Chapter VI
CAMS

INTRODUCTION

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. A familiar example is the camshaft of an automobile engine, where the cams drive the push rods (the followers) to open and close the valves in synchronization with the motion of the pistons.

Types of cams

Cams can be classified based on their physical shape.

a) Disk or plate cam (Fig. 6.1a and b): The disk (or plate) cam has an irregular contour to impart a specific motion to the follower. The follower moves in a plane perpendicular to the axis of rotation of the camshaft and is held in contact with the cam by springs or gravity.

Fig. 6.1 Plate or disk cam.

b) Cylindrical cam (Fig. 6.2): The cylindrical cam has a groove cut along its cylindrical surface. The roller follows the groove, and the follower moves in a plane parallel to the axis of rotation of the cylinder.

Fig. 6.2 Cylindrical cam.

c) Translating cam (Fig. 6.3a and b). The translating cam is a contoured or grooved plate sliding on a guiding surface(s). The follower may oscillate (Fig. 6.3a) or reciprocate (Fig. 6.3b). The contour or the shape of the groove is determined by the specified motion of the follower.
Fig. 6.3 Translating cam

**Types of followers:**

(i) Based on surface in contact. (*Fig. 6.4*)

(a) Knife edge follower
(b) Roller follower
(c) Flat faced follower
(d) Spherical follower

(ii) Based on type of motion: (*Fig. 6.5*)

(a) Oscillating follower
(b) Translating follower
(iii) Based on line of motion:

(a) Radial follower: The lines of movement of in-line cam followers pass through the centers of the camshafts (Fig. 6.4a, b, c, and d).

(b) Off-set follower: For this type, the lines of movement are offset from the centers of the camshafts (Fig. 6.6a, b, c, and d).

![Fig. 6.6 Off set followers](image)

**Cam nomenclature (Fig. 6.7):**

- **Cam Profile**: The contour of the working surface of the cam.
- **Tracer Point**: The point at the knife edge of a follower, or the center of a roller, or the center of a spherical face.
- **Pitch Curve**: The path of the tracer point.
Base Circle  The smallest circle drawn, tangential to the cam profile, with its center on the axis of the camshaft. The size of the base circle determines the size of the cam.

Prime Circle  The smallest circle drawn, tangential to the pitch curve, with its center on the axis of the camshaft.

Pressure Angle  The angle between the normal to the pitch curve and the direction of motion of the follower at the point of contact.

Types of follower motion:
Cam follower systems are designed to achieve a desired oscillatory motion. Appropriate displacement patterns are to be selected for this purpose, before designing the cam surface. The cam is assumed to rotate at a constant speed and the follower raises, dwells, returns to its original position and dwells again through specified angles of rotation of the cam, during each revolution of the cam.

Some of the standard follower motions are as follows:
They are, follower motion with,
  (a) Uniform velocity
  (b) Modified uniform velocity
  (c) Uniform acceleration and deceleration
  (d) Simple harmonic motion
  (e) Cycloidal motion

Displacement diagrams: In a cam follower system, the motion of the follower is very important. Its displacement can be plotted against the angular displacement $\theta$ of the cam and it is called as the displacement diagram. The displacement of the follower is plotted along the y-axis and angular displacement $\theta$ of the cam is plotted along x-axis. From the displacement diagram, velocity and acceleration of the follower can also be plotted for different angular displacements $\theta$ of the cam. The displacement, velocity and acceleration diagrams are plotted for one cycle of operation i.e., one rotation of the cam. Displacement diagrams are basic requirements for the construction of cam profiles. Construction of displacement diagrams and calculation of velocities and accelerations of followers with different types of motions are discussed in the following sections.

