Cam Design

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, <u>paper cutting machines, spinning and weaving textile machineries, feed mechanism of automatic lathes etc</u>

Classification of Followers

The followers may be classified as discussed below :

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 Fig1 (*a*). 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.

(*b*) ***Roller follower.*** When the contacting end of the follower is a roller, it is called a roller follower, as shown in Fig 1 (*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 1 (*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 1 (*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.

(*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 Fig1 (*d*). It may be noted that when a flat-faced follower is used in automobile engines, high surface stresses are produced. In order to minimize these stresses, the flat end of the follower is machined to a spherical shape.

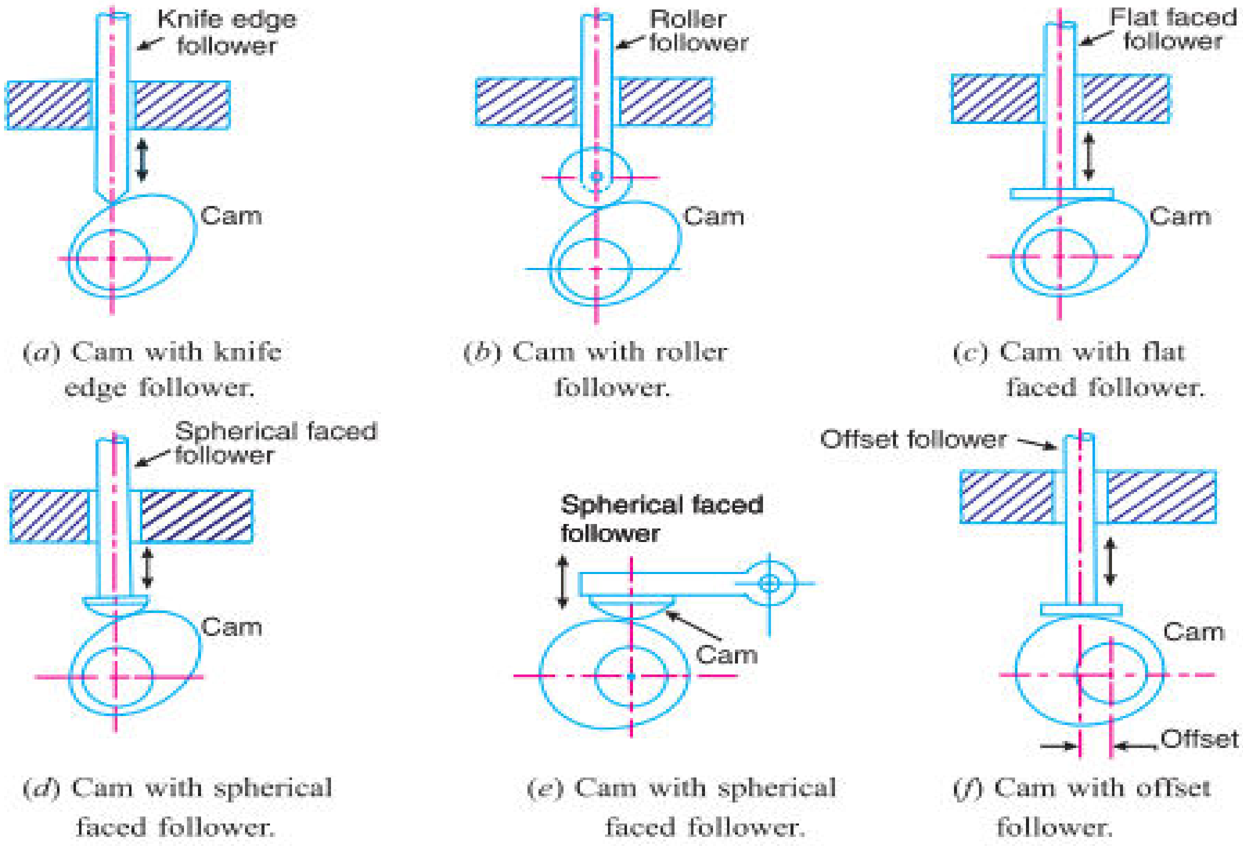


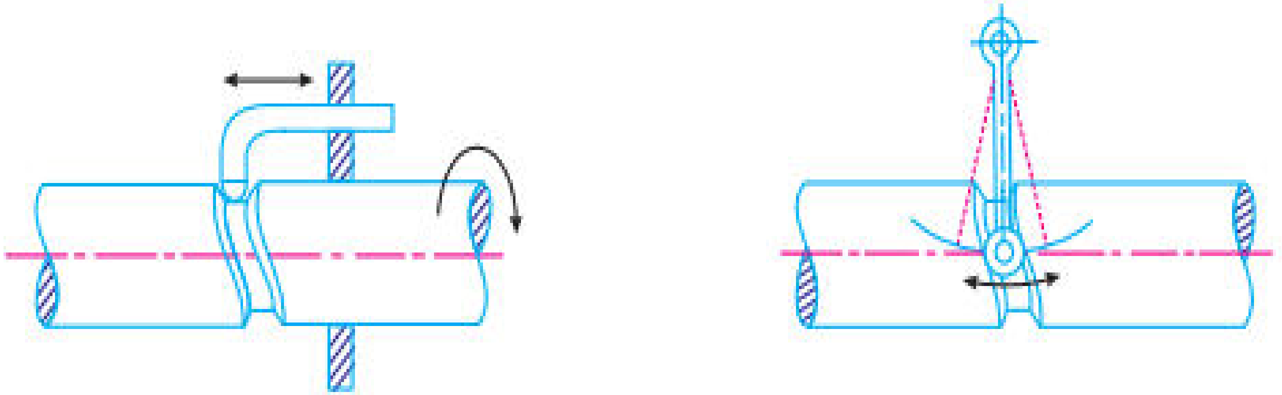
Figure (1) classification of followers

Classification of Cams

Though the cams may be classified in many ways, yet the following two types are important from 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 Fig 1 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 2 (*a*) and (*b*) respectively.



(*a*) Cylindrical cam with reciprocating follower. (*b*) Cylindrical cam with oscillating follower.

Figure (2) Cylindrical Cam

Note: <u>In actual practice, radial cams are widely used. Therefore our discussion will be only confined to radial cams.</u>

Terms Used in Radial Cams

Fig. 3 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 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.

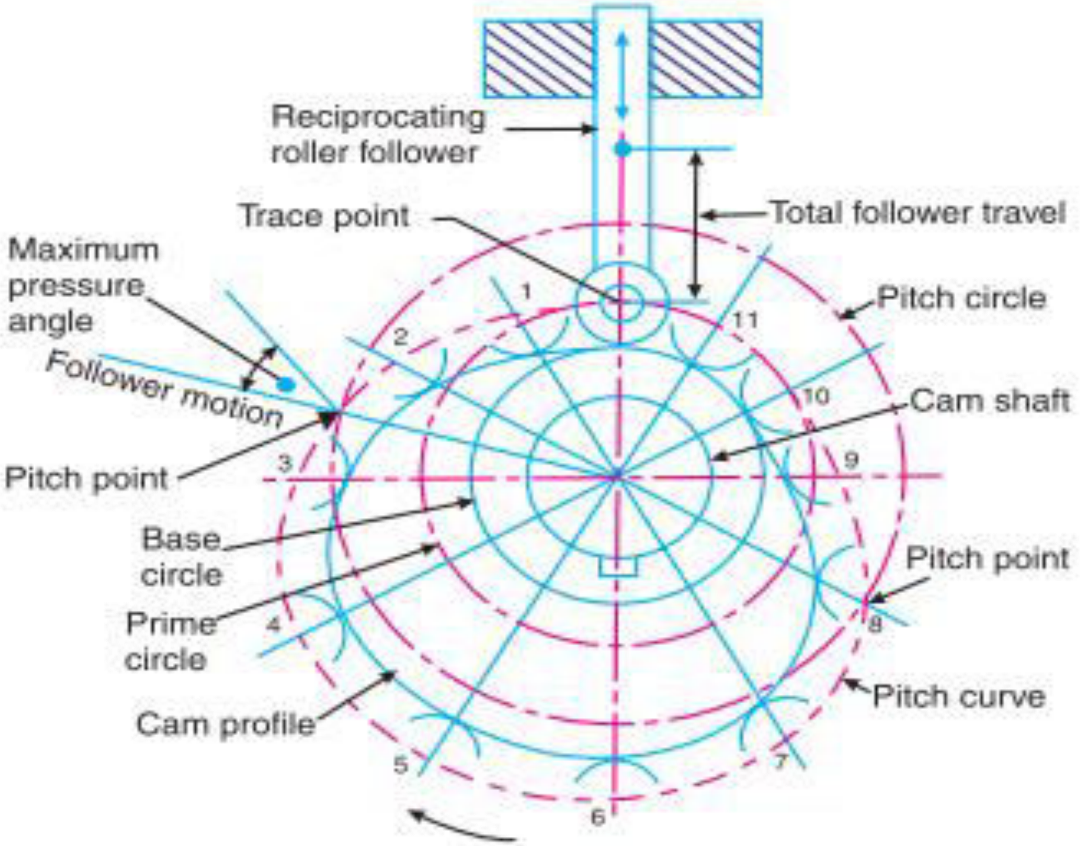


Figure (3) terms used in radial cams

Construction of Cam Profile for a Radial Cam

In order to draw the cam profile for a radial cam, first of all the displacement diagram for the given motion of the follower is drawn. Then by constructing the follower in its proper position at each angular position, the profile of the working surface of the cam is drawn.

In constructing the cam profile, the principle of kinematic inversion is used, *i.e.* the cam is imagined to be stationary and the follower is allowed to rotate in the ***opposite direction*** to the ***cam rotation.*** The construction of cam profiles for different types of follower with different types of motions is discussed in the following examples.

Example (1). 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.

Construction

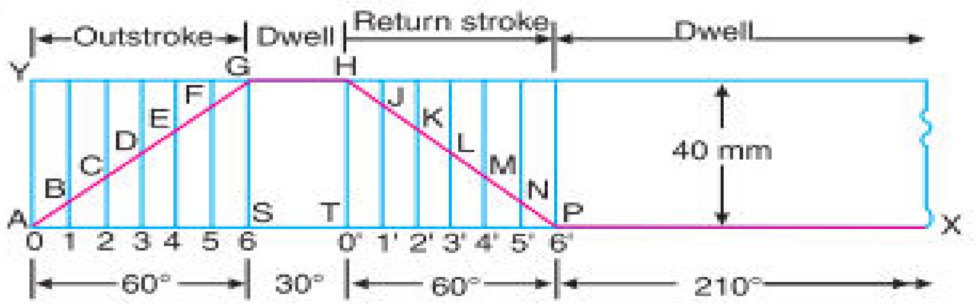


Figure (4) Displacement diagram

First of all, the displacement diagram, as shown in Fig. 4, 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.

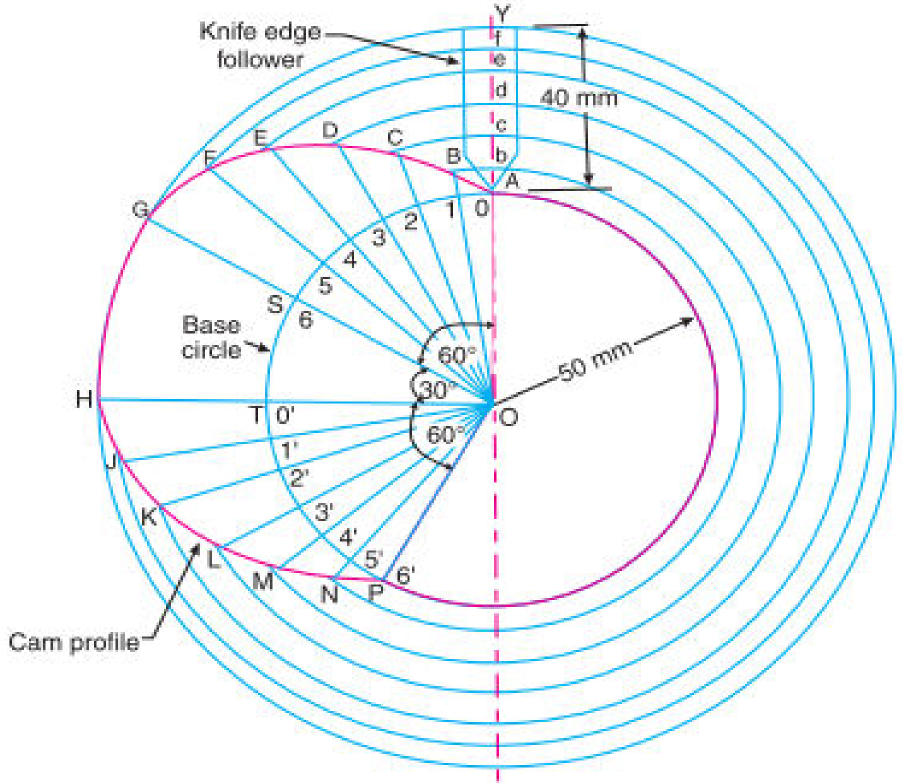
2. Draw vertical line *AY* equal to the stroke of the follower (*i.e.* 40 mm) and complete the rectangle as shown in Fig 4.

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.4

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



Figure(5)

1. Draw a base circle with radius equal to the minimum radius of the cam (i.e. 50 mm) with O as center.
2. Since the axis of the follower passes through the axis of the cam shaft, therefore mark trace point A, as shown in Fig. 5.
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. 5.
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.

Notes : The points B, C, D .... L, M, N may also be obtained as follows:

1. Mark AY = 40 mm on the axis of the follower, and set of Ab, Ac, Ad... etc. equal to the distances 1B, 2C, 3D... etc. as in displacement diagram.
2. From the centre of the cam O, draw arcs with radii Ob, Oc, Od etc. The arcs intersect the produced lines O1, O2... etc. at B, C, D ... L, M, N.

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

The profile of the cam when the axis of the follower is offset from the axis of the cam shaft, as shown in Fig. 6, is drawn as discussed in the following steps :

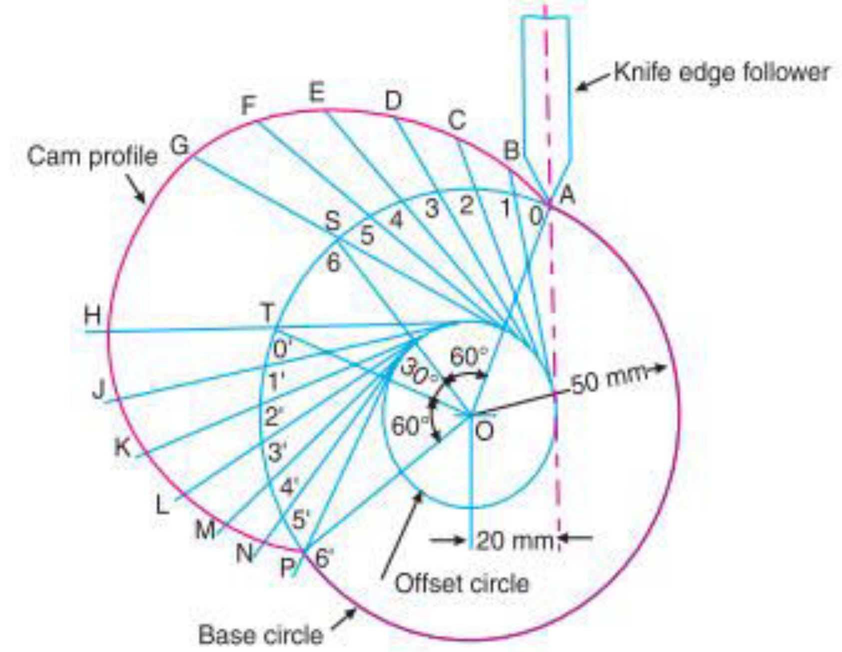


Figure (6)

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.6.
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.

Example 2: 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.

Solution. Given : S = 40 mm = 0.04 m; O θ = 90° = π /2 rad = 1.571 rad ; R θ = 60° = π /3 rad. = 1.047 rad.

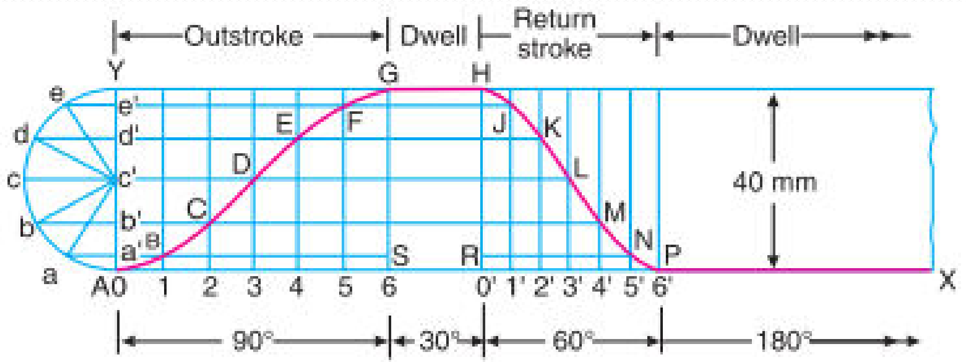


Figure (7) Displacement Diagram

First of all, the displacement diagram, as shown in Fig 20.13, 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 Fig. 7.
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 Fig. 20.13. 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, as shown in Fig. 8, is drawn in the similar way as is discussed in Example1

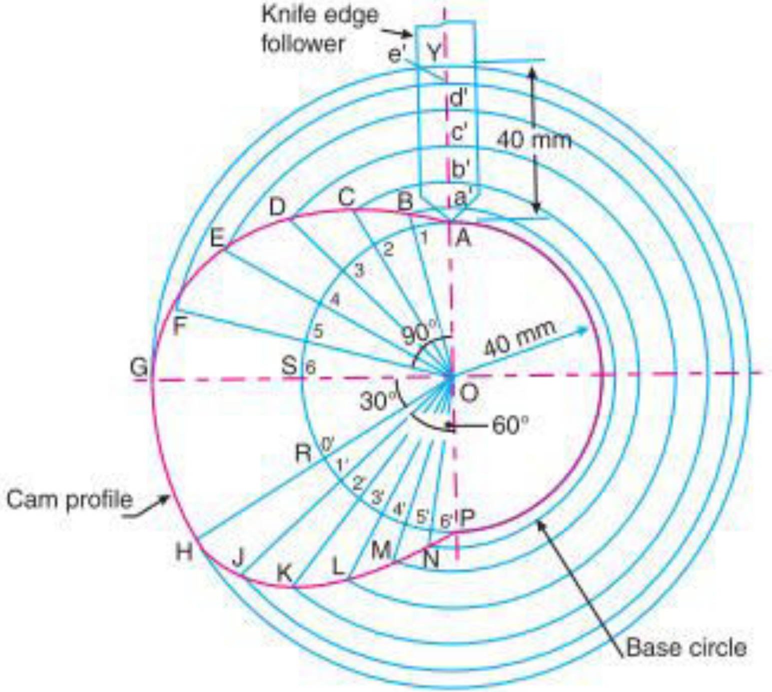


Figure (8)

(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 Fig. (9), is drawn in the similar way as discussed in Example 1.

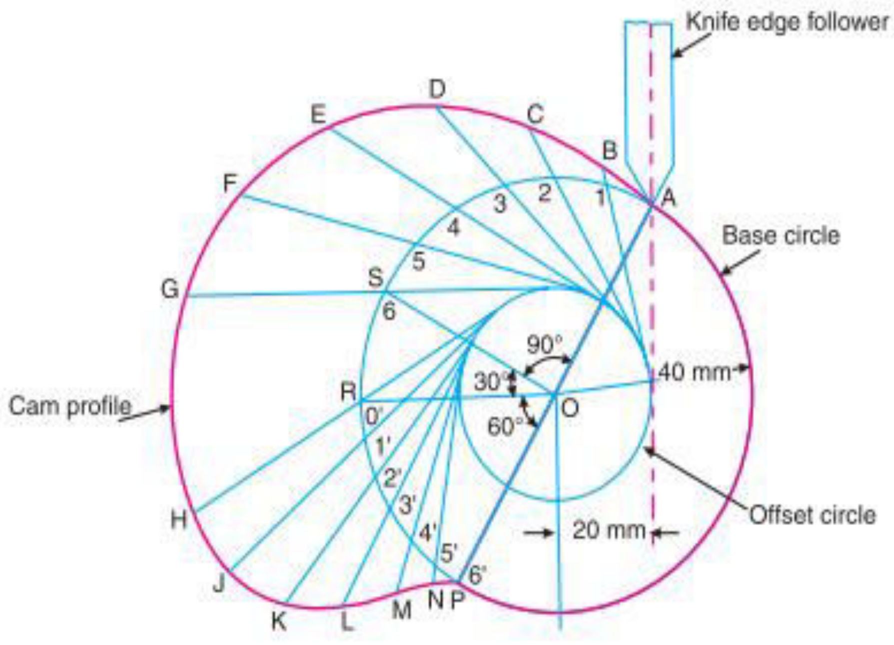


Figure (9)