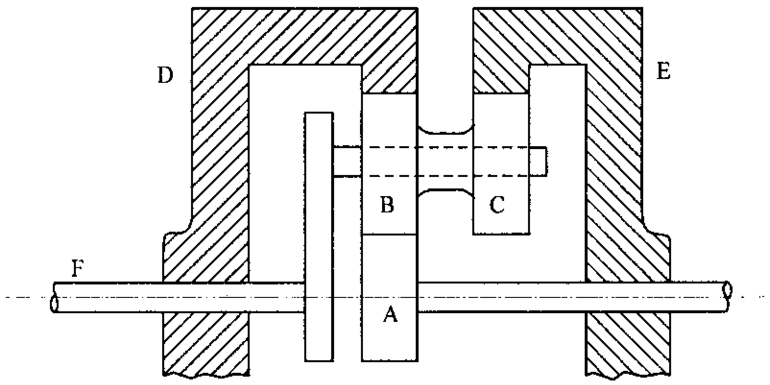


Fig. 7.48

9. (a) An epicyclic gear train is shown in fig. 7.10. The number of teeth on wheels 2,3,4 and 5 are 50, 20, 40 and 30 respectively. Gear 2 is kept stationary and arm A is rotated at 300 rpm clockwise. Find the speed and direction of gear 5.

   (b) If the gear 5 develops 5 kW, what is the torque required to hold arm stationary? Neglect frictional losses. **[Ans.** – 700 rpm, –90.45 N-m]

10. In an epicyclic gear train of sun and planet type, the pitch circle diameter of the annular wheel A is to be nearly equal to 220 mm and the module is 4 mm. When the annular wheel is stationary, the spider which carries three planet gears P and equal size has to make one revolution for every five revolution of the driving spindle carrying sun wheel S. Determine the number of teeth on all the wheels and also the exact pitch diameter of the wheel A.

    (VTU - July 2006) **[Ans.** $z_C = 56,\ z_P = 21, z_S = 21, z_S = 14, d_A = 224$ mm)

11. In the epicyclic gear train shown in fig. 7.19, wheels A, D and E are free to rotate on the axis P. The compound wheel BC rotate on the axis Q at the end of the arm R. All the gears have equal pitch. The number of external teeth on gears A, B and C are 12, 30 and 14 respectively. The gears D and E are annular gears. The gear A rotates at 60 rpm in the clockwise direction and the gear D rotates at 300 rpm counter clockwise. Determine the speed and direction of the arm R and the gear E. **(VTU - July 2003)**

    [Ans. –267.27 rpm, – 321.815 rpm]

12. A fixed annular gear A and a smaller concentric rotating gear B are connected by a compound wheel C-D. The gear C mesh with gear A and D with B. The compound gear revolves on a pin on the arm R which revolves about the axis of A and B. The number of teeth on gears A, B and D are 150, 40 and 100 respectively. Determine the number of teeth on gear C if the gears A and C being twice the module of gears B and D. How many revolutions will B make for one complete revolution of arm R ? **(VTU - July 2007)**

    [Ans. 80, 5.6875 revolutions]

8

CAMS

Introduction

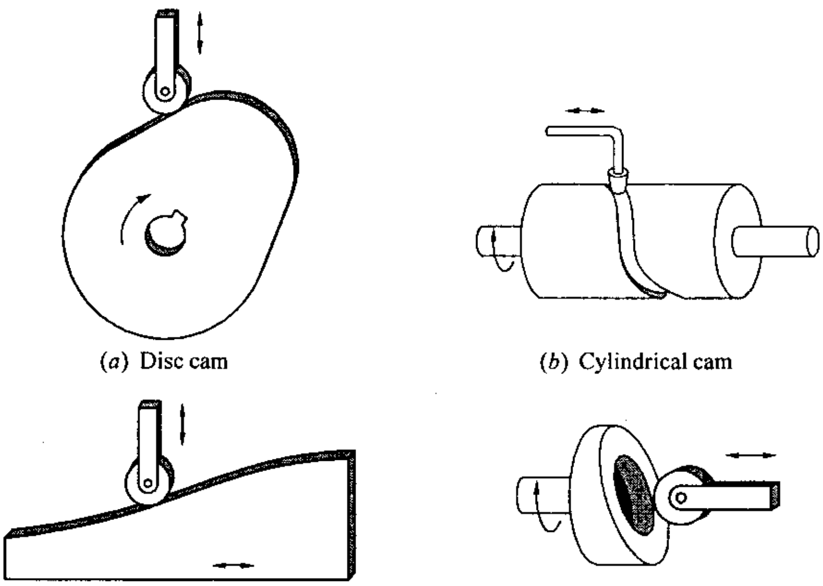
A *cam* is a mechanical member for transmitting a desired motion to a follower by direct contact. The simplest cam mechanism consist of a cam, a follower and a frame. The cam accepts an input motion similar to a crank and imparts a resultant motion to a follower.

The unique feature of a cam is that it can impart a very distinct motion to its follower. Cams can be used to obtain irregular motion that would be difficult to obtain from other linkages. Cams are used in automotive engines and automation equipments.

The disadvantages of cams are manufacturing cost, poor wear resistance and relatively poor high speed capability.

Types of cams

Cams are classified according to their basic shapes. The different types of cams are: disc cam, cylindrical cam, wedge cam, and face cam.



(*a*) Disc cam (*b*) Cylindrical cam

(*c*) Wedge cam (*d*) Face cam

Fig. 8.1

Disc or *radial cams* are the simplest and most common type of cam. It is formed on a disc or plate. The radial distance from the center of rotation of the disc is varied throughout the circumference of the cam. Allowing a follower to ride on this outer edge gives the follower a radial motion (fig. 8.1 *a*).

A *cylindrical* or *drum cam* is formed on a cylinder. A groove is cut into the cylinder, which varies along the axis of rotation. Attaching a follower that rides in the groove gives the follower motion along the axis of rotation (fig. 8.1 *b*).

A *wedge cam* is formed on a translated block. As the cam translates, the follower moves up and down, perpendicular to the plane or translation (fig. 8.1 *c*).

A *face* or *end cam* is a cylindrical cam in which the groove is cut on the face of the cylinder. As the cam rotates, the follower reciprocates as shown in fig. 8.1 *d*.

The discussion and explanation in this chapter is confined to disc cams only.

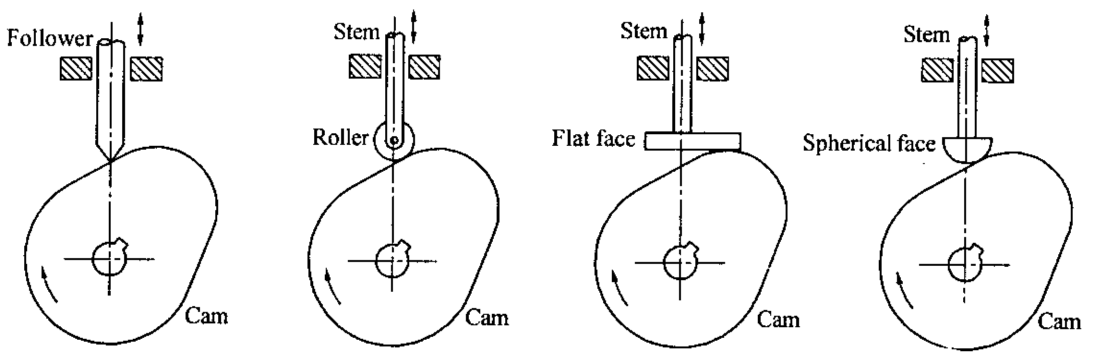
Types of followers

Followers are classified by their shape, position and motion.

Follower shape: The follower shape for a radial cam may vary considerably. It may consist of a point or knife-edge, roller, flat, rounded or curved surface.

A knife-edge follower consists of a follower that is formed to a point and drags on the edge of the cam. It is the simplest form, but the sharpe edge produces high contact stresses and wear rapidly (fig. 8.2 *a*).

A roller follower consists of a roller that is pinned to the follower stem as shown in fig. 8.2 *b*. As the cam rotates, the roller maintain contact with the cam and rolls on the cam surface. This is the most commonly used follower, as the friction and contact stresses are lower than those for the knife-edge follower. However a roller follower can possibly jam during steep cam displacements.



(*a*) Knife edge follower (*b*) Roller follower (*c*) Flat-face follower (*d*) Spherical-face follower

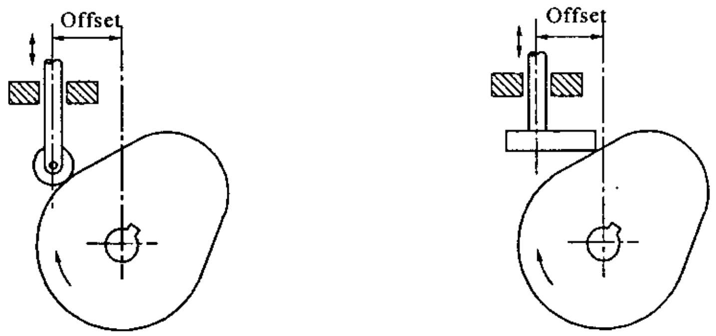
Fig. 8.2 Follower shapes

A flat faced follower is shown in fig. 8.2 *c*. It can be used with a steep cam motion. The friction forces in this type are greater than those of the roller follower.

A sperical - faced follower shown in fig. 8.2 *d* consists of a follower with a radius face that contact the cam. The spherical faced follower can be used with a steep cam motion without jamming.

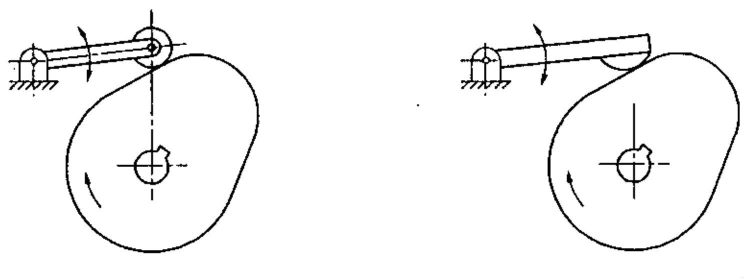
Follower position: The position of translating followers can be classified into two groups.

1. *In-line follower:* In in-line follower, the line of translation extends through the center of rotation of the cam (refer fig. 8.2).
2. *Off-set follower:* In off-set follower, the line of the motion is off-set from the center of rotation of the cam (refer fig. 8.3)



(*a*) Offset roller follower (*b*) Offset flat faced follower

Fig. 8.3 Offset follower



(*a*) Oscillating roller follower (*b*) Oscillating sperical faced follower

Fig. 8.4 Oscillating follower

Follower motion: The path of the follower can be classified into two groups.

1. *Translating follower:* The path of the translating follower is along a straight line (fig. 8.2).
2. *Oscillating arm or pivoted follower:* The motion of the oscillating arm follower is along a curved path such as an arc (fig. 8.4).

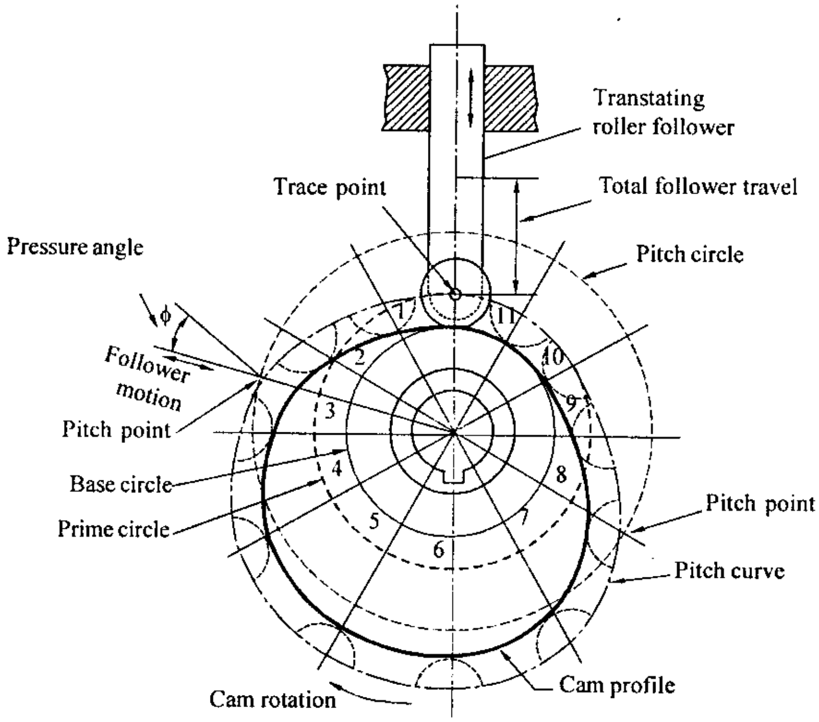


Fig. 8.5

Definitions: *(Refer fig. 8.5)*

Cam profile is the actual working surface contour of the cam.

Base *circle* is the smallest circle drawn to the cam profile from the cam center.

The *trace point* is the point on the follower located at the knife edge in knife edge follower or roller center in roller follower.

The *pitch curve* is the path of the trace point. For a knife edge follower the pitch curve and the cam surfaces are identical.

Prime circle is the smallest circle drawn to the pitch curve from the cam center.

The *pressure angle* is the angle between the normal to the pitch curve and the instantaneous direction of the follower motion.

Pitch point is the piont on the pitch curve having the maximum pressure angle.

The *pitch circle* is one with its center at the cam axis passing thorough the pitch point.

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

Dwell is the period during which the follower is at rest.

Displacement diagram : It is a rectangular co-ordinate layout of the follower motion in one cycle of cam operation. The rise of the follower is shown as the ordinate with the length of the abscissa arbitrarily chosen. The abscissa is divided into equal cam angles or equal time divisions since the cam usually rotates at a constant speed.

Motion 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
4. Cycloidal motion.

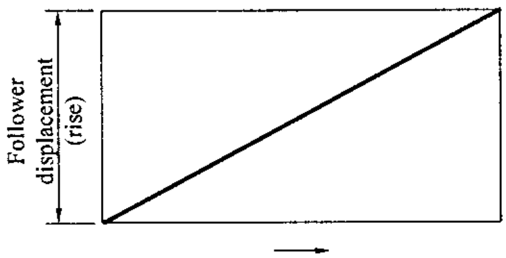


Fig. 8.6

Uniform velocity : This curve of polynomial family ($n = 1$) is the simplest of all. It has a straight line displacement curve at a constant slope as shown in fig. 8.6. We see that the displacement is uniform, the velocity is constant, and the acceleration is zero during the rise. But at the ends where the dwell meets this curve, we have theoretically infinite acceleration. This acceleration transmits a high shock through the follower linkage. In order to have the acceleration within finite limits, it is necessary to modify the conditions which govern the motion of the follower. This may be done by rounding off sharp corners of the displacement diagram.

Simple harmonic motion : As a point moves around the circumference of a circle with a constant velocity, its projection on the diameter of the circle moves with SHM. The resulting motion of the follower on such cam is simple harmonic movement similar to that of a swinging pendulum. The displacement diagram is constructed as follows:

1. Draw the ordinate and abscissa axes, and divide the angular displacement of the cam during rise into number of equal parts-usually six. Draw vertical lines from the divisions on the angular displacement axis.
2. Lay off the total rise S on the ordinate. This is the diameter of the harmonic circle.
3. Draw a semi-circle over the rise and divide the circle into the same number of equal arcs as chosen in step 1.
4. Draw horizontal lines from the division points on the semi circle to the corresponding division lines on the angular displacement axis.

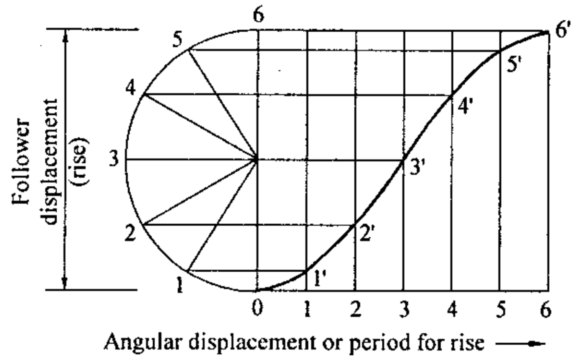


Fig. 8.7

5. Draw a smooth curve through the points of intersection of horizontal lines and the vertical lines.
6. A harmonic return or fall is constructed as a mirror image to fig. 8.7.

Uniform acceleration and retardation : This curve of the polynomial family has the property of constant positive and negative accelerations. The curve's abrupt change of acceleration at the dwell ends and the transition piont produces noise and vibration. Thus, this curve should be used only at low speeds. One of the reasons for the popularity of this curve is the ease of the determining the inertia forces, which are proportional to the constant accelerations. The displacement diagram is constucted as follows:

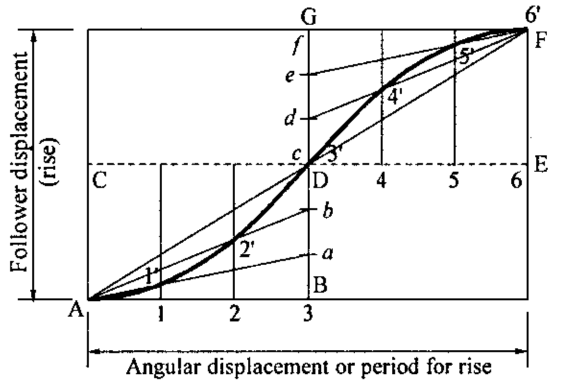


Fig. 8.8

1. Draw the ordinate and abscissa axes with the total rise of the follower as ordinate and the angular displacement of the cam during rise as abscissa.
2. For equal uniform acceleration and retardation, divide the follower rise and the angular displacement for rise into two halves i.e., the first half quadrant ABCD for acceleration and the second half quadrant DEFG for retardation.
3. Divide both the horizontal (AB) and vertical axes (BD) of the quadrant ABCD into 3 equal parts and draw vertical lines from the horizontal divisions.

4. From the corner A, draw straight lines to the vertical divisions i.e., Join A-*a*, A-*b* and A-*c*.
5. Draw a smooth curve through the points of intersection of the vertical lines and the lines drawn from corner A. The curve AD represent acceleration.
6. Repeat the steps 3 through 5 for the remaining half of the curve in the quadrant DEFG. The curve DF represent retardation.