(a) Follower motion with Uniform velocity:
Fig.6.8 shows the displacement, velocity and acceleration patterns of a follower having uniform velocity type of motion. Since the follower moves with constant velocity, during rise and fall, the displacement varies linearly with $\theta$. Also, since the velocity changes from zero to a finite value, within no time, theoretically, the acceleration becomes infinite at the beginning and end of rise and fall.
(b) Follower motion with modified uniform velocity:

It is observed in the displacement diagrams of the follower with uniform velocity that the acceleration of the follower becomes infinite at the beginning and ending of rise and return strokes. In order to prevent this, the displacement diagrams are slightly modified. In the modified form, the velocity of the follower changes uniformly during the beginning and end of each stroke. Accordingly, the displacement of the follower varies parabolically during these periods. With this modification, the acceleration becomes constant during these periods, instead of being infinite as in the uniform velocity type of motion. The displacement, velocity and acceleration patterns are shown in fig.6.9.
(c) **Follower motion with uniform acceleration and retardation (UARM):**

Here, the displacement of the follower varies parabolically with respect to angular displacement of cam. Accordingly, the velocity of the follower varies uniformly with respect to angular displacement of cam. The acceleration/retardation of the follower becomes constant accordingly. The displacement, velocity and acceleration patterns are shown in fig. 6.10.
\(s = \text{Stroke of the follower}\)

\(\theta_o \text{ and } \theta_r = \text{Angular displacement of the cam during outstroke and return stroke.}\)

\(\omega = \text{Angular velocity of cam.}\)

Time required for follower outstroke = \(t_o = \frac{\theta_o}{\omega}\)

Time required for follower return stroke = \(t_r = \frac{\theta_r}{\omega}\)

Average velocity of follower = \(\frac{s}{t}\)
Average velocity of follower during outstroke = \( \frac{s}{2} \) = \( \frac{s}{t_o} = \frac{v_{o \text{min}} + v_{o \text{max}}}{2} \)

\( v_{o \text{min}} = 0 \)

\( \therefore v_{o \text{max}} = \frac{2s}{t_o} = \frac{2\omega s}{\theta_o} = \text{Max. velocity during outstroke.} \)

Average velocity of follower during return stroke = \( \frac{s}{2} \) = \( \frac{s}{t_r} = \frac{v_{r \text{min}} + v_{r \text{max}}}{2} \)

\( v_{r \text{min}} = 0 \)

\( \therefore v_{r \text{max}} = \frac{2s}{t_r} = \frac{2\omega s}{\theta_r} = \text{Max. velocity during return stroke.} \)

Acceleration of the follower during outstroke = \( a_o = \frac{v_{o \text{max}}}{t_o/2} = \frac{4\omega^2 s}{\theta_o^2} \)

Similarly acceleration of the follower during return stroke = \( a_r = \frac{4\omega^2 s}{\theta_r^2} \)

(d) Simple Harmonic Motion: In fig.6.11, the motion executed by point \( P' \), which is the projection of point \( P \) on the vertical diameter is called simple harmonic motion. Here, \( P \) moves with uniform angular velocity \( \omega_p \), along a circle of radius \( r \) (\( r = s/2 \)).

![Simple Harmonic Motion Diagram](image)

Displacement = \( y = r \sin \alpha = r \sin \omega_p t \); \( y_{\text{max}} = r \) \hspace{1cm} [d1]

Velocity = \( \dot{y} = \omega_p r \cos \omega_p t \); \( \dot{y}_{\text{max}} = r\omega_p \) \hspace{1cm} [d2]

Acceleration = \( \ddot{y} = -\omega_p^2 r \sin \omega_p t = -\omega_p^2 y \); \( \ddot{y}_{\text{max}} = -r\omega_p^2 \) \hspace{1cm} [d3]
s= Stroke or displacement of the follower.

θ_o = Angular displacement during outstroke.

θ_r = Angular displacement during return stroke

ω = Angular velocity of cam.

\[ t_o = \frac{\theta_o}{\omega} \]

\[ t_r = \frac{\theta_r}{\omega} \]

Max. velocity of follower during outstroke = \( v_{o\text{max}} = r\omega_p \) (from d2)

\[ v_{o\text{max}} = \frac{s}{2} \frac{\pi}{t_o} = \frac{\pi \omega s}{2 \theta_o} \]

Similarly, Max. velocity of follower during return stroke = \( v_{r\text{max}} = \frac{s}{2} \frac{\pi}{t_r} = \frac{\pi \omega s}{2 \theta_r} \)

Max. acceleration during outstroke = \( a_{o\text{max}} = r\omega_p^2 \) (from d3)

\[ a_{o\text{max}} = \frac{s}{2} \left( \frac{\pi}{t_o} \right)^2 = \frac{\pi^2 \omega^2 s}{2 \theta_o^2} \]

Similarly, Max. acceleration during return stroke = \( a_{r\text{max}} = \frac{s}{2} \left( \frac{\pi}{t_r} \right)^2 = \frac{\pi^2 \omega^2 s}{2 \theta_r^2} \)
(e) Cycloidal motion:
Cycloid is the path generated by a point on the circumference of a circle, as the circle rolls without slipping, on a straight/flat surface. The motion executed by the follower here, is similar to that of the projection of a point moving along a cycloidal curve on a vertical line as shown in figure 6.12.

