rotating, reciprocating or oscillating depending upon the shape of the cam. Complicated motions, which are otherwise difficult to achieve, can easily be produced with the help of cam.
A cam mechanism usually consists of a cam (the driver) and a follower (the driven) frame.

APPLICATIONS OF CAM AND FOLLOWER MECHANISM:

Because of the simplicity and ease of adoption, cams are widely used in the industries.
Following are the applications of cams:

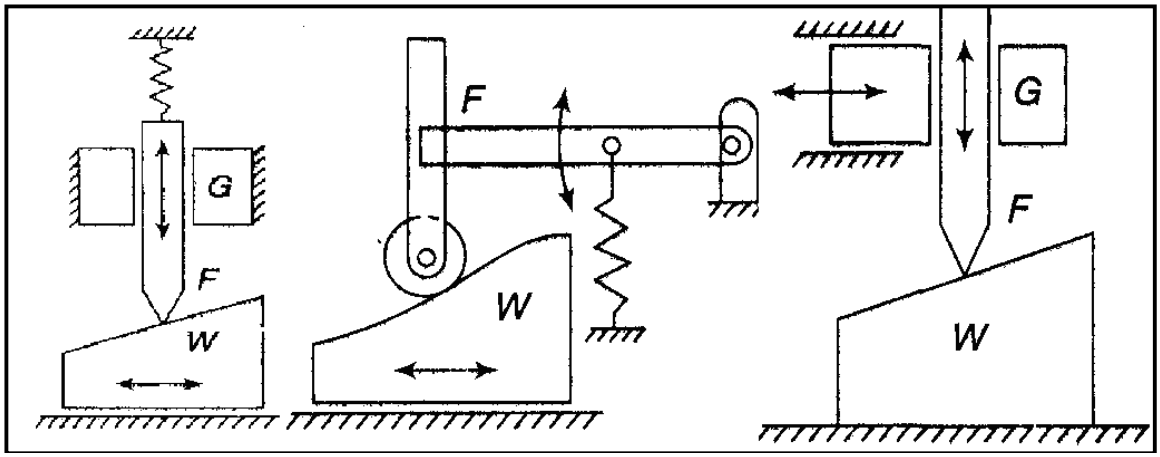
1. Automatic machines
2. Valve mechanisms of I.C. Engines
3. Workshop machine tools
4. Spinning and weaving machines used in textile industries
5. Timing systems of automotive engines
6. In paper industries

CLASSIFICATION OF CAM:

Cams are classified as follows:

A) ACCORDING TO SHAPE OF THE CAM:

Wedge and the flat cams



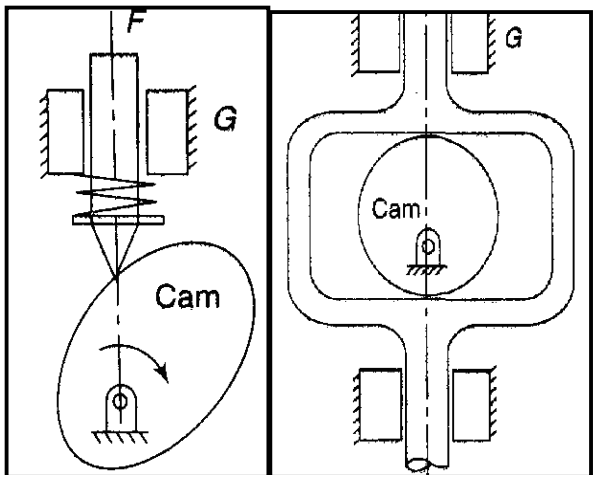
(a) (b) (c)

Figure. 1 Wedge and Flat cams

A wedge cam has a wedge, which in general, has a translational motion. The follower can translate or oscillate, refer figure 1(a & b). A spiral is used to maintain the contact between the cam and

follower. Figure. 1 (c) shows a cam in which a flat plate is used instead of wedge. In the groove the follower is held.

Radial or disc cam



a. **(b)**

Figure.2 Radial cam

A cam in which the follower moves radially from the center rotation of the cam is known as radial or disc cam. Figure 2. (a & b). The follower, which translates or oscillates, is held in contact by far the most popular because of its simplicity and compactness.

