CAMS

Introduction

A cam is a rotating machine element which gives reciprocating or oscillating motion to another element known as follower. The cam and the follower have a line contact and constitute a higher pair. The cams are usually rotated at uniform speed by a shaft, but the follower motion is predetermined and will be according to the shape of the cam. The cam and follower is one of the simplest as well as one of the most important mechanisms found in modern machinery today.

The cams are widely used for operating the inlet and exhaust valves of internal combustion engines, automatic attachment of machineries, paper cutting machines, spinning and weaving textile machineries, feed mechanism of automatic lathes etc.

Q) Explain how Followers are Classified with proper diagram?

The followers may be classified as discussed below :

1. According to the surface in contact.

The followers, according to the surface in contact, are as follows :

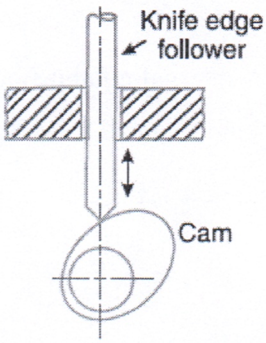
(a) Knife edge follower. When the contacting end of the follower has a sharp knife edge, it is called a knife edge follower, as shown in Fig(a). The sliding motion takes place between the contacting surfaces (i.e. the knife edge and the cam surface). It is less used in practice because the small area of contacting surface results in excessive wear. In knife edge followers, a considerable side thrust exists between the follower and the guide.

(b) Roller follower. When the contacting end of the follower is a roller, it is called a roller follower, as shown in Fig(b). Since the rolling motion takes place between the contacting surfaces (i.e. the roller and the cam), therefore the rate of wear is greatly reduced. In roller followers also the side thrust exists between the follower and the guide. The roller followers are extensively used where more space is available such as in stationary gas and oil engines and aircraft engines.

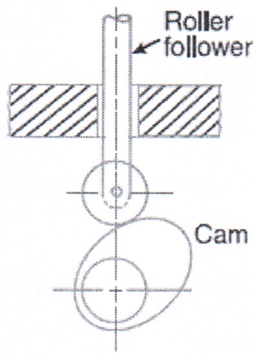
(c) Flat faced or mushroom follower. When the contacting end of the follower is a perfectly flat face, it is called a flat-faced follower, as shown in Fig(c). It may be noted that the side thrust between the follower and the guide is much reduced in case of flat faced followers. The only side thrust is due to friction between the contact surfaces of the follower and the cam. The relative motion between these surfaces is largely of sliding nature but wear may be reduced by off-setting the axis of the follower, as shown in Fig(f) so that when the cam rotates, the follower also rotates about its own axis. The flat faced followers are generally used where space is limited such as in cams which operate the valves of automobile engines.

Note : When the flat faced follower is circular, it is then called a mushroom follower.

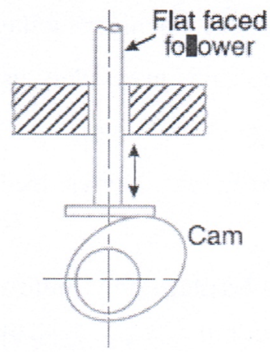
(d) Spherical faced follower. When the contacting end of the follower is of spherical shape, it is called a spherical faced follower, as shown in Fig(d). It may be noted that when a flat-faced follower is used in automobile engines, high surface stresses are produced. In order to minimise these stresses, the flat end of the follower is machined to a spherical shape.



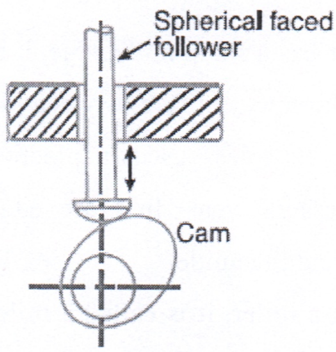
(*a*) Cam with knife edge follower.



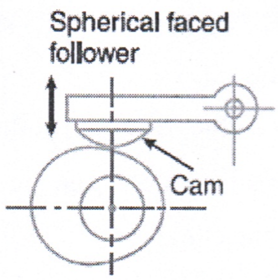
(*b*) Cam with roller follower.



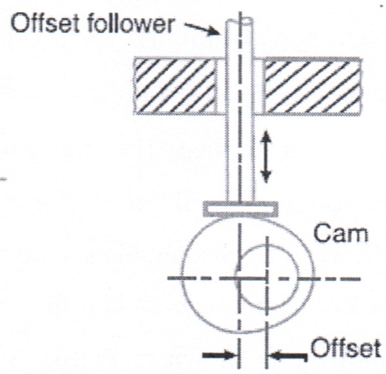
(*c*) Cam with flat faced follower.



(*d*) Cam with spherical faced follower.



(*e*) Cam with spherical faced follower.



(*f*) Cam with offset follower.

2. According to the motion of the follower.

The followers, according to its motion, are of the following two types:

(a) Reciprocating or translating follower. When the follower reciprocates in guides as the cam rotates uniformly, it is known as reciprocating or translating follower. The followers as shown in Fig (a) to (d) are all reciprocating or translating followers.

(b) Oscillating or rotating follower. When the uniform rotary motion of the cam is converted into predetermined oscillatory motion of the follower, it is called oscillating or rotating follower. The follower, as shown in Fig(e), is an oscillating or rotating follower.

3. According to the path of motion of the follower. The followers, according to its path of motion, are of the following two types:

(a) Radial follower. When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial follower. The followers, as shown in Fig.(a) to (e), are all radial followers.

(b) Off-set follower. When the motion of the follower is along an axis away from the axis of the cam centre, it is called off-set follower. The follower, as shown in Fig.(f), is an off-set follower.

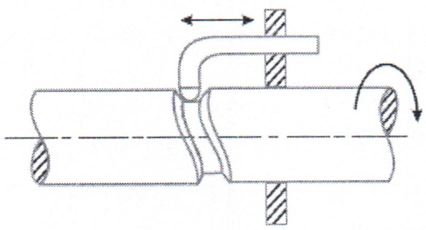
Note : In all cases, the follower must be constrained to follow the cam. This may be done by springs, gravity or hydraulic means. In some types of cams, the follower may ride in a groove.

Q) Explain Classification of Cams?

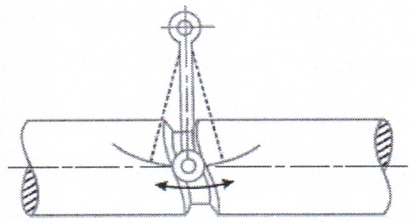
Cams may be classified into following two types as per the subject point of view :

1. Radial or disc cam. In radial cams, the follower reciprocates or oscillates in a direction perpendicular to the cam axis. The cams as shown in above Fig. are all radial cams.

2. Cylindrical cam. In cylindrical cams, the follower reciprocates or oscillates in a direction parallel to the cam axis. The follower rides in a groove at its cylindrical surface. A cylindrical grooved cam with a reciprocating and an oscillating follower is shown in Fig below (a) and (b) respectively.



(*a*) Cylindrical cam with reciprocating follower.

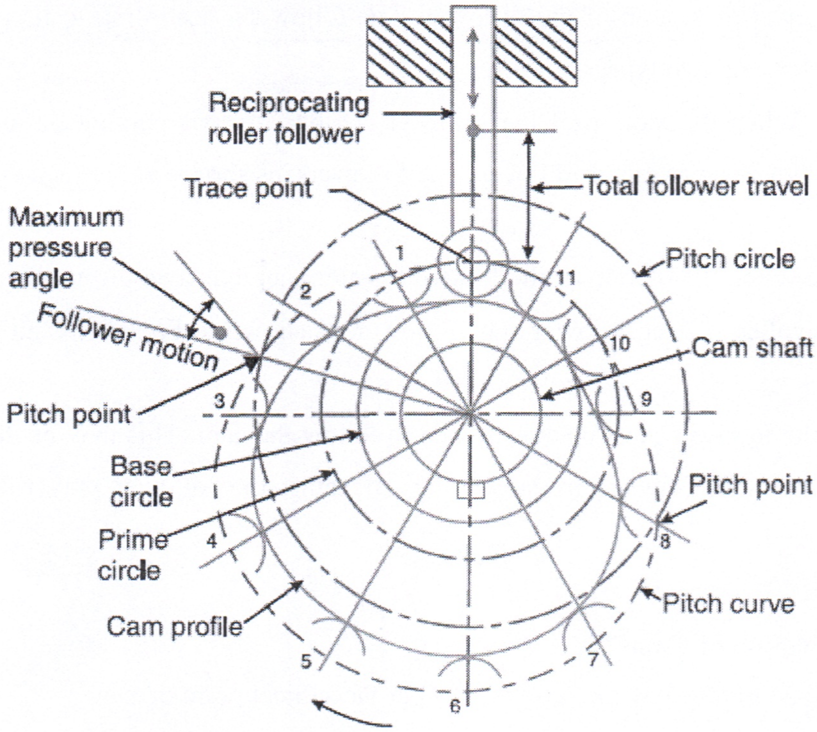


(*b*) Cylindrical cam with oscillating follower.

Note : In actual practice, radial cams are widely used.

Terms Used in Radial Cams

Fig. shows a radial cam with reciprocating roller follower. The following terms are important in order to draw the cam profile.



1. Base circle. It is the smallest circle that can be drawn to the cam profile.

2. Trace point. It is a reference point on the follower and is used to generate the pitch curve. In case of knife edge follower, the knife edge represents the trace point and the pitch curve corresponds to the cam profile. In a roller follower, the centre of the roller represents the trace point.

3. Pressure angle. It is the angle between the direction of the follower motion and a normal to the pitch curve. This angle is very important in designing a cam profile. If the pressure angle is too large, a reciprocating follower will jam in its bearings.

4. Pitch point. It is a point on the pitch curve having the maximum pressure angle.

5. Pitch circle. It is a circle drawn from the centre of the cam through the pitch points.

6. Pitch curve. It is the curve generated by the trace point as the follower moves relative to the cam. For a knife edge follower, the pitch curve and the cam profile are same whereas for roller follower, they are separated by the radius of the roller.

7. Prime circle. It is the smallest circle that can be drawn from the centre of the cam and tangent to the pitch curve. For a knife edge and a flat face follower, the prime circle and the base circle are identical. For a roller follower, the prime circle is larger than the base circle by the radius of the roller.

8. Lift or stroke. It is the maximum travel of the follower from its lowest position to the topmost position.

Q) What are different Motions of the Follower?

The follower, during its travel, may have one of the following motions.

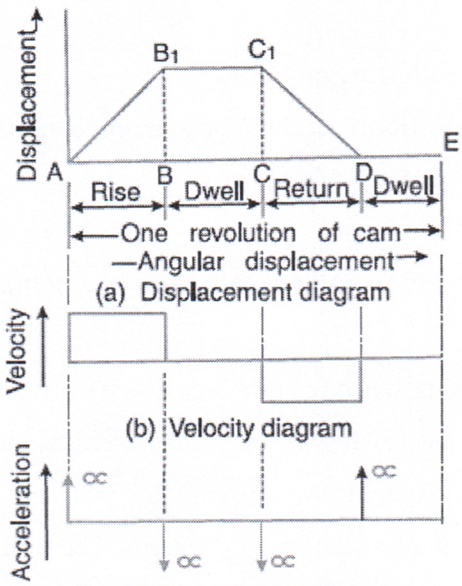
1. Uniform velocity, 2. Simple harmonic motion, 3. Uniform acceleration and retardation, and 4. Cycloidal motion.

Q) Explain Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Uniform Velocity?