An equal uniform acceleration and retardation during return is constructed as a mirror image to fig. 8.8

Cycloidal or sine acceleration curve : This curve as the name implies, is basically generated from a cycloid. A *cycloid* is the locus of a point on a circle which is rolled on a straight line without slipping. The rise *S* is equal to the circumference of the rolling circle. For high speeds, the cycloidal curve is the best of all contours if the accuracy of machining can be maintained at the beginning and at the end of the stroke where other curves exhibit their difficulties. It has the lowest vibration, wear, stress, noise and shock. The displacement diagram is constructed as follows:

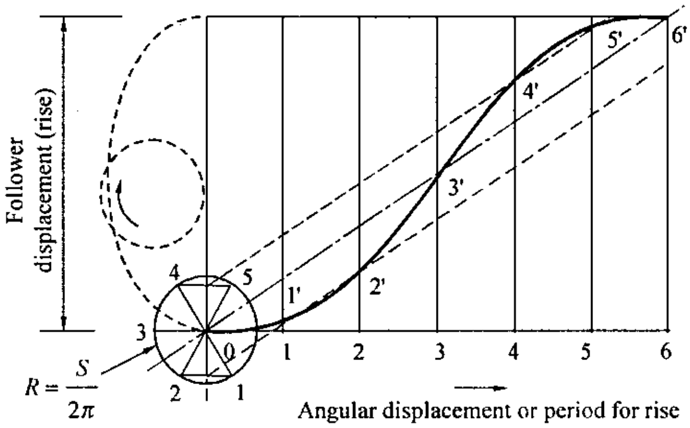


Fig. 8.9

1. Draw the ordinate and the abscissa axes with the total rise *S* equal to the circumference of the rolling circle in the ordinate.
2. Divide the angular displacement of the cam during outstroke into 6 equal parts.
3. Draw the diagonal OA.
4. Draw a circle with O as center and radius equal to $S/(2\pi)$ which is divided into same number of equal parts chosen in step 2.
5. Project these points horizontally on the vertical center line of the rolling circle.
6. From the points thus obtained, draw lines parallel to OA, giving the intersection to the respective cam angle divisions. Draw a smooth curve through the intersection points.

A cycloidal return or fall is constructed as a mirror image of fig. 8.9.

Characteristic of the curves

The characteristic curves of displacement, velocity, and acceleration on a time base are helpful in studying the suitability of a cam, especially if it is to be used at high speeds. The characteristic curves for various motions during outward stoke are described below.

Uniform velocity: *(Refer fig. 8.10)* For uniform velocity, the displacement curve is a straight line of constant slope. The acceleration and retardation of the follower at the begining and at the end of each stroke would require to be infinitely high. Because of the infinite acceleration, uniform velocity is not suitable for high speed applications.

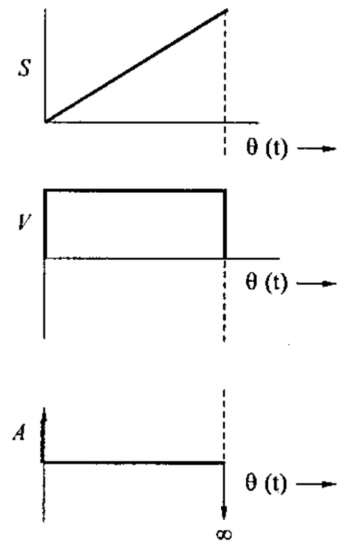


Fig. 8.10

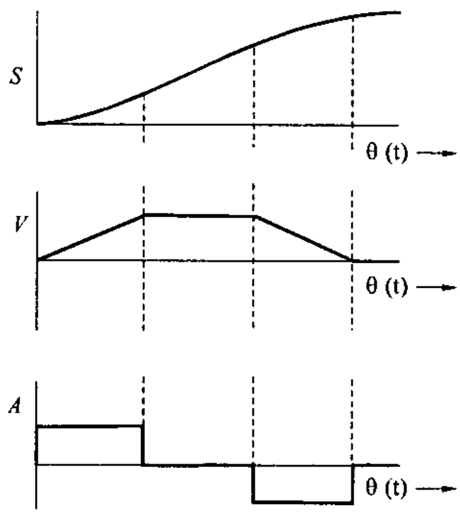


Fig. 8.11

Modified uniform velocity : *(Refer fig. 8.11)* The acceleration can be reduced to finite value by rounding off the sharp corners on the displacement diagram. The rounded corners are parabolic arcs. The velocity of the follower increases gradually to its maximum value at the begining of the stroke and decreases gradually to zero at the end of the stroke. Although the acceleration have been reduced to finite values, as compared with uniform velocity motion, there still remain severe discontinuities which limit the usefulness of this motion.

Uniform acceleration : Since the displacement of the follower has to take place in definite time, the acceleration of the follower will be minimum compared to any other motion. The first half of the displacement takes place with uniform acceleration and the second half of the displacement takes place with an equal uniform retardation as shown in fig. 8.12. The velocity varies directly with time. The abrupt changes in the acceleration curve cause infinite jerk, which makes the motion undesirable for high speed applications.

Let S = Stroke (rise) of the follower in m

θ = Angular displacement of the cam in radians

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

Maximum velocity of the follower $V\text{ (m/s)} = \frac{2\omega S}{\theta}$

Maximum acceleration of the follower $A\text{ (m/s}^2) = \frac{4\omega^2 S}{\theta^2}$

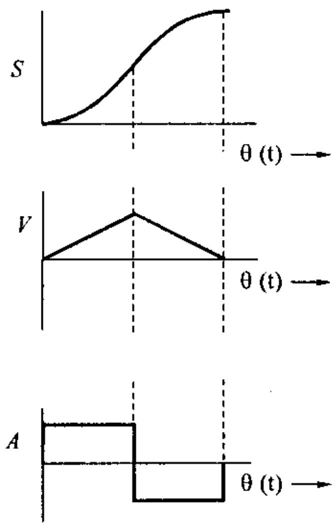


Fig. 8.12

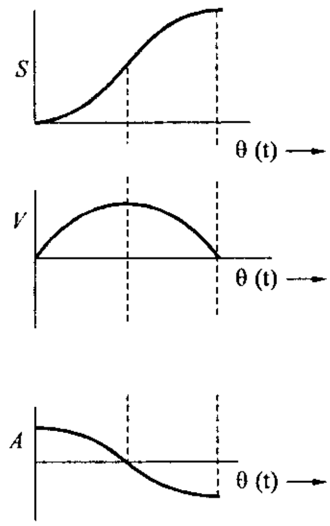


Fig. 8.13

Simple harmonic motion : The displacement curve for simple harmonic motion is shown in fig. 8.13. The velocity curve is a sine curve and the acceleration curve is a cosine curve. The acceleration is smooth, only if the rise and fall periods are both 180°. If these periods are unequal or are adjacent to dwell periods, then discontinuities occur in the acceleration curve and result in infinite jerk.

Maximum velocity of the follower $V = \frac{\pi \omega S}{2\theta}$

Maximum acceleration of the follower $A = \frac{\pi^2 \omega^2 S}{2\theta^2}$

Cycloidal motion: For cycloidal motion the displacement, velocity, and acceleration curves are smooth as shown in fig. 8.14. The cycloidal motion provides zero acceleration at both ends of action. Therefore it can be coupled to a dwell at each end. Thus cycloidal motion is best suited for high speed cams.

Maximum velocity of the follower $V = \frac{2\omega S}{\theta}$

Maximum acceleration of the follower $A = \frac{2\pi\omega^2 S}{\theta^2}$

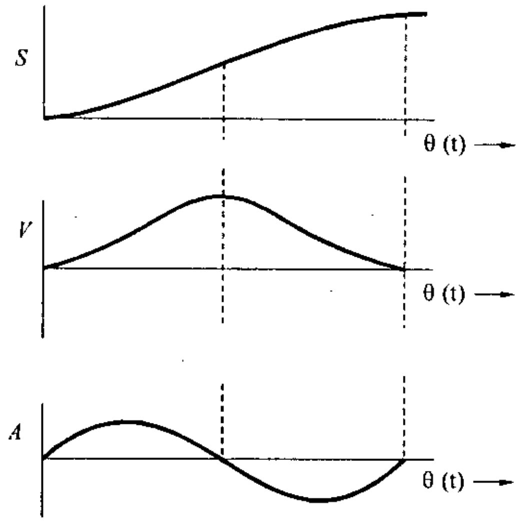


Fig. 8.14

Example 8.1

A cam with 25 mm as a minimum radius is rotating clockwise at a uniform speed of 100 rpm, and has to give the motion to the knife-edge follower as defined below:

1. Follower to move outwards through 25 mm during 120° of cam rotation.
2. Follower to dwell for the next 60° of cam rotation.
3. Follower to return to its starting position during next 90° of cam rotation.
4. Follower to dwell for the rest of the cam rotation.

The displacement of the follower takes place with uniform and equal acceleration and retardation on both the outward and return strokes. Draw the cam profiles when, (a) follower axis passes through the axis of the cam, and (b) follower axis is offet to righ by 10 mm from the axis of the cam. Determine the maximum velocity and acceleration during outstroke and return stroke.

Solution :

(a) In line follower : The following construction steps are necessary to develop the cam profile.

1. Draw the displacement diagram for the given data as shown in fig. 8.15a.
2. Draw the base circle with centre O and radius equal to 25 mm.
3. Draw the knife edge follower in its 0° position as shown in fig. 8.15b. Join OA.

4. Mark off angle AOB = 120°, angle BOC = 60°, angle COD = 90° and angle DOA = 90° in a direction opposite that of the cam's rotation to represent outward stroke, dwell, return and dwell respectively.

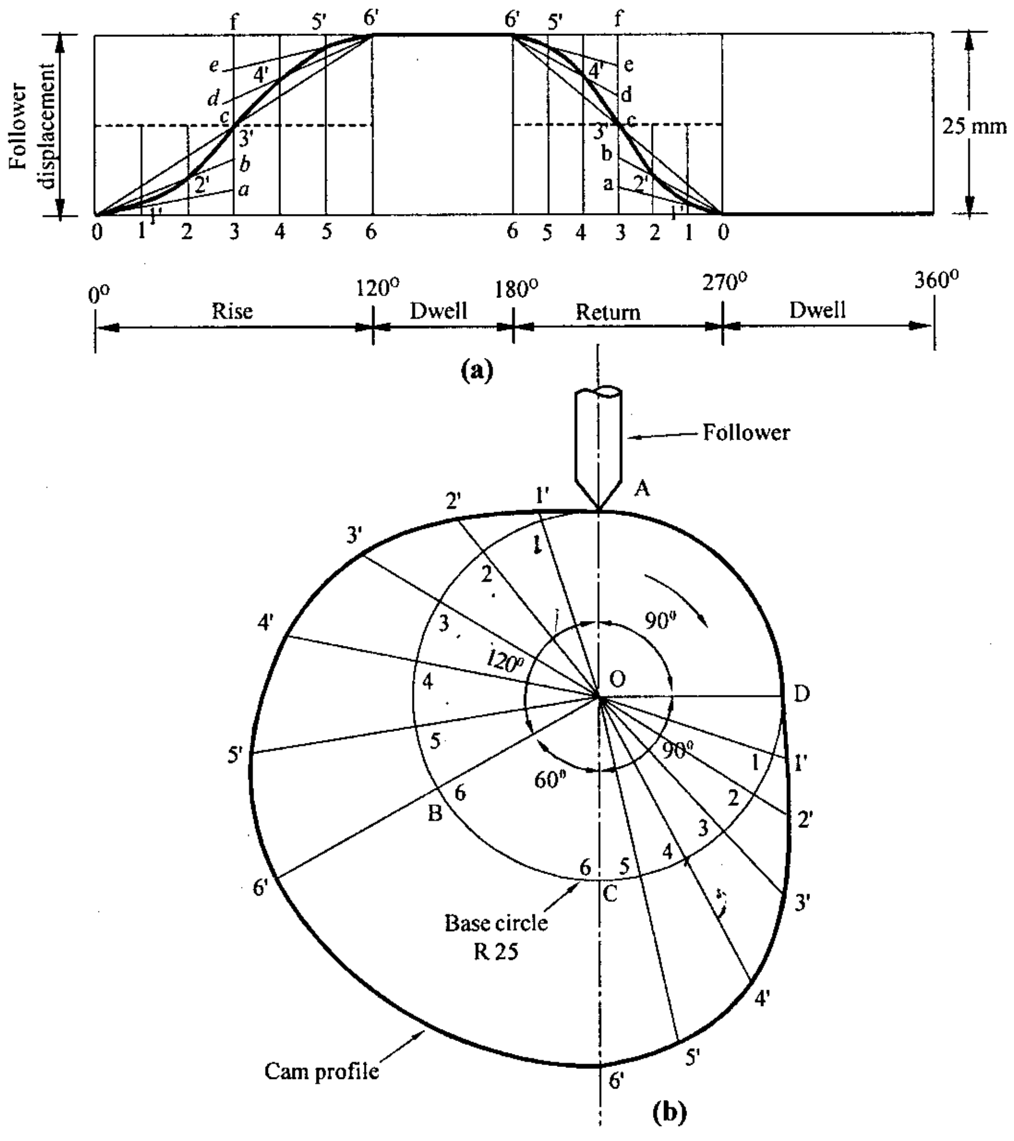


Fig. 8.15

5. Divide the arc AB (ascent) and arc CD (descent), each into 6 equal parts (same number of equal parts as in the displacement diagram) and number them 1,2,3, etc.
6. Draw radial line passing through each of these points.

7. Transfer displacement 11', 22', etc., from the displacement diagram on to the appropriate radial lines, measuring from the base circle to get 1', 2', etc.
8. Draw a smooth curve through 1', 2', etc ., to get the required cam profile.
9. With O as center and O6' as radius draw the arc 6'6' to represent the dwell in the lifted position.
10. Darken the arc AD of the base circle to represent the dwell in the lowest position. The curve A-6'-6'-D-A represent the required cam profile.

(b) Offset follower : The same displacement diagram is used as before, but this time the follower is offset to the right as shown in fig. 8.15c.

Construction :

1. Draw the offset circle with center O and radius equal to 10 mm (offset distance). Draw vertical tangent to the offset circle.
2. Draw the base circle with centre O and radius equal to 25 mm. This circle will cut the vertical tangent at A.
3. Draw the knife edge follower in its 0° position at A and join OA.

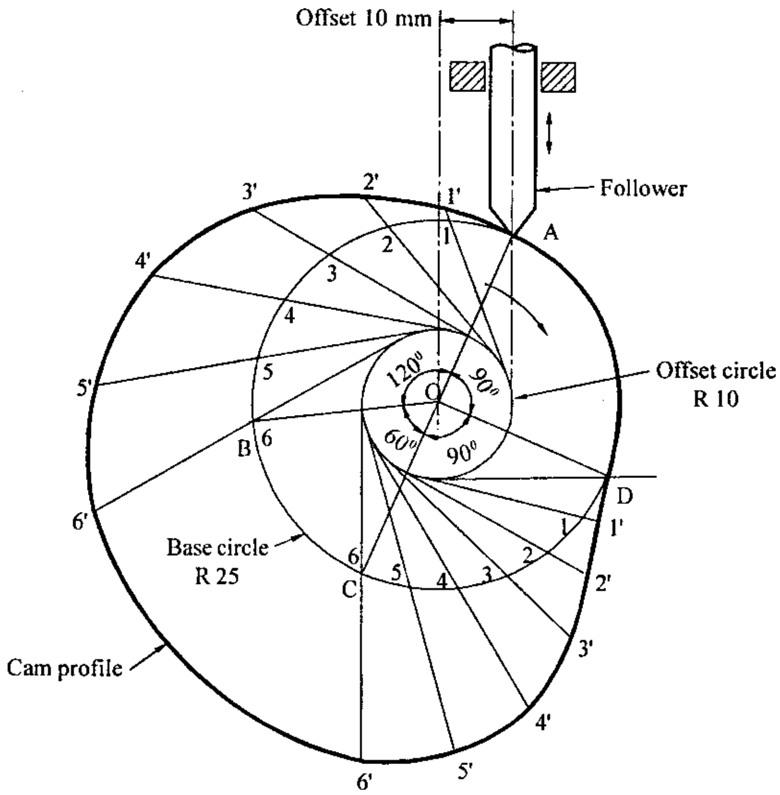


Fig. 8.15 (c)

4. Mark off angle AOB = 120°, angle BOC = 60°, angle COD = 90° and angle DOA = 90° in the counterclockwise direction to represent ascent, dwell, descent and dwell respectively.
5. Divide the arc AB and CD each into 6 equal parts and through each of the points thus obtained draw tangents to the offset circle.
6. Transfer displacement 11', 22', etc., from the displacement diagram to the appropriate tangents measuring form the base circle to get points 1', 2', etc.
7. Draw a smooth curve through 1', 2', etc.
8. With O as center and O6' as radius draw the arc 6'6' to represent the dwell in the lifted position.
9. Darken the arc AD of the base circle to represent the dwell in the lowest position. The curve A-6'-6'-D-A represent the required cam profile.

Angular velocity $\omega = \dfrac{2\pi n}{60} = \dfrac{2\pi \times 1000}{60} = 104.72$ rad/s

Maximum velocity of follower during rise

$$V = \frac{2\,\omega S}{\theta} = \frac{2 \times 104.72 \times 0.025 \times 180}{120 \times \pi} = 2.5 \text{ m/s}$$

Maximum velocity of follower during return

$$V = \frac{2 \times 104.72 \times 0.025 \times 180}{90 \times \pi} = 3.33 \text{ m/s}$$

Maximum acceleration during rise

$$A = \frac{4\omega^2 S}{\theta^2} = 4 \times 104.\,72^2 \times 0.025 \times \left(\frac{180}{120 \times \pi}\right)^2 = 250 \text{ m/s}^2$$

Maximum acceleration during return

$$A = 4 \times 104.72^2 \times 0.025 \times \left(\frac{180}{90 \times \pi}\right)^2 = 444.44 \text{ m/s}^2$$

Example 8.2

A cam rotating clockwise at uniform speed of 300 rpm operates a reciprocating follower through a roller 10 mm diameter. The follower motion is defined below.

1. Follower to move outwards during 120° of the cam rotation with equal uniform acceleration and deceleration.
2. Follower to dwell in the lifted position for next 30° of cam rotation.
3. Follower to return to its starting position during 120° of cam rotation with SHM.
4. Follower to dwell for the rest of the cam rotation.

The stroke of the follower is 30 mm. The minimum radius of the cam is 20 mm. Draw the profile of the cam when (a) line of stroke of the follower passes through the center of the cam shaft, and

(b) line of the stroke of the follower is offset 10 mm from the axis of the cam shaft. Find the maximum velocity and acceleration of the follower during its outward stroke and inward stroke.

Solution :

(a) In-Line follower : The following steps are necessary to develope the cam profile.

1. Draw the displacement diagram for the given data as shown in fig. 8.16 a.
2. Draw the base circle with center O and radius equal to 20 mm (fig. 8.16 b)

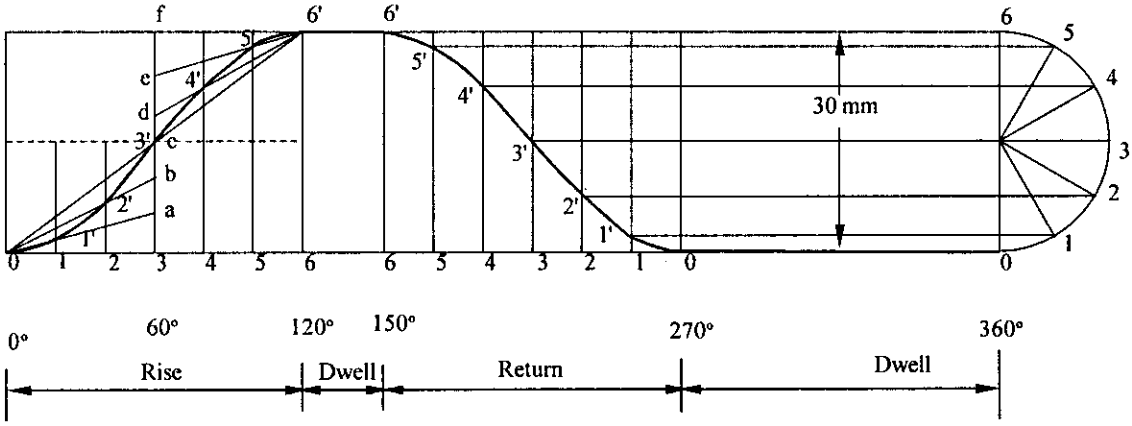


Fig. 8.16 (a)

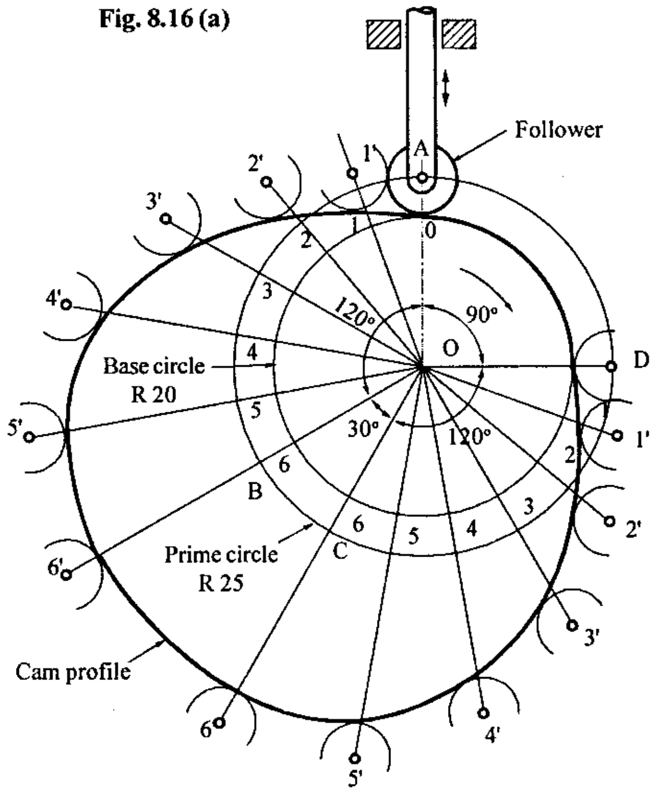


Fig. 8.16 (b)

3. Draw the prime circle with center O and radiius OA = base circle radius + radius of the roller = 20 + 5 = 25 mm.
4. Draw the roller follower in its lowest (0°) position. Join the center of the cam O and the center of the roller A.
5. Mark off angle AOB = 120°, BOC = 30°, angle COD = 120° and angle DOA = 90° in a direction opposite that of the cam's rotation to represent rise, dwell, return and dwell respectively.
6. Divide the angular displacement during outward stroke (angle AOB) and return stroke (angle COD) each into 6 equal parts and number them as shown.
7. Draw radial lines passing through each of these points on the prime circle.
8. Transfer displacements 11', 22', etc., from the displacement diagram to the appropriate radial lines, measuring from the prime circle to get points 1', 2', etc.
9. Points 1', 2', etc., as centers, draw circles (follower outlines) equal to the radius of the roller.
10. Draw a smooth curve tangent to these follower outlines.
11. With O as center draw an arc, tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
12. With O as center draw an arc, tangent to the follower outlines at A and D to represent the dwell in the lowest position.

(b) Offset follower : The same displacement diagram is used as before, but this time the follower is offset to the right as shown in fig. 8.16c.

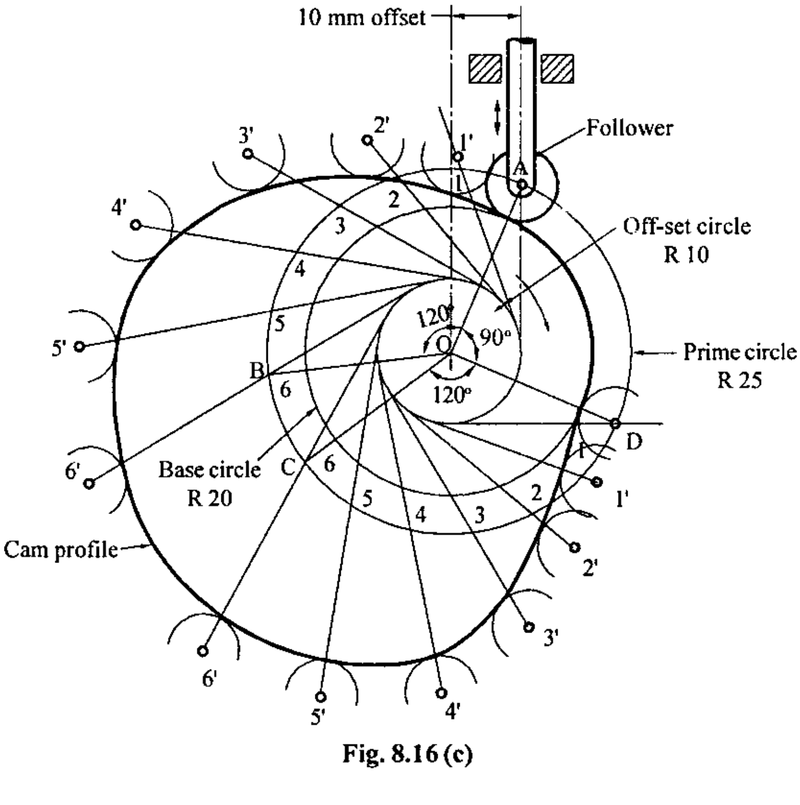


Fig. 8.16 (c)

Construction :

1. Draw the offset circle with center O and radius equal to 10 mm. Draw a vertical tangent to the offset circle.
2. Draw the base circle with centre O and radius equal to 20 mm.
3. Draw the prime circle with centre O and radius equal to 25 mm. The prime circle cuts the vertical tangent at point A. Join OA.
4. With A as center draw the follower in its 0° position.
5. Mark off angles as before starting from OA.
6. Divide the arcs AB and CD as before and through each of the points thus obtained draw tangents to the offset circle.
7. Transfer displacements 11', 22', etc., from the displacement diagram to the appropriate tangents, measuing from the prime circle to get points 1',2', etc.
8. From points 1', 2', etc., draw the follower outlines.
9. Draw a smooth curve tangent to these follower outlines.
10. With O as center draw an arc tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
11. With O as center draw an arc tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Angular velocity $\omega = \dfrac{2\pi n}{60} = \dfrac{2\pi \times 300}{60} = 31.42 \text{ rad/s}$

Maximum velocity during outward stroke,

$$V = \frac{2\omega S}{\theta} = \frac{2 \times 31.42 \times 0.03 \times 180}{120 \times \pi} = 0.9 \text{ m/s}$$

Maximum velocity during return stroke,

$$V = \frac{\pi\omega S}{2\theta} = \frac{\pi \times 31.42 \times 0.03 \times 180}{2 \times 120 \times \pi} = 0.7 \text{ m/s}$$

Maximum acceleration during outward stroke

$$A = \frac{4\omega^2 S}{\theta^2} = 4 \times 31.42^2 \times 0.03 \times \left(\frac{180}{120 \times \pi}\right)^2 = 27 \text{ m/s}^2$$

Maximum acceleration during return stroke

$$A = \frac{\pi^2\omega^2 S}{2\theta^2} = \frac{\pi^2 \times 31.42^2 \times 0.03}{2} \times \left(\frac{180}{120 \times \pi}\right)^2 = 33.3 \text{ m/s}^2$$

Example 8.3

From the following data, draw the profile of a cam in which the follower moves with SHM during ascent while it moves with UADM during descent. Least radius of cam = 50 mm, Angle of ascent = 48°, Angle of descent = 60°, Angle of dwell between ascent and descent = 42°, Lift of follower = 40 mm, Diameter of roller = 20 mm, Distance between line of action of the follower and axis of cam = 20 mm. **(VTU, July 2006)**

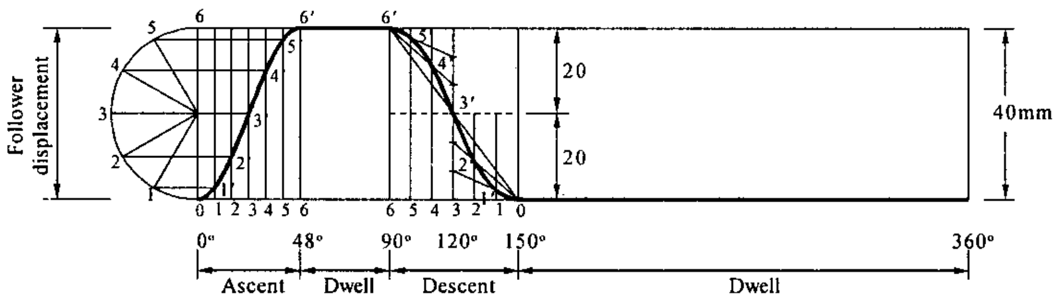


Fig. 8.17 (a)

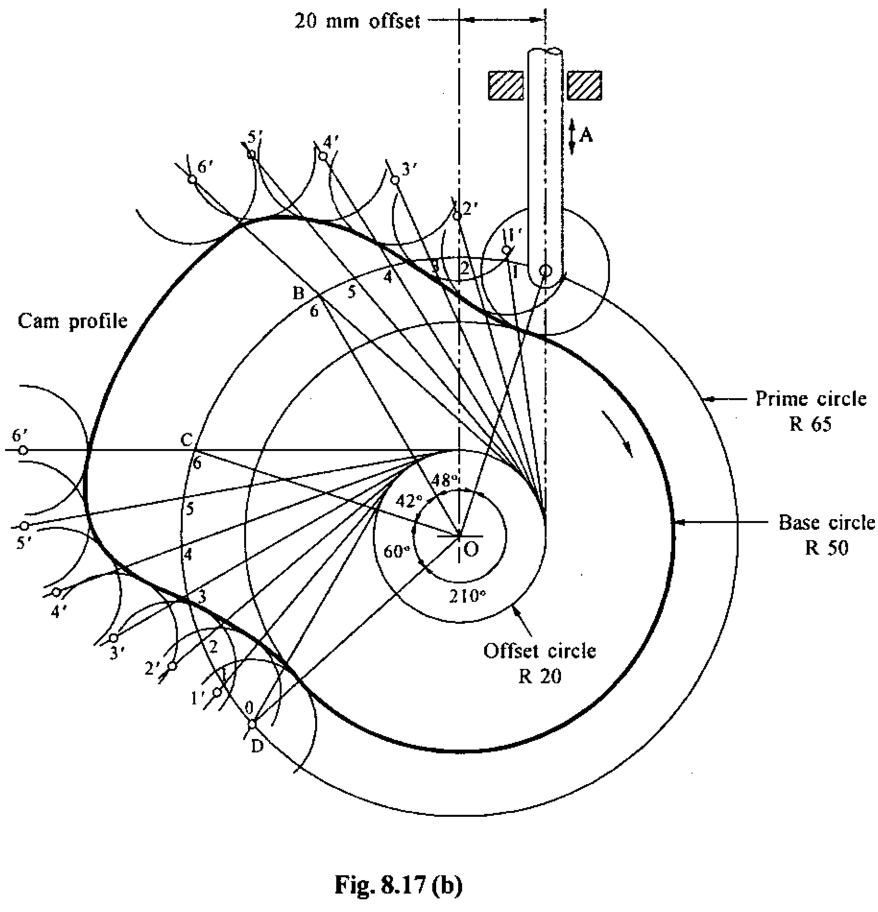


Fig. 8.17 (b)

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.17 (a).
2. Draw the base circle with O as center and radius equal to 50 mm.
3. Draw the prime circle with O as center and radius equal to the sum of the base circle radius and roller radius, i.e., 50 + 15 = 65 mm.
4. Draw the offset circle with O as center and radius equal to 20 mm. Draw a vertical tangent to the off-set circle. The vertical tangent cuts the prime circle at A. Join OA.
5. With A as center draw the roller follower in its 0° position.
6. Mark off the angle AOB = 48°, angle BOC = 42°, angle COD = 60° and angle DOA = 180° to represent ascent, dwell, descent and dwell respectively.
7. Divide the arc AB (angle of ascent) and arc CD (angle of descent) on the prime circle each into 6 equal parts and number them as 1, 2, 3, ... etc. Through each of the points thus obtained, draw tangents to the offset circle.
8. Transfer the displacements 11', 22', ... etc., from the displacement diagram to the appropriate tangents, measuring from the prime circle to get points 1', 2', ... etc.
9. With points 1', 2', ... etc as centers draw follower outlines.
10. Draw a smooth curve tangent to these follower outlines.
11. With O as center draw an arc, tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
12. With O as center draw an arc, tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Example 8.4

A roller follower is offset to the left by 12 mm. The base circle radius of the cam is 30 mm. The desired displacement of the follower Y for any cam rotation θ is listed in the table given below. Layout the can profile if the radius of roller follower is 10 mm. The cam rotates in clockwise direction.

Cam rotation q °	0	30	60	90	120	150	180	210	240	270	300	330
Displacement Y(mm)	0	2.5	9.2	18.7	28.3	35	37.5	35	28.3	18.7	9.2	2.5

Solution : **(VTU, Aug. 2001)**

Offset towards left = 12 mm

Base circle radius = 30 mm

Radius of roller = 10 mm

∴ Prime circle radius = 30 + 10 = 40 mm

Construction: *(Refer fig. 8.18)*

1. Draw the offset circle with center O and radius equal to 12 mm. Draw a vertical tangent to the left of the offset circle.
2. Draw the base circle with center O and radius equal to 30 mm
3. Draw the prime circle with center O and radius equal to 40 mm. The prime circle cuts the vertical tangent at point A. Join OA.
4. With A as center draw the roller follower in its 0° position.
5. Divide the prime circle into 12 equal angular intervals corresponding to the incremental angle given in the angle of rotation of cam - follower displacement table. Through each of points thus obtained, draw tangents to the offset circle.
6. Transfer the displacements from the given displacement table to the appropriate tangents measuring from the prime circle to get points 1', 2', ... etc.
7. From points 1', 2', ... etc., draw the roller follower outlines.
8. Draw a smooth cam profile, tangent to these follower outlines.

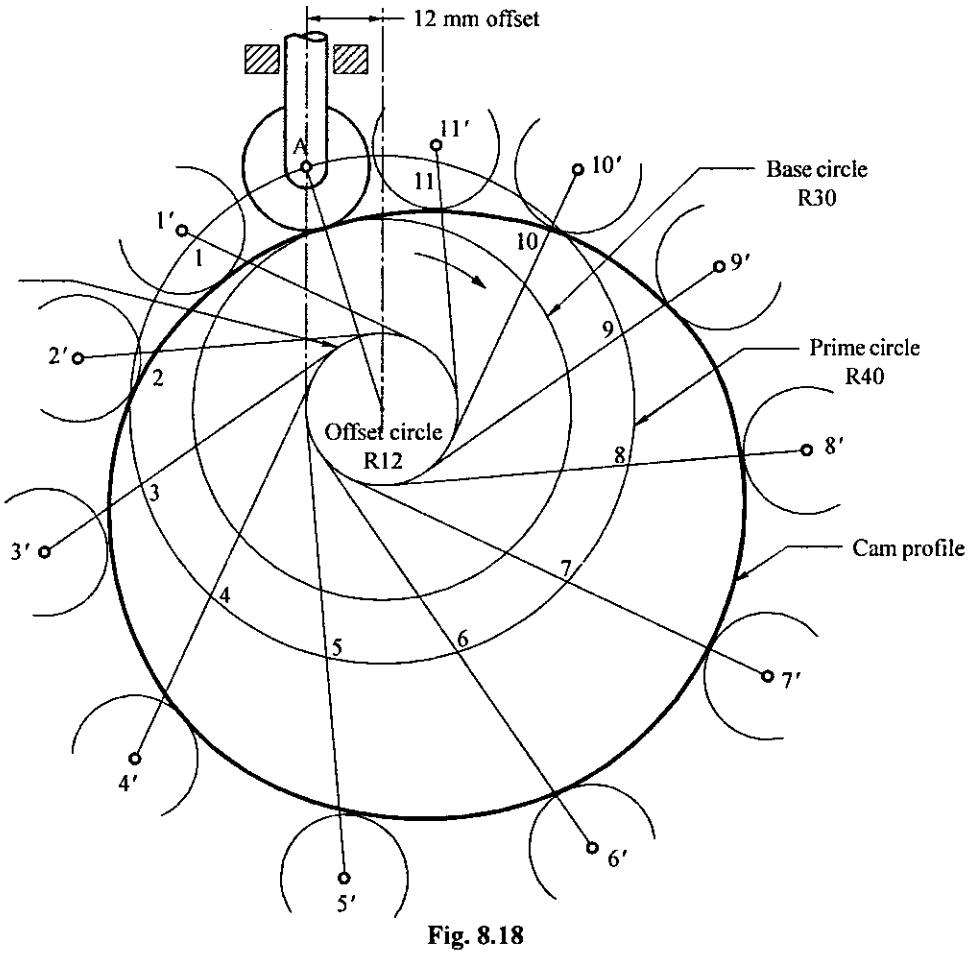


Fig. 8.18

Example 8.5

Draw full size cam profile with roller of 25 mm diameter attached to the follower to give lift of 35 mm. Axis of the follower is offset to the right of cam axis by 18 mm. Ascent of the follower takes place with SHM in 0.05 second. followed by a period of rest 0.0125 second. The follower then descends with UARM during 0.125 second. and the remaining period rest at the minimum lifted position. The acceleration being 3/5 times retardation. The cam rotates in clockwise direction at a constant speed 240 rpm and the base circle radius is 50 mm. **(VTU, Jan. 2005)**

Solution :

Roller diameter = 25 mm

Lift S = 35 mm

Offset towards right = 18 mm

Speed of the cam = 240 rpm = $\frac{240}{60}$ = 4 rps = 4 × 360 degrees/s

Ascend time = 0.05 s with SHM

Angular displacement of the cam during ascend = 0.05 × 4 × 360 = 72°

Rest period = 0.0125 s

Angular displacement of the cam during rest period = 0.0125 × 4 × 360 = 18°

Descend time = 0.125 s with uniform acceleration and retardation

Angular displacement of the cam during descend = 0.125 × 4 × 360 = 180°

Acceleration = $\frac{3}{5}$ × retardation

or Acceleration period = $\frac{5}{3}$ × retardation period

∴ Angular displacement of the cam during acceleration period = $\frac{5}{8}$ × 180 = 112.5°

Angular displacement of the cam during deceleration period = $\frac{3}{8}$ × 180 = 67.5°

Height lowered by the follower during acceleration = $\frac{5}{8}$ × 35 = 21.875 mm

Height lowered by the follower during retardation = $\frac{3}{8}$ × 35 = 13.125 mm

Base circle radius = 50 mm

Prime circle radius = 50 + 12.5 = 62.5 mm

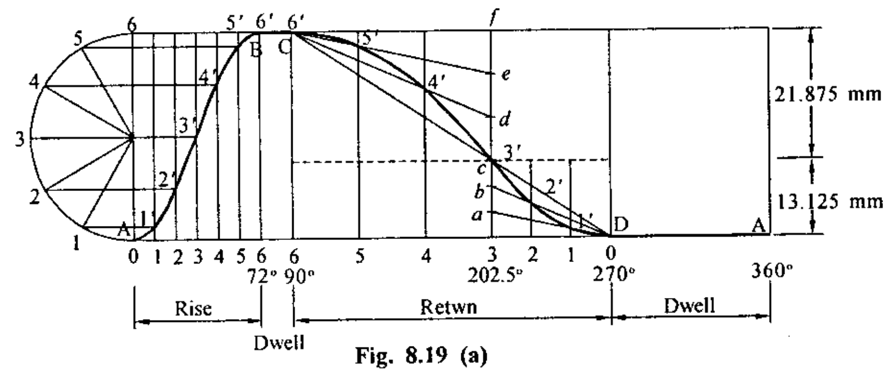


Fig. 8.19 (a)

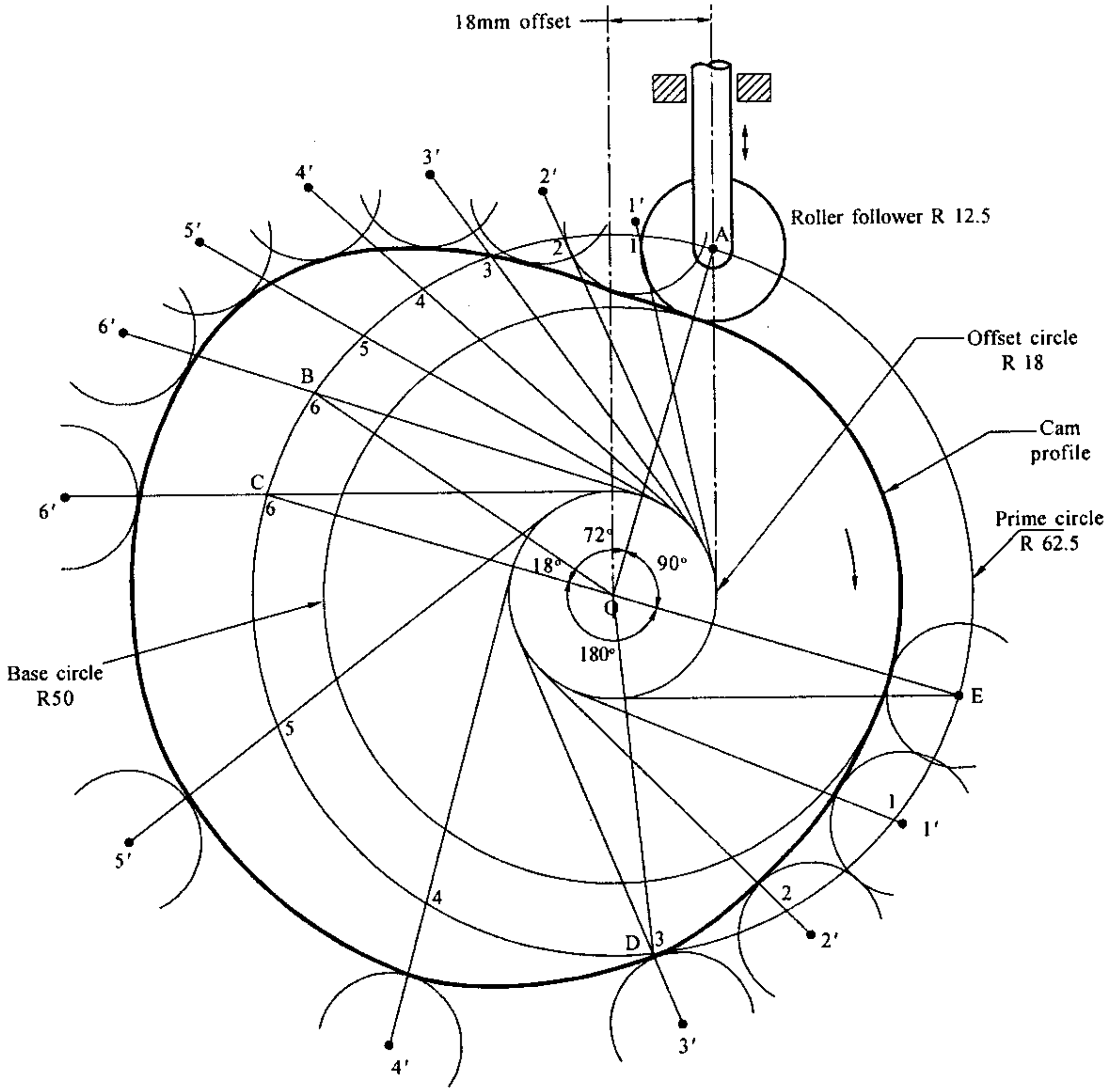


Fig. 8.19 (b)

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.19a.
2. Draw the offset circle with center O and radius equal to 18 mm. Draw a vertical tangent to the right of the offset circle (fig. 8.19b).
3. Draw the base circle with center O and radius equal to 50 mm.
4. Draw the prime circle with center O and radius equal to 62.5 mm. The prime circle cuts the vertical tangent at point A. Join OA.
5. With A as center draw the roller follower in its 0° position.
6. Mark off angle AOB = 72°, angle BOC = 18°, angle COD = 112.5°, angle DOE = 67.5° and angle DOA = 90° in a direction opposite that of cam's rotation to represent rise, dwell, return with acceleration, return with retardation and dwell respectively.
7. Divide the arc AB (rise) into 6 equal parts, arc CD (acceleration) into 3 equal parts and arc DE (retardation) into 3 equal parts and number them as shown. Through each of points thus obtained draw tangents to the offset circle.
8. Transfer displacements 11', 22', ... etc, from the displacement diagram to the appropriate tangents measuring from the prime circle to get points 1', 2', ... etc.
9. Points 1',2', ... etc., as centers, draw the roller follower outlines.
10. Draw a smooth curve, tangent to these follower outlines.
11. With O as center draw an arc tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
12. With O as center draw an arc tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Example 8.6

A cam of base circle radius 50 mm is to operate a roller follower of 20 mm diameter. The follower is to have SHM. The speed of the cam is 360 rpm clockwise. Draw the cam profile for the cam lift of 40 mm. Angle of ascent = 60°, angle of dwell = 40° and angle of descent = 90°, followed by dwell again. Also calculate the maximum velocity and acceleration during ascent and descent. **(VTU, July 2005)**

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.20 (a).
2. Draw the base circle with O as center and radius equal to 50 mm.
3. Draw the prime circle with O as center and radius equal to the sum of the base circle radius and roller radius i.e., 50 + 10 = 60 mm
4. Draw the roller follower in its lowest (0°) position. Mark the center of the roller as A. Join OA.

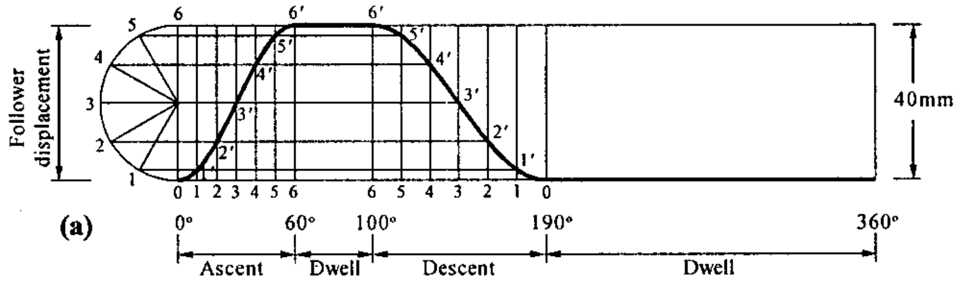


Fig. 8.20 (a)

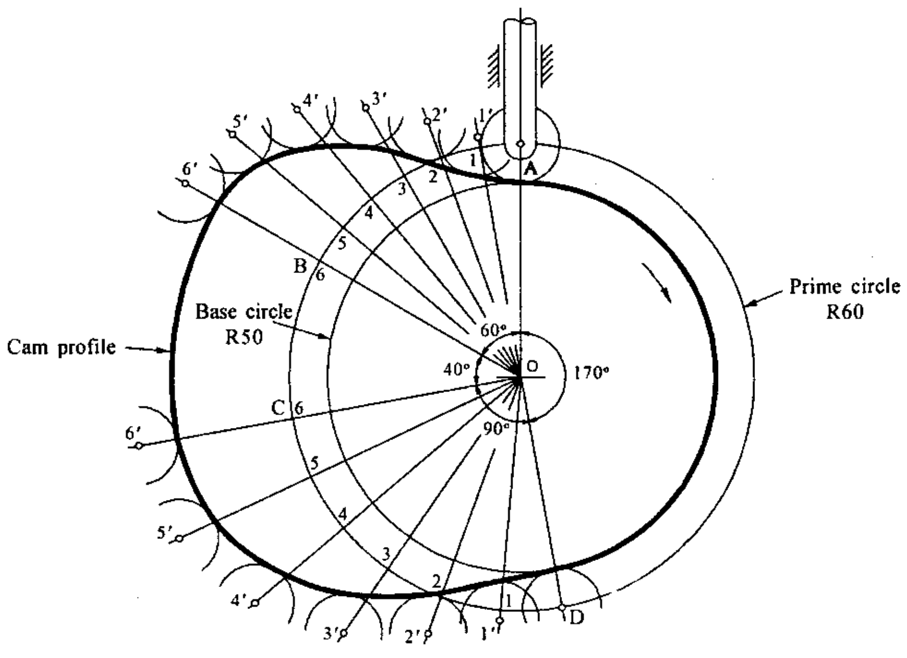


Fig. 8.20 (b)

5. Mark off the angle AOB = 60°, BOC = 40°, COD = 90° and DOA = 170° in a direction opposite that of the cam's rotation to represent ascent, dwell, descent and dwell respectively.
6. Divide the arc AB (angle of ascent) on the prime circle, and arc CD (angle of descent) on the prime circle each into 6 equal parts and lable them by numbers as shown.
7. Draw radial lines passing through each of these points.
8. Transfer the displacements 11', 22', ... etc., from the displacement diagram to the appropriate radial lines, measuring from the prime circle to get points 1', 2', etc.
9. With the points thus obtained as centers draw the follower outlines.
10. Draw a smooth curve tangent to these follower outlines.

11. With O as center draw an arc, tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
12. With O as center draw an arc, tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Angular velocity $\omega = \frac{2\pi n}{60} = \frac{2\pi \times 360}{60} = 10\pi$ rad/s

Maximum velocity of the follower during ascend $V = \frac{\pi \omega S}{2\theta}$

$$= \frac{\pi \times 10\pi \times 0.04 \times 180}{2 \times 60 \times \pi} = 1.885 \text{ m/s}$$

Maximum acceleration of the follower during ascend $A = \frac{\pi^2 \omega^2 S}{2\theta^2}$

$$= \frac{\pi^2 \times (10\pi)^2 \times 0.04}{2 \times (60 \times \pi / 180)^2} = 177.65 \text{ m/s}^2$$

Maximum velocity of the follower during descend $V = \frac{\pi \omega S}{2\theta}$

$$= \frac{\pi \times (10\pi) \times 0.04 \times 180}{2 \times 90 \times \pi} = 1.257 \text{ m/s}$$

Maximum acceleration of the follower during descend $A = \frac{\pi^2 \omega^2 S}{2\theta^2}$

$$= \frac{\pi^2 \times (10\pi)^2 \times 0.04}{2 \times (90 \times \pi / 180)^2} = 124 \text{ m/s}^2$$

Example 8.7

A vertical spindle supplied with a plane horizontal face at its lower end is actuated by a cam keyed to a uniformly rotating shaft. The spindle is raised through a distance of 30 mm in one fourth remain at rest for one - fourth, is lowered in one - third and remains at rest for the remainder of a complete revolution of the cam shaft. Draw profile of the cam, assuming that the least radius of the cam is 30 mm and that the spindle moves with uniform acceleration and deceleration both during ascent and descent. However, during descent, deceleration period is half the acceleration period. Assume that the axis of the spindle passes through cam center and the cam rotates in anticlockwise direction.

Solution:

Angular displacement of the cam during rise $= \frac{1}{4} \times 360 = 90^{\circ}$

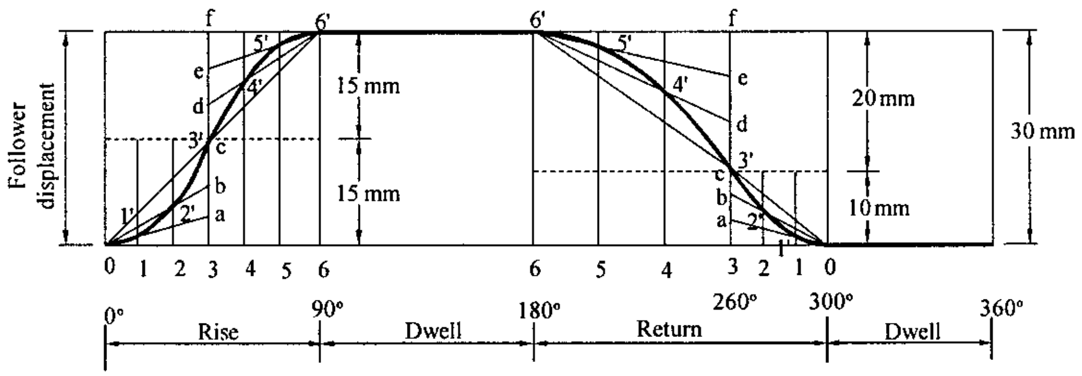


Fig. 8.21 (a)

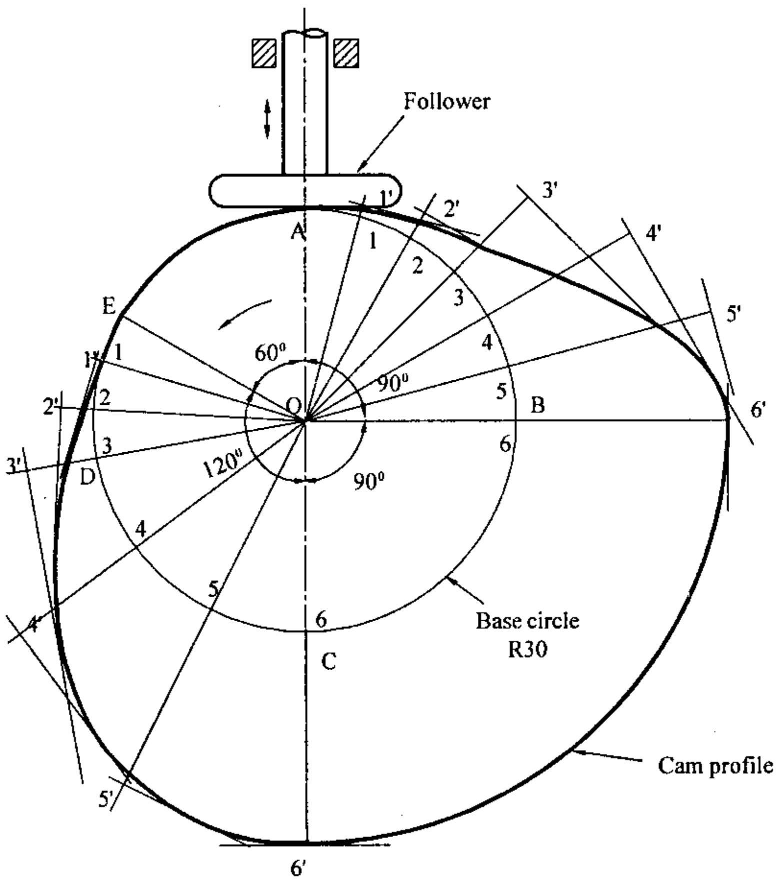


Fig. 8.21 (b)

$$\text{Angular displacement of the cam during dwell} = \frac{1}{4} \times 360 = 90^o$$

$$\text{Angular displacement of the cam during return} = \frac{1}{3} \times 360 = 120^o$$