![Fig.6.12](image)

The construction of displacement diagram and the standard patterns of velocity and acceleration diagrams are shown in fig.6.13. Compared to all other follower motions, cycloidal motion results in smooth operation of the follower.

The expressions for maximum values of velocity and acceleration of the follower are shown below.

\[ s = \text{Stroke or displacement of the follower.} \]

\[ d = \text{dia. of cycloid generating circle} = \frac{s}{\pi} \]

\[ \theta_o = \text{Angular displacement during outstroke.} \]

\[ \theta_r = \text{Angular displacement during return stroke} \]

\[ \omega = \text{Angular velocity of cam.} \]

\[ t_o = \text{Time taken for outstroke} = \frac{\theta_o}{\omega} \]

\[ t_r = \text{Time taken for return stroke} = \frac{\theta_r}{\omega} \]

\[ v_{o_{\text{max}}} = \text{Max. velocity of follower during outstroke} = \frac{2\omega s}{\theta_o} \]

\[ v_{r_{\text{max}}} = \text{Max. velocity of follower during return stroke} = \frac{2\omega s}{\theta_r} \]
\[ a_{o\text{max}} = \text{Max. acceleration during outstroke} = \frac{2\pi \omega^2 s}{\theta_o^2} \]

\[ a_{r\text{max}} = \text{Max. acceleration during return stroke} = \frac{2\pi \omega^2 s}{\theta_r^2} \]

Fig. 6.13
Solved problems
(1) Draw the cam profile for following conditions:

Follower type = Knife edged, in-line; lift = 50mm; base circle radius = 50mm; out stroke with SHM, for $60^\circ$ cam rotation; dwell for $45^\circ$ cam rotation; return stroke with SHM, for $90^\circ$ cam rotation; dwell for the remaining period. Determine max. velocity and acceleration during out stroke and return stroke if the cam rotates at 1000 rpm in clockwise direction.

Displacement diagram:

Cam profile: Construct base circle. Mark points 1,2,3….. in direction opposite to the direction of cam rotation. Transfer points a,b,c…..l from displacement diagram to the cam profile and join them by a smooth free hand curve. This forms the required cam profile.
Calculations:

Angular velocity of cam = \( \omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 1000}{60} = 104.76 \text{ rad/sec} \)

Max. velocity of follower during outstroke = \( v_{o_{max}} = \frac{\pi \omega s}{2\theta_o} = \)

\[ = \frac{\pi \times 104.76 \times 50}{2 \times \pi / 3} = 7857 \text{mm/sec} = 7.857 \text{m/sec} \]

Similarly Max. velocity of follower during return stroke = \( v_{r_{max}} = \frac{\pi \omega s}{2\theta_r} = \)

\[ = \frac{\pi \times 104.76 \times 50}{2 \times \pi / 2} = 5238 \text{mm/sec} = 5.238 \text{m/sec} \]

Max. acceleration during outstroke = \( a_{o_{max}} = r\omega^2 \) (from d3) = \( \frac{\pi^2 \omega^2 s}{2\theta_o^2} = \)

\[ = \frac{\pi^2 \times (104.76)^2 \times 50}{2 \times \left(\frac{\pi}{3}\right)^2} = 2469297.96 \text{mm/sec}^2 = 2469.3 \text{m/sec}^2 \]

Similarly, Max. acceleration during return stroke = \( a_{r_{max}} = \frac{\pi^2 \omega^2 s}{2\theta_r^2} = \)

\[ = \frac{\pi^2 \times (104.76)^2 \times 50}{2 \times \left(\frac{\pi}{2}\right)^2} = 1097465.76 \text{mm/sec}^2 = 1097.5 \text{m/sec}^2 \]
(2) Draw the cam profile for the same operating conditions of problem (1), with the follower offset by 10 mm to the left of cam center.