Spiral cam

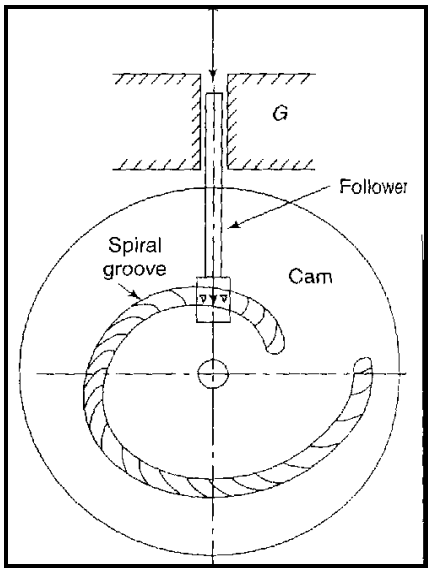


Figure. 3 Spiral cam

A spiral cam is a face in which a grove is cut in the form of spiral as shown in figure. 3. The spiral groove consists of teeth, which mesh with a pinion follower. Here in this type of cam the velocity of the follower varies with the radial distance of the groove from the axis of the cam. This type of cam finds application on compressors.

Cylindrical cam

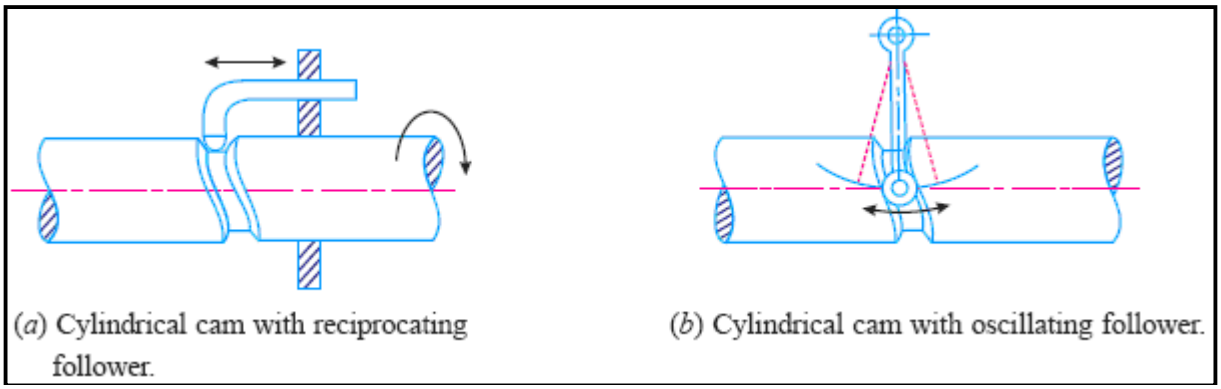


Figure. 4 Cylindrical cam

A circumferential contour is cut in the surface of a cylinder, which rotates about its axis. The follower is oscillated or translated in the direction of this axis. Cylindrical cam is sometimes termed as Barrel cam or drum cam. The cylindrical cam has been employed internally as well as externally as follows:

The plane cylindrical cam is one with a groove cut in its surface to constrain a roller follower in a desired motion. This is a positive drive type, which is second in popularity to the radial disc cam. The end or bell cam has its working surface the end of a cylinder. This cam required a spring or gravity to maintain contact with its follower.

Conjugate, complementary or double disc cam

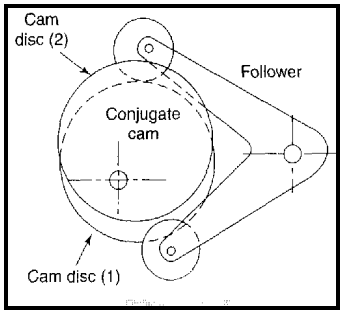


Figure. 5 Conjugate cam

A conjugate cam is a double disc cam. The two discs being keyed together and are in constant touch with two rollers of a follower. Thus the follower gets a positive constrain, when the requirements are low wear, low noise, better control of the follower. High speed, high dynamic loads, then the cams recommended to use, are conjugate type.

Globoidal cams

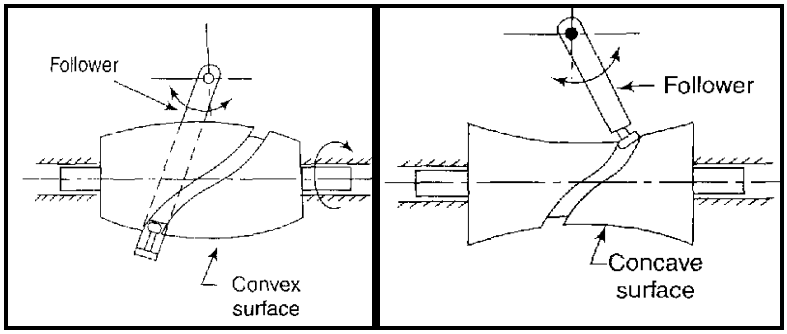


Figure. 6 Globoidal cams

When a circumferential contour is cut on the surface of rotation either concave or convex of the cam to impart motion to the follower, which has an oscillatory motion. When an angle of oscillation of the follower is large and it is required to operate the cam for moderate speeds this type of cam is mostly used.

