

CAMS:

- OVER VIEW

1. Introduction to Cams.
2. CAMS and its classification.
3. Followers and its classification.
4. Terminologies used in CAMS. (Cams nomenclature)
5. Follower motion and motion analysis of SHM.
6. Motion with uniform acceleration and deceleration.
7. Motion with uniform velocity.
8. cycloidal motion.
9. Cams profile with different followers.
10. Numericals.

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## 4.1: INTRODUCTION:

A Cam is basically a rotating machine Element provides rotatory, reciprocating or Oscillating motion to the other Element which is attached to it known as a follower.

A Cam can also be defined as an rotating machine element which converts rotatory motion into the reciprocating motion. The Cam may be rotating or reciprocating whereas the follower may be rotating, reciprocating or Oscillating.

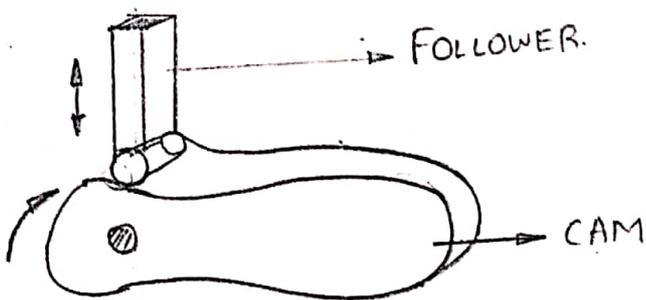
Any desired complicated output motions which are difficult otherwise to achieve can be easily obtained with the help of Cams.

The cams have wide variety of applications in Internal Combustion (IC) Engines, Machine tools, printing control mechanism etc.

## 4.2: CAM MECHANISMS:

The necessary elements of a cam mechanisms are:

- A driver member known as the Cam.
- A driven member called the Follower.
- A frame which acts as the support and guide the follower. Refer fig 4-1.



(Fig 4-1)

3: CAMS Classification:

Based on the construction of the cams, it is classified as  
(i) Radial Cam (also called Disc Cam). (iv) spiral (or) Face Cams  
(ii) Cylindrical cam. (v) spherical cams  
(iii) Wedge Cam. (vi) Conjugate Cams.

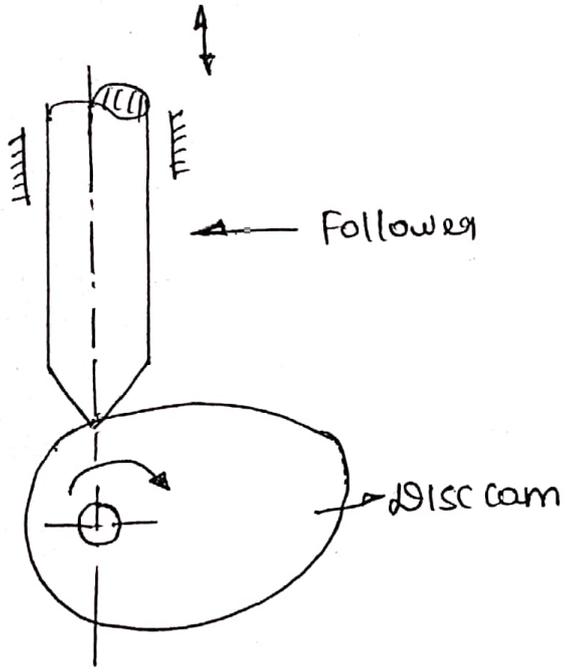


Fig 4.2(a) Disc Cam.

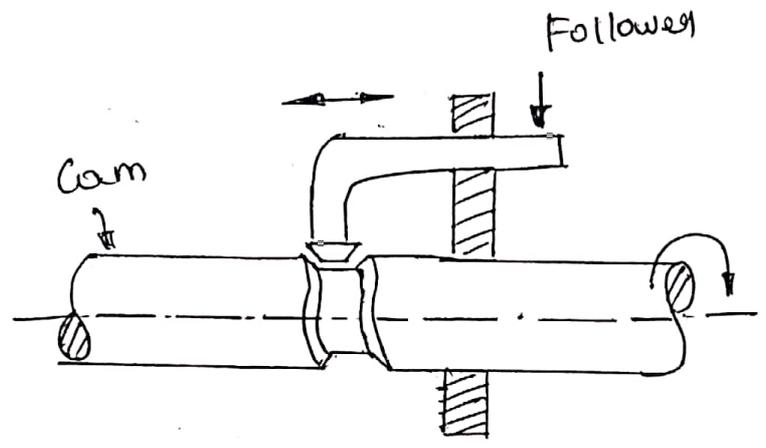


Fig 4.2(b): cylindrical cam.

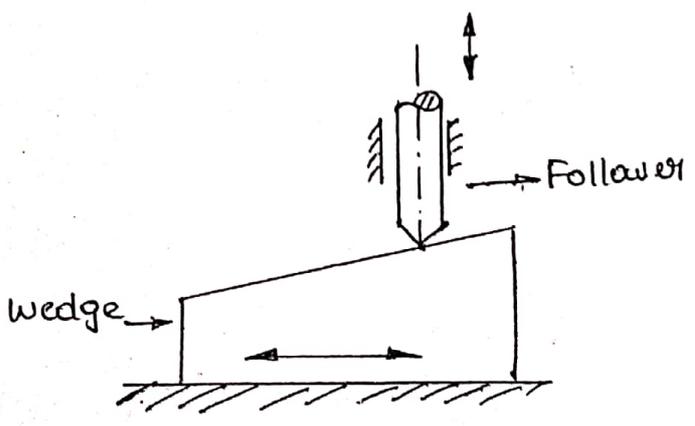


Fig 4.2(c): Wedge Cams.

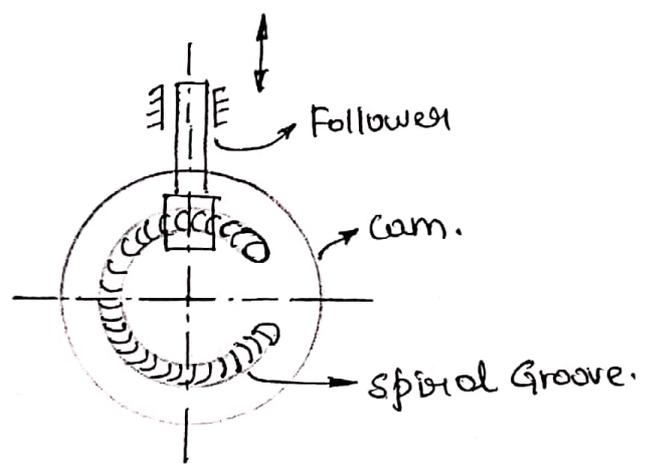


Fig 4.2(d): spiral cam.

## Based On Construction / Shape

### (i) Radial Cams or Disc Cams.

- A cam in which the follower moves radially from the centre of rotation of the cam is known as radial or disc cam. Fig 4.2(a).

(ii) Cylindrical Cam: A cam in which, the follower oscillates or reciprocates in the direction parallel to the axis of the rotation. Refer Fig 4.2(b).

(iii) Wedge or Flat Cams: A cam in which the follower moves along the wedge shape (Inclined shape (or) Trapezium shape). A wedge has a translatory motion where as the follower has translatory or Oscillatory motion. Refer Fig 4.2(c)

(iv) Spiral Cams (or) Face Cam: A cam in which the follower oscillates along the circular plate in which spiral groove is cut and a pin gear follower meshes with teeth cut on spiral groove. Refer Fig 4.2(d)

(v) Spherical Cams: A cam in which the follower oscillates about an axis perpendicular to the axis surface of rotation of the cam. Refer Fig 4.2(e).

(vi) Conjugate Cams: These cams have double discs which are in direct touch with the balls of the follower. Fig 4.2(f)

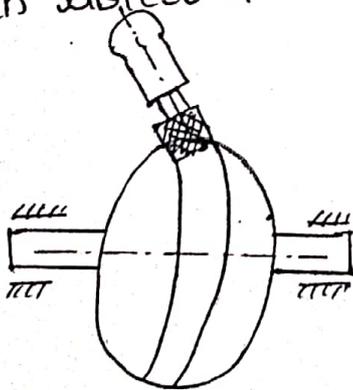
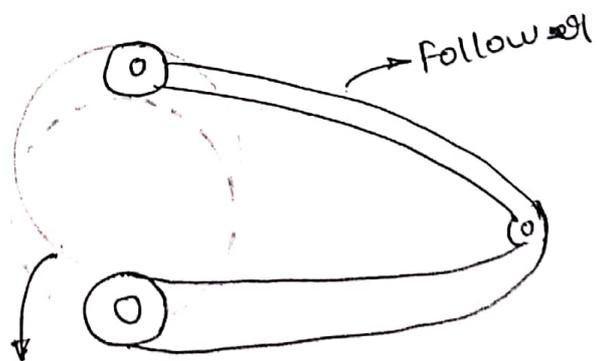


Fig 4.2(e): Spherical Cams.



Conjugate Cams.

Fig 4.2(f) Conjugate Cams.

## Classification of Followers.

Follower is guided by the movement of cam.

Follower may be classified according to

- (i) Type of Movement.
- (ii) shape at the point of contact.
- (iii) Distance between cam shaft and follower axis.

### 4.3.1: Type of Movement:

(a) Oscillatory Follower: These type of follower follows oscillatory motion. The cam rotates with uniform speed. Figure 4-3(a)

(b) Translatory Follower: These type of follower follows translatory motion while the cam rotates with uniform speed. Figure. 4-3(b).