Displacement diagram: Same as previous case.

Cam profile: Construction is same as previous case, except that the lines drawn from 1, 2, 3,... are tangential to the offset circle of 10mm dia. as shown in the fig.
(3) **Draw the cam profile for following conditions:**

Follower type = roller follower, in-line; lift = 25mm; base circle radius = 20mm; roller radius = 5mm; out stroke with UARM, for 120° cam rotation; dwell for 60° cam rotation; return stroke with UARM, for 90° cam rotation; dwell for the remaining period. Determine max. velocity and acceleration during out stroke and return stroke if the cam rotates at 1200 rpm in clockwise direction.

**Displacement diagram:**

![Displacement diagram](image_url)

**Cam profile:** Construct base circle and prime circle (25mm radius). Mark points 1,2,3…..in direction opposite to the direction of cam rotation, on prime circle. Transfer points a,b,c…..l from displacement diagram. At each of these points a,b,c… draw circles of 5mm radius, representing rollers. Starting from the first point of contact between roller and base circle, draw a smooth free hand curve, tangential to all successive roller positions. This forms the required cam profile.
Calculations:

Angular velocity of the cam = \( \omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 1200}{60} = 125.71 \text{rad/sec} \)

Max. velocity during outstroke = \( v_{o\text{max}} = \frac{2s}{t_o} = \frac{2\omega s}{\theta_o} = \)

\[ = \frac{2 \times 125.71 \times 25}{2 \times \pi / 3} = 2999.9 \text{mm/sec} = 2.999 \text{m/sec} \]

Max. velocity during return stroke = \( v_{r\text{max}} = \frac{2s}{t_r} = \frac{2\omega s}{\theta_r} = \frac{2 \times 125.71 \times 25}{\pi / 2} = \)

\[ = 3999.86 \text{mm/sec} = 3.999 \text{m/sec} \]

Acceleration of the follower during outstroke = \( a_o = \frac{v_{o\text{max}}}{t_o/2} = \frac{4\omega^2 s}{\theta_o^2} = \)

\[ = \frac{4 \times (125.71)^2 \times 25}{(2 \times \pi / 3)^2} = 35975 \text{mm/sec}^2 = 359.975 \text{m/sec}^2 \]

Similarly acceleration of the follower during return stroke = \( a_r = \frac{4\omega^2 s}{\theta_r^2} = \)

\[ = \frac{4 \times (125.71)^2 \times 25}{(\pi / 2)^2} = 63956 \text{mm/sec}^2 = 639.956 \text{m/sec}^2 \]
(4) Draw the cam profile for conditions same as in (3), with follower off set to right of cam center by 5mm and cam rotating counter clockwise.

Displacement diagram: Same as previous case.

Cam profile: Construction is same as previous case, except that the lines drawn from 1,2,3,… are tangential to the offset circle of 10mm dia. as shown in the fig.
(5) **Draw the cam profile for following conditions:**

Follower type = roller follower, off set to the right of cam axis by 18mm; lift = 35mm; base circle radius = 50mm; roller radius = 14mm; out stroke with SHM in 0.05sec; dwell for 0.0125sec; return stroke with UARM, during 0.125sec; dwell for the remaining period. During return stroke, acceleration is 3/5 times retardation. Determine max. velocity and acceleration during out stroke and return stroke if the cam rotates at 240 rpm.

**Calculations:**

Cam speed = 240rpm. Therefore, time for one rotation = \( \frac{60}{240} = 0.25 \text{sec} \)

Angle of out stroke = \( \theta_o = \frac{0.05}{0.25} \times 360 = 72^\circ \)

Angle of first dwell = \( \theta_{w1} = \frac{0.0125}{0.25} \times 360 = 18^\circ \)

Angle of return stroke = \( \theta_r = \frac{0.125}{0.25} \times 360 = 180^\circ \)

Angle of second dwell = \( \theta_{w2} = 90^\circ \)