Spherical cam

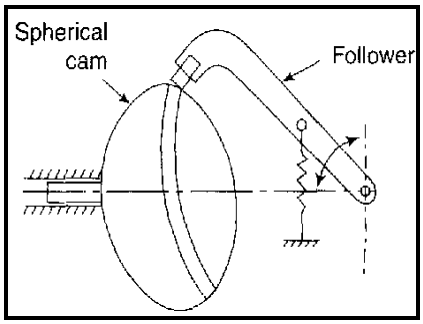


Figure. 7Spherical cam

It has a rotating portion of a sphere that oscillates a follower having its axis perpendicular to the cam axis. A spherical surface groove is provided in the spherical cam to translate the motion to the follower.

B) ACCORDING TO THE MOVEMENT OF THE FOLLOWER:

Rise – return – rise (R-R-R)

In this type, there is alternate rise and return of the follower with no periods of dwells. The follower has a linear or an angular displacement. It use is limited.

Dwell-Rise-Return-Dwell (D-R-R-D)

The cam includes rise and return of the follower after dwell. This type is frequently used than R-R-R type.

Dwell-Rise-Dwell-Return-Dwell (D-R-D-R-D)

This type of cam is most widely used. As the name implies it has dwelling, which is followed by rise and dwell and subsequent by return as shown in figure.

C) ACCORDING TO MANNER OF CONSTRAINT OF THE FOLLOWER:

To reproduce exactly the motion translated by the cam to the follower it is necessary that the two remain in touch at all speeds and all times.

According to manner in which the constraint motion is achieved, the cams are classified as:

Pre-loaded spring cams

A compression spring is used for the purpose of keeping the contact between the cam and follower.

Positive drive cams

In this type, constant touch between the cam and follower is maintained by a roller follower operating in the groove of cam as shown in figure. Under normal working conditions the follower cannot go out of the groove. A constraint or positive drive is also obtained by the use of a conjugate cam.

Gravity cams

if the rise of the cam is achieved by the rising surface of the cam, and the return by the force of gravity or due to the weight of the cam, the cam is known as a gravity cam. Due to their uncertain behavior, gravity cams are less preferred.

CLASSIFICATION OF THE FOLLOWER:

A) ACCORDING TO THE SHAPE:
The followers are classified as follows:

Knife-edge follower
When the end of a follower, which is in contact with the cam, has a sharp knife-edge, it is called a knife-edge follower. Figure. 8(a) The sliding takes place between the contacting surfaces i.e. the knife-edge and the cam surface. The cam is not of much use as excessive wear occurs at the contacting surfaces.
Roller follower

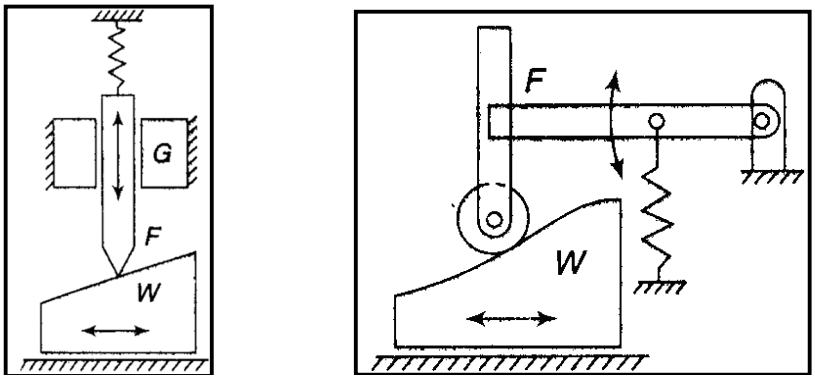
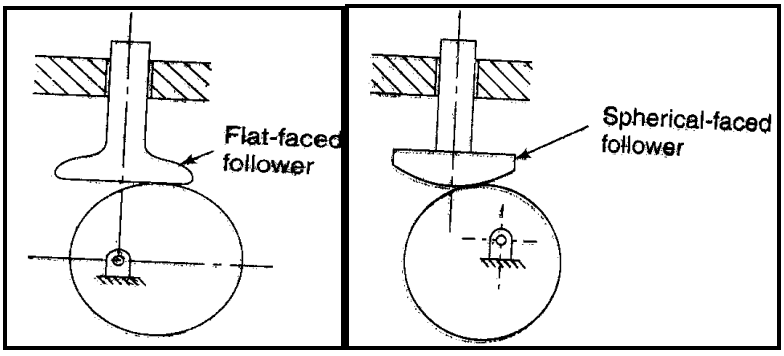