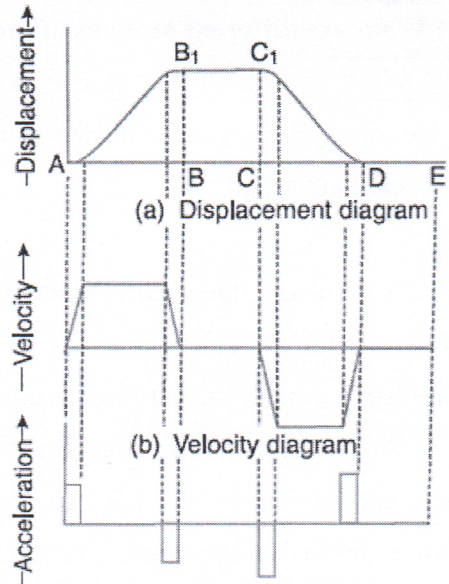
The displacement, velocity and acceleration diagrams when a knife-edged follower moves with uniform velocity are shown in Fig. (a), (b) and (c) respectively. The abscissa (base) represents the time (i.e. the number of seconds required for the cam to complete one revolution) or it may represent the angular displacement of the cam in degrees. The ordinate represents the displacement, or velocity or acceleration of the follower.

Since the follower moves with uniform velocity during its rise and return stroke, therefore the slope of the displacement curves must be constant. In other words, AB_1 and C_1D must be straight lines. We can see that the follower remains at rest during part of the cam rotation. The periods during which the follower remains at rest are known as dwell periods, as shown by lines B_1C_1 and DE in Fig.(a). From Fig.(c), we see that the acceleration or retardation of the follower at the beginning and at the end of each stroke is infinite. This is due to the fact that the follower is required to start from rest and has to gain a velocity within no time. This is only possible if the acceleration or retardation at the beginning and at the end of each stroke is infinite. These conditions are however, impracticable.

In order to have the acceleration and retardation within the finite limits, it is necessary to modify the conditions which govern the motion of the follower. This may be done by rounding off the sharp corners of the displacement diagram at the beginning and at the end of each stroke, as shown in Fig.(a). By doing so, the velocity of the follower increases gradually to its maximum value at the beginning of each stroke and decreases gradually to zero at the end of each stroke as shown in Fig.(b). The modified displacement, velocity and acceleration diagrams are shown in Fig. The round corners of the displacement diagram are usually parabolic curves because the parabolic motion results in a very low acceleration of the follower for a given stroke and cam speed.



Displacement, velocity and acceleration diagrams when the follower moves with uniform velocity.

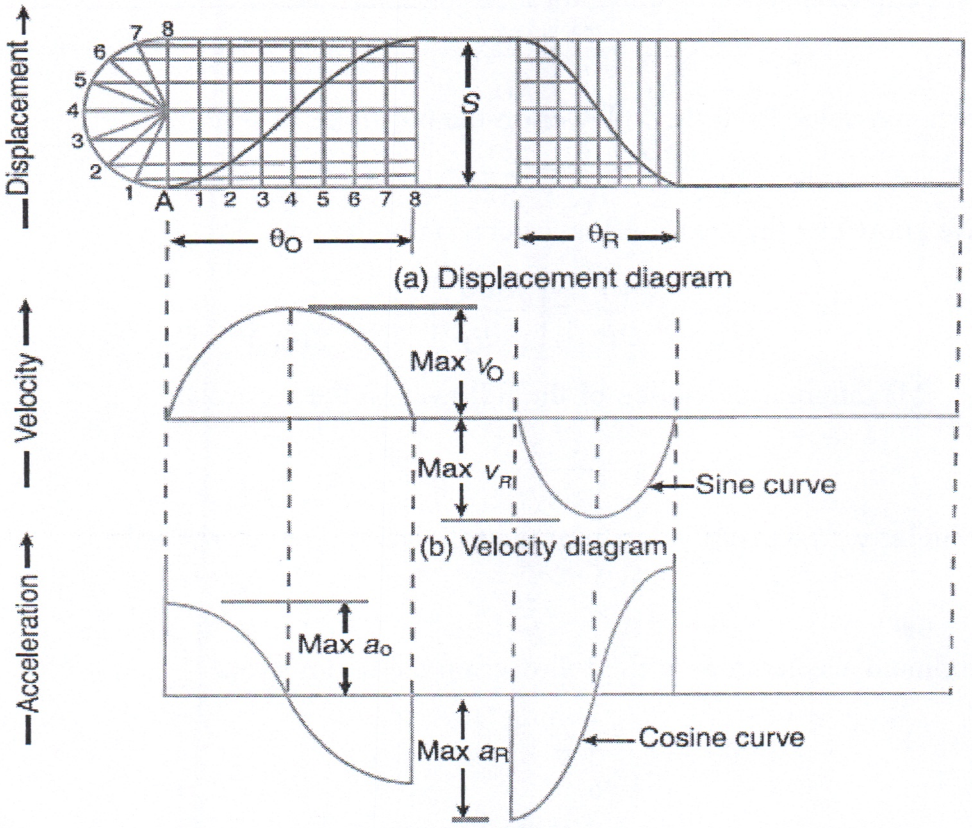


Modified displacement, velocity and acceleration diagrams when the follower moves with uniform velocity.

Q) Explain Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Simple Harmonic Motion?

The displacement, velocity and acceleration diagrams when the follower moves with simple harmonic motion are shown in Fig. (a), (b) and (c) respectively. The displacement diagram is drawn as follows :

1. Draw a semi-circle on the follower stroke as diameter.
2. Divide the semi-circle into any number of even equal parts (say eight).
3. Divide the angular displacements of the cam during out stroke and return stroke into the same number of equal parts.
4. The displacement diagram is obtained by projecting the points as shown in Fig(a). The velocity and acceleration diagrams are shown in Fig (b) and (c) respectively. Since the follower moves with a simple harmonic motion, therefore velocity diagram consists of a sine curve and the acceleration diagram is a cosine curve. We see from Fig.(b) that the velocity of the follower is zero at the beginning and at the end of its stroke and increases gradually to a maximum at mid-stroke. Acceleration of the follower is maximum at the beginning and at the ends of the stroke and diminishes to zero at mid-stroke.



(a) Displacement diagram
(b) Velocity diagram
(c) Acceleration diagram

Let S = Stroke of the follower,

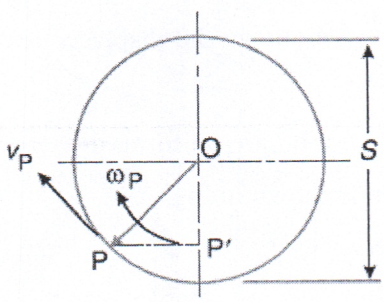
θ_O and θ_R = Angular displacement of the cam during out stroke and return stroke of the follower respectively, in radians, and

ω = Angular velocity of the cam in rad/s.

∴ Time required for the out stroke of the follower in seconds,

$$t_O = \theta_O / \omega$$

Consider a point P moving at a uniform speed ωP radians per sec round the circumference of a circle with the stroke S as diameter, as shown in Fig. below. The point P′ (which is the projection of a point P on the diameter) executes a simple harmonic motion as the point P rotates. The motion of the follower is similar to that of point P′.



∴ Peripheral speed of the point P',

$$v_P = \frac{\pi S}{2} \times \frac{1}{t_O} = \frac{\pi S}{2} \times \frac{\omega}{\theta_O}$$

and maximum velocity of the follower on the outstroke,

$$v_O = v_P = \frac{\pi S}{2} \times \frac{\omega}{\theta_O} = \frac{\pi \omega S}{2\theta_O}$$

We know that the centripetal acceleration of the point P,

$$a_P = \frac{(v_P)^2}{OP} = \left(\frac{\pi \omega . S}{2\theta_O}\right)^2 \times \frac{2}{S} = \frac{\pi^2 \omega^2 . S}{2(\theta_O)^2}$$

∴ Maximum acceleration of the follower on the outstroke,

$$a_O = a_P = \frac{\pi^2 \omega^2 . S}{2(\theta_O)^2}$$

Similarly, maximum velocity of the follower on the return stroke,

$$v_R = \frac{\pi \omega . S}{2\theta_R}$$

and maximum acceleration of the follower on the return stroke,

$$a_R = \frac{\pi^2 \omega^2 . S}{2(\theta_R)^2}$$

Q) Explain Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Uniform Acceleration and Retardation?

The displacement, velocity and acceleration diagrams when the follower moves with uniform acceleration and retardation are shown in Fig.(a), (b) and (c) respectively. We see that the displacement diagram consists of a parabolic curve and may be drawn as discussed below :

1. Divide the angular displacement of the cam during outstroke (θ_O) into any even number of equal parts (say eight) and draw vertical lines through these points as shown in Fig.(a).

2. Divide the stroke of the follower (S) into the same number of equal even parts.

3. Join Aa to intersect the vertical line through point 1 at B. Similarly, obtain the other points C, D etc. as shown in Fig.(a). Now join these points to obtain the parabolic curve for the out stroke of the follower.

4. In the similar way as discussed above, the displacement diagram for the follower during return stroke may be drawn.

Since the acceleration and retardation are uniform, therefore the velocity varies directly with the time. The velocity diagram is shown in Fig.(b).

Let S = Stroke of the follower,

θ_O and θ_R = Angular displacement of the cam during out stroke and return stroke of the follower respectively, and

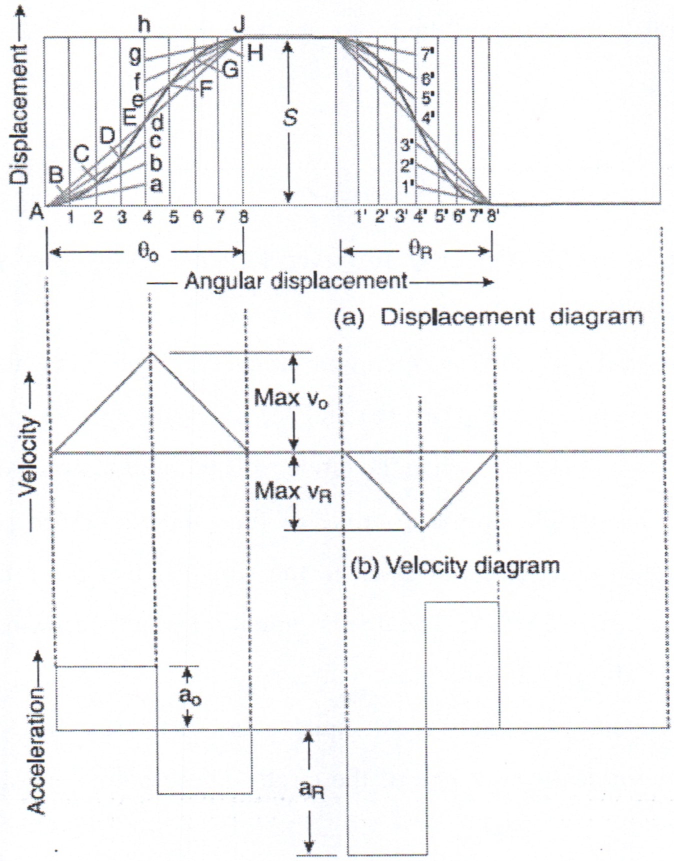
ω = Angular velocity of the cam.

We know that time required for the follower during outstroke, $t_O = \theta_O / \omega$

and time required for the follower during return stroke, $t_R = \theta_R / \omega$

Mean velocity of the follower during outstroke = S/t_O

and mean velocity of the follower during return stroke = S/t_R



(a) Displacement diagram

(b) Velocity diagram

(c) Acceleration diagram

Since the maximum velocity of follower is equal to twice the mean velocity, therefore maximum velocity of the follower during outstroke,

$$v_O = \frac{2S}{t_O} = \frac{2\omega.S}{\theta_O}$$

Similarly, maximum velocity of the follower during return stroke,

$$v_R = \frac{2\omega.S}{\theta_R}$$

We see from the acceleration diagram, as shown in Fig. (c), that during first half of the outstroke there is uniform acceleration and during the second half of the out stroke there is uniform retardation. Thus, the maximum velocity of the follower is reached after the time (t_O / 2) (during out stroke) and (t_R /2) (during return stroke).

∴ Maximum acceleration of the follower during outstroke,

$$a_O = \frac{v_O}{t_O/2} = \frac{2 \times 2\omega.S}{t_O.\theta_O} = \frac{4\omega^2.S}{(\theta_O)^2} \quad \ldots (\because \; t_O = \theta_O/\omega)$$

Similarly, maximum acceleration of the follower during return stroke,

$$a_R = \frac{4\omega^2.S}{(\theta_R)^2}$$

Q) Explain Displacement, Velocity and Acceleration Diagrams when the Follower Moves with Cycloidal Motion?

The displacement, velocity and acceleration diagrams when the follower moves with cycloidal motion are shown in Fig.(a), (b) and (c) respectively. We know that cycloid is a curve traced by a point on a circle when the circle rolls without slipping on a straight line.

In case of cams, this straight line is a stroke of the follower which is translating and the circumference of the rolling circle is equal to the stroke (S) of the follower. Therefore the radius of the rolling circle is $S / 2\pi$. The displacement diagram is drawn as discussed below :

1. Draw a circle of radius $S / 2\pi$ with A as centre.

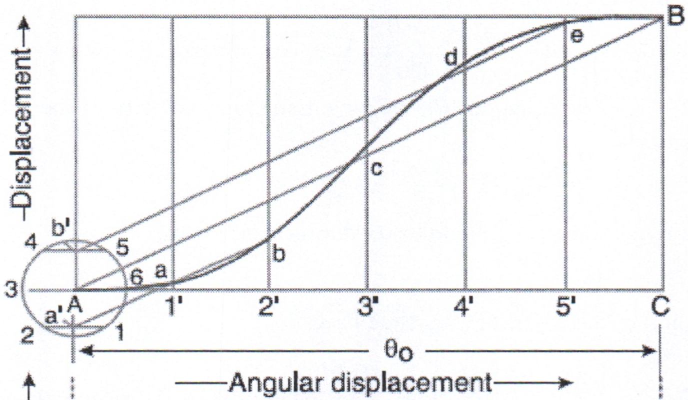
2. Divide the circle into any number of equal even parts (say six). Project these points horizontally on the vertical centre line of the circle. These points are shown by a′ and b′ in Fig.(a).

3. Divide the angular displacement of the cam during outstroke into the same number of equal even parts as the circle is divided. Draw vertical lines through these points.

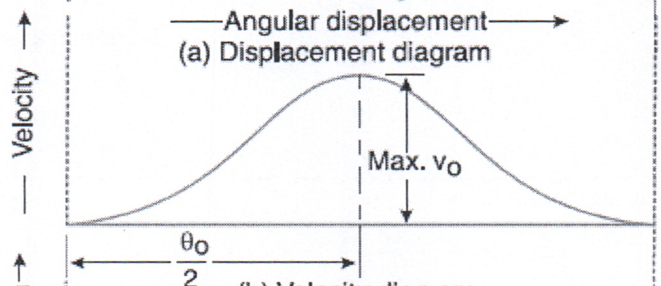
4. Join AB which intersects the vertical line through 3′ at c. From a′ draw a line parallel to AB intersecting the vertical lines through 1′ and 2′ at a and b respectively.

5. Similarly, from b′ draw a line parallel to AB intersecting the vertical lines through 4′ and 5′ at d and e respectively.

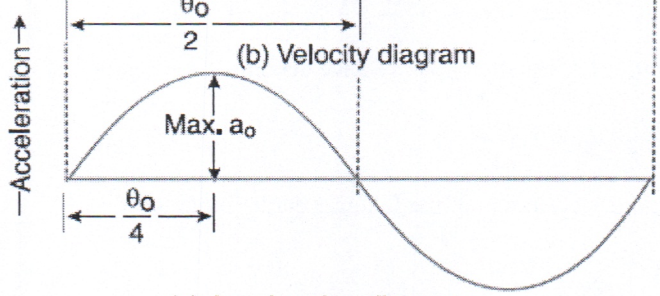
6. Join the points A a b c d e B by a smooth curve. This is the required cycloidal curve for the follower during outstroke.



(a) Displacement diagram



(b) Velocity diagram



(c) Acceleration diagram

Let θ = Angle through which the cam rotates in time t seconds, and

ω = Angular velocity of the cam.

We know that displacement of the follower after time t seconds,

$$x = S\left[\frac{\theta}{\theta_O} - \frac{1}{2\pi}\sin\left(\frac{2\pi\theta}{\theta_O}\right)\right] \qquad \ldots (i)$$

Velocity of the follower after time t seconds,

$$\frac{dx}{dt} = S\left[\frac{1}{\theta_O} \times \frac{d\theta}{dt} - \frac{2\pi}{2\pi\theta_O}\cos\left(\frac{2\pi\theta}{\theta_O}\right)\frac{d\theta}{dt}\right]$$

. . . [Differentiating equation (*i*)]

$$= \frac{S}{\theta_O} \times \frac{d\theta}{dt}\left[1 - \cos\left(\frac{2\pi\theta}{\theta_O}\right)\right] = \frac{\omega S}{\theta_O}\left[1 - \cos\left(\frac{2\pi\theta}{\theta_O}\right)\right] \qquad \ldots (ii)$$

The velocity is maximum, when

$$\cos\left(\frac{2\pi\theta}{\theta_O}\right) = -1 \quad \text{or} \quad \frac{2\pi\theta}{\theta_O} = \pi \quad \text{or} \quad \theta = \theta_O / 2$$

Substituting $\theta = \theta_O / 2$ in equation (*ii*), we have maximum velocity of the follower during outstroke,

$$v_O = \frac{\omega.S}{\theta_O}(1+1) = \frac{2\,\omega.S}{\theta_O}$$

Similarly, maximum velocity of the follower during return stroke,

$$v_R = \frac{2\,\omega.S}{\theta_R}$$

Now, acceleration of the follower after time *t* sec,

$$\frac{d^2x}{dt^2} = \frac{\omega.S}{\theta_O}\left[\frac{2\pi}{\theta_O}\sin\left(\frac{2\pi\theta}{\theta_O}\right)\frac{d\theta}{dt}\right] \quad \text{. . . [Differentiating equation } (ii)]$$

$$= \frac{2\,\pi\,\omega^2.S}{(\theta_O)^2}\sin\left(\frac{2\pi\theta}{\theta_O}\right) \quad \text{. . .} \left(\because \frac{d\theta}{dt} = \omega\right) \quad \text{. . . } (iii)$$

The acceleration is maximum, when

$$\sin\left(\frac{2\pi\theta}{\theta_O}\right) = 1 \quad \text{or} \quad \frac{2\pi\theta}{\theta_O} = \frac{\pi}{2} \quad \text{or} \quad \theta = \theta_O / 4$$

Substituting $\theta = \theta_O / 4$ in equation (*iii*), we have maximum acceleration of the follower during outstroke,

$$a_O = \frac{2\pi\omega^2.S}{(\theta_O)^2}$$

Similarly, maximum acceleration of the follower during return stroke,

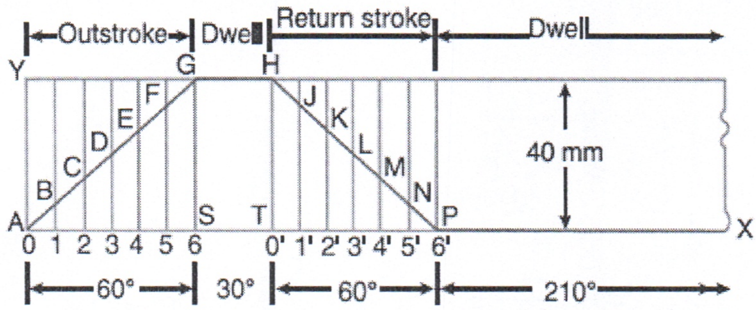
$$a_R = \frac{2\pi\omega^2.S}{(\theta_R)^2}$$

The velocity and acceleration diagrams are shown in Fig. (b) and (c) respectively.

Problems

Q) A cam is to give the following motion to a knife-edged follower :

1. Outstroke during 60° of cam rotation ; 2. Dwell for the next 30° of cam rotation ; 3. Return stroke during next 60° of cam rotation, and 4. Dwell for the remaining 210° of cam rotation. The stroke of the follower is 40 mm and the minimum radius of the cam is 50 mm. The follower moves with uniform velocity during both the outstroke and return strokes. Draw the profile of the cam when (a) the axis of the follower passes through the axis of the cam shaft, and (b) the axis of the follower is offset by 20 mm from the axis of the cam shaft.



First of all, the displacement diagram, as shown in Fig., is drawn as discussed in the following steps :

1. Draw a horizontal line AX = 360° to some suitable scale. On this line, mark AS = 60° to represent outstroke of the follower, ST = 30° to represent dwell, TP = 60° to represent return stroke and PX = 210° to represent dwell.

2. Draw vertical line AY equal to the stroke of the follower (i.e. 40 mm) and complete the rectangle as shown in Fig.

3. Divide the angular displacement during outstroke and return stroke into any equal number of even parts (say six) and draw vertical lines through each point.

4. Since the follower moves with uniform velocity during outstroke and return stroke, therefore the displacement diagram consists of straight lines. Join AG and HP.

5. The complete displacement diagram is shown by AGHPX in Fig.

(a) Profile of the cam when the axis of follower passes through the axis of cam shaft

The profile of the cam when the axis of the follower passes through the axis of the cam shaft, as shown in Fig., is drawn as follows in the following steps :

1. Draw a base circle with radius equal to the minimum radius of the cam (i.e. 50 mm) with O as centre.

2. Since the axis of the follower passes through the axis of the cam shaft, therefore mark trace point A, as shown in Fig.

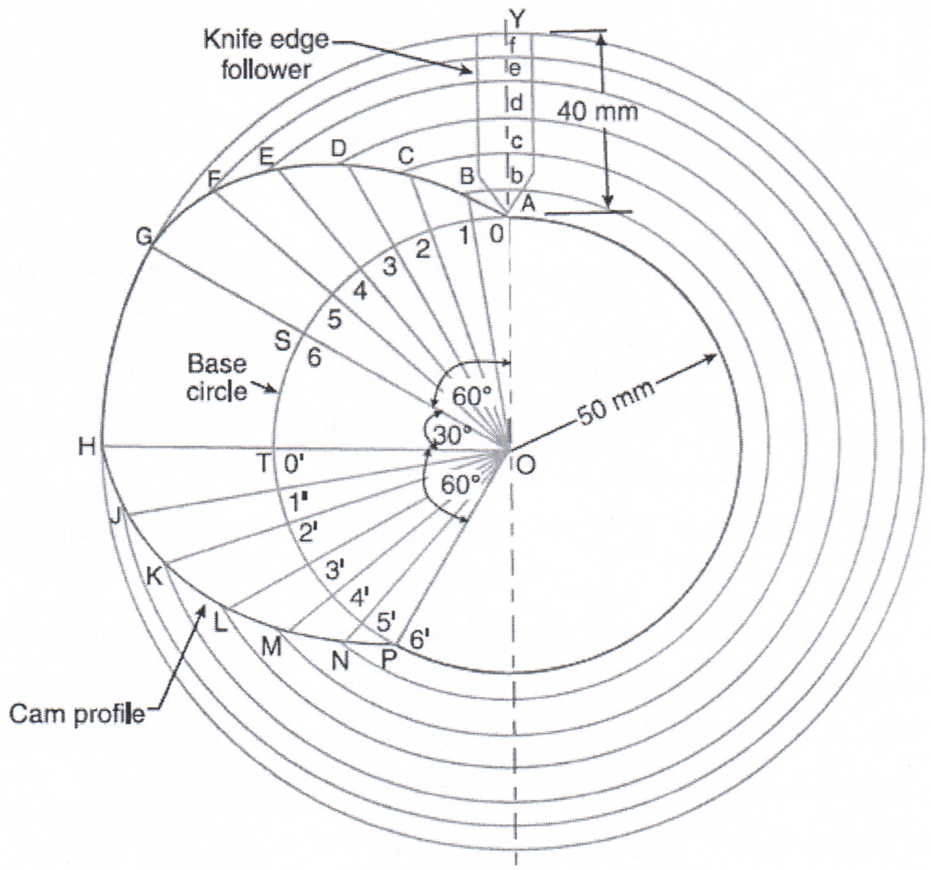
3. From OA, mark angle AOS = 60° to represent outstroke, angle SOT = 30° to represent dwell and angle TOP = 60° to represent return stroke.

4. Divide the angular displacements during outstroke and return stroke (i.e. angle AOS and angle TOP) into the same number of equal even parts as in displacement diagram.

5. Join the points 1, 2, 3 ...etc. and 0′ ,1′ , 2′ , 3′ , ... etc. with centre O and produce beyond the base circle as shown in Fig.

6. Now set off 1B, 2C, 3D ... etc. and 0′ H,1′ J ... etc. from the displacement diagram.

7. Join the points A, B, C,... M, N, P with a smooth curve. The curve AGHPA is the complete profile of the cam.



Profile of the cam when the axis of the follower is offset by 20 mm from the axis of the cam shaft is drawn as discussed in the following steps :

1. Draw a base circle with radius equal to the minimum radius of the cam (i.e. 50 mm) with O as centre.

2. Draw the axis of the follower at a distance of 20 mm from the axis of the cam, which intersects the base circle at A.

3. Join AO and draw an offset circle of radius 20 mm with centre O.

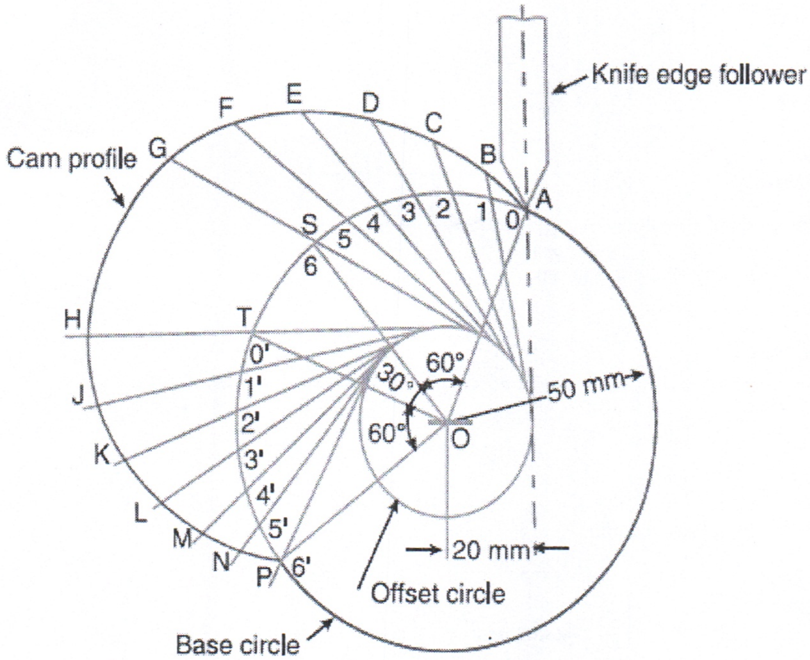
4. From OA, mark angle AOS = 60° to represent outstroke, angle SOT = 30° to represent dwell and angle TOP = 60° to represent return stroke.

5. Divide the angular displacement during outstroke and return stroke (i.e. angle AOS and angle TOP) into the same number of equal even parts as in displacement diagram.

6. Now from the points 1, 2, 3 ... etc. and 0′,1′, 2′,3′ ... etc. on the base circle, draw tangents to the offset circle and produce these tangents beyond the base circle as shown in Fig.

7. Now set off 1B, 2C, 3D ... etc. and 0′ H, 1′ J ... etc. from the displacement diagram.

8. Join the points A, B, C ...M, N, P with a smooth curve. The curve AGHPA is the complete profile of the cam.



Q) A cam, with a minimum radius of 25 mm, rotating clockwise at a uniform speed is to be designed to give a roller follower, at the end of a valve rod, motion described below :

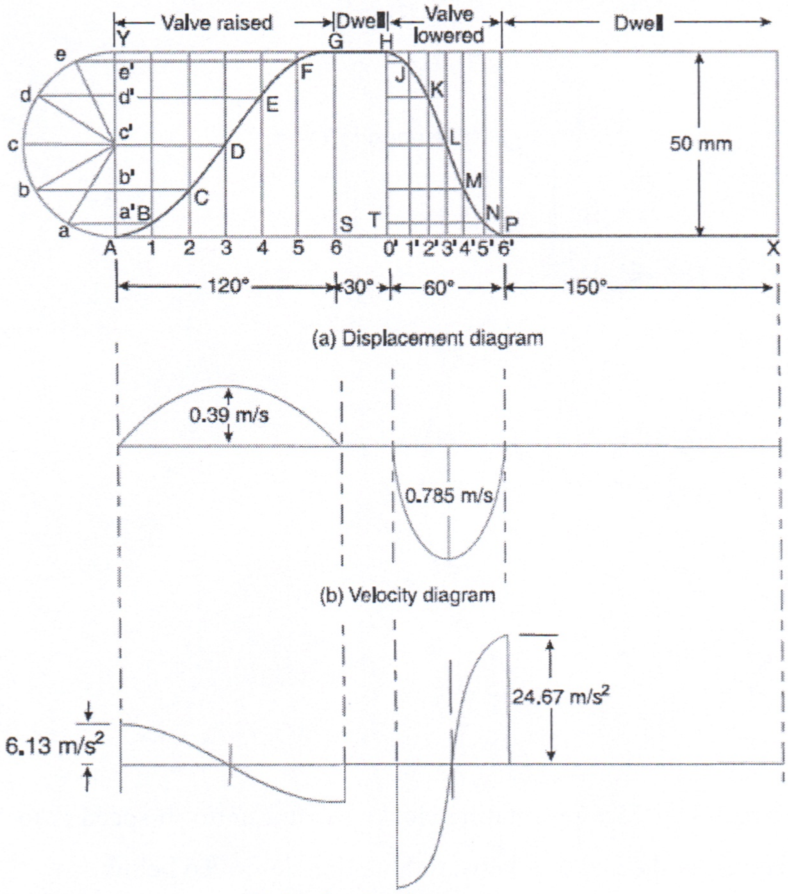
1. To raise the valve through 50 mm during 120° rotation of the cam ;
2. To keep the valve fully raised through next 30°;
3. To lower the valve during next 60°; and
4. To keep the valve closed during rest of the revolution i.e. 150° ;

The diameter of the roller is 20 mm and the diameter of the cam shaft is 25 mm. Draw the profile of the cam when (a) the line of stroke of the valve rod passes through the axis of the cam shaft, and (b) the line of the stroke is offset 15 mm from the axis of the cam shaft. The displacement of the valve, while being raised and lowered, is to take place with simple harmonic motion. Determine the maximum acceleration of the valve rod when the cam shaft rotates at 100 r.p.m. Draw the displacement, the velocity and the acceleration diagrams for one complete revolution of the cam.

Solution:

Given : S = 50 mm = 0.05 m ; $\theta_O = 120° = 2\pi/3$ rad = 2.1 rad ; $\theta_R = 60° = \pi/3$ rad = 1.047 rad ; N = 100 r.p.m.

Since the valve is being raised and lowered with simple harmonic motion, therefore the displacement diagram, as shown in Fig.(a), is drawn as discussed in theory.



(a) Displacement diagram

(b) Velocity diagram

(c) Acceleration diagram

(a) Profile of the cam when the line of stroke of the valve rod passes through the axis of the cam shaft

The profile of the cam, as shown in Fig., is drawn as discussed in the following steps :

1. Draw a base circle with centre O and radius equal to the minimum radius of the cam (i.e. 25 mm).

2. Draw a prime circle with centre O and radius,

OA = Min. radius of cam + 0.5 * Dia. of roller = 25+10 = 35 mm

3. Draw angle AOS = 120° to represent raising or out stroke of the valve, angle SOT = 30° to represent dwell and angle TOP = 60° to represent lowering or return stroke of the valve.

4. Divide the angular displacements of the cam during raising and lowering of the valve (i.e angle AOS and TOP) into the same number of equal even parts as in displacement diagram.

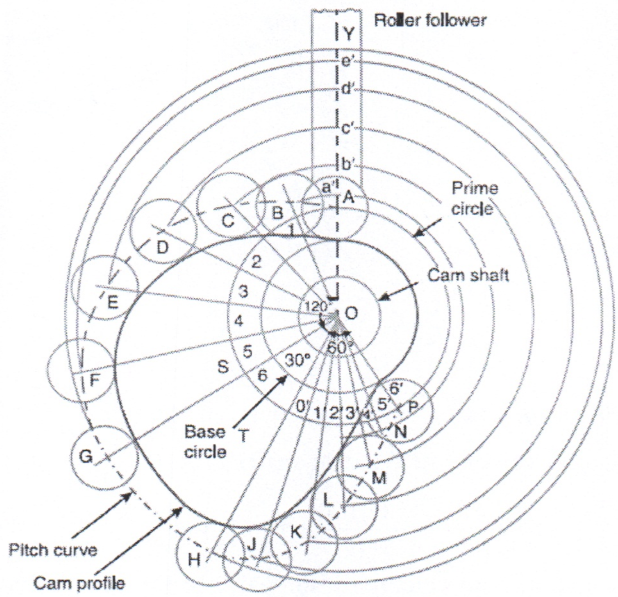
5. Join the points 1, 2, 3, etc. with the centre O and produce the lines beyond prime circle as shown in Fig.

6. Set off 1B, 2C, 3D etc. equal to the displacements from displacement diagram.

7. Join the points A, B, C ... N, P, A. The curve drawn through these points is known as pitch curve.

8. From the points A, B, C ... N, P, draw circles of radius equal to the radius of the roller.

9. Join the bottoms of the circles with a smooth curve as shown in Fig. This is the required profile of the cam.



(b) Profile of the cam when the line of stroke is offset 15 mm from the axis of the cam shaft

The profile of the cam when the line of stroke is offset from the axis of the cam shaft, as shown in Fig. may be drawn as discussed in the following steps :

1. Draw a base circle with centre O and radius equal to 25 mm.

2. Draw a prime circle with centre O and radius OA = 35 mm.

3. Draw an off-set circle with centre O and radius equal to 15 mm.

4. Join OA. From OA draw the angular displacements of cam i.e. draw angle AOS = 120°, angle SOT = 30° and angle TOP = 60°.

5. Divide the angular displacements of the cam during raising and lowering of the valve into the same number of equal even parts (i.e. six parts) as in displacement diagram.

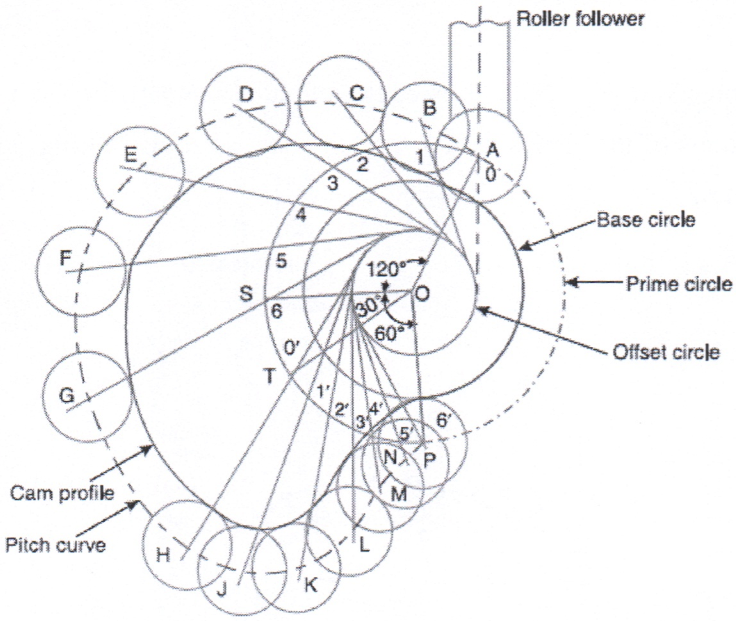
6. From points 1, 2, 3 .... etc. and 0′ ,1′ , 3′ , ...etc. on the prime circle, draw tangents to the offset circle.

7. Set off 1B, 2C, 3D... etc. equal to displacements as measured from displacement diagram.

8. By joining the points A, B, C ... M, N, P, with a smooth curve, we get a pitch curve.

9. Now A, B, C...etc. as centre, draw circles with radius equal to the radius of roller.

10. Join the bottoms of the circles with a smooth curve as shown in Fig. This is the required profile of the cam.



Maximum acceleration of the valve rod

We know that angular velocity of the cam shaft,

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 100}{60} = 10.47 \text{ rad/s}$$

We also know that maximum velocity of the valve rod to raise valve,

$$v_O = \frac{\pi \omega S}{2\theta_O} = \frac{\pi \times 10.47 \times 0.05}{2 \times 2.1} = 0.39 \text{ m/s}$$

and maximum velocity of the valve rod to lower the valve,

$$v_R = \frac{\pi \omega S}{2\theta_R} = \frac{\pi \times 10.47 \times 0.05}{2 \times 1.047} = 0.785 \text{ m/s}$$

$$a_O = \frac{\pi^2 \omega^2 . S}{2(\theta_0)^2} = \frac{\pi^2 (10.47)^2 0.05}{2(2.1)^2} = 6.13 \text{ m/s}^2$$

and maximum acceleration of the valve rod to lower the valve,

$$a_R = \frac{\pi^2 \omega^2 . S}{2(\theta_R)^2} = \frac{\pi^2 (10.47)^2 0.05}{2(1.047)^2} = 24.67 \text{ m/s}^2$$

Q) It is required to set out the profile of a cam to give the following motion to the reciprocating follower with a flat mushroom contact face :

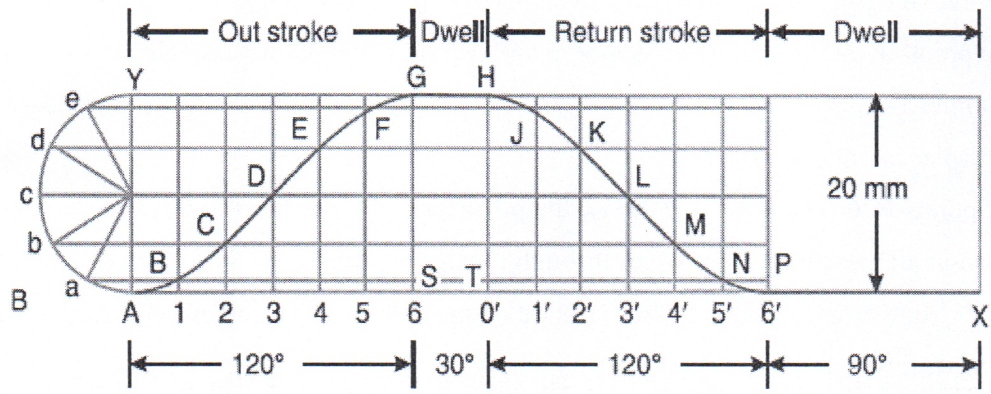
(i) Follower to have a stroke of 20 mm during 120° of cam rotation ;

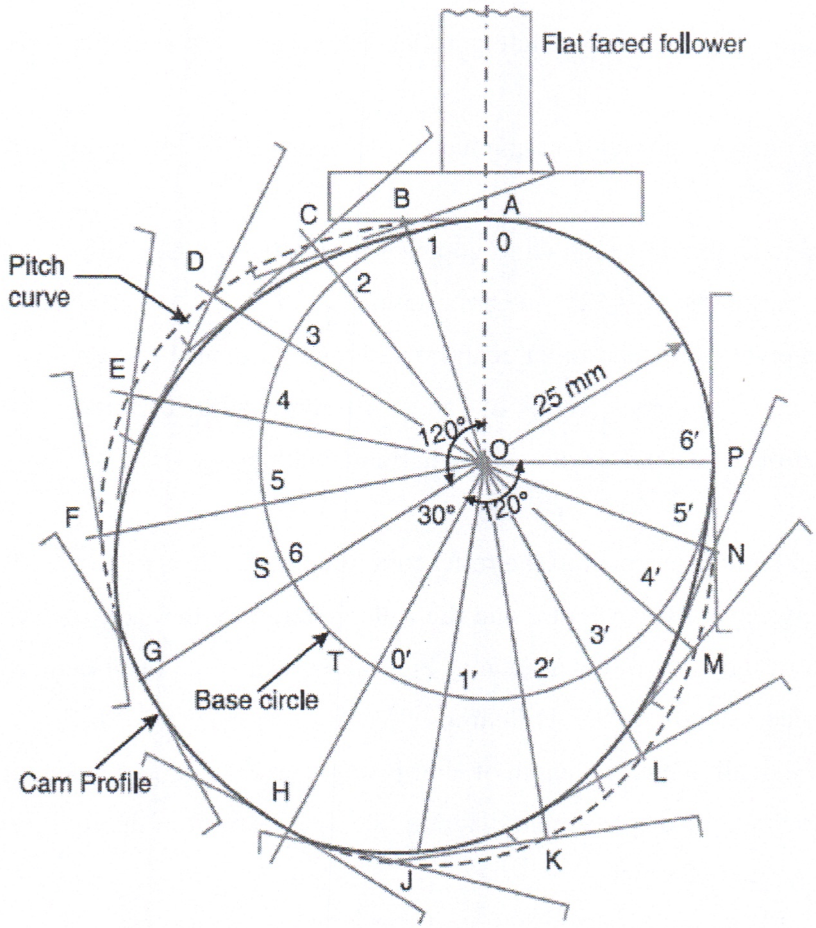
(ii) Follower to dwell for 30° of cam rotation ;

(iii) Follower to return to its initial position during 120° of cam rotation ; and

(iv) Follower to dwell for remaining 90° of cam rotation.

The minimum radius of the cam is 25 mm. The out stroke of the follower is performed with simple harmonic motion and the return stroke with equal uniform acceleration and retardation.





Now the profile of the cam driving a flat reciprocating follower, as shown in Fig, is drawn as discussed in the following steps :

1. Draw a base circle with centre *O* and radius *OA* equal to the minimum radius of the cam (*i.e.* 25 mm).

2. Draw angle AOS = 120° to represent the outward stroke, angle SOT = 30° to represent dwell and angle TOP = 120° to represent inward stroke.

3. Divide the angular displacement during outward stroke and inward stroke (*i.e.* angles AOS and TOP) into the same number of equal even parts as in the displacement diagram.

4. Join the points 1, 2, 3 . . . etc. with centre O and produce beyond the base circle.

5. From points 1, 2, 3 . . . etc., set off 1B, 2C, 3D . . . etc. equal to the distances measured from the displacement diagram.

6. Now at points B, C, D . . . M, N, P, draw the position of the flat-faced follower. The axis of the follower at all these positions passes through the cam centre.

7. The curve drawn tangentially to the flat side of the follower is the required profile of the cam, as shown in Fig.

Q) 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 120° rotation of the cam ;

(b) Follower to return to its initial position during next 120° rotation of the cam ;

(c) Follower to dwell during the next 120° of cam rotation.

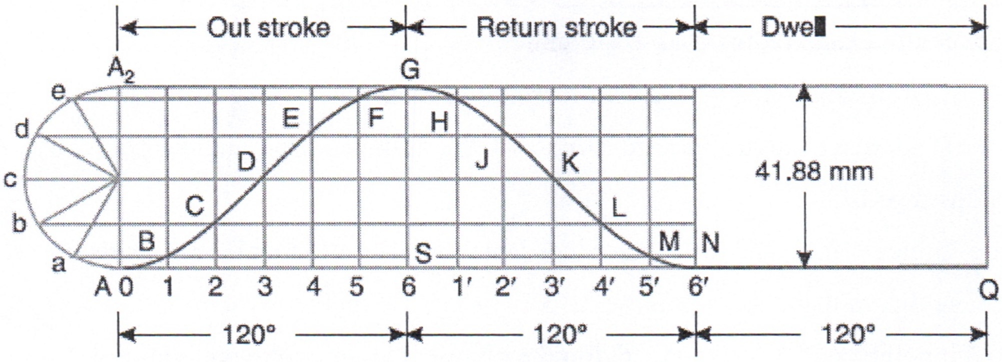
The distance between pivot centre and roller centre = 120 mm ; distance between pivot centre and cam axis = 130 mm ; minimum radius of cam = 40 mm ; radius of roller = 10 mm ; inward and outward strokes take place with simple harmonic motion.

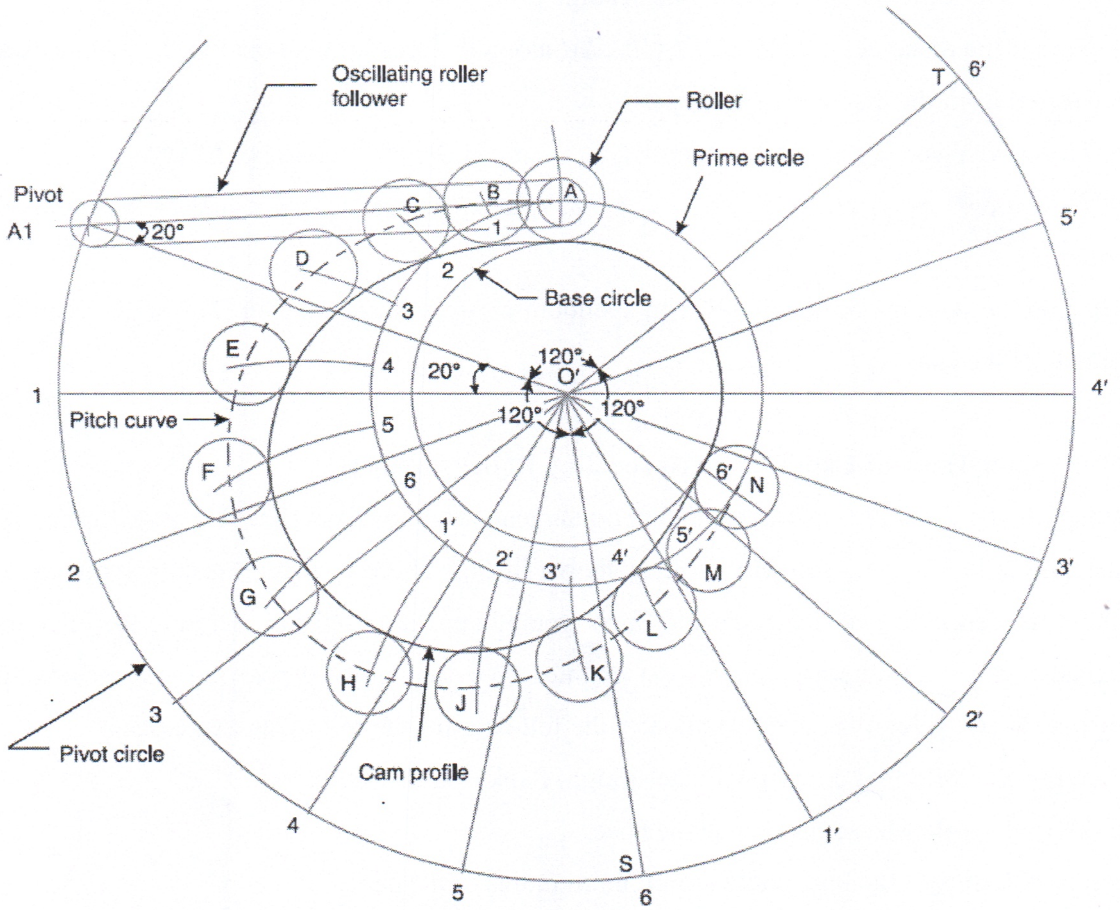
Construction

We know that the angular displacement of the roller follower = 20° = 20× π/180 = π / 9 rad

Since the distance between the pivot centre and the roller centre (i.e. the radius A_1A) is 120 mm, therefore length of the arc AA_2, as shown in Fig. along which the displacement of the roller actually takes place = 120× π / 9 = 41.88 mm

Since the angle is very small, therefore length of chord AA_2 is taken equal to the length of arc AA_2. Thus in order to draw the displacement diagram, we shall take lift of the follower equal to length of chord AA_2 i.e. 41.88 mm.





The profile of the cam to drive an oscillating roller follower, as shown in Fig. is drawn as discussed in the following steps :

1. First of all, draw a base circle with centre *O* and radius equal to the minimum radius of the cam (*i.e.* 40 mm)

2. Draw a prime circle with centre *O* and radius *OA*

= Min. radius of cam + radius of roller = 40 + 10 = 50 mm

3. Now locate the pivot centre A_1 such that OA_1 = 130 mm and AA_1 = 120 mm. Draw a pivot circle with centre O and radius $OA1$ = 130 mm.

4. Join OA_1. Draw angle A_1OS = 120° to represent the outward stroke of the follower, angle SOT = 120° to represent the inward stroke of the follower and angle $TOA1$ = 120° to represent the dwell.

5. Divide angles A_1OS and SOT into the same number of equal even parts as in the displacement diagram and mark points 1, 2, 3 . . . 4′ , 5′ , 6′ on the pivot circle.

6. Now with points 1, 2, 3 . . . 4′ , 5′ , 6′ (on the pivot circle) as centre and radius equal to A_1A (*i.e.* 120 mm) draw circular arcs to intersect the prime circle at points 1, 2, 3 . . .4′ , 5′ , 6′ .

7. Set off the distances 1*B*, 2*C*, 3*D*... 4′*L*, 5′*M* along the arcs drawn equal to the distances as measured from the displacement diagram.

8. The curve passing through the points *A*, *B*, *C*....*L*, *M*, *N* is known as pitch curve.

9. Now draw circles with *A*, *B*, *C*, *D*....*L*, *M*, *N* as centre and radius equal to the radius of roller.

10. Join the bottoms of the circles with a smooth curve as shown in Fig. This is the required profile of the cam.

Q) Explain Tangent Cam with Reciprocating Roller Follower

When the flanks of the cam are straight and tangential to the base circle and nose circle, then the cam is known as a **tangent cam,** as shown in Fig. These cams are usually symmetrical about the centre line of the cam shaft. Such type of cams are used for operating the inlet and exhaust valves of internal combustion engines. We shall now derive the expressions for displacement, velocity and acceleration of the follower for the following two cases :

1. When the roller has contact with the straight flanks ; and

2. When the roller has contact with the nose.

Let r_1 = Radius of the base circle or minimum radius of the cam,

r_2 = Radius of the roller,

r_3 = Radius of nose,

α = Semi-angle of action of cam or angle of ascent,

θ = Angle turned by the cam from the beginning of the roller displacement,

φ = Angle turned by the cam for contact of roller with the straight flank, and

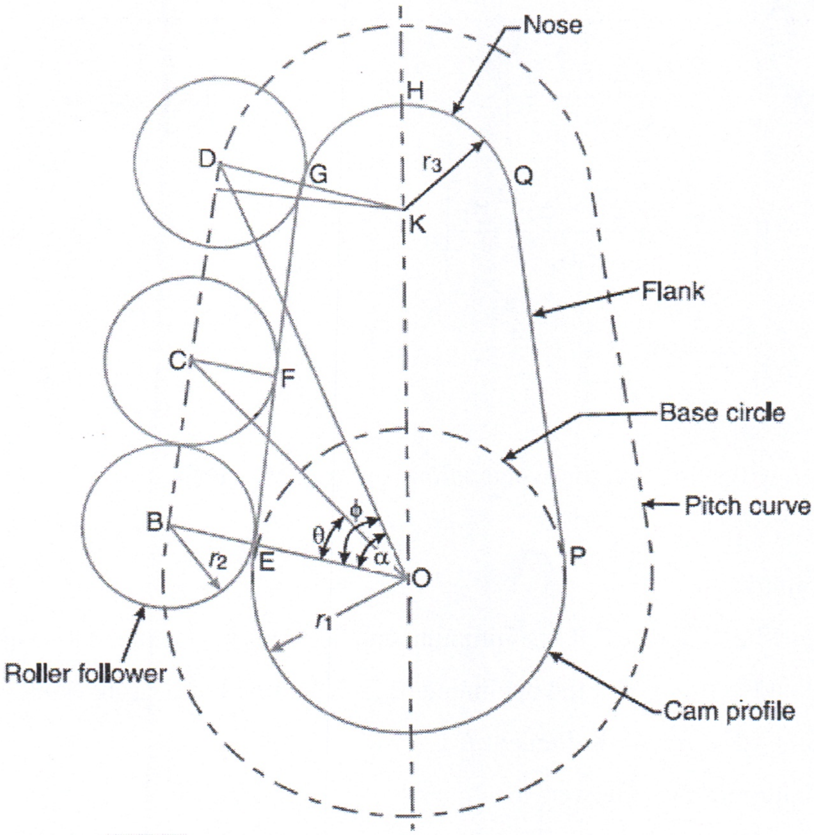
ω = Angular velocity of the cam.

1. ***When the roller has contact with straight flanks.*** A roller having contact with straight flanks is shown in Fig. The point O is the centre of cam shaft and the point K is the centre of nose. *EG* and *PQ* are straight flanks of the cam. When the roller is in lowest position, (*i.e.* when the roller has contact with the straight flank at *E*), the centre of roller lies at *B* on the pitch curve.

Let the cam has turned through an angle* θ (less than φ) for the roller to have contact at any point (say *F*) between the straight flanks *EG*. The centre of roller at this stage lies at *C*. Therefore displacement (or lift or stroke) of the roller from its lowest position is given by

$$x = OC - OB = \frac{OB}{\cos\theta} - OB = OB\left(\frac{1-\cos\theta}{\cos\theta}\right)$$

$$= (r_1 + r_2)\left(\frac{1-\cos\theta}{\cos\theta}\right) \qquad \ldots (\because\ OB = OE + EB = r_1 + r_2) \ldots (i)$$



Differentiating equation (*i*) with respect to *t*, we have velocity of the follower,

$$v = \frac{dx}{dt} = \frac{dx}{d\theta} \times \frac{d\theta}{dt} = (r_1 + r_2)\left(\frac{\sin\theta}{\cos^2\theta}\right)\frac{d\theta}{dt}$$

$$= \omega(r_1 + r_2)\left(\frac{\sin\theta}{\cos^2\theta}\right) \qquad \ldots (\because\ d\theta/dt = \omega) \ldots (ii)$$

From equation ***(ii)***, we see that when θ increases, sin θ increases and cos θ decreases. In other words, sin θ / $\cos^2\theta$ increases. Thus the velocity is maximum where θ is maximum.

This happens when $\theta = \varphi$ *i.e.* when the roller just leaves contact with the straight flank at *G* or when the straight flank merges into a circular nose.

∴ Maximum velocity of the follower,

$$v_{max} = \omega(r_1 + r_2)\left(\frac{\sin\phi}{\cos^2\phi}\right)$$

Now differentiating equation ***(ii)*** with respect to *t*, we have acceleration of the follower,

$$a = \frac{dv}{dt} = \frac{dv}{d\theta} \times \frac{d\theta}{dt}$$

$$= \omega(r_1 + r_2)\left(\frac{\cos^2\theta.\cos\theta - \sin\theta \times 2\cos\theta \times -\sin\theta}{\cos^4\theta}\right)\frac{d\theta}{dt}$$

$$= \omega^2 (r_1 + r_2)\left(\frac{\cos^2\theta + 2\sin^2\theta}{\cos^3\theta}\right) \qquad \ldots \left(\because \frac{d\theta}{dt} = \omega\right)$$

$$= \omega^2 (r_1 + r_2)\left[\frac{\cos^2\theta + 2(1 - \cos^2\theta)}{\cos^3\theta}\right]$$

$$= \omega^2 (r_1 + r_2)\left(\frac{2 - \cos^2\theta}{\cos^3\theta}\right) \qquad \ldots (iii)$$

A little consideration will show that the acceleration is minimum when

$\frac{2 - \cos^2\theta}{\cos^3\theta}$ is minimum.

This is only possible when $(2 - \cos^2\theta)$ is minimum and $\cos^3\theta$ is maximum. This happens when $\theta = 0°$, *i.e.* when the roller is at the beginning of its lift along the straight flank (or when the roller has contact with the straight flank at *E*).

∴ Minimum acceleration of the follower,

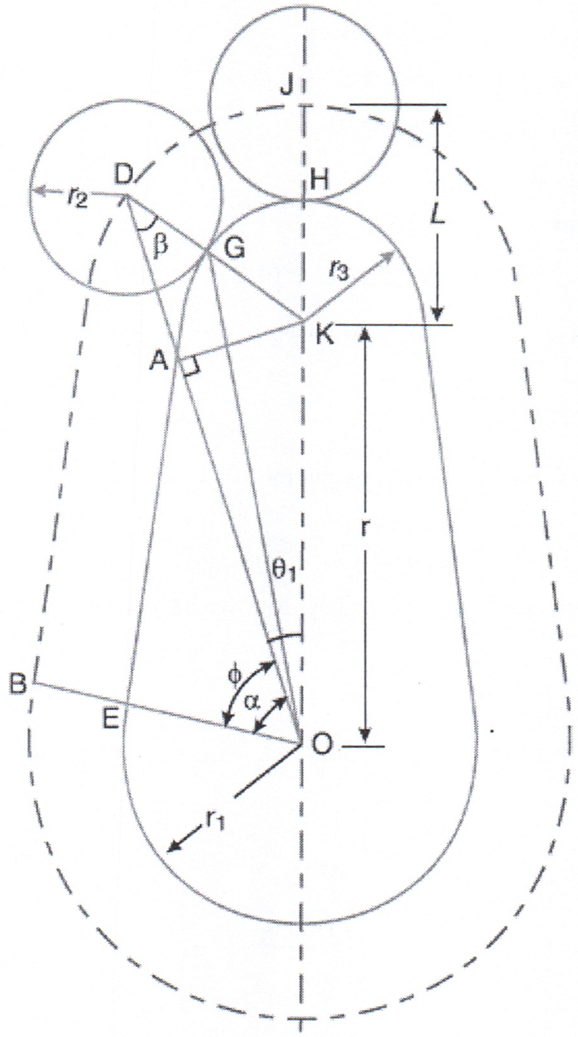
$$a_{min} = \omega^2 (r_1 + r_2)$$

The acceleration is maximum when $\theta = \varphi$, *i.e.* when the roller just leaves contact with the straight flank at *G* or when the straight flank merges into a circular nose.

∴ Maximum acceleration of the follower,

$$a_{max} = \omega^2 (r_1 + r_2)\left(\frac{2 - \cos^2\phi}{\cos^3\phi}\right)$$

2. ***When the roller has contact with the nose.*** A roller having contact with the circular nose at G is shown in Fig. The centre of roller lies at D on the pitch curve. The displacement is usually measured from the top position of the roller, *i.e.* when the roller has contact at the apex of the nose (point H) and the centre of roller lies at J on the pitch curve.



Let θ_1 = Angle turned by the cam measured from the position when the roller is at the top of the nose.

The displacement of the roller is given by

$$x = OJ - OD = OJ - (OA + AD) = (OK + KJ) - (OA + AD)$$

Substituting $OK = r$ and $KJ = KH + HJ = r_3 + r_2 = L$, we have

$$x = (r + L) - (OK \times \cos\theta_1 + DK\cos\beta)$$

$$= (r + L) - (r\cos\theta_1 + L\cos\beta) \qquad \ldots (\because DK = KJ = r_3 + r_2 = L)$$

$$= L + r - r\cos\theta_1 - L\cos\beta \qquad \ldots (i)$$

Now from right angled triangles *OAK* and *DAK*,

$$AK = DK\sin\beta = OK\sin\theta_1$$

or

$$L\sin\beta = r\sin\theta_1$$

Squaring both sides,

$$L^2\sin^2\beta = r^2\sin^2\theta_1 \text{ or } L^2(1 - \cos^2\beta) = r^2\sin^2\theta_1$$

$$L^2 - L^2\cos^2\beta = r^2\sin^2\theta_1 \text{ or } L^2\cos^2\beta = L^2 - r^2\sin^2\theta_1$$

$$\therefore \qquad L\cos\beta = (L^2 - r^2\sin^2\theta_1)^{\frac{1}{2}}$$

Substituting the value of $L\cos\beta$ in equation (*i*), we get

$$x = L + r - r\cos\theta_1 - (L^2 - r^2\sin^2\theta_1)^{\frac{1}{2}} \qquad \ldots (ii)$$

Differentiating equation (*ii*) with respect to *t*, we have velocity of the follower,

$$v = \frac{dx}{dt} = \frac{dx}{d\theta_1} \times \frac{d\theta_1}{dt}$$

$$= -r \times -\sin\theta_1 \times \frac{d\theta_1}{dt} - \frac{1}{2}(L^2 - r^2\sin^2\theta_1)^{-\frac{1}{2}}(-r^2 \times 2\sin\theta_1\cos\theta_1)\frac{d\theta_1}{dt}$$

$$= r\sin\theta_1 \times \frac{d\theta_1}{dt} + \frac{1}{2}(L^2 - r^2\sin^2\theta_1)^{-\frac{1}{2}} r^2 \times \sin 2\theta_1 \times \frac{d\theta_1}{dt}$$

$$= \omega . r\left[\sin\theta_1 + \frac{r\sin 2\theta_1}{2(L^2 - r^2\sin^2\theta_1)^{\frac{1}{2}}}\right] \qquad \ldots \left(\text{Substituting } \frac{d\theta_1}{dt} = \omega\right) \ldots (iii)$$

Now differentiating equation (*iii*) with respect to *t*, we have acceleration of the follower,

$$a = \frac{dv}{dt} = \frac{dv}{d\theta_1} \times \frac{d\theta_1}{dt}$$

$$= \omega . r\left[\cos\theta_1 + \frac{(L^2 - r^2\sin^2\theta_1)^{\frac{1}{2}}(r \times 2\cos 2\theta_1 + r\sin 2\theta_1 \times \frac{1}{2}(L^2 - r^2\sin^2\theta_1)^{-\frac{1}{2}}(r^2 \times 2\sin\theta_1\cos\theta_1)}{2(L^2 - r^2\sin^2\theta_1)}\right]\frac{d\theta_1}{dt}$$

Substituting $\frac{d\theta_1}{dt} = \omega$ and multiplying the numerator and denominator of second term by $(L^2 - r^2 \sin^2 \theta_1)^{\frac{1}{2}}$, we have

$$a = \omega^2 . r \left[\cos\theta_1 + \frac{(L^2 - r^2 \sin^2 \theta_1)(2r\cos 2\theta_1) + \frac{1}{2} \times r^3 \sin^2 2\theta_1}{2(L^2 - r^2 \sin^2 \theta_1)^{3/2}} \right]$$

$$= \omega^2 . r \left[\cos\theta_1 + \frac{L^2 \times 2r\cos 2\theta_1 - 2r^3 \sin^2 \theta_1 . \cos 2\theta_1 + \frac{1}{2} \times r^3 (2\sin\theta_1 \cos\theta_1)^2}{2(L^2 - r^2 \sin^2 \theta_1)^{3/2}} \right]$$

$$= \omega^2 . r \left[\cos\theta_1 + \frac{2L^2 . r\cos 2\theta_1 - 2r^3 . \sin^2 \theta_1 (1 - 2\sin^2 \theta_1) + 2r^3 \sin^2 \theta_1 (1 - \sin^2 \theta_1)}{2(L^2 - r^2 \sin^2 \theta_1)^{3/2}} \right]$$

$$= \omega^2 . r \left[\cos\theta_1 + \frac{L^2 . r\cos 2\theta_1 + r^3 \sin^4 \theta_1}{(L^2 - r^2 \sin^2 \theta_1)^{3/2}} \right]$$

Notes : 1. Since θ_1 is measured from the top position of the roller, therefore for the roller to have contact at the apex of the nose (*i.e.* at point *H*),then θ1 = 0, and for the roller to have contact where straight flank merges into a nose (*i.e.* at point *G*), then θ1 = α − φ .

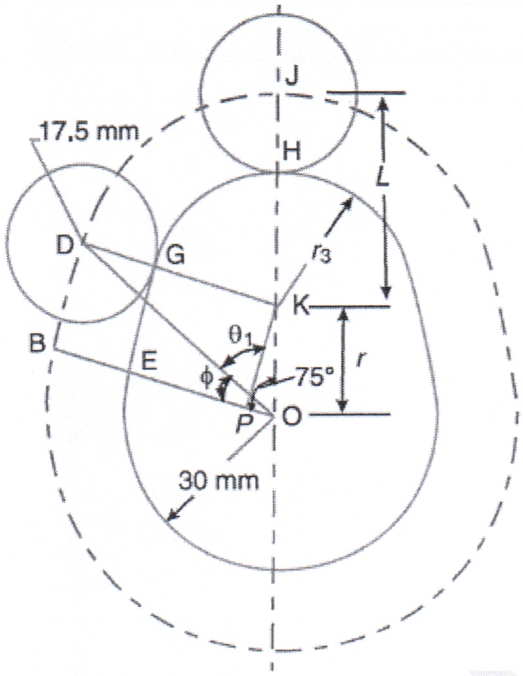
2. The velocity is zero at *H* and maximum at *G*.

3. The acceleration is minimum at *H* and maximum at *G*.

4. From Fig we see that the distances *OK* and *KD* remains constant for all positions of the roller when it moves along the circular nose. In other words, a tangent cam operating a roller follower and having contact with the nose is equivalent to a slider crank mechanism (*i.e.* *ODK*) in which the roller is assumed equivalent to the slider *D*, crank *OK* and connecting rod *DK*. Therefore the velocity and acceleration of the roller follower may be obtained graphically using relative velocity method and acceleration diagrams.

Q) In a symmetrical tangent cam operating a roller follower, the least radius of the cam is 30 mm and roller radius is 17.5 mm. The angle of ascent is 75° and the total lift is 17.5 mm. The speed of the cam shaft is 600 r.p.m. Calculate : **1.** the principal dimensions of the cam ; **2.** the accelerations of the follower at the beginning of the lift, where straight flank merges into the circular nose and at the apex of the circular nose. Assume that there is no dwell between ascent and descent.

Solution. Given : r_1 = 30 mm ; r_2 = 17.5 mm ; α = 75° ; Total lift = 17.5 mm ; N = 600 r.p.m. or ω= 2 π × 600/60 = 62.84 rad/s



1. Principal dimensions of the cam

Let r = OK = Distance between cam centre and nose centre,

r_3 = Nose radius, and

φ = Angle of contact of cam with straight flanks.

From the geometry of Fig. above,

$$r + r_3 = r_1 + \text{Total lift}$$

$$= 30 + 17.5 = 47.5 \text{ mm}$$

$\therefore \quad r = 47.5 - r_3 \quad \ldots (i)$

Also, $\quad OE = OP + PE \quad$ or $\quad r_1 = OP + r_3$

$\therefore \quad OP = r_1 - r_3 = 30 - r_3 \quad \ldots (ii)$

Now from right angled triangle *OKP*,

$$OP = OK \times \cos\alpha \quad \ldots (\because \cos\alpha = OP/OK)$$

or $\quad 30 - r_3 = (47.5 - r_3)\cos 75° = (47.5 - r_3)0.2588 = 12.3 - 0.2588\, r_3$

$\ldots (\because OK = r)$

$\therefore \quad r_3 = 23.88$ mm **Ans.**

and $\quad r = OK = 47.5 - r_3 = 47.5 - 23.88 = 23.62$ mm **Ans.**

Again, from right angled triangle *ODB*,

$$\tan\phi = \frac{DB}{OB} = \frac{KP}{OB} = \frac{OK\sin\alpha}{r_1 + r_2} = \frac{23.62\sin 75°}{30 + 17.5} = 0.4803$$

$\therefore \quad \phi = 25.6°$ **Ans.**

2. *Acceleration of the follower at the beginning of the lift*

We know that acceleration of the follower at the beginning of the lift, *i.e.* when the roller has contact at E on the straight flank,

$$a_{min} = \omega^2 (r_1 + r_2) = (62.84)^2 (30+17.5)^2 = 187\ 600 \ \text{mm/s}^2$$

$$= 187.6 \text{ m/s}^2 \textbf{ Ans.}$$

Acceleration of the follower where straight flank merges into a circular nose

We know that acceleration of the follower where straight flank merges into a circular nose *i.e.* when the roller just leaves contact at G,

$$a_{max} = \omega^2 (r_1 + r_2)\left[\frac{2-\cos^2\phi}{\cos^3\phi}\right] = (62.84)^2(30+17.5)\left(\frac{2-\cos^2 25.6^\circ}{\cos^3 25.6^\circ}\right)$$

$$= 187\,600\left(\frac{2-0.813}{0.733}\right) = 303\ 800 \ \text{mm/s}^2 = 303.8 \text{ m/s}^2 \textbf{ Ans.}$$

Acceleration of the follower at the apex of the circular nose

We know that acceleration of the follower for contact with the circular nose,

$$a = \omega^2 . r\left[\cos\theta_1 + \frac{L^2 . r\cos 2\theta_1 + r^3\sin^4\theta_1}{(L^2 - r^2\sin^2\theta_1)^{3/2}}\right]$$

Since θ_1 is measured from the top position of the follower, therefore for the follower to have contact at the apex of the circular nose (*i.e.* at point H), $\theta_1 = 0$.

$\therefore$ Acceleration of the follower at the apex of the circular nose,

$$a = \omega^2 . r\left(1 + \frac{L^2 . r}{L^3}\right) = \omega^2 . r\left(1 + \frac{r}{L}\right) = \omega^2 . r\left(1 + \frac{r}{r_2 + r_3}\right)$$

$$= (62.84)^2\, 23.62\left(1 + \frac{23.62}{17.5 + 23.88}\right) = 146\ 530 \ \text{mm/s}^2 \quad \ldots (\because L = r_2 + r_3)$$

$$= 146.53 \text{ m/s}^2 \textbf{ Ans.}$$

Q) Explain Circular Arc Cam with Flat-faced Follower

When the flanks of the cam connecting the base circle and nose are of convex circular arcs, then the cam is known as ***circular arc cam.*** A symmetrical circular arc cam operating a flat-faced follower is shown in Fig. below in which O and Q are the centres of cam and nose respectively. EF and GH are two circular flanks whose centres lie at P and P' respectively. The centres * P and P'

lie on lines EO and GO produced.

Let r_1 = Minimum radius of the cam or radius of the base circle = OE,

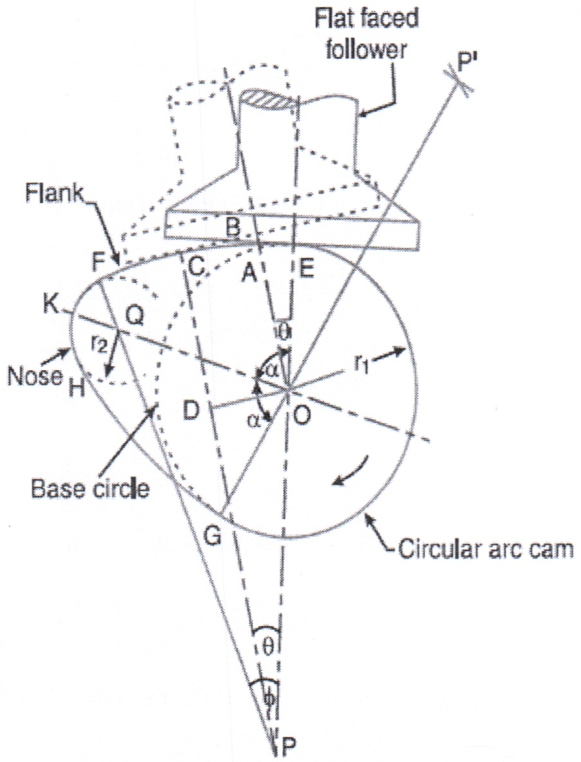
r_2 = Radius of nose,

R = Radius of circular flank = PE,

2α = Total angle of action of cam = angle EOG,

α = Semi-angle of action of cam or angle of ascent = angle *EOK*, and

φ = Angle of action of cam on the circular flank.



1. When the flat face of the follower has contact on the circular flank.

Let us consider that the flat face of the follower has contact at E (i.e. at the junction of the circular flank and base circle). When the cam turns through an angle θ (less than φ) relative to the follower, the contact of the flat face of the follower will shift from E to C on the circular flank, such that flat face of the follower is perpendicular to PC. Since OB is perpendicular to BC, therefore OB is parallel to PC. From O, draw OD perpendicular to PC. From the geometry of the figure, the displacement or lift of the follower (x) at any instant for contact on the circular flank, is given by

$x = BA = BO - AO = CD - EO$ . . . **(i)**

We know that

$CD = PC - PD = PE - OP \cos\theta$

$= OP + OE - OP \cos\theta = OE + OP (1 - \cos\theta)$

Substituting the value of CD in equation (*i*),

$$x = OE + OP(1-\cos\theta) - EO = OP(1-\cos\theta)$$

$$= (PE - OE)(1-\cos\theta) = (R - r_1)(1-\cos\theta) \quad \ldots (ii)$$

Differentiating equation (*ii*) with respect to t, we have velocity of the follower,

$$v = \frac{dx}{dt} = \frac{dx}{d\theta} \times \frac{d\theta}{dt} = \frac{dx}{d\theta} \times \omega \quad \ldots \left(\text{substituting } \frac{d\theta}{dt} = \omega\right)$$

$$= (R - r_1)\sin\theta \times \omega = \omega(R - r_1)\sin\theta \quad \ldots (iii)$$

From the above expression, we see that at the beginning of the ascent (*i.e.* when $\theta = 0$), the velocity is zero (because $\sin 0 = 0$) and it increases as θ increases. The velocity will be maximum when $\theta = \phi$, *i.e.* when the contact of the follower just shifts from circular flank to circular nose. Therefore maximum velocity of the follower,

$$v_{max} = \omega(R - r_1)\sin\phi$$

Now differentiating equation (*iii*) with respect to t, we have acceleration of the follower,

$$a = \frac{dv}{dt} = \frac{dv}{d\theta} \times \frac{d\theta}{dt} = \frac{dv}{d\theta} \times \omega$$

$$= \omega(R - r_1)\cos\theta \times \omega = \omega^2 (R - r_1)\cos\theta \quad \ldots (iv)$$

From the above expression, we see that at the beginning of the ascent (*i.e.* when $\theta = 0$), the acceleration is maximum (because $\cos 0 = 1$) and it decreases as θ increases. The acceleration will be minimum when $\theta = \phi$.

$\therefore$ Maximum acceleration of the follower,

$$a_{max} = \omega^2 (R - r_1)$$

and minimum acceleration of the follower,

$$a_{min} = \omega^2 (R - r_1)\cos\phi$$

2. *When the flat face of the follower has contact on the nose.*

The flat face of the follower having contact on the nose at C is shown in Fig. The centre of curvature of the nose lies at Q. In this case, the displacement or lift of the follower at any instant when the cam has turned through an angle θ (greater than φ) is given by

$x = AB = OB - OA = CD - OA \ldots (\because OB = CD) \ldots$ **(*i*)**

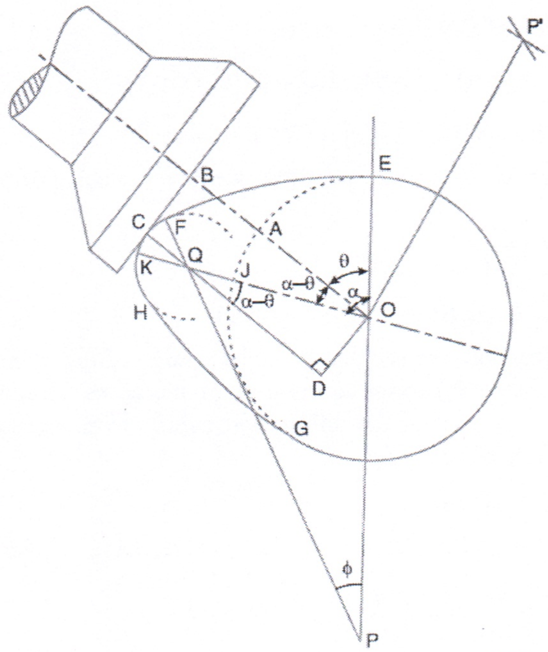
But $CD = CQ + QD = CQ + OQ \cos(\alpha - \theta)$

Substituting the value of CD in equation **(*i*)**, we have

$x = CQ + OQ\cos(\alpha - \theta) - OA \ldots$ **(*ii*)**

The displacement or lift of the follower when the contact is at the apex K of the nose *i.e.* when $\alpha - \theta = 0$ is

* $x = CQ + OQ - OA = r_2 + OQ - r_1$



Differentiating equation (*ii*) with respect to *t*, we have velocity of the follower,

$$v = \frac{dx}{dt} = \frac{dx}{d\theta} \times \frac{d\theta}{dt} = \frac{dx}{d\theta} \times \omega$$

$$= OQ \sin(\alpha - \theta)\omega = \omega \times OQ \sin(\alpha - \theta) \quad \ldots (iii)$$

. . .($\because$ CQ, OQ, OA and α are constant)

From the above expression, we see that the velocity is zero when $\alpha - \theta = 0$ or $\alpha = \theta$ *i.e.* when the follower is at the apex *K* of the nose. The velocity will be maximum when $(\alpha - \theta)$ is maximum. This happens when the follower changes contact from circular flank to circular nose at point *F*, *i.e.* when $(\alpha - \theta) = \phi$.

Now differentiating equation (*iii*) with respect to *t*, we have acceleration of the follower,

$$a = \frac{dv}{dt} = \frac{dv}{d\theta} \times \frac{d\theta}{dt} = \frac{dv}{d\theta} \times \omega$$

$$= -\omega \times OQ \cos(\alpha - \theta)\omega = -\omega^2 \times OQ \cos(\alpha - \theta) \quad \ldots (iv)$$

The negative sign in the above expression shows that there is a retardation when the follower is in contact with the nose of the cam.

From the above expression, we see that retardation is maximum when $\alpha - \theta = 0$ or $\theta = \alpha$, *i.e.* when the follower is at the apex *K* of the nose.

$\therefore$ Maximum retardation = $\omega^2 \times OQ$

The retardation is minimum when $\alpha - \theta$ is maximum. This happens when the follower changes contact from circular flank to circular nose at point *F* *i.e.* when $\theta = \phi$.

$\therefore$ Minimum retardation = $\omega^2 \times OQ \cos(\alpha - \phi)$

Previous JNTUK questions

1. Sketch and explain different cam follower systems based on the surface contact.
2. Define the term pressure angle with reference to cams.

3. What is the difference between the cam angle and pressure angle?
4. Draw the displacement, velocity and acceleration diagrams for a follower moving with uniform velocity. Also draw the modified displacement, velocity and acceleration diagrams. Why a modification in these diagram is are done?
5. Draw the displacement, velocity and acceleration diagrams for a follower when it moves with SHM. Derive the expression for velocity and acceleration during out stroke and return strokes of the follower.
6. Draw the displacement, velocity and acceleration diagrams for a follower when it moves with uniform acceleration and retardation. Derive the expression for velocity and acceleration during out stroke and return strokes of the follower.
7. Construct the profile of a cam to suit the following specifications: Cam shaft diameter=40 mm; Least radius of cam=25 mm; Diameter of roller=25 mm; Angle of lift =1200; Angle of fall =1500; Lift of the follower =40 mm; Number of pauses are two of equal intervals between motions. During the lift, the motion is S.H.M. During the fall the motion is uniform acceleration and deceleration. The speed of the cam shaft is uniform. The line of stroke of the follower is off-set 12.5mm from the centre of the cam.
8. Particulars of a symmetric tangent cam operating a roller follower are as under: Least radius of cam: 3cm; Roller radius: 1.5cm; angle of ascent:75^0; Total lift: 1.5 cm; Speed of cam shaft: 600rpm. Calculate the principal dimensions and the equations of displacement curve when the follower is in contact with straight flank and circular nose.
9. Derive an expression to find the velocity of the roller follower for a tangent cam when roller is in contact with nose.
10. From the following data draw the cam profile in which the follower moves with SHM during ascent and uniformly accelerated and decelerated motion during descent. The diameter of the roller follower is 30mm and lift of the follower is 40 mm.
    i) Angle of ascent = 48^0 and angle of descent = 60^0
    ii) Angle of dwell between ascent and descent = 42^0
    iii) The least radius of the cam is 50 mm and the distance between line of action of follower and axis of cam = 20 mm If the cam rotates at 360 rpm ccw, find the maximum velocity and acceleration of the follower during ascent and descent.
11. Describe the various factors which govern the choice of the cam profile?

12. A symmetric tangent cam with a roller follower has the following Minimum radius of the cam = 40 mm; Lift = 20 mm; speed = 360 rpm; diameter of the roller = 44 mm; angle of ascent = 60^0. Calculate the acceleration of follower at the beginning of the lift. Also find its values when the roller just touches the nose and is at the apex of the circular nose. Sketch the variation of displacement, velocity and acceleration during ascent.
13. What do mean by pressure angle in a cam? Discuss its importance in cam design?
14. A cam having a lift of 10 mm operates the suction valve of a 4-stroke petrol engine. The least radius of the cam is 20 mm and nose radius is 2.5 mm. The crank angle of the engine, when suction valve open is 4^0 after TDC and it is 50^0 after BDC when the suction valve closes. The cam shaft has a speed of 1000 rpm. The cam is of circular type with circular nose and flanks. It is integral with cam shaft and operates as a flat-faced follower. Find i) the max. velocity of the valve; ii) the max. acceleration and retardation of the valve and iii) the min. force to be exerted by the spring to overcome inertia of the valve parts which weigh 2 N.