Since acceleration is 3/5 times retardation during return stroke,

\[ a = \frac{3}{5}r \text{ (from acceleration diagram)} \therefore \frac{a}{r} = \frac{3}{5} \]

But \[ a = \frac{v_{\text{max}}}{t_a} ; r = \frac{v_{\text{max}}}{t_r} \therefore \frac{a}{r} = \frac{t_r}{t_a} = \frac{3}{5} \]

Displacement diagram is constructed by selecting \( t_a \) and \( t_r \) accordingly.
Angular velocity of cam = \( \omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 240}{60} = 25.14 \text{ rad/sec} \)

Max. velocity of follower during outstroke = \( v_{o\text{max}} = \frac{\pi \omega s}{\theta_o} = \frac{\pi \times 25.14 \times 35}{2 \times (2 \times \pi / 5)} = 1099.87 \text{ mm/sec} = 1.1 \text{ m/sec} \)

Similarly Max. velocity during return stroke = \( v_{r\text{max}} = \frac{\pi \omega s}{\theta_r} = \frac{\pi \times 25.14 \times 35}{5 \times \pi \times \pi} = 559.9 \text{ mm/sec} = 0.56 \text{ m/sec} \)

Max. acceleration during outstroke = \( a_{o\text{max}} = \frac{r \omega^2}{s} \) (from d3) = \( \frac{\pi^2 \omega^2 s}{2 \theta_o^2} = \frac{\pi^2 \times (25.14)^2 \times 35}{2 \times (2 \times \pi / 5)^2} = 69127.14 \text{ mm/sec}^2 = 69.13 \text{ m/sec}^2 \)

acceleration of the follower during return stroke =
\[ a_r = \frac{v_{r\text{max}}}{t_r} = \frac{2\omega s}{5 \times \pi / 8 \times \omega} = \frac{16 \times \omega^2 \times s}{5 \times \pi \times \theta_r} = \frac{16 \times (25.14)^2 \times 35}{5 \times \pi \times \pi} = 7166.37 \text{ mm/sec}^2 = 7.17 \text{ m/sec}^2 \]

similarly retardation of the follower during return stroke =
\[ r_r = \frac{v_{r\text{max}}}{t_r} = \frac{2\omega s}{3 \times \pi / 8 \times \omega} = \frac{16 \times \omega^2 \times s}{3 \times \pi \times \theta_r} = \frac{16 \times (25.14)^2 \times 35}{3 \times \pi \times \pi} = 11943.9 \text{ mm/sec}^2 = 11.94 \text{ m/sec}^2 \]
(6) Draw the cam profile for following conditions:
Follower type = knife edged follower, in line; lift = 30mm; base circle radius = 20mm; out stroke with uniform velocity in 120° of cam rotation; dwell for 60°; return stroke with uniform velocity, during 90° of cam rotation; dwell for the remaining period.

Displacement diagram:

Cam profile:
(7) **Draw the cam profile for following conditions:**

Follower type = oscillating follower with roller as shown in fig.; base circle radius = 20mm; roller radius = 7mm; follower to rise through 40° during 90° of cam rotation with cycloidal motion; dwell for 30°; return stroke with cycloidal motion during 120° of cam rotation; dwell for the remaining period. Also determine the max. velocity and acceleration during outstroke and return stroke, if the cam rotates at 600 rpm.

Lift of the follower = \( S = \text{length AB} \approx \text{arc AB} = OA \times \theta = 76 \times 40 \times \frac{\pi}{180} = 53 \text{ mm.} \)

Radius of cycloid generating circle = \( \frac{53}{2 \times \pi} = 8.4 \text{ mm} \)

**Displacement diagram;**
Angular velocity of cam = \( \omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 600}{60} = 62.86 \) rad/sec

\( v_{o_{\text{max}}} = \text{Max. velocity of follower during outstroke} = \frac{2\omega s}{\phi_o} = \frac{2 \times 62.86 \times 53}{\pi} = 4240.2 \text{ mm/sec} \)

\( v_{r_{\text{max}}} = \text{Max. velocity of follower during return stroke} = \frac{2\omega s}{\phi_r} = \frac{2 \times 62.86 \times 53}{\frac{2 \times \pi}{3}} = 3180 \text{ mm/sec} \)