Figure. 8 (a). Knief edge follower **(b). Rollar follower**

When the end of the follower in contact with the cam is a roller the follower is termed as roller follower. Figure. 8 (b). Here, notice to be made that at the contact surface, the rolling motion is takes place, hence, rate of wear is reduced. In both, knife-edge and roller follower side thrust exists between the follower and the guide. Roller followers are extremely used where more space is available as in stationary gas engines, I.C. Engines and oil engines and also in aircraft engines.
Flat faced or mushroom follower
When the contacting end of the follower is a perfectly flat face, it is called a flat-faced follower as shown in figure (a). Side thrust between the follower and the guide is much reduced in case of flat-faced followers. Relative motion between the contacting surfaces is mostly sliding nature but wear be reduced by offsetting the axis of the follower. They are generally used where space is limited such as cams used in valve mechanics of automobile engines.
Spherical faced follower



(a) **(b)**

Figure. 9 (a) Flat faced follower (b) Spherical faced follower

When the shape of the surface, which is in contact with the cam, is spherical, the follower is known as Spherical faced follower. Figure- (b). The flat end of the follower is machined to a spherical shape in order to minimize high surface stresses produced during operation.

B) ACCORDING TO THE MOTION OF THE FOLLOWER:

The followers are classified as follows:

Reciprocating or translating follower

when the follower reciprocates in guide as the cam rotates uniformly, it is known as reciprocating or translating follower.

Oscillating or rotating follower

When the uniform rotary motion of the cam is converted into perpendicular oscillatory motion of the follower, it is called as oscillating or rotating follower.

C) ACCORDING TO LOCATION OF THE LINE OF MOVEMENT:

Radial Follower

If the line of movement of the follower passes through the center of the cam, the follower is known as a radial follower.

Offset Follower

If the line of movement of the follower offset through the center of the cam, the follower is known as a radial follower.

1. A cam with 50 mm minimum diameter is rotating clockwise at a uniform speed of 700 rpm and has to give the motion to the knife edge follower as below;
   i) Follower to complete outward stroke of 40 mm during 120 degree of cam rotation with equal acceleration and retardation.
   ii) Follower to dwell for 60 degree of cam rotation
   iii) Follower to return to initial position during 90 degree of cam rotation with SHM.
   iv) Dwell period is for remaining period.
   Draw the cam profile when the line of action of knife edge follower is passing through center of rotation of cam.

2. Use the following data in drawing the profile of a cam in which a flat faced follower is raised with uniform acceleration and deceleration and his lowered with simple harmonic motion:

Least radius of cam = 30 mm
Lift of follower = 45 mm
Angle of ascent = 60°
Angle of dwell between ascent and descent = 40°
Angle of descent = 75°

3. Draw the cam profile for following conditions:

   Follower type = knife edged follower, in line; follower rises by 24mm with SHM in 1/4 rotation, dwells for 1/8 rotation and then raises again by 24mm with UARM in 1/4 rotation and dwells for 1/16 rotation before returning with SHM. Base circle radius = 30 mm.

4. Draw the cam profile for following conditions:

   Follower type = roller follower, off set to the right of cam axis by 18 mm; lift = 40 mm; base circle radius = 50mm; roller radius = 14 mm; out stroke with SHM in 0.05sec; dwell for 0.0125sec; return stroke with UARM, during 0.125sec; dwell for the remaining period. During return stroke, acceleration is 3/5 times retardation. Determine maximum velocity and acceleration during out stroke and return stroke if the cam rotates at 240 rpm.

5. Draw a cam profile to drive an oscillating roller follower to the specifications given below :
(a) Follower to move outwards through an angular displacement of 20° during the first 110° rotation of the cam;
(b) Follower to dwell for 50^0 rotation of cam;
(c) Follower to return to its initial position during next 100° rotation of the cam ;
(d) Follower to dwell for remaining angle of cam rotation.

The distance between pivot centre and roller centre = 120 mm ; distance between pivot centre and cam axis = 130 mm ; minimum radius of cam = 40 mm ; radius of roller = 10 mm ; inward and outward strokes take place with simple harmonic motion and uniform velocity respectively.

References:

1. Theory of Machines, Rattan S S, Tata McGraw-Hill
2. Theory of Machines and Mechanisms, Uicker J J Jr., Pennock G R, Shigley J E, Oxford Press.
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Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*_____		
			Total Marks		

Teacher Sign

Kinematics and Theory of Machines

BE04000171

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