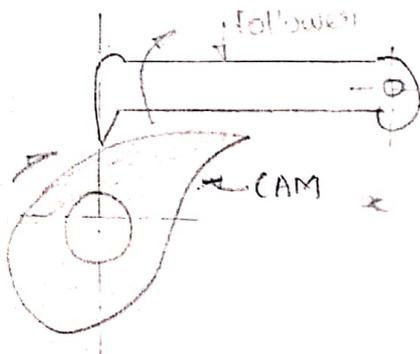


Fig 4.3(a): Oscillating Follower

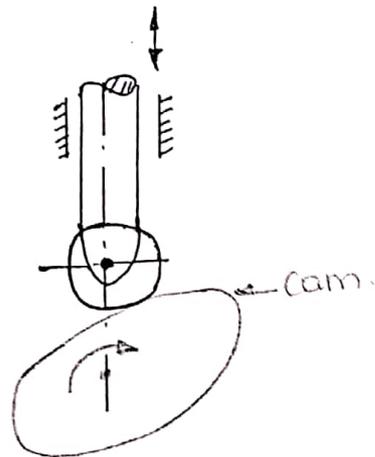


Fig 4.3(b). Translatory Follower.

### 4.3.1.2: Shape at the point of contact.

(a) Knief Edge Follower: The end of the follower which comes in contact with cam is in the form of knief edge. It is simple in its construction and can be used with any type of cam. fig 4.3(c).

(b) Roller Follower: The follower has a <sup>cylindrical</sup> roller at the end of the follower which is in contact with the cam. Wear rate is considerably less as compared to Knief edge follower Fig 4.3(d).

### 4.3.1.3: Distance between the camshaft and follower axis

(a) Inline follower: The Follower is said to be inline when the centre of the rotation of the cam and the follower displacement are in the same vertical line. Fig 4.3(f).

(b) Offset-follower: When the centre of rotation of the cam and the follower displacement are not in same vertical line but offset to certain distance, then this type of follower is known as offset follower. Fig 4.3(g).

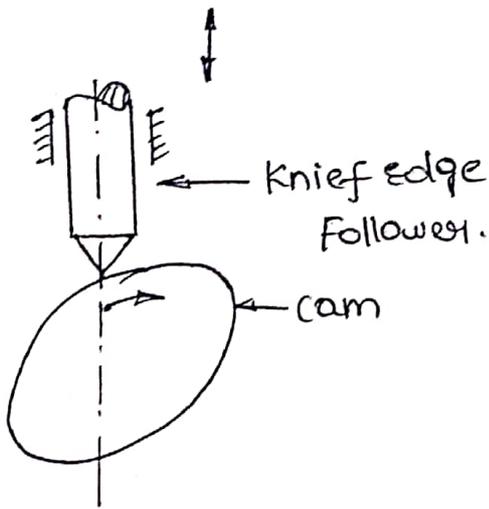


Fig 4.3(f): Inline Follower.

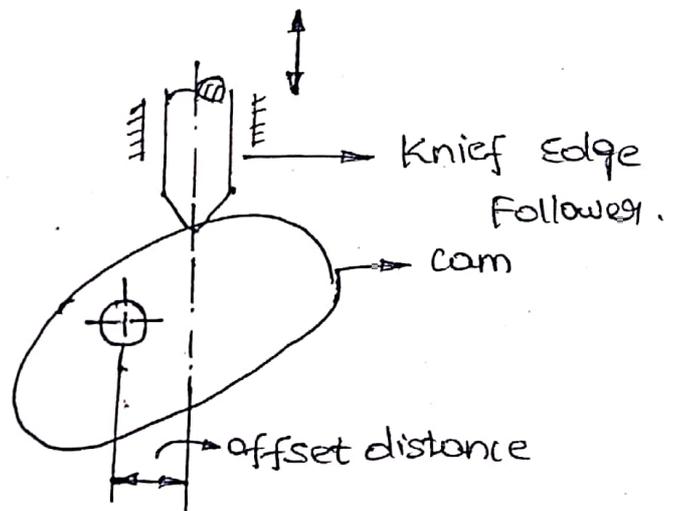


Fig 4.3(g): Offset Follower.

(c) Flat Faced or Mushroom Follower:

As the name suggests, the follower has a flat or a spherical face in contact with the cam. Figure. 4.3(e).

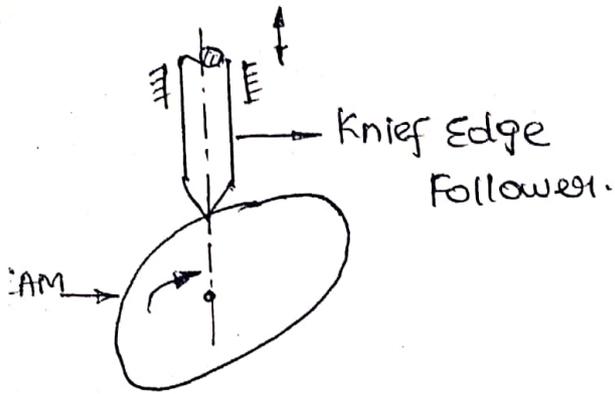


Fig: 4.3(c): Knife Edge Follower.

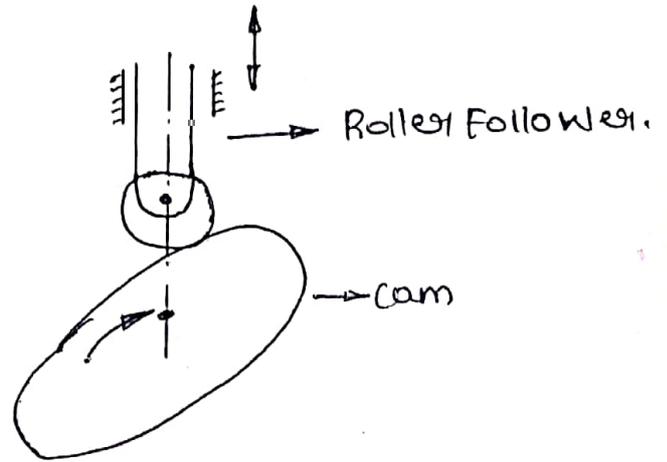


Fig: 4.3(d): Roller Follower.

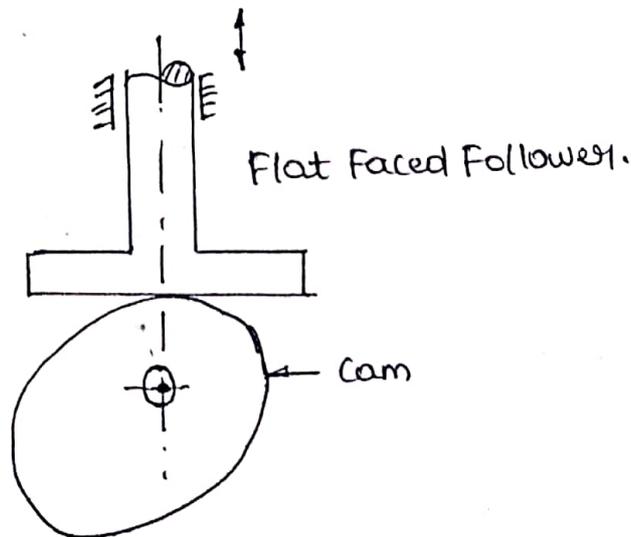


Fig 4.3(e): Flat Faced Follower.

## 4.4. NOMENCLATURES FOR CAM PROFILE (TERMINOLOGIES)

The following nomenclatures are shown in figure which are required to draw the cam profile.

1. CAM PROFILE: The actual surface of the cams which comes in contact with the follower is known as cam profile. This is the actual working curve of the cam.
2. TRACE POINT: Trace point is the reference point on the follower to produce a pitch curve. It is situated at the knife edge in knife edge follower and at the centre in a roller follower.
3. PRIME CIRCLE: Prime circle is the smallest circle that can be drawn from the cam centre and pitch curve.
4. PITCH CURVE: Pitch curve is the curve traced by the trace point if it is assumed that follower is rotating around the cam instead of the cam rotation.
5. BASE CIRCLE: Base circle is the smallest circle that can be drawn from the cam centre to the cam profile.
6. PITCH POINT: Pitch point is the point on the pitch curve having maximum pressure angle.
7. PRESSURE ANGLE: Pressure angle is the angle made between the normal to the pitch curve and line of motion of the follower. Pressure angle is one of the important ~~while~~ aspect while designing a cam. It is denoted by symbol ( $\phi$ ).
8. PITCH CIRCLE: Pitch circle is the circle having centre at the centre of the cam and radius equal to distance between the centre of cam and pitch point. - 7 -

7. LIFT OF FOLLOWER OR STROKE : Lift of follower or stroke is the maximum displacement of the follower from its lowest position to the topmost position.

8. DWELL : Dwell is the period during which the follower remains stationary or simply the follower is at rest.

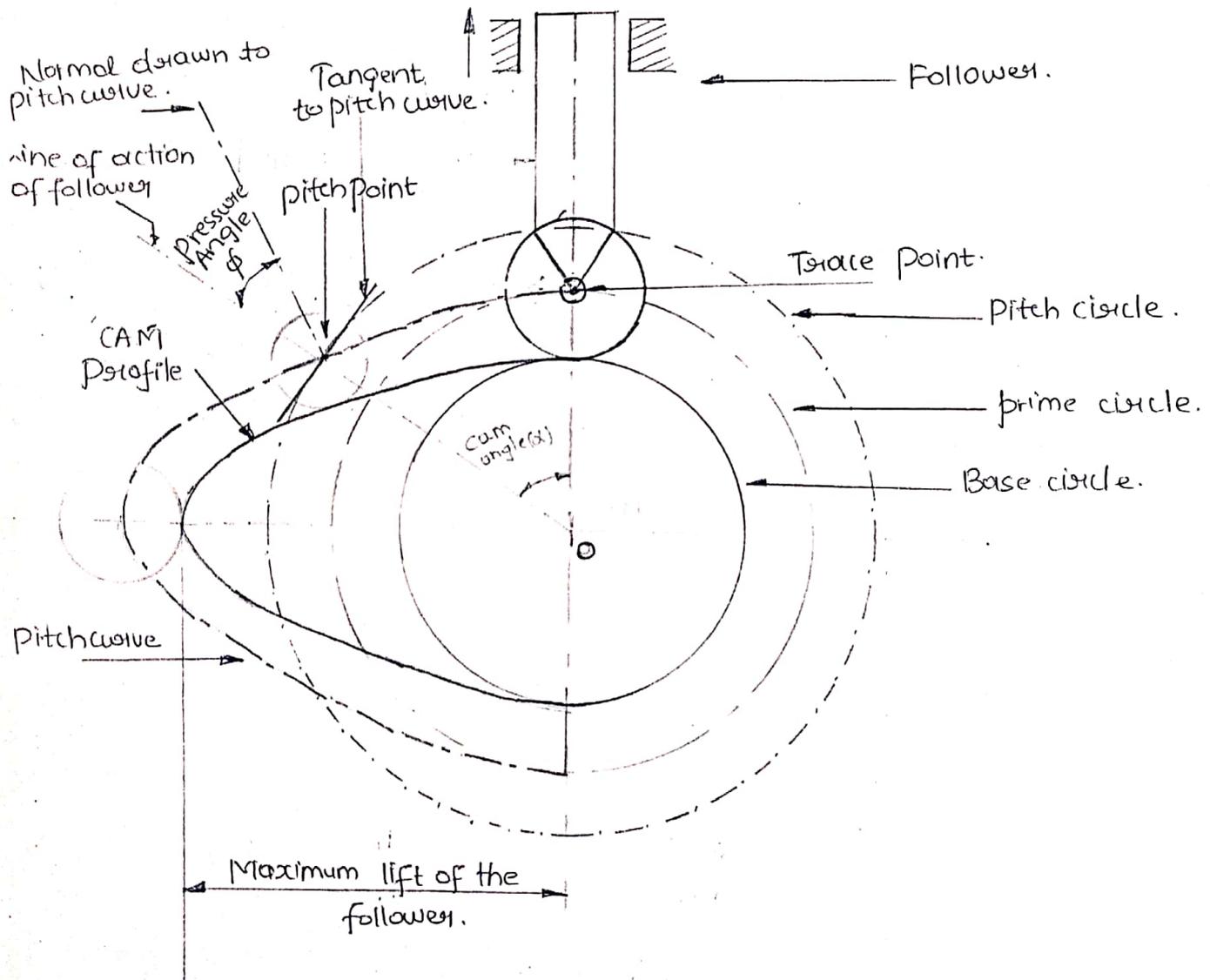


Fig.

f.s: Angle of Ascent, dwell, Descent and action.

Angle of Ascent.

The angle of rotation of cam from the position where the follower begins to rise until it reaches its highest position.

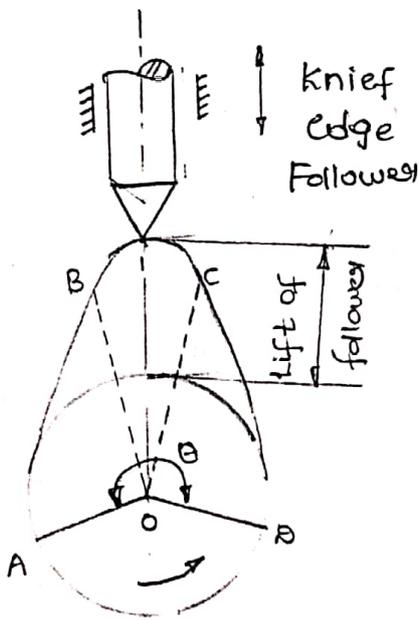
This angle is known as Angle of Ascent.

Angle of Ascent is also known as Outward angle, Outstroke angle, rise angle.

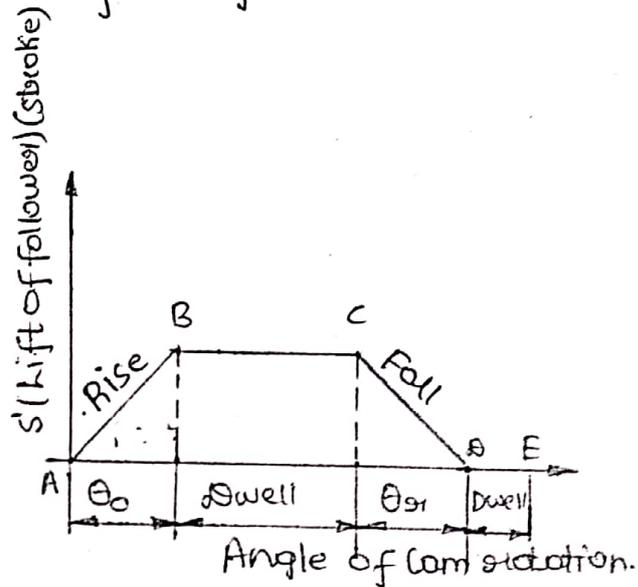
It is represented as  $[\theta_0]$ .

Referring to the figure 4.5(a) the  $\hat{A}OB$  is the angle of ascent.

Follower starts lifting upwards from point A to B. (Fig 4.5(b))



(a) (Fig 4.5)



(b) Displacement Diagram.

Dwell: The cam moves from point 'B' to 'c' without no change in the position of the follower. This is known as dwell.

The line BC in the displacement diagram represents dwell position. It is also known as Angle of rest.

It is represented as  $[\theta_d]$ .

Angle of descent:- The cam moves from 'c' to 'D' and the follower comes downwards. This is known as angle of descent.

Angle of descent is also known as angle of return, (or) angle of fall. It is represented as  $[\theta_1]$ .

In this position the follower falls from highest position to lowest position. It is shown by the line CD on displacement diagram.

The line 'D' to 'E' again represents the dwell. This is the dwell position after return stroke.

The total angle covered by the cam during its rotation is known as action of angle of cam. It is represented as  $[\theta]$ .

## 4.6. MOTION OF THE FOLLOWER:-

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

- Simple Harmonic Motion [S.H.M]
- Uniform Velocity Motion. (or) Uniform Motion.
- Uniform acceleration and deceleration motion (UARM)
- Cycloidal Motion.

### 4.6.1: SIMPLE HARMONIC MOTION [S.H.M]

When the particle moves around a circumference of a circle with uniform angular velocity, its projection on the diameter of the circle will make simple Harmonic Motion [SHM].

The Velocity of the projection will be maximum at the centre and zero at the ends of the diameter.

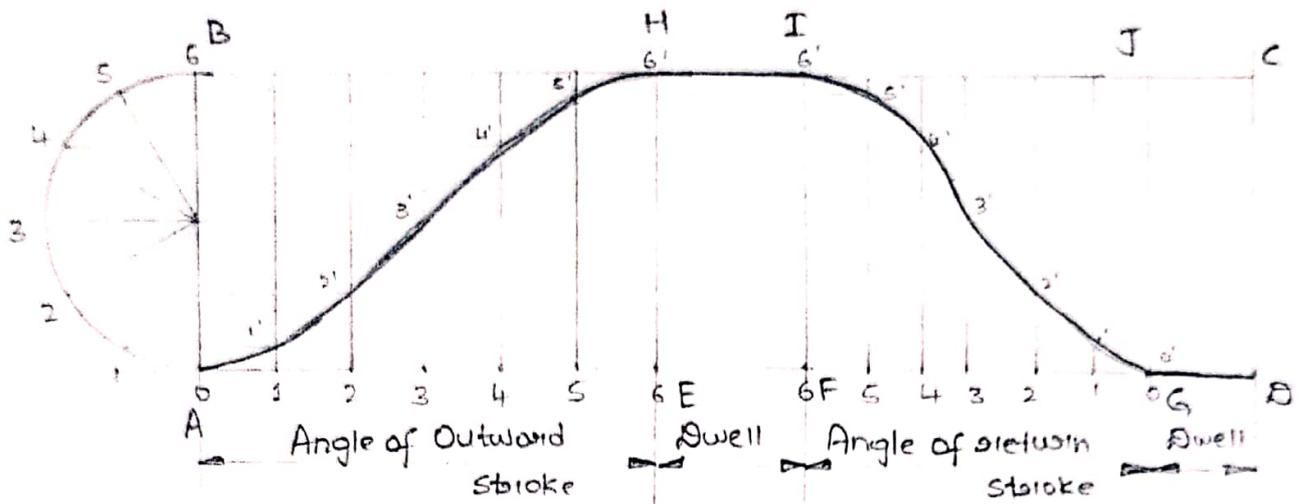
But for acceleration and deceleration the projection will be maximum at the ends of the diameter and zero at the centre.

The displacement, velocity and acceleration diagrams when the follower moves with simple Harmonic Motion (S.H.M) are shown in figure 4.6(a), (b), (c).