\( a_{o_{\text{max}}} = \text{Max. acceleration during outstroke} = \frac{2\pi \omega^2 s}{\phi_o^2} = \frac{2 \times \pi \times (62.86)^2 \times 53}{\left(\frac{\pi}{2}\right)^3} = 533077 \text{ mm/sec}^2 = 533.1 \text{ m/sec}^2. \)

\( a_{r_{\text{max}}} = \text{Max. acceleration during return stroke} = \frac{2\pi \omega^2 s}{\phi_r^2} = \frac{2 \times \pi \times (62.86)^2 \times 53}{\left(\frac{2 \times \pi}{3}\right)^3} = 299855.8 \text{ mm/sec}^2 = 299.8 \text{ m/sec}^2. \)

**Cam profile:** Draw base circle and prime circle. Draw another circle of radius equal to the distance between cam center and follower pivot point. Take the line joining cam center and pivot point as reference and draw lines indicating successive angular displacements of cam. Divide these into same number of divisions as in the displacement diagram. Show points 1’, 2’, 3’… on the outer circle. With these points as centers and radius equal to length of follower arm, draw arcs, cutting the prime circle at 1,2,3…. Transfer points a,b,c.. on to these arcs from displacement diagram. At each of these points a,b,c… draw circles of 7mm radius, representing rollers. Starting from the first point of contact between roller and base circle, draw a smooth free hand curve, tangential to all successive roller positions. This forms the required cam profile.
(8) Draw the cam profile for following conditions:

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

Angle of out stroke (1) = \( \theta_{01} = \frac{1}{4} \times 360^\circ = 90^\circ \)

Angle of dwell (1) = \( \frac{1}{8} \times 360^\circ = 45^\circ \)

Angle of out stroke (2) = \( \theta_{02} = \frac{1}{4} \times 360^\circ = 90^\circ \)

Angle of dwell (2) = \( \frac{1}{16} \times 360^\circ = 22.5^\circ \)

Angle of return stroke = \( \theta_r = \left[ 1 - \left( \frac{1}{4} + \frac{1}{8} + \frac{1}{4} + \frac{1}{16} \right) \right] \times 360 = \frac{5}{16} \times 360^\circ = 112.5^\circ \)

Displacement diagram:
(9) **Draw the cam profile for following conditions:**

Follower type = flat faced follower, in line; follower rises by 20mm with SHM in 120° of cam rotation, dwells for 30° of cam rotation; returns with SHM in 120° of cam rotation and dwells during the remaining period. Base circle radius = 25mm.

**Displacement diagram:**

**Cam profile:** Construct base circle. Mark points 1,2,3.....in direction opposite to the direction of cam rotation, on prime circle. Transfer points a,b,c.....l from displacement diagram. At each of these points a,b,c... draw perpendicular lines to the radials, representing flat faced followers. Starting from the first point of contact between follower and base circle, draw a smooth free hand curve, tangential to all successive follower positions. This forms the required cam profile.
Draw the cam profile for following conditions:
Follower type = roller follower, in line; roller dia. = 5mm; follower rises by 25mm with SHM in 180° of cam rotation, falls by half the distance instantaneously; returns with Uniform velocity in 180° of cam rotation. Base circle radius = 20m.

Displacement diagram:

Cam profile:
(11) **Draw the cam profile for following conditions:**

Follower type = roller follower, off-set to the right by 5mm; lift = 30mm; base circle radius = 25mm; roller radius = 5mm; out stroke with SHM, for 120° cam rotation; dwell for 60° cam rotation; return stroke during 120° cam rotation; first half of return stroke with Uniform velocity and second half with UARM; dwell for the remaining period.

**Displacement diagram:**

![Displacement diagram](image)

**Cam profile:**

![Cam profile](image)
A push rod of valve of an IC engine ascends with UARM, along a path inclined to the vertical at 60°. The same descends with SHM. The base circle diameter of the cam is 50mm and the push rod has a roller of 60mm diameter, fitted to its end. The axis of the roller and the cam fall on the same vertical line. The stroke of the follower is 20mm. The angle of action for the outstroke and the return stroke is 60° each, interposed by a dwell period of 60°. Draw the profile of the cam.

Displacement diagram:

Cam profile: