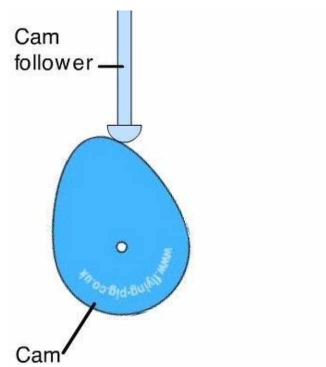
# ME3491 THEORY OF MACHINES

## NOTES UNIT 1

## 1.10. CAM

A cam is a mechanical device used to transmit motion to a follower by direct contact. The driver is called the cam and the driven member is called the follower. In a cam follower pair, the cam normally rotates while the follower may translate or oscillate.

Type of cams, Type of followers, Displacement, Velocity and acceleration time curves for cam profiles, Disc cam with reciprocating follower having knife edge, roller follower, Follower motions including SHM, Uniform velocity, Uniform acceleration and retardation and Cycloidal motion.




### 1.10.1 Types of cams

**According to the surface in contact.**

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

- **Knife edge follower.**

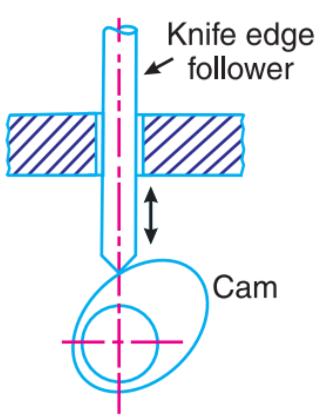
When the contacting end of the follower has a sharp knife edge, it is called a knife edge follower, as shown in Figure. The sliding motion takes place between the contacting surfaces (i.e. the knife edge and the cam surface). It is seldom used in practice because the small area of contacting surface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

- **Roller follower.**

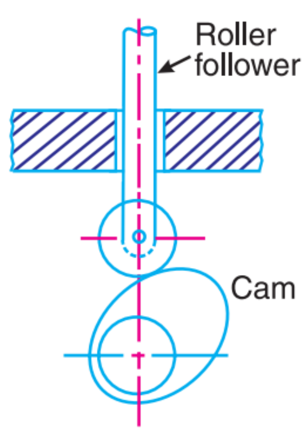
When the contacting end of the follower is a roller, it is called a roller follower, as shown in Figure. Since the rolling motion takes place between the contacting surfaces (i.e. the roller and the cam), therefore the rate of wear is greatly reduced. In roller followers also the side thrust exists between 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.

- **Flat faced or mushroom follower.**

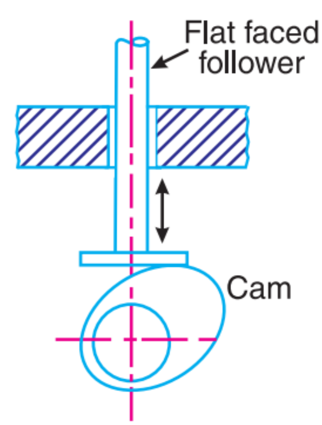
When the contacting end of the follower is a perfectly flat face, it is called a flat-faced follower, as shown in Figure. It may be noted that the side thrust between the follower and the guide is much reduced in case of flat faced followers. The only side thrust is due to friction between the contact surfaces of the follower and the cam.



Cam with knife edge follower.



Cam with roller follower.



Cam with flat faced follower.

***According to the motion of the follower.***

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

- **Reciprocating or translating follower.** When the follower reciprocates in guides 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 predetermined oscillatory motion of the follower, it is called oscillating or rotating follower. The follower, as shown in Fig 20.1 (e), is an oscillating or rotating follower.

***According to the path of motion of the follower.***

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

- ***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. 20.1 (a) to (e), are all radial followers.*

- ***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.*

## 1.10.2.Terms Used in Radial Cams

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.

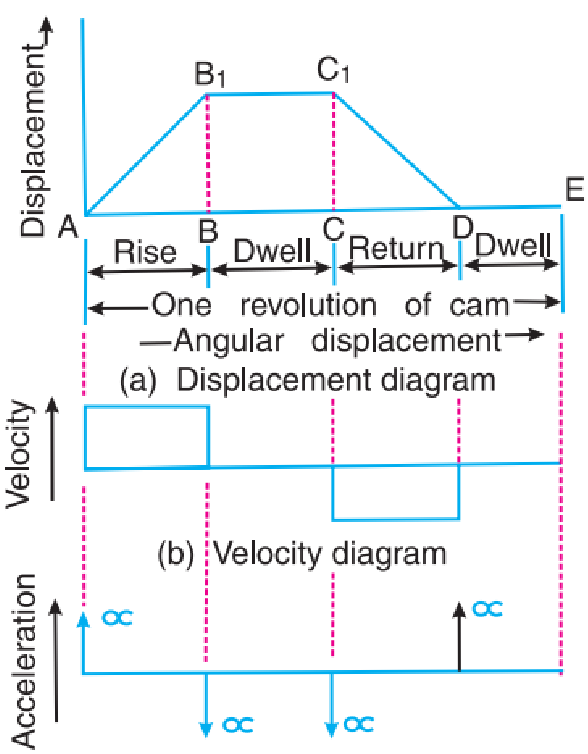
6. Pitch curve. It is the curve generated by the trace point as the follower moves relative to the cam. For a knife edge follower, the pitch curve and the cam profile are same whereas for a roller follower, they are separated by the radius of the roller.

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.

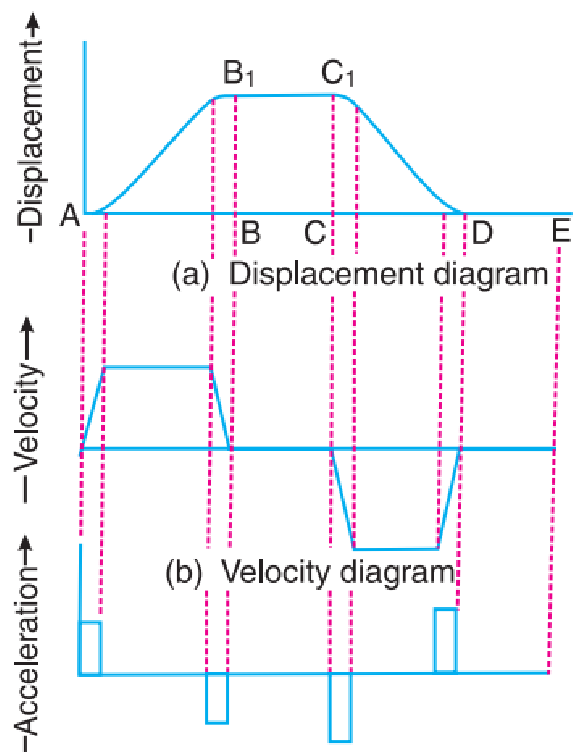
8. Lift or stroke. It is the maximum travel of the follower from its lowest position to the topmost position.

**1.10.3.** ***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 Figures. 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, AB1 and C1D must be straight lines. A little consideration will show 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 B1C1 and DE .From Figure 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.



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



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

## 1.10.4. 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 Figure.

The displacement diagram is drawn as follows :

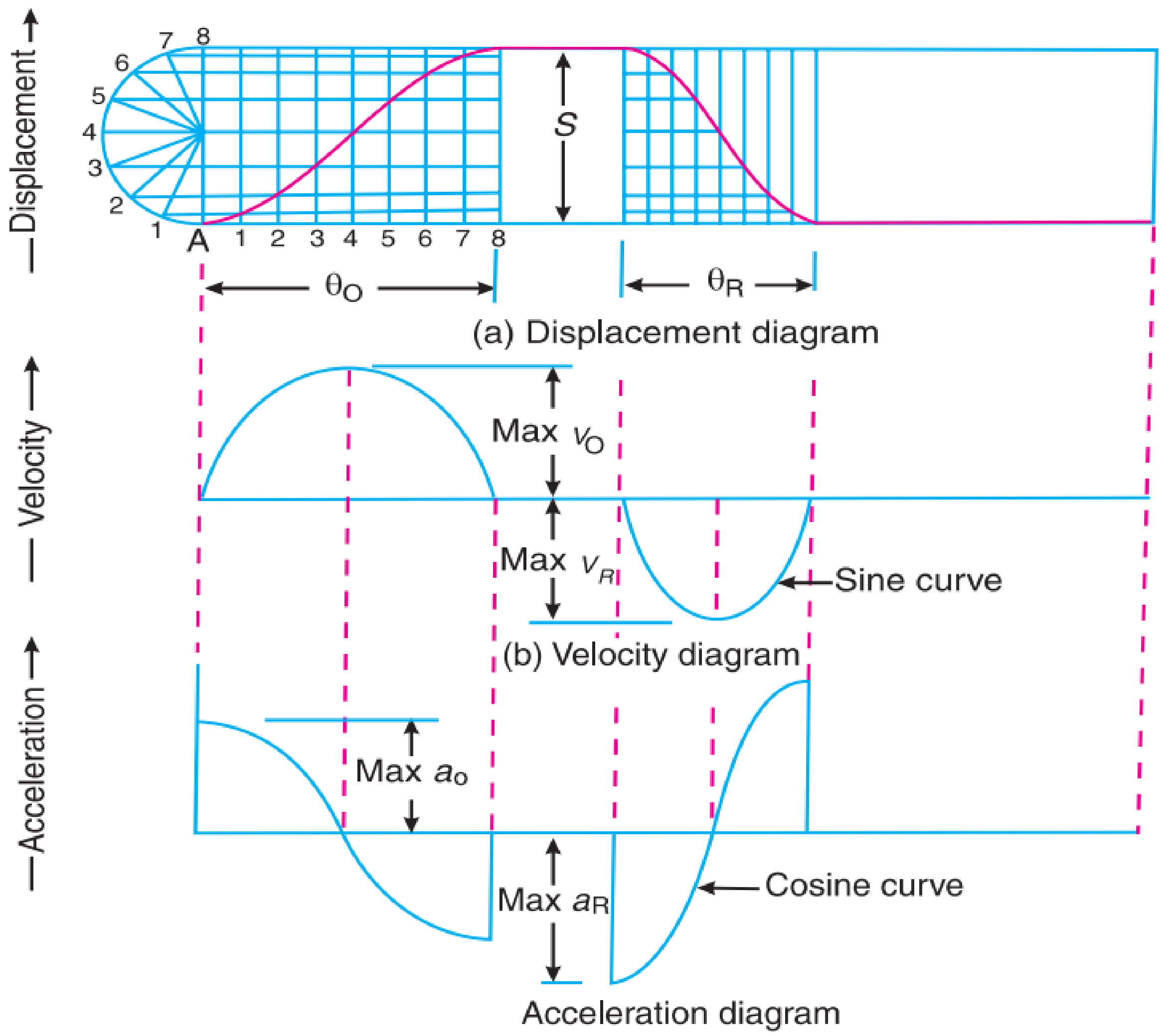
1. Draw a semi-circle on the follower stroke as diameter.

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 Figure.

The velocity and acceleration diagrams are shown in Fig. 20.6 (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 Figure 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. On the other hand, the acceleration of the follower is maximum at the beginning and at the ends of the stroke and diminishes to zero at mid-stroke.

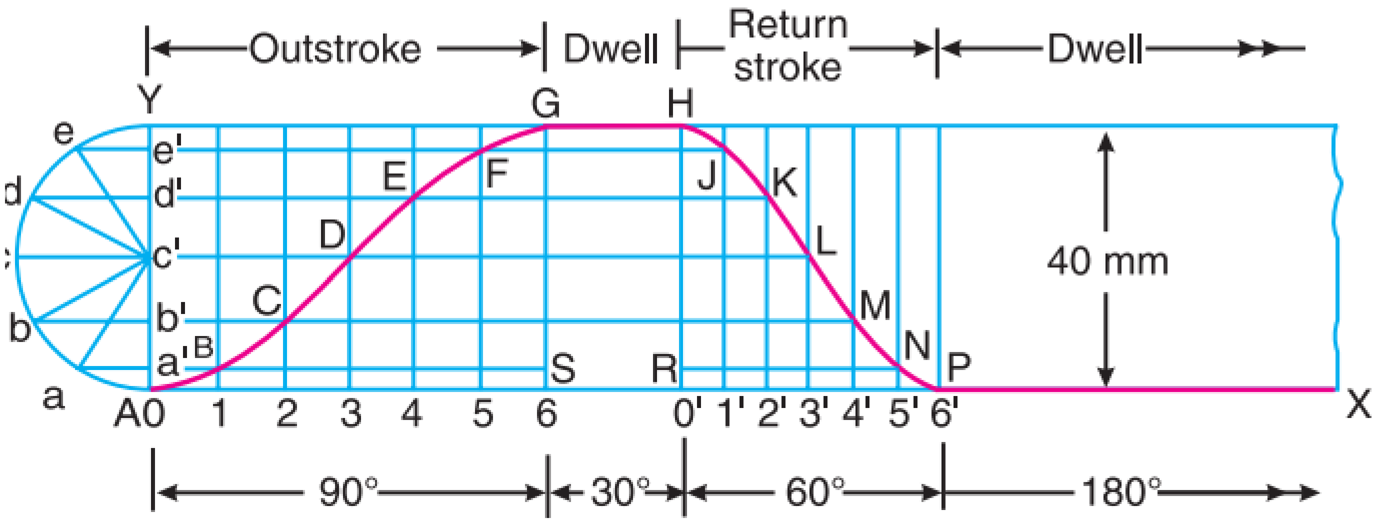



**Problem**

A cam is to be designed for a knife edge follower with the following data : 1. Cam lift = 40 mm during 90° of cam rotation with simple harmonic motion. 2. Dwell for the next 30°. 3. During the next 60° of cam rotation, the follower returns to its original position with simple harmonic motion. 4. Dwell during the remaining 180°. Draw the profile of the cam when (a) the line of stroke of the follower passes through the axis of the cam shaft, and (b) the line of stroke is offset 20 mm from the axis of the cam shaft. The radius of the base circle of the cam is 40 mm. Determine the maximum velocity and acceleration of the follower during its ascent and descent, if the cam rotates at 240 r.p.m.

***Given :***

S = 40 mm = 0.04 m; θO = 90° = π /2 rad = 1.571 rad ; θR = 60° = π /3 rad = 1.047 rad ; N = 240 r.p.m




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

1. Draw horizontal line AX = 360° to some suitable scale. On this line, mark AS = 90° to represent out stroke ; SR = 30° to represent dwell ; RP = 60° to represent return stroke and PX = 180° to represent dwell.

2. Draw vertical line AY = 40 mm to represent the cam lift or stroke of the follower and complete the rectangle as shown in Figure.

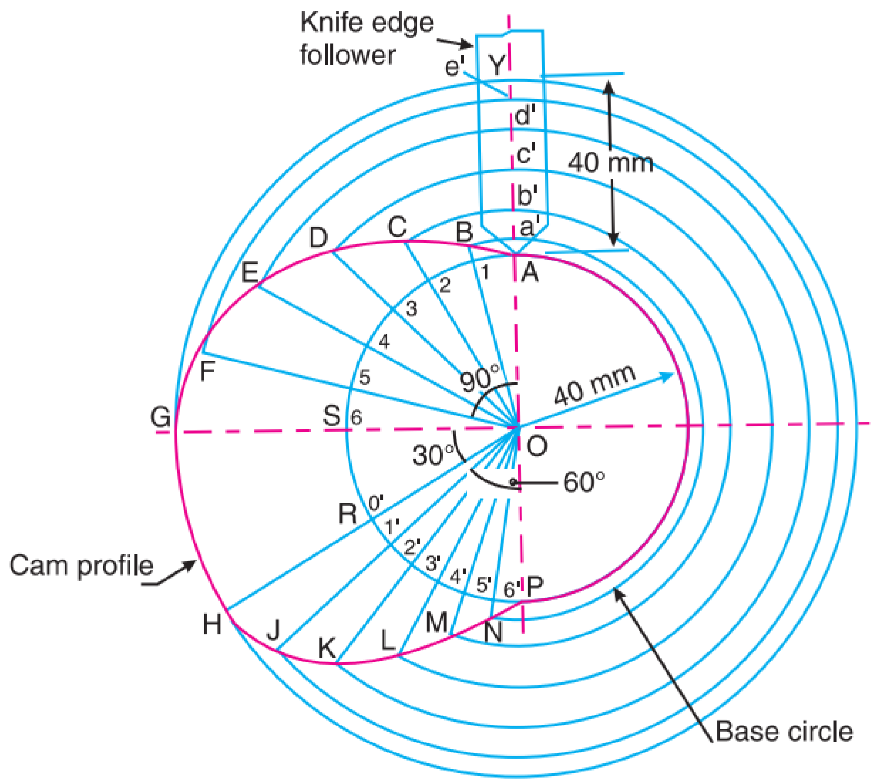
3. Divide the angular displacement during out stroke and return stroke into any equal number of even parts (say six) and draw vertical lines through each point.

4. Since the follower moves with simple harmonic motion, therefore draw a semicircle with AY as diameter and divide into six equal parts.

5. From points a, b, c ... etc. draw horizontal lines intersecting the vertical lines drawn through 1, 2, 3 ... etc. and 0′ ,1′ , 2′ ...etc. at B, C, D ... M, N, P. 6. Join the points A, B, C ... etc. with a smooth curve as shown in Figure.. This is the required displacement diagram.

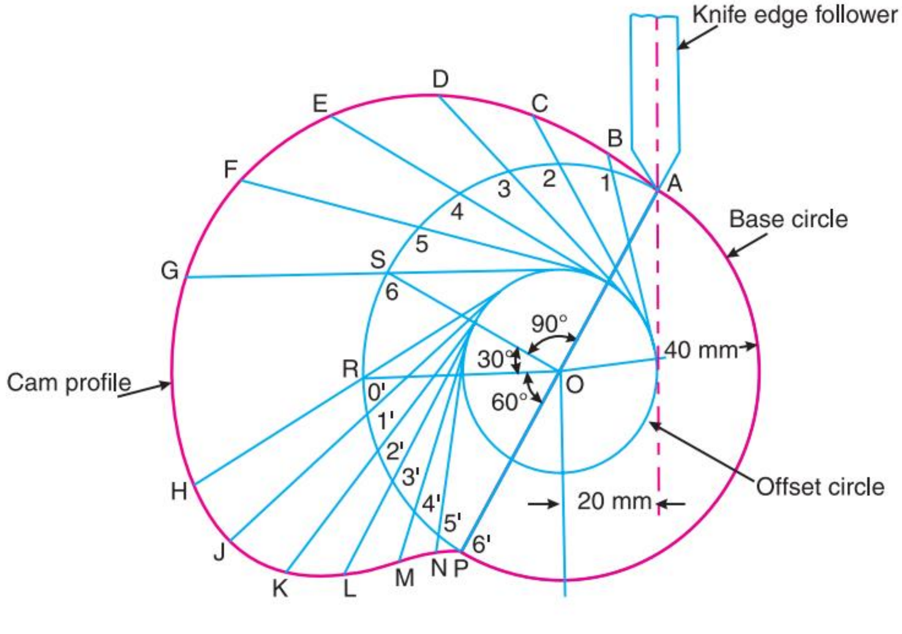
**(a)Profile of the cam when the line of stroke of the follower passes through the axis of the cam shaft**

The profile of the cam when the line of stroke of the follower passes through the axis of the cam shaft,




***(b)Profile of the cam when the line of stroke of the follower is offset 20 mm from the axis of the cam shaft***

The profile of the cam when the line of stroke of the follower is offset 20 mm from the axis of the cam shaft, as shown in Figure.




**Maximum velocity of the follower during its ascent and descent**

We know that angular velocity of the cam,

$$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 240}{60} = 25.14 \text{ rad/s}$$

We also know that the maximum velocity of the follower during its ascent,

$$v_O = \frac{\pi \omega . S}{2\theta_O} = \frac{\pi \times 25.14 \times 0.04}{2 \times 1.571} = 1 \text{ m/s}$$

and maximum velocity of the follower during its descent,

$$v_R = \frac{\pi \omega . S}{2\theta_R} = \frac{\pi \times 25.14 \times 0.04}{2 \times 1.047} = 1.51 \text{ m/s}$$

We know that the maximum acceleration of the follower during its ascent,

$$a_O = \frac{\pi^2 \omega^2 . S}{2(\theta_O)^2} = \frac{\pi^2 (25.14)^2 0.04}{2(1.571)^2} = 50.6 \text{ m/s}^2$$

and maximum acceleration of the follower during its descent

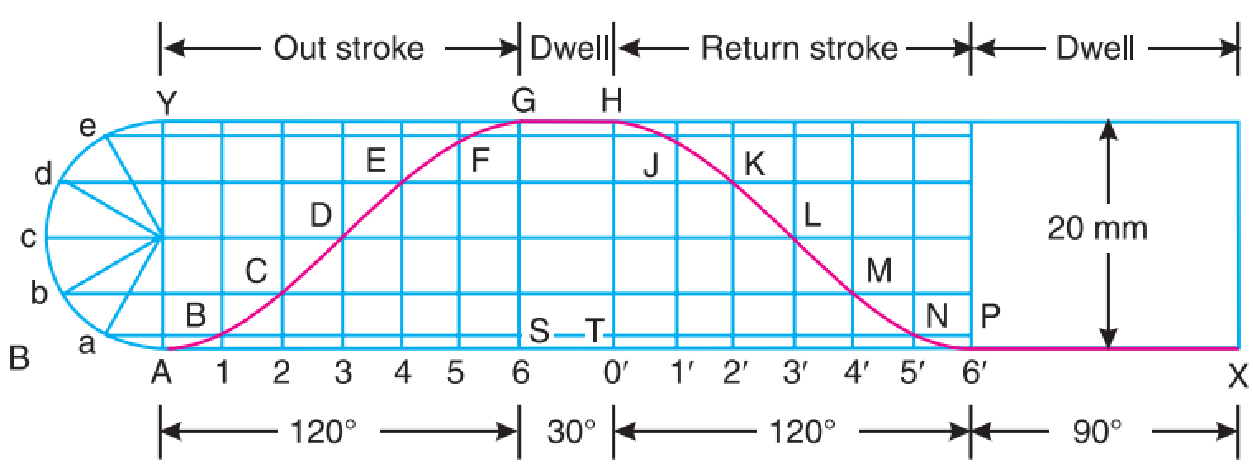
$$a_R = \frac{\pi^2 \omega^2 . S}{2(\theta_R)^2} = \frac{\pi^2 (25.14)^2 0.04}{2(1.047)^2} = 113.8 \text{ m/s}^2$$

**Problem**

A cam drives a flat reciprocating follower in the following manner : During first 120° rotation of the cam, follower moves outwards through a distance of 20 mm with simple harmonic motion. The follower dwells during next 30° of cam rotation. During next 120° of cam rotation, the follower moves inwards with simple harmonic motion. The follower dwells for the next 90° of cam rotation. The minimum radius of the cam is 25 mm. Draw the profile of the cam.

**Solution:**

Since the follower moves outwards and inwards with simple harmonic motion, therefore the displacement diagram, is shown in figure.

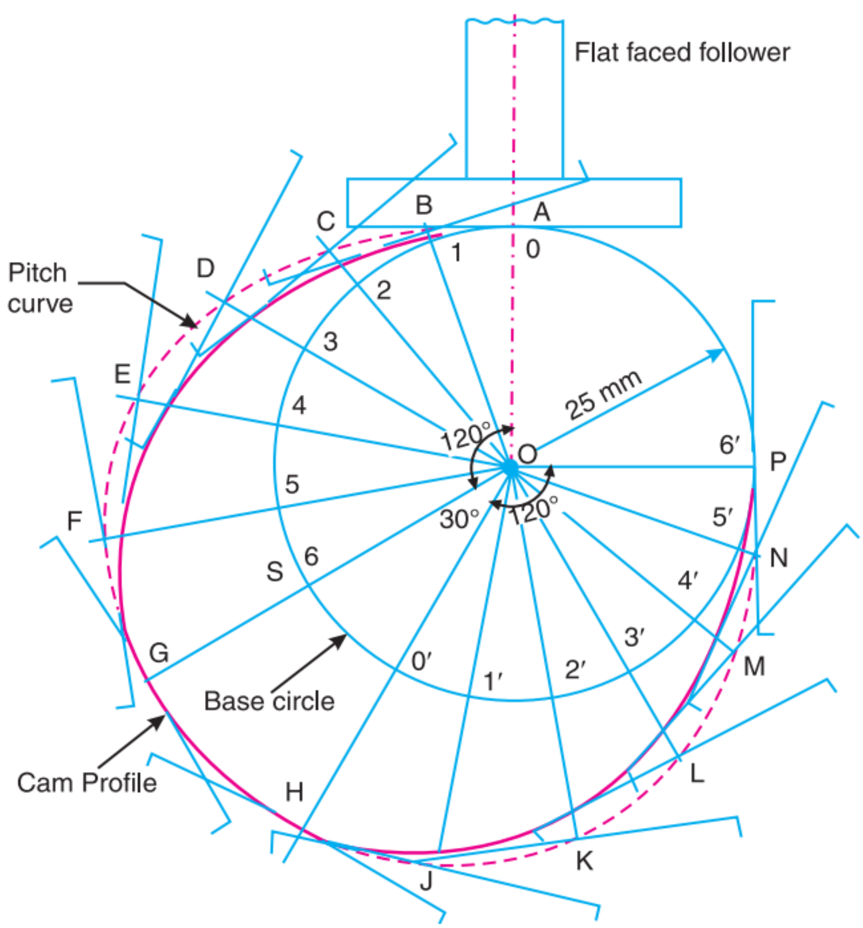


Now the profile of the cam driving a flat reciprocating follower, as shown in Fig. 20.20, is drawn as discussed in the following steps :

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 Figure.