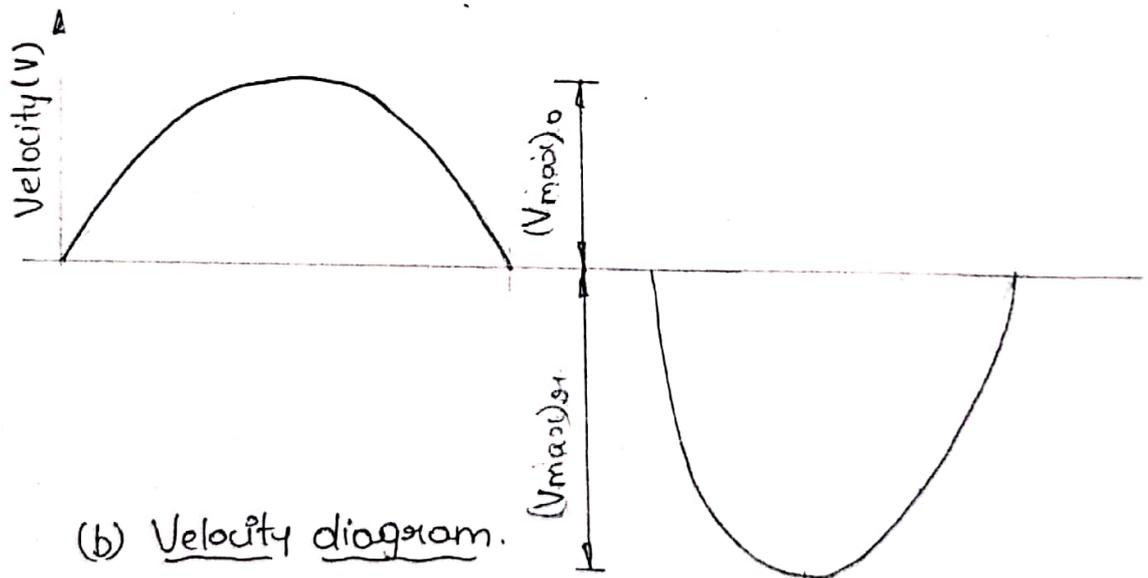
The displacement diagram is drawn as follows:

- Firstly draw a semicircle on the follower stroke as diameter.
- Divide the semicircle into any number of equal even parts (say six or eight)
- Divide the angular displacements of the cam during outward stroke and return stroke into same number of equal parts.

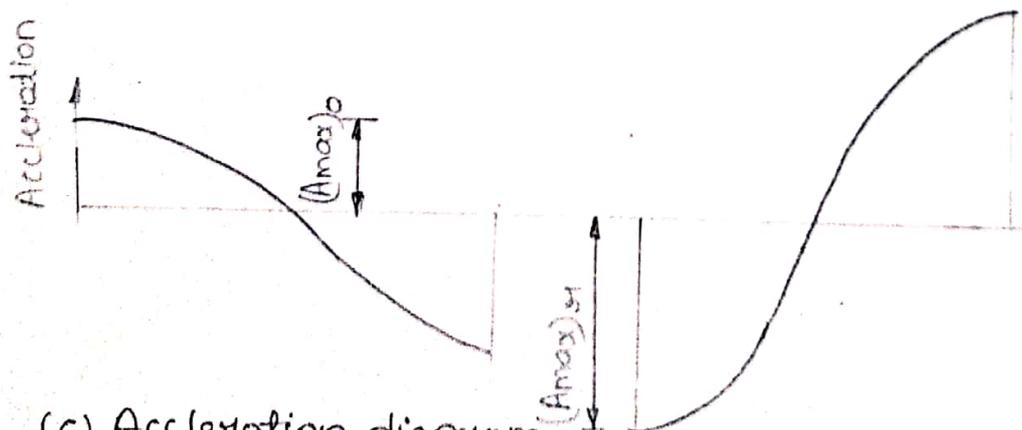
(iv) The points on the displacement diagram are obtained by projecting the points as shown in figure 4.6(a). The complete displacement curve is given by AHIGD.



(a) Displacement Diagram



(b) Velocity diagram.



(c) Acceleration diagram.

(Fig 4.6)

## Expression for Maximum Velocity and acceleration during Outward and return stroke for Simple Harmonic Motion.

1) Maximum Velocity during Outward stroke:-

$$[V_{max}]_o = \frac{S}{2} \times \frac{\pi \omega}{[\theta_o]}$$

Where

S = Stroke (lift) of the follower.

$\omega$  = Angular Velocity of the cam.

$\theta_o$  = Angle turned by cam during outstroke.

$\theta_{st}$  = Angle turned by cam during return stroke.

ii) Maximum Velocity during return stroke:

$$[V_{max}]_{st} = \frac{S}{2} \times \frac{\pi \omega}{[\theta_{st}]}$$

iii) Maximum Acceleration during Outward stroke:

$$[A_{max}]_o = \frac{S}{2} \times \left[ \frac{\pi \omega}{[\theta_o]} \right]^2$$

$$\omega = \frac{2\pi N}{60} \quad (N = \text{speed of cam})$$

iv) Maximum Acceleration during return stroke:

$$[A_{max}]_{st} = \frac{S}{2} \times \left[ \frac{\pi \omega}{[\theta_{st}]} \right]^2$$

4.6.2: UNIFORM VELOCITY MOTION OR UNIFORM MOTION.

The motion of a follower is said to be uniform when it travels the same distance in each succeeding time interval. Hence its velocity will be constant.

During uniform velocity motion of a follower, the displacement of the follower is directly proportional to the cam angle (displacement).

Figure 4.7 (a), (b), (c) shows the displacement diagram, velocity and acceleration diagrams when a knife-edge follower moves with uniform velocity.