Dwell in the lowest position $= 360 - (90 + 90 + 120) = 60^o$

During return stroke (120° cam rotation), the deceleration period is half the acceleration period.

$$\therefore \text{ Angular displacement of the cam during accleration} = \frac{2}{3} \times 120 = 80^o$$

Angular displacement of the cam during deceleration $= 120 - 80 = 40^o$

$$\text{Distance moved by the follower during acceleration} = \frac{2}{3} \times 30 = 20 \text{ mm}$$

Distance moved by the follower during deceleration $= 30 - 20 = 10$ mm

Construction :

1. Draw the displacement diagram for the given data as shown in fig. 8.21a.
2. Draw the base circle with center O and radius equal to 30 mm (fig. 8.21b).
3. Draw the follower in its lowest (0°) position, tangent to the base circle.
4. Mark off angle AOB = 90°, angle BOC = 90°, COD = 80°, DOE = 40° and angle DOA = 60° in a direction opposite that of the cam's rotation to represent rise, dwell, return with acceleration and retardation and dwell respectively.
5. Divide the arc AB (rise) into 6 equal parts, arc CD (acceleration) into 3 equal parts and arc DE (retuardation) into 3 equal parts and number them as shown.
6. Draw radial lines passing through each of these points.
7. Transfer displacment 11', 22', etc., from the displacement diagram on to the appropriate radial lines, measuring from the base circle to get 1', 2', etc.
8. Draw the follower profile at each position - in this case simply a line perpendicular to the appropriate radial line.
9. Draw a smooth curve tangent to each of the follower profile.
10. With O as center draw an arc tangent to the follower outlines located at 6' a 16' to get the dwell in the lifted position.
11. With O as center draw an arc, tangent to the follower outlines at A and E to represent the dwell in the lowest position.

Example 8.8

A flat-faced mushroom follower is raised through a distance of 25 mm is 120° rotation of the cam, remains at rest for the next 30° and is lowered during further 120° rotation of the cam. The raising of the follower takes place with cycloidal motion and the lowering with uniform acceleration and deceleration. However, the uniform acceleration is 2/3 of the uniform deceleration. The least radius of the cam is 25 mm. Draw the cam profile assuming clockwise rotation of the cam.

(VTU, Aug. 2000)

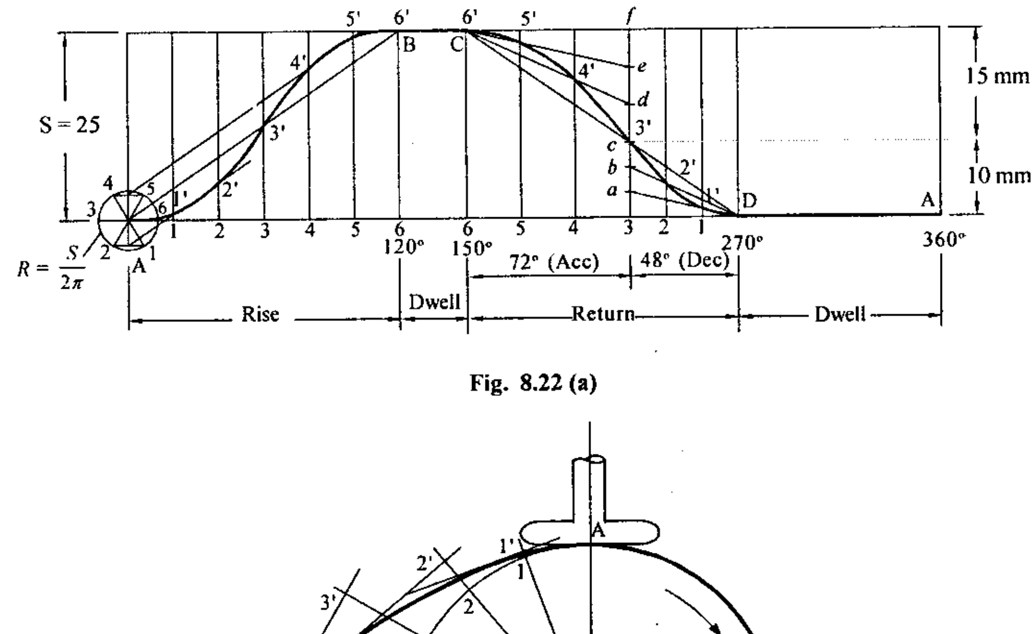


Fig. 8.22 (a)

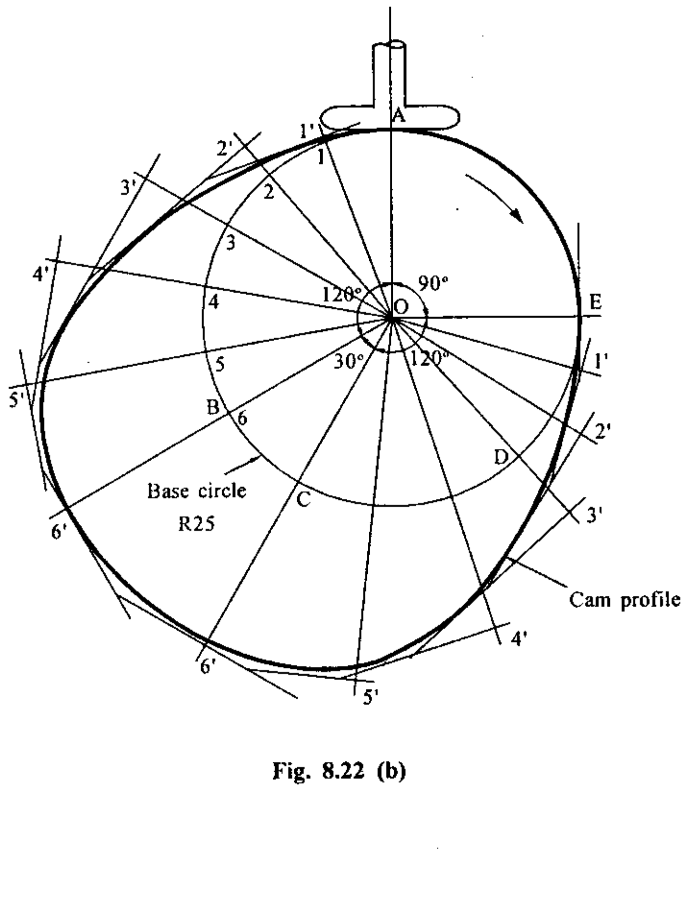


Fig. 8.22 (b)

Lift $S = 25$ mm

Rise = 120° with cycloidal motion

Rolling circle radius $= \frac{S}{2\pi} = \frac{25}{2 \times \pi} = 3.98$ mm

Dwell in the lifted position = 30°

Return = 120° with uniform acceleration and deceleration.

Acceleration $= \frac{2}{3}$ deceleration

or Acceleration period $= \frac{3}{2}$ deceleration period.

Angular rotation of the cam during acceleration $= \frac{3}{5} \times 120 = 72°$

Angular rotation of the cam during decleration $= \frac{2}{5} \times 120 = 48°$

Fall of the follower during acceleration $= \frac{3}{5} \times 25 = 15$ mm

Fall of the follower during deceleration $= \frac{2}{5} \times 25 = 10$ mm

Dwell in the lowered position $= 360 - (120 + 30 + 120) = 90°$

Base circle radius $r_b = 25$ mm

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.22a.
2. Draw the base circle with center O and radius equal to 25 mm (fig. 8.22b).
3. Draw the flat faced follower in its lowest (0°) position tangent to the base circle.
4. Mark off angle AOB = 120°, angle BOC = 30°, angle COD = 72°, DOE = 48° and angle DOA = 90° in a direction opposite that of cam's rotation to represent rise, dwell, return with acceleration, retardation and dwell respectively.
5. Divide arc AB (rise) into 6 equal parts, arc CD (acceleration) into 3 equal parts and arc DE (retardation) into 3 equal parts and label them as shown.
6. Draw radial lines passing through each of these points.
7. Transfer displacements 11', 22',...... etc., from the displacement diagram on to the appropriate radial lines, measuring from the base circle to get 1', 2', ... etc.
8. Draw the follower profile at each position, in this case simply a line perpendicular to the appropriate radial line.
9. Draw a smooth cam profile tangent to each of the follower profile.

11. With O as center draw an arc, tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
12. With O as center draw an arc, tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Example 8.9

Draw the profile of the cam to give the following motion to the follower :

Follower to move through 30 mm during 180° of cam rotation with cycloidal motion. Follower to return with cycloidal motion during 180° of cam rotation. Base circle diameter of the cam is 30 mm and the roller diameter of the follower is 10 mm. The axis of the roller is offset by8 mm to right. Determine the maximum velocity and acceleration of the follower during the outstroke, when the cam rotates at 2000 rpm. **(VTU, March 2001)**

Solution :

Lift $S = 30\,\text{mm}$

Rise = 180° with cycloidal motion

Return = 180° with cycloidal motion

Base circle radius = 30 mm

Roller diameter = 10 mm

$$\text{Prime circle radius} = 30 + \frac{10}{2} = 35\ \text{mm}$$

Offset towards right = 8 mm

Speed of the cam n = 2000 rpm

$$\text{Rolling circle radius} = \frac{S}{2\pi} = \frac{30}{2\pi} = 4.78\ \text{mm}$$

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.23a.
2. Draw the offset circle with center O and radius equal to 8 mm. Draw a vertical tangent to the right of the offset circle (fig. 8.23b).
3. Draw the base circle with center O and radius equal to 30 mm.
4. Draw the prime circle with center O and radius equal to 35 mm. The prime circle cuts the vertical tangent at point A. Join OA.
5. With A as center draw the roller follower in its 0° position.
6. Mark off angle AOB = 180°, angle BOA = 180° in a direction opposite that of cam's rotation to represent rise and return respectively. Assume the cam rotates in the clockwise direction.

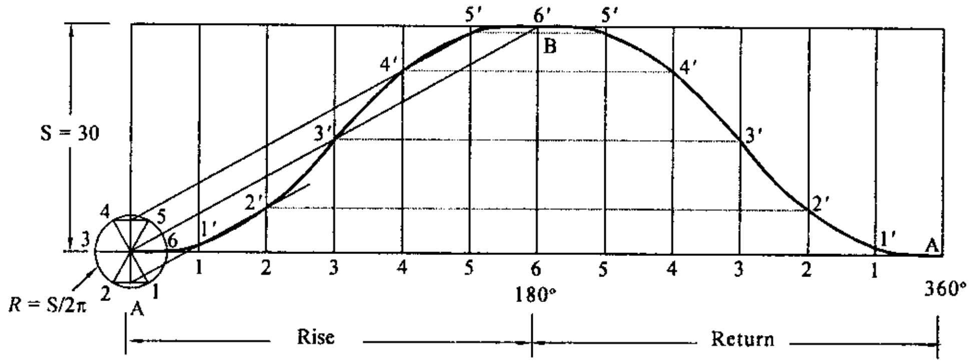


Fig. 8.23 (a)

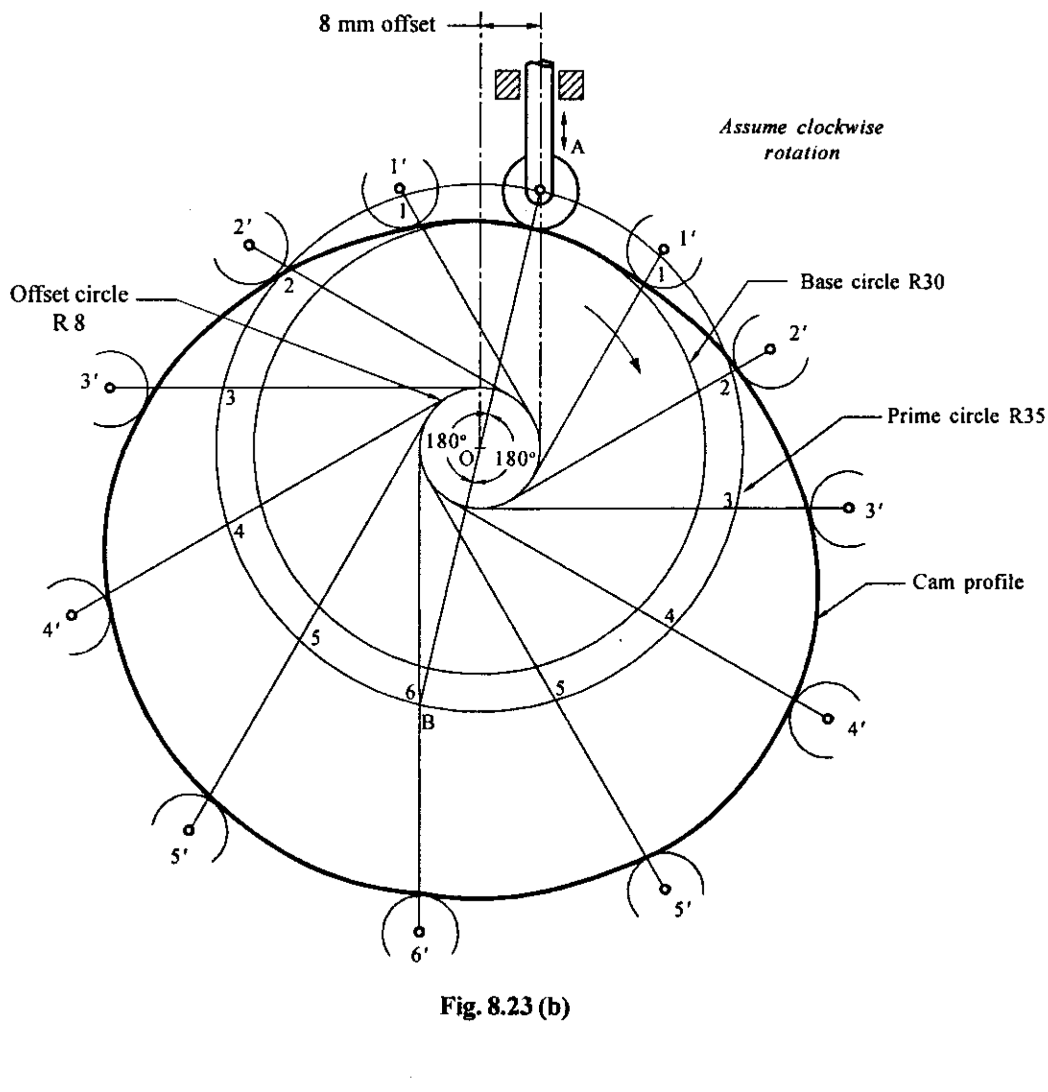


Fig. 8.23 (b)

7. Divide the arc AB (rise) and arc BA (return) into each 6 equal angular intervals corresponding to those used in the displacement diagram and number them as shown. Through each of the points thus obtained, draw tangents to the offset circle.
8. Transfer displacements 11', 22',...... etc., from the displacement diagram to the appropriate tangents measuring from the prime circle to get points 1', 2', ... etc.
9. Points 1', 2', etc., as centers draw the roller follower outlines.
10. Draw a smooth cam profile, tangent to these follower outlines.

Example 8.10

A cam rotates at a uniform speed of 360 rpm, and gives an oscillating follower, 65 mm long an angular displacement of 30° in each stroke. The follower is fitted with a roller 30 mm diameter which makes contact with the cam. The outward and inward displacements of the follower each occupy 120° cam rotation and there is no dwell in the lifted position. If the follower moves throughout with SHM, draw the profile of the cam. The axis of the fulcrum is 88 mm from the axis of the cam and the least distance of the roller axis from the cam axis is 50 mm.

Solution :

$R = 65$ mm., $\phi = 30^\circ$

$\therefore$ Length of arc of travel $\quad S = \dfrac{R\phi\pi}{180} = \dfrac{65 \times \pi \times 30}{180} = 34.03$ mm

Construction : *(Refer fig. 8.24)*

1. Draw the displacement diagram taking lift equal to 34.03 mm as shown in fig. 8.24a.
2. Draw the base circle with centre O and radius equal to prime circle radius minus the radius of the roller, i.e., 50 – 15 = 35 mm. (fig. 8.24 b)
3. Draw the prime circle with center O and radius equal to 50 mm.
4. Draw the pivot circle with center O and radius equal to 88 mm.
5. Draw the follower in its 0° position, tangent to the base circle.
6. Locate the pivot point P on the pivot circle such that AP = 65 mm. Join OP.
7. Mark off angles as before starting from OP.
8. Divide the arcs PB and BC, each into 6 equal parts and name them *a*, *b*, *c*, etc., as shown.
9. With each of the points thus obtained as center and with radius equal to 65 mm, draw circular arcs to represent the path of roller center. The circular arcs will cuts the prime curcle at 1,2, etc.
10. Transfer displacement 11', 22', etc., from the displacement diagram to the appropriate circular arcs, measuring from the prime circle to get 1', 2', etc.

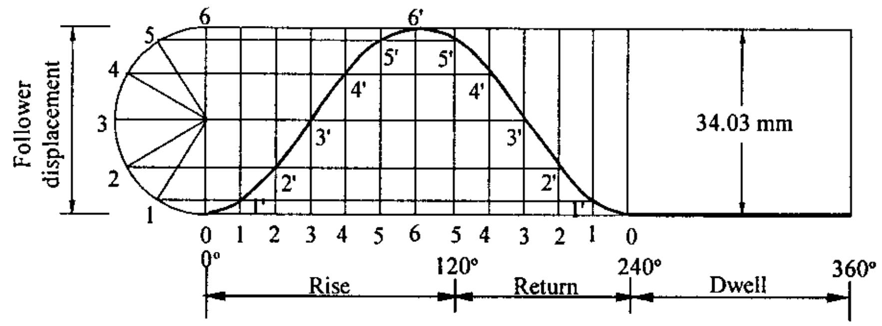


Fig. 8.24 (a)

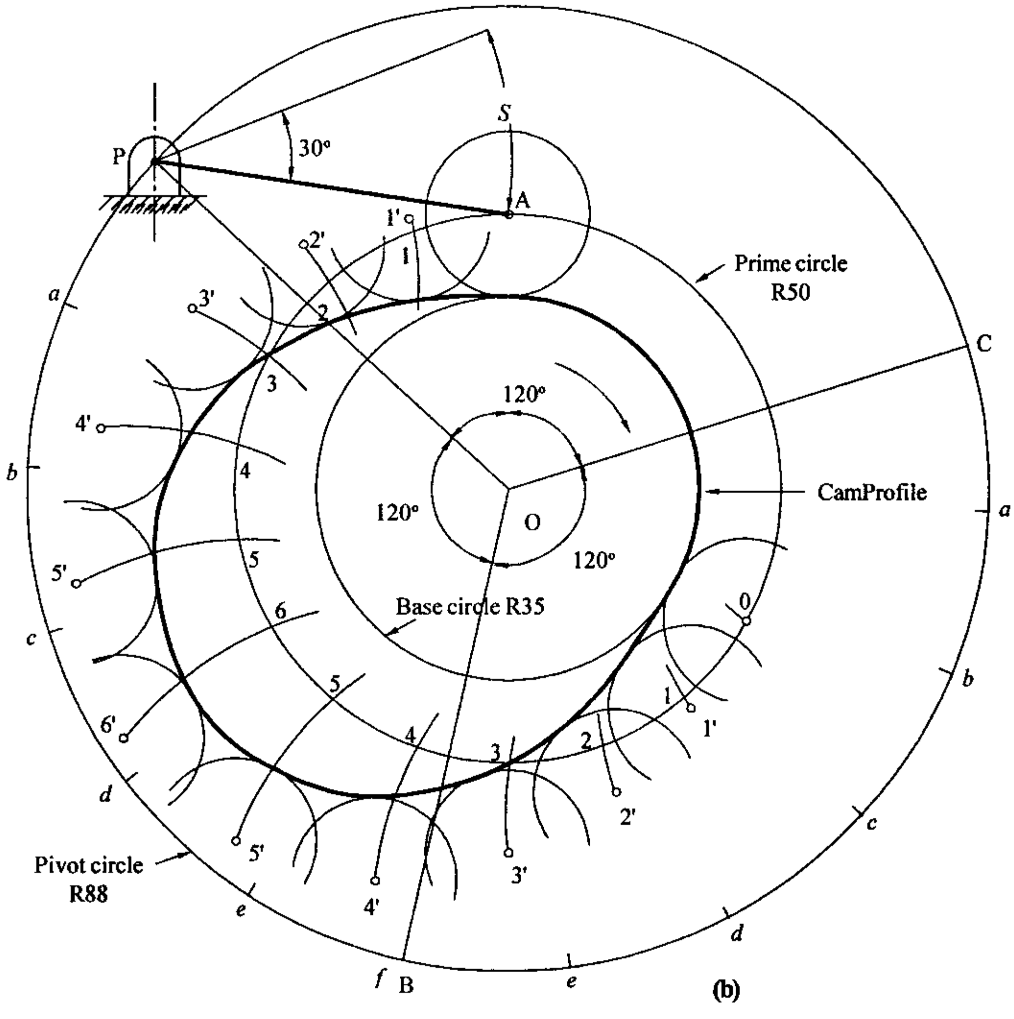


Fig. 8.24 (b)

11. With the pionts thus obtained as centers draw the follower outlines.
12. Draw a smooth curve tangent to these follower outlines.
13. With O as center draw an arc tangent to the follower outlines at A and C to represent the dwell in the lowest position.

Example 8.11

A cam rotates at a uniform speed of 200 rpm clockwise and gives an oscillating follower 70 mm long and an angular displacement of 30° in each stroke. The follower is fitted with a roller of 20 mm diameter which makes contact with the cam. The outward and inward displacement of the follower each occupying 120° of cam rotation with a dwell of 60° cam rotation in between. Outward motion of the follower is SHM and inward motion of the follower is uniform and equal acceleration and retardation motion. Base circle radius is 30 mm. The fulcrum is 70 mm to the left and 40 mm above the cam shaft center. Draw the cam profile. **(VTU, July 2004)**

Solution:

Length of the oscillating follower = 70 mm

Angular displacement $\phi = 30°$

Length of arc of travel $S = \frac{R\phi\pi}{180} = \frac{70\times30\times\pi}{180} = 36.65$ mm

Construction:

1. Draw the displacement diagram for the given data by taking the lift equal to 36.65 mm as shown in fig. 8.25 (a).
2. Draw the base circle with center O and radius equal to 30 mm.
3. Draw the prime circle with center O and radius equal to the sum of base circle radius and roller radius. i.e., 30 + 10 = 40 mm
4. Locate the fulcrum P which is 70 mm to the left and 40 mm above the cam center O. Join OP. With O as center and OP as radius, draw the pivot circle.
5. Draw the roller follower in its 0° position and join the roller center A and the fulcrum P which is the oscillating link.
6. Mark off the angles starting from OP but in the opposite direction of cam's rotation. i.e., angle POB = 120°, angle BOC = 60°, angle COD = 120°, and angle DOP = 60° to represent rise, dwell, return and dwell respectively.
7. Divide the arcs PB and CD on the pivot circle each in to 6 equal parts and name them as $a, b, c, ...$ etc as shown.
8. With each of the points thus obtained as center and with radius equal to piviot circle radius OP, draw circular arcs to represent the path of roller center. The circular arcs will cut the prime circle at 1, 2, ... etc.

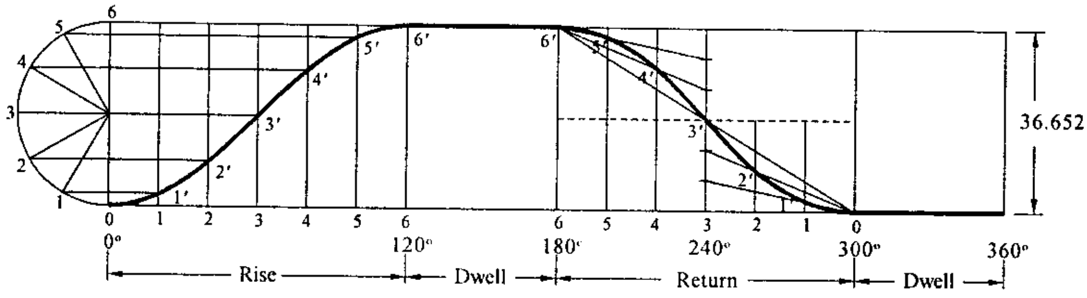


Fig. 8.25 (a)

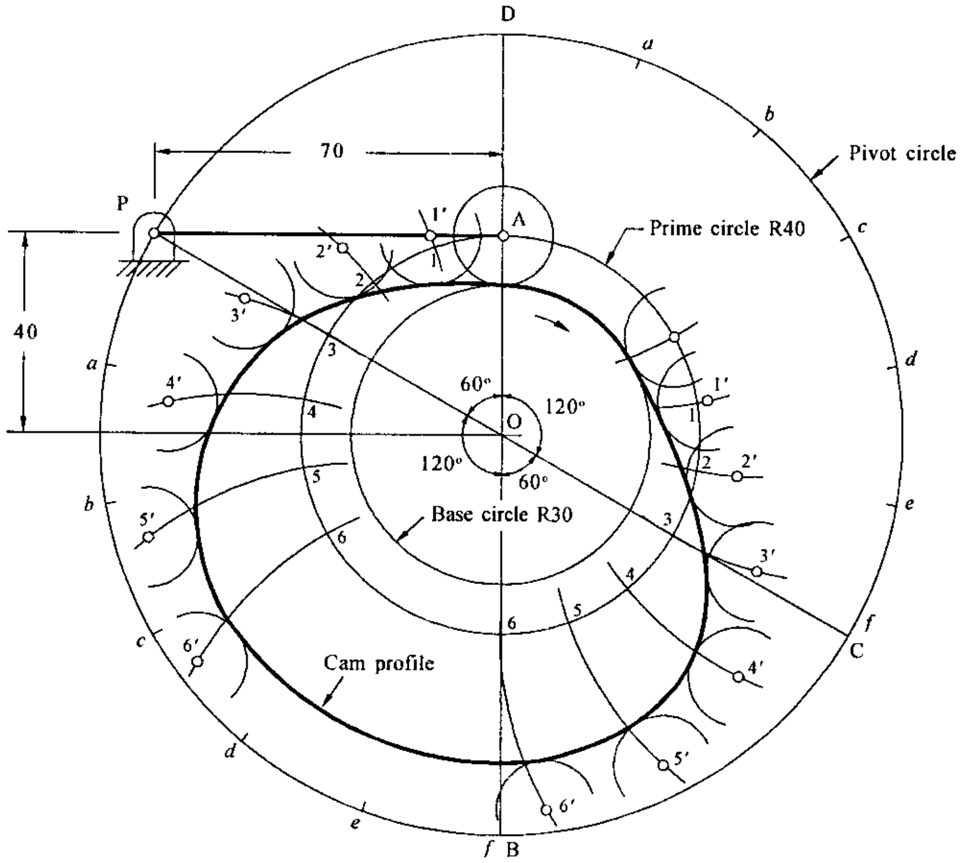


Fig. 8.25 (b)

9. Transfer displacement 11', 22', ... etc, from the displacement diagram to the appropriate circular arcs, measuring from the prime circle to get 1', 2', ... etc.
10. With the points thus obtained as centers draw the roller follower outlines.
11. Draw a smooth curve tangent to these follower outlines.

Example 8.12

The exhaust valve of a diesel engine has a lift of 31.4 mm. It is operated by a cam to give cycloidal motion during the opening and closing periods, each of which corresponds to 60° of cam rotation and dwell for the rest of cam rotation. The follower is provided with a roller 10 mm radius and its line of stroke is radial. Draw the profile of the cam, if the minimum radius of the cam is 20 mm. Determine the maximum velocity and acceleration of the follower during outward stroke for 2000 rpm.

***Construction :** (Refer fig. 8.26)*

1. Draw the displacement diagram as shown in fig. 8.26a. By drawing the rolling circle with center O and radius equal to lift / (2π) = 31.4 / (2π) = 5 mm. Complete the displacement diagram as explained in the previous article.

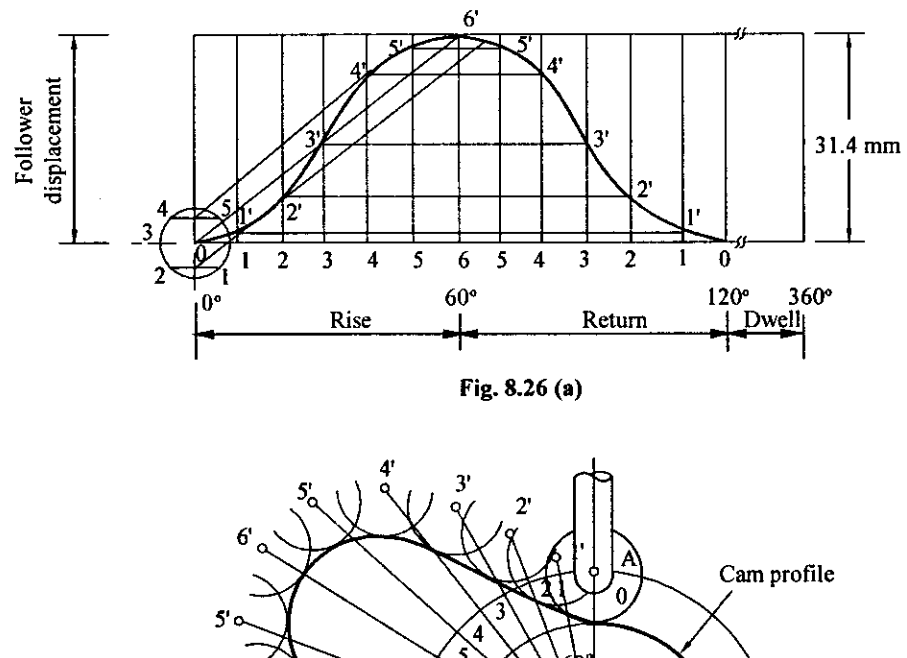


Fig. 8.26 (a)

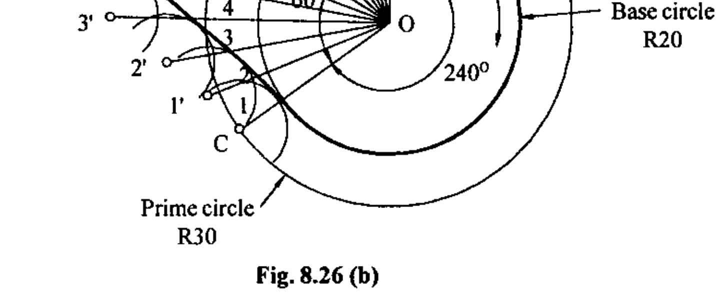


Fig. 8.26 (b)

2. Draw the base circle with center O and radius equal to 20 mm.
3. Draw the prime circle with center O and radius OA = base circle radius + radius of the roller = 20 + 10 = 30 mm.
4. Draw the roller in its 0° position, tangent to the base circle.
5. Mark off angle AOB = 60°, angle BOC = 60° and angle COA = 240° in a direction opposite that of the cam's rotation to represent the rise return and dwell respectively (assume clockwise rotation of cam).
6. Divide arcs AB and BC each into 6 equal parts (same number of equal parts as in the displacement diagram) and number them as shown in fig. 8.26b.
7. Draw radial lines passing through each of these points.
8. Transfer displacement 11', 22', etc., from the displacement diagram on to the appropriate radial lines, measuring from the prime circle to get 1', 2', etc.
9. From points 1', 2', etc., draw the follower outlines.
10. Draw a smooth curve tangent to these follower outlines to get the required cam profile.
11. With O as center draw an arc tangent to the follower outlines at A and C to represent the dwell in the lowest position.

Maximum velocity of the follower $V = \dfrac{2\omega S}{\theta}$

$$= \frac{2 \times 2\pi \times 1000 \times 0.0314 \times 180}{60 \times 60 \times \pi} = 6.28 \text{ m/s}$$

Maximum acceleration $A = \dfrac{2\pi\omega^2 S}{\theta^2}$

$$= 2\pi \times \left(\frac{2\pi \times 1000}{60}\right)^2 \times 0.0314 \times \left(\frac{180}{60 \times \pi}\right)^2 = 1972.9 \text{ m/s}^2$$

Example 8.13

Draw the profile for a disc cam with reciprocating knife edge follower on the center line of the cam shaft. The radius of the bse circle is 35 mm and the cam rotates in anti-clockwise direction at 100 rpm. The follower is to move upward 30 mm, with simple harmonic motion in 0.1 second., to dwell in 0.15 second., to move upwards another 30 mm, with simple harmonic motion in 0.15 second., to return with uniform velocity to the starting point in the remaining period of one complete revolution of the cam shaft.

Solution :

Speed of the cam = 100 rpm $= \dfrac{100}{60}$ rps

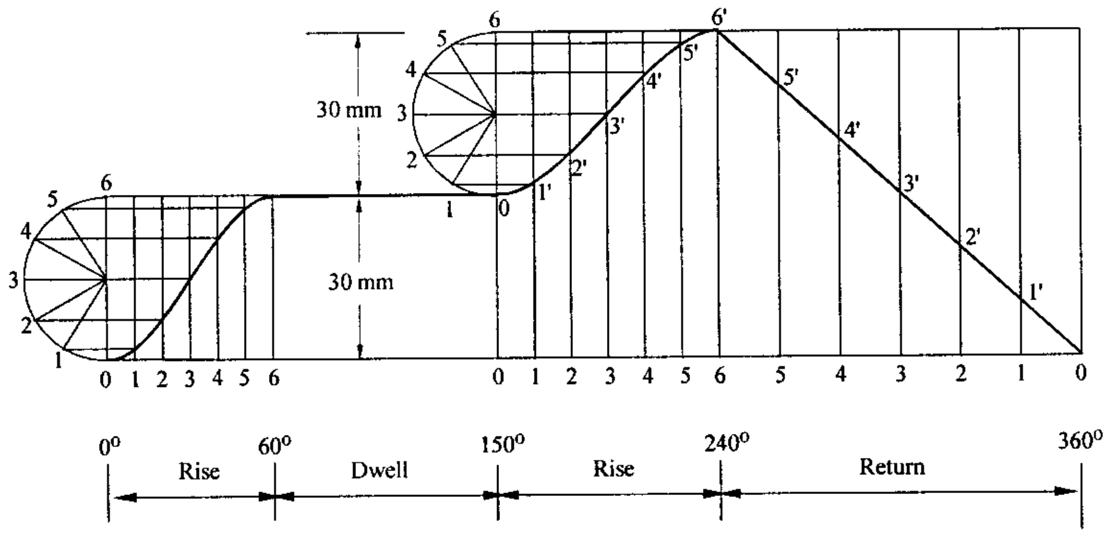


Fig. 8.27 (a)

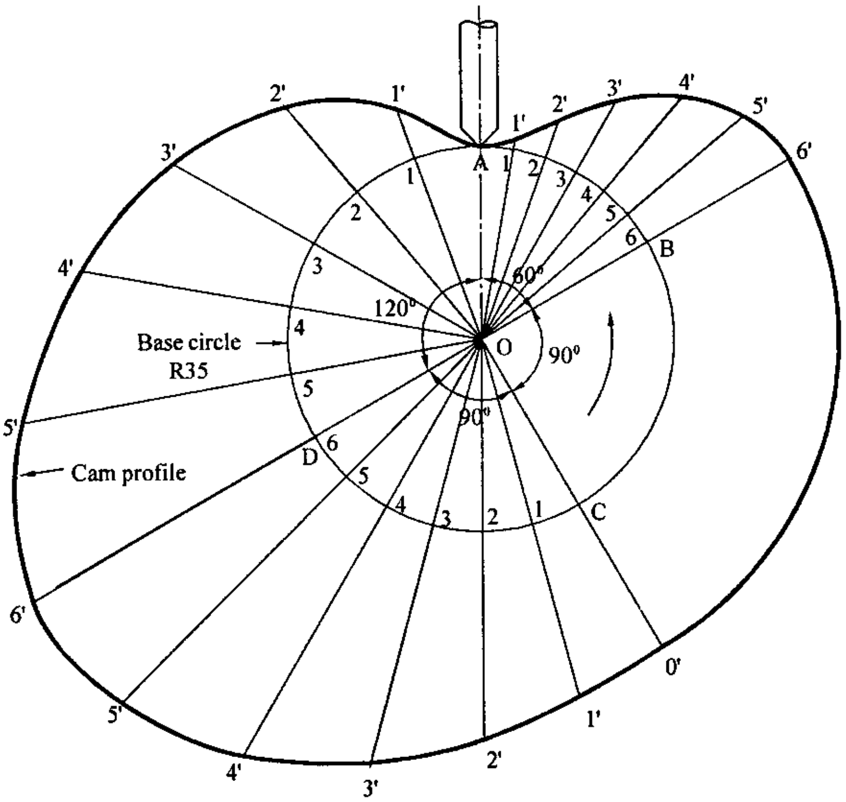


Fig. 8.27 (b)

$$\text{Rotation of the cam in 1 second} = \frac{100}{60} \text{ revolutions}$$

$$= \frac{100}{60} \times 360 \text{ degrees}$$

$$\text{Rotation of cam during dwell period of 0.1 s} = \frac{100}{60} \times 360 \times 0.1 = 60^\circ$$

$$\text{Rotation of cam during dwell period of 0.15 s} = \frac{100}{60} \times 360 \times 0.15 = 90^\circ$$

$$\text{Rotation of cam during second rise period of 0.15 s} = \frac{100}{60} \times 360 \times 0.15 = 90^\circ$$

$$\text{Return} = 360 - (60 + 90 + 90) = 120^\circ$$

***Construction :** (Refer fig. 8.27)*

1. Draw the displacement diagram for the given data as shown in fig. 8.27a.
2. Draw the base circle with center O and radius equal to 35 mm.
3. Draw the knife edge follower in its 0° position as shown in fig. 8.27b, and join OA.
4. Mark off angle AOB = 60°, angle BOC = 90°, angle COD = 90°, and angle DOA = 120° in a direction opposite to that of the cam's rotation to represent rise, dwell, rise, and return respectively.
5. Divide the arcs AB (rise), CD (rise), and DA (return) each into 6 equal parts and number them 1, 2, 3, etc.
6. Draw radial lines passing through each of these points.
7. Transfer displacement 11', 22', etc., from the displacement diagram on to the appropriate radial lines, measuring from the base circle to get 1', 2', etc.
8. Draw a smooth curve through 1', 2', etc., to get the required cam profile.
9. With O as center and O6' as radius, draw an arc 6'-O' to represent the dwell in the lifted position.

Example 8.14

A cam with a base circle radius of 35 mm is rotating at a uniform speed of 100 rpm in counterclockwise direction. Draw the profile of the disc cam with reciprocating knife edge follower on the center line of the cam shaft for the following motion.

1. Follower to move upward 30 mm with simple harmonic motion in 0.1 second.
2. Follower to dwell in next 0.15 second.
3. Follower to move upward to another 30 mm with simple harmonic motion in 0.15 second.

4. Follower to return to its starting position with uniform acceleration and retardation in the remaining period of one complete revolution of the cam shaft. However, the acceleration period is twice the retardation period.

Determine the maximum velocity and acceleration of the follower during its outward stroke.

(VTU, Aug. 2007)

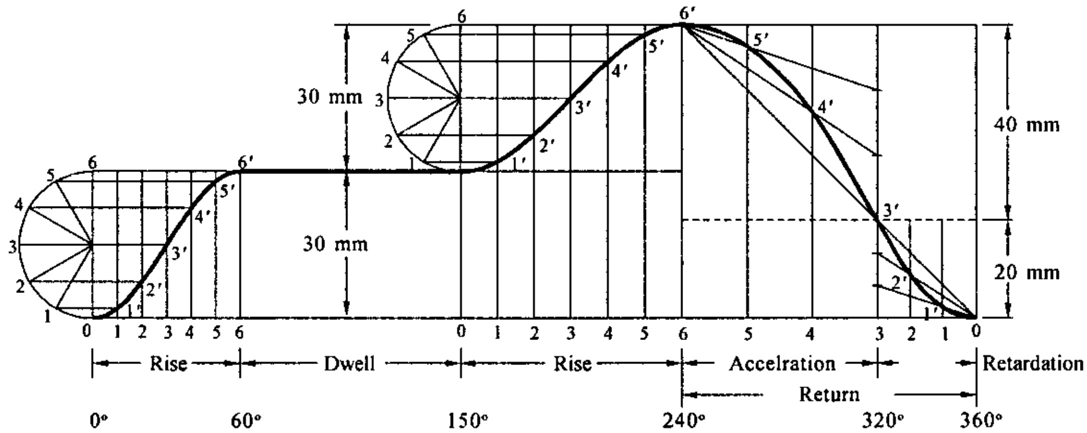


Fig. 8.28 (a)

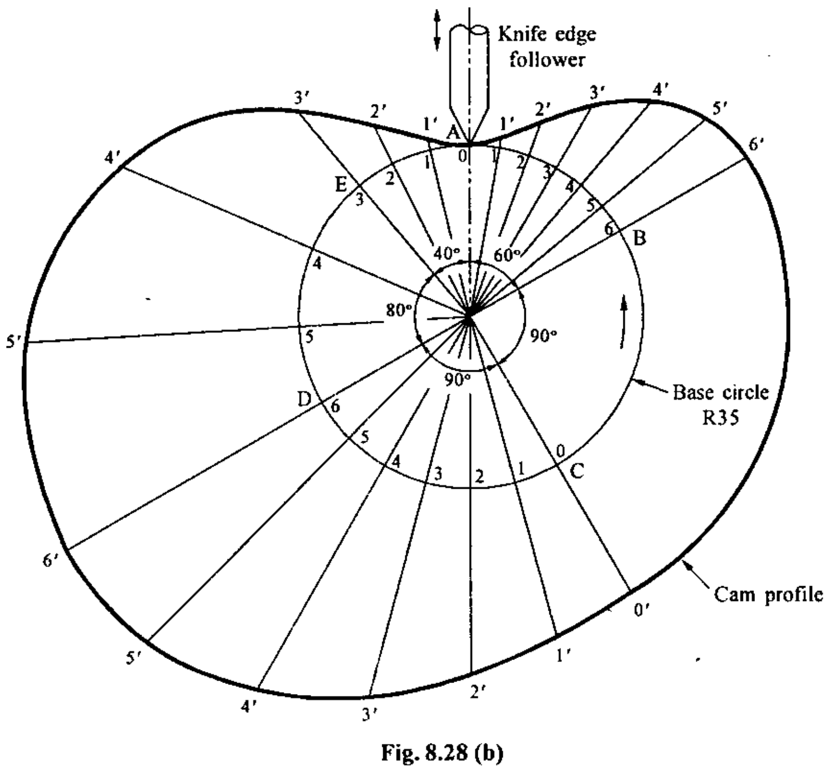


Fig. 8.28 (b)

Solution:

Speed of the cam = 100 rpm = $\frac{100}{60}$ rps

Rotation of the cam in 1 second = $\frac{100}{60}$ revolutions = $\frac{100}{60} \times 360$ degrees/s

Rotation of cam during first rise (0.1 s) = $\frac{100}{60} \times 360 \times 0.1 = 60^\circ$

Rotation of cam during dwell (0.15 s) = $\frac{100}{60} \times 360 \times 0.15 = 90^\circ$

Rotation of cam during second rise (0.15 s) = $\frac{100}{60} \times 360 \times 0.15 = 90^\circ$

Rotation of cam during return = $360 - (60 + 90 + 90) = 120^\circ$

Total lift of the follower = 30 + 30 = 60 mm

The acceleration period = 2 times retardation period

$\therefore$ Rotation of the cam during acceleration = $120 \times \frac{2}{3} = 80^\circ$

Height lowered by the follower during acceleration = $60 \times \frac{2}{3} = 40$ mm

Rotation of the cam during retardation = $120 \times \frac{1}{3} = 40^\circ$

Height lowered by the follower during retardation = $60 \times \frac{1}{3} = 20$ mm

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.28(a).
2. Draw the base circle with O as center and radius equal to 35 mm.
3. Draw the Knife edge follower in its 0° position as shown in fig. 8.28(b)
4. Mark off angle AOB = 60°, angle BOC = 90°, angle COD = 90°, angle DOE = 80° and EOF = 40° in a direction opposite to that of the cam's rotation to represent rise, dwell, rise, return with acceleration and retardation respectively.
5. Divide the arc AB (first rise) into 6 equal parts, arc CD (second rise) into 6 equal parts, arc DE (acceleration) into 3 equal parts and arc EA (retardation) into 3 equal parts and name them.
6. Draw radial lines passing through each of these points.
7. Transfer the displacement 11', 22', ... etc, from the displacement diagram on to the appropriate radial lines, measuring from the base circle to get 1', 2', ... etc.

8. Draw a smooth curve through 1', 2', ... etc to get the required cam profile.
9. With O as center and O6' as radius, draw an arc 6'-O' to represent the dwell in the lifted position.

Maximum velocity of the follower during first rise with SHM $V = \frac{\pi \omega S}{2\theta}$

$$= \frac{\pi \times 2\pi \times 100}{60} \times \frac{0.03 \times 180}{2 \times 60 \times \pi} = 0.471 \text{ m/s}$$

Maximum acceleration of the follower during first rise with SHM $A = \frac{\pi^2 \omega^2 S}{2\theta^2}$

$$= \pi^2 \times \left(\frac{2\pi \times 100}{60}\right)^2 \times \frac{0.03}{2} \times \left(\frac{180}{60 \times \pi}\right)^2 = 14.804 \text{ m/s}^2$$

Example 8.15

A push rod of a valve of an internal combustion engine ascends with uniform equal acceleration and deceleration, along a path inclined to the vertical at 60°. The same descends with simple harmonic motion. The base circle diameter of the cam is 50 mm and the push rod has a roller of 15 mm diameter fitted to its end. The axis of the roller and the cam fall on the same vertical straight line. The stroke of the follower is 30 mm in the direction inclined to the lift as viewed from the front at an angle of 60° to the vertical. The angle of action for the out stroke and the return stroke is 90° each interposed by a dwell period of 90°. Draw the profile of the cam.

Construction : *(Refer fig. 8.29)*

1. Draw the displacement diagram for the given data as shown in fig. 8.29a.
2. Draw the base circle with O as center and radius equal to 25 mm.
3. Draw the prime circle with O as center and radius OA = base circle radius + roller radius = 25 + 7.5 = 32.5 mm.
4. Draw the roller follower in its 0° position as shown in fig. 8.29b.
5. Mark off angle AOB = 90°, angle BOC = 90°, angle COD = 90°, and angle DOA = 90° in the direction opposite to that of the cam's rotation to represent the rise, dwell, return and dwell respectively.
6. Divide the angular displacement during rise (angle AOB) and return (angle COD) each into 6 equal parts and number them 1, 2, 3, etc.
7. From O, draw radial lines to each of these points.
8. From points 1, 2, 3, etc., draw lines inclined to the radial lines at an angle of 60° as shown.
9. Transfer displacement 11' 22', etc., from the displacement diagram on to the appropriate 60° lines, measuring from the prime circle to get points 1', 2', etc.

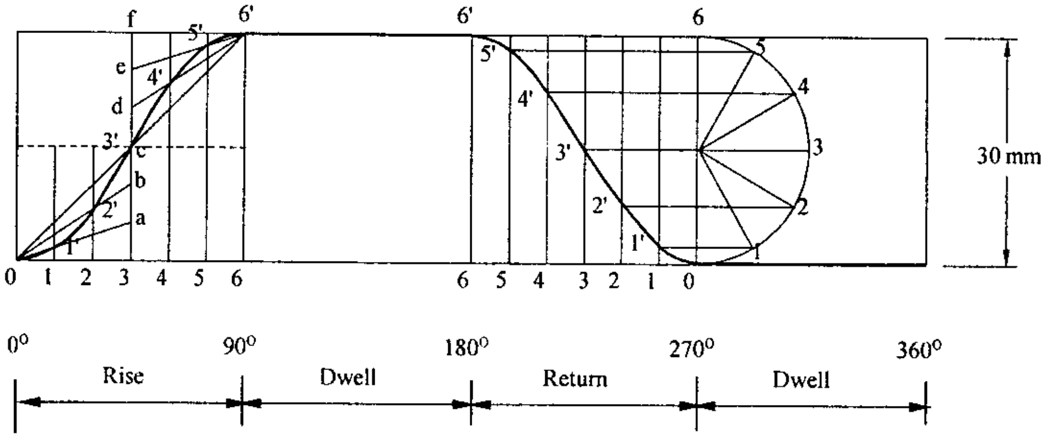


Fig. 8.29 (a)

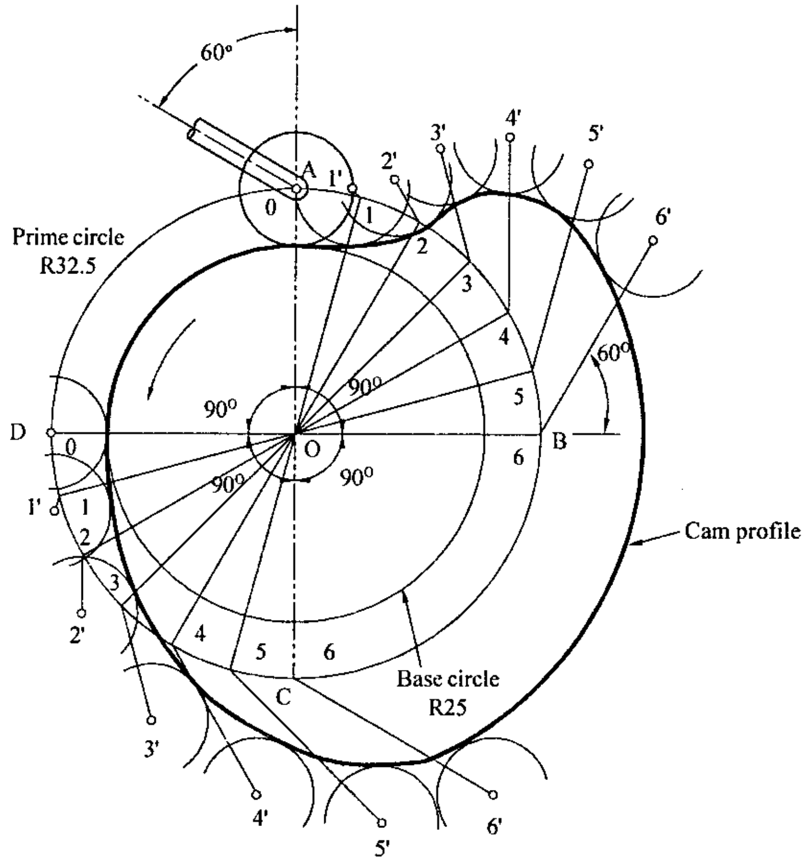


Fig. 8.29 (b)

10. From points 1', 2', etc., as centers draw the follower outlines.
11. Draw a smooth curve tangent to these roller circles.
12. With O as center draw an arc, tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
13. With O as center draw an arc, tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Example 8.16

A push rod operated by a cam is to rise and fall with SHM along an inclined path. The least radius of the cam is 40 mm. The push rod carries a roller 30 mm diameter at its lower end. In the lower position the roller center is vertically above the cam axis. Maximum displacement of the follower is 40 mm in the direction 30° to the right of the vertical. The time of lift is 0.15 second, the time of fall = 0.1 second and the time of rest at the upper end is 0.05 second. Draw the cam profile if it rotates at a speed of 100 rpm in clockwise direction. **(VTU, Jan 2006)**

Solution:

Lift along 30° line with vertical = 40 mm

Speed of the cam = 100 rpm = $\frac{100}{60}$ rps

Rotation of the cam in one second = $\frac{100}{60}$ revolution = $\frac{100}{60} \times 360$ degrees/s

Rotation of the cam during rise (0.15 s) = $\frac{100}{60} \times 360 \times 0.15 = 90^\circ$

Rotation of the cam during rest (0.05 s) = $\frac{100}{60} \times 360 \times 0.05 = 30^\circ$

Rotation of the cam during fall (0.1 s) = $\frac{100}{60} \times 360 \times 0.1 = 60^\circ$

Assume the remaining rotation is the dwell of the follower in the lowest position.

Construction:

1. Draw the displacement diagram for the given data as shown in fig. 8.30 (a)
2. Draw the base circle with O as center and radius equal to 40 mm.
3. Draw the prime circle with O as center and radius equal to the sum of the base circle radius and roller radius i.e., 40 + 15 = 55 mm.
4. Draw the roller follower in its 0° position and draw the roller follower link at an angle of 30° to the vertical and towards right as shown in fig. 8.30 (b). MArk the center of the roller as A. Join OA.

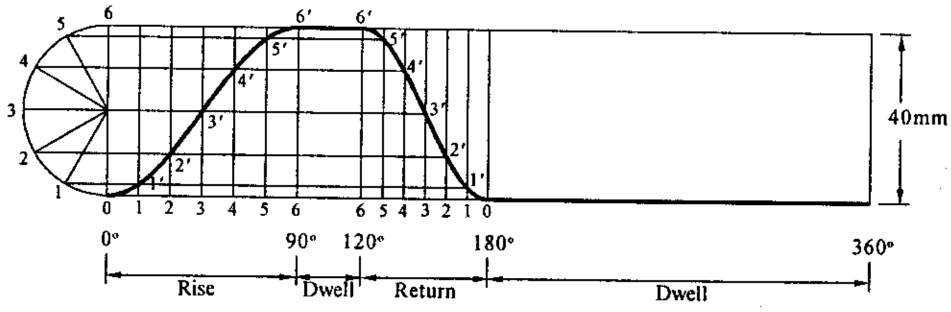


Fig. 8.30 (a)

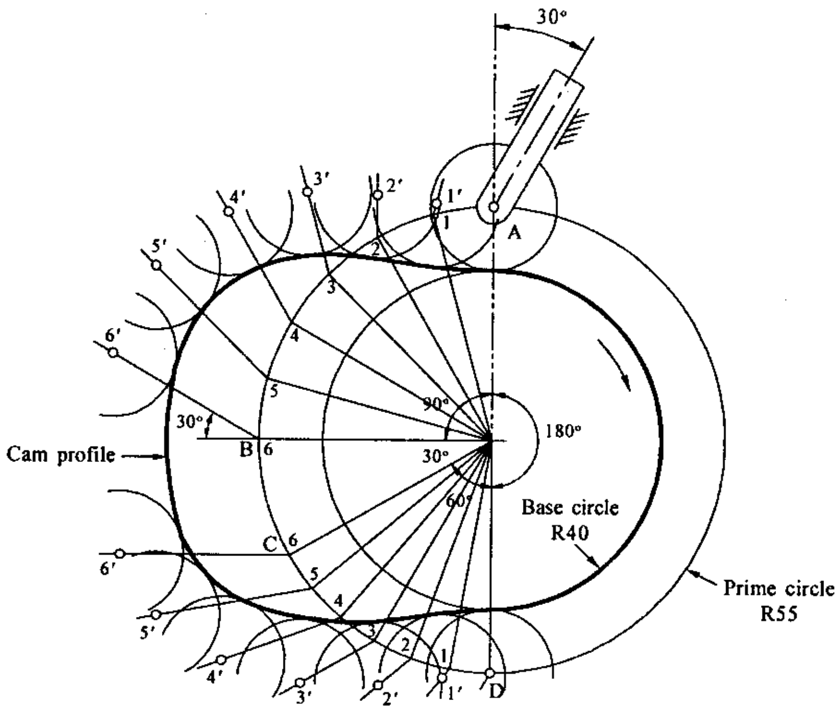


Fig. 8.30 (b)

5. Mark off the angle AOB = 90°, angle BOC = 30°, angle COD = 60° and angle DOA = 180° in a direction opposite that of the cam's rotation to represent ascent, dwell, descent and dwell respectively.
6. Divide the angular displacement during ascent (arc AB on the prime circle) and angular displacement during descent (arc CD on the prime circle) each into 6 equal parts and number then as 1, 2, 3, ... etc.

7. From O, draw radial lines to these points.
8. From points 1, 2, 3, ... etc., draw lines inclined to the radial lines at an angle of 30° as shown to represent the path of the follower link.
9. Transfer the displacements 11', 22', etc from the displacement diagram to the appropriate 30° lines, measuring from the prime circle to get points 1', 2', ... etc.
10. With the pints thus obtained as centers draw the follower outlines.
11. Draw a smooth curve tangent to these follower outlines during ascent and descent.
12. With O as center draw an arc, tangent to the follower outlines located at 6' and 6' to get the dwell in the lifted position.
13. With O as center draw an arc, tangent to the follower outlines at A and D to represent the dwell in the lowest position.

Example 8.17

Draw the cam profile for cam with roller reciprocating follower. The axis of the follower passes through the axis of the cam. Particulars of the cam and the follower motion are as follows :

Roller diameter	= 10 mm
Minimum radius of the cam	= 20 mm
Total lift	= 25 mm

The cam has to lift the follower with simple harmonic motion during 180° of cam rotation, then allow the follower to drop suddenly half way, and further return the follower with uniform velocity during the remaining 180° of cam rotation. Show the position of the key on the camshaft to which the cam is mounted. The cam rotates in anti-clockwise direction.

Solution :

First draw the displacement diagram as shown in fig. 8.30a, and proceed for the drawing the profile of the cam in the similar way as described in the previous problems. The profile of the cam is shown in fig. 8.30 b.

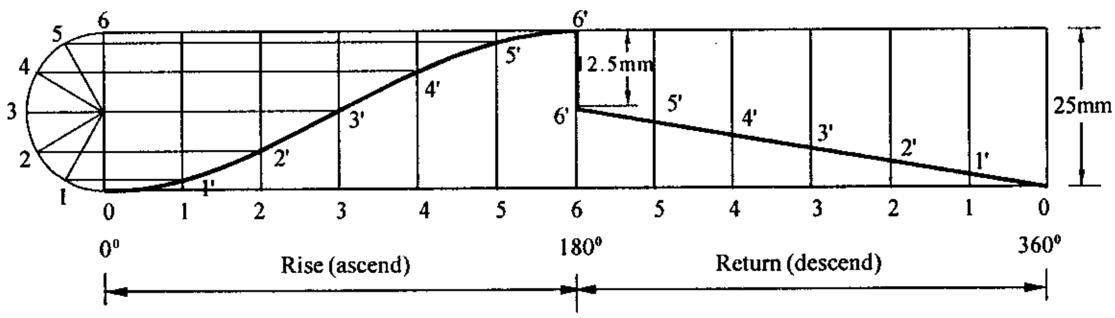


Fig. 8.30 (a)

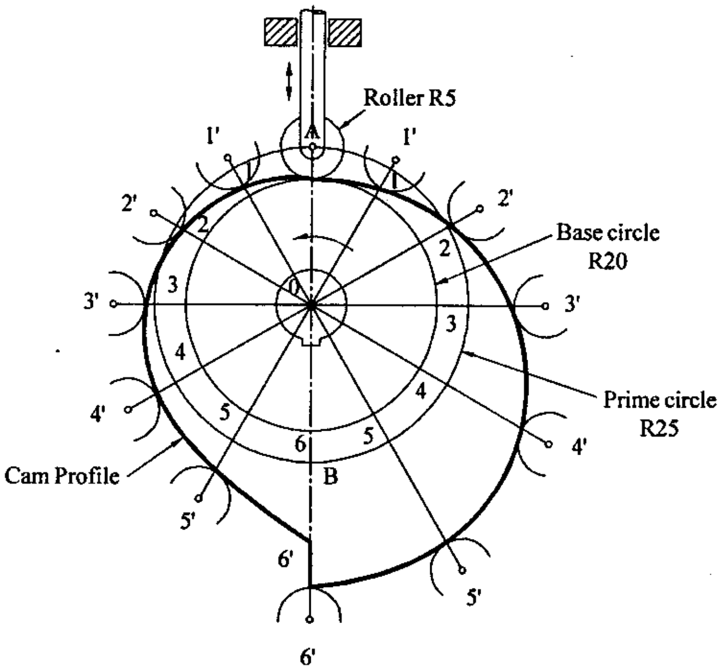


Fig. 8.30 (b)

Positive - return cam : In all cam systems, the positive contact between the cam and the follower during return stroke is maintained by gravity or by suitable spring. Fig. 8.31 shows a positive -return disc cam with a flat - face follower. The cam must be designed to give same motion characteristics during the outward and return stroke so that the distance between the faces is constant at all times. In order to achieve different motions on the outward and the return strokes with a positive return disc cam, it is necessary to use two discs such that each disc drives in one direction. If the disc cam is circular in shape, and the center of the camshaft is located other than at the center of the circle, the resulting mechanism is the Scotch yoke mechanism.

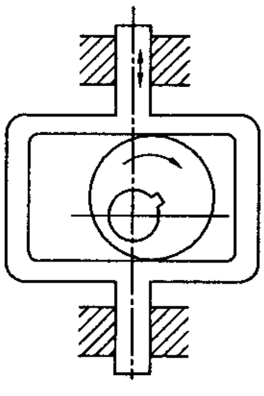


Fig. 8.31

Example 6.18

A positive return cam rotating clockwise drives a flat faced yoke as shown in fig. 6.23. The lift for the outward motion is as follows.

Cam angle $\theta°$	0	30	60	90	120	150	180
Lift S (mm)	0	2	4.5	10	17	23.5	25.5

Layout the cam using a minimum radius of 25 mm. Complete the proportionate sketch of the follower.

Solution :

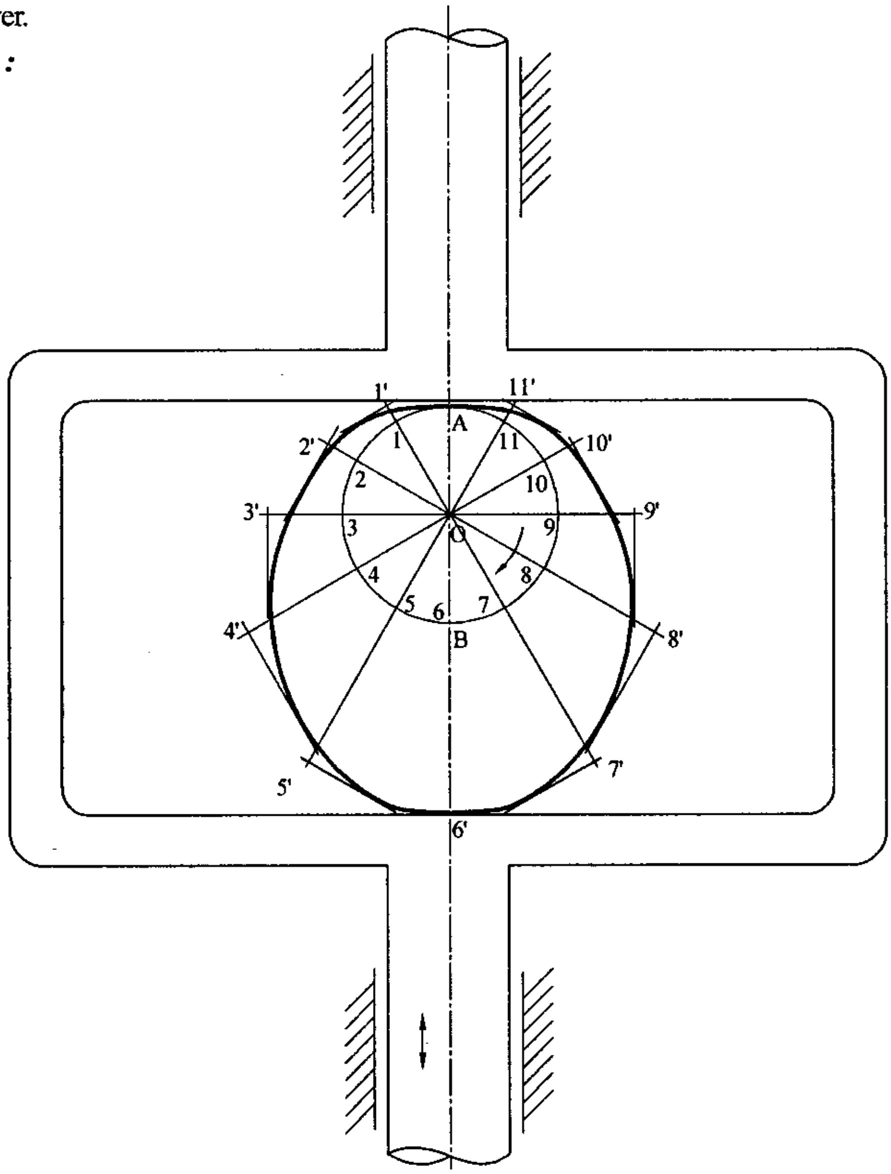


Fig. 8.32

Construction : *(Refer fig. 8.32)*

1. Draw the base circle with center O and radius equal to 25 mm.
2. Mark the angle AOB = 180° and BOA = 180° in a direction opposite to that of the cam's rotation.
3. Divide the angular displacement during outward stroke (angle AOB) and return stroke (angle BOA) each into 6 equal parts (∵ the step value given in the table is 30°).
4. Draw radial lines through each of these points.
5. Transfer displacements form the displacement table to the appropriate radial lines, measuring from the base circle to get points 1', 2', 3', etc.
6. Draw line perpendicular to the appropriate radial line through the points 1', 2', etc., to represent the follower profile.
7. Draw a smooth cam profile tangent to each of the follower profile.
8. Complete the proportionate sketch of the flat faced yoke follower as shown in the figure.

EXERCISE - 8

1. A cam with 25 mm as minimum radius is rotating in clockwise direction at a uniform speed of 600 rpm and has to give the motion to the knife-edge follower as defined below :
   1. Follower to move outwards through 25 mm during 180° of cam rotating with UARM.
   2. Follower to dwell for the next 60° of cam rotation.
   3. Follower to return to its starting position during the rest of the cam rotation with SHM.

   Draw the cam profile when
   a) Follower axis passes through the axis of the cam, and
   b) Follower axis is offset to right by 10 mm from the axis of the cam. Determine the maximum velocity and acceleration during out-stroke and return stroke.

   [**Ans.** 1 m/s, 40 m/s^2, 1.178 m/s, 111.03 m/s^2]
2. Draw the profile of a cam with roller reciprocating follower. The cam is to lift the follower with uniform equal acceleration and retardation during 1/2 of the cam rotation, then allow the follower to drop suddenly to a distance equal to 1/4 the lift, and then to return to its initial position with SHM during the remaining 1/2 the cam rotation. The cam rotates at a uniform speed of 400 rpm in counter clockwise direction. The base circle radius of the cam is 40 mm, the diameter of the roller is 20 mm and the lift is 40 mm. Draw the profile of the cam with the roller follower, when

   a) Line of stroke of the follower passes through the center of the cam shaft and
   b) Line of stroke of the follower is offset 10 mm towards the left from the axis of the cam shaft.

   Find the maximum velocity and acceleration of the follower during its outward stroke and inward stroke. [**Ans.** 1.06 m/s, 28.44 m/s^2, 0.628 m/s, 26.32 m/s^2]

3. A push rod operated by a cam is to rise and fall with SHM along an inclined straight path. The maximum radius of the cam is 30 mm and the push rod is fitted at its lower end with a roller of 18 mm diameter. The roller center is vertically above the cam center in its lowest position and the inclination of the stroke is 30° to the right of the vertical line. The maximum displacement of the roller along its line of stroke is 40 mm. The cam rotates at 100 rpm in clockwise direction. The time for rise is 0.2 second, dwell period at the maximum lifted position is 0.05 second, the time for fall is 0.15 second, and the rest is the dwell period. Draw the cam profile.
4. The following table gives the value of lift S of the roller follower for angular displacement θ of the cam shaft.

θ°	0	45	60	90	120	150	180	210	225	240	270	300	350	360
S(mm)	0	0	1.0	3.5	9.5	13.5	15.5	20	20	19.5	13.5	2.5	0	0

The diameter of the roller is 15 mm and the minimum distance between the center of the roller and the center of the cam is to be 30 mm. The cam rotates at 420 rpm in clockwise direction. Draw the contour of the cam when,

a) the line of stroke of the follower passes through the cam center and

b) the line of stroke passes 8 mm to the left of the center of the cam shaft.

5. A cam rotates at uniform speed of 300 rpm in clockwise direction gives an oscillating follower 70 mm long, an angular displacement of 18° in each stroke. The follower is fitted with a roller 25 mm diameter which makes contact with the cam. The outward and inward displacement of the follower each occupy 72° cam rotation with equal intervals between these movements. The outward and inward stroke both take place with SHM. The axis of the fulcrum is 100 mm from the axis of the cam and the distance between the roller center and the cam center is 55 mm. Draw the cam profile.
6. Draw the profile of the cam with knife edge follower. The follower is raised through a distance of 30 mm in 1/3 revolution of the cam and is lowered in 1/3 revolution with equal intervals between these movements. The least radius of the cam is 30 mm and the line of stroke of the follower passes through the center line of the cam shaft. The follower must move with the following data.

   Out stroke : SHM, Return stroke: Constant acceleration 80° and constant retardation 40°
7. Draw the profile of a cam operating a roller reciprocating follower with the following data: Minimum radius of cam = 25 mm, lift = 30 mm, roller diameter = 15 mm. The cam lift the follower for 120° with SHM followed by a dwell period of 30°. Then the follower lowers down during 150° of the cam rotation with uniform acceleration and deceleration followed by a dwell period. If the cam rotates at a uniform speed of 150 rpm, calculate the maximum velocity and acceleration of the follower during return. **(VTU, July 2002)**

   [**Ans.** 0.36 m/s, 4.32 m/s^2]

8. The following data relate to a cam profile in which the roller follower moves with uniform acceleration and retardation motion during ascent and descent.

   Minimum radius of cam = 25 mm, roller radius = 8 mm, lift = 32 mm, offset of follower axis = 12 mm, angle of ascent = 60°, angle of descent = 90°, angle of dwell between ascent and descent = 45°, speed of the cam = 200 rpm. Draw the cam profile. **(VTU, Jan 2007)**

9. A cam rotates at a uniform speed of 300 rpm clockwise and gives an oscillating follower of 75 mm long, an angular displacement of 30° in each stroke. The follower if fitted with a roller of 20 mm diameter which makes contact with the cam. The outward and inward displacemnets of the follower each occupying 120° cam rotation and there is no dwell in the lifted position. The follower moves throughout with SHM. The axis of the fulcrum is 80 mm from the axis of the cam and the least distance of roller axis from cam axis is 40 mm. **(VTU, Jan 2004)**

8. Draw the profile of the cam for the following details:
   a. Minimum radius of the cam - 20 mm
   b. Rotation - counter clockwise at 1000 rpm.
   c. Outward stroke - UARM - 120°.
   d. Follower - 10 mm dia roller
   e. Lift of the follower - 20 mm
   f. Dwell at full lift - 60°
   g. Return stroke - SHM during 120°
   h. Offset - follower axis 5 mm to the right of the axis of cam

   Calculate the maximum acceleration during return stroke. **(VTU, Jan 2008)**

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