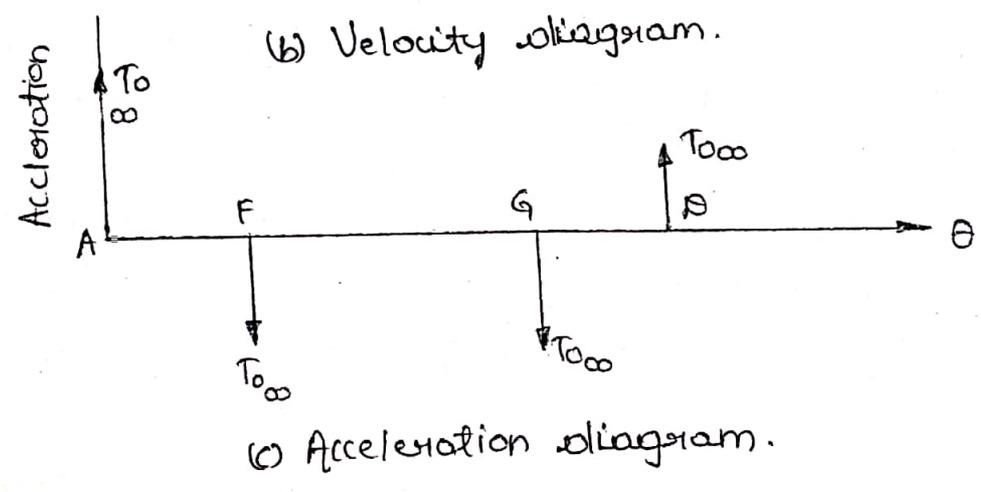
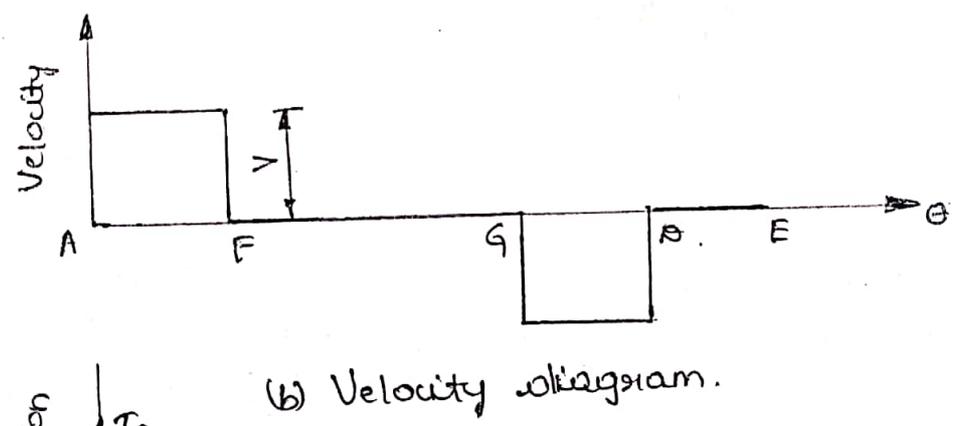
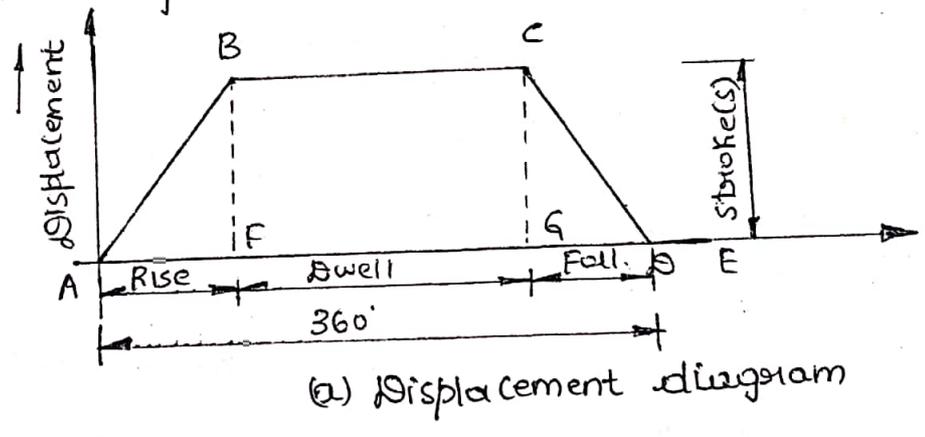


Fig 4.7

Referring to the figure 4-7(a) the follower moves with uniform velocity during its rise and return stroke, which means the equal distances are travelled by the follower in equal time intervals.

Hence the slopes AB and CD represents displacements of the follower during outward and return stroke respectively. The period of rest of the follower is known as dwell period. The line BC and DE represents dwell period after outward and return stroke respectively.

Maximum Velocity and Acceleration during Outward and return stroke for uniform Velocity Motion:-

(i) Maximum Velocity :  $[V_{max}]_0 = \frac{S\omega}{\theta_0}$

(ii) Maximum Acceleration:  $[A_{max}]_0 = 0$

Since the velocity is uniform (constant), i.e. there is no change of velocity, the acceleration of the follower is zero. (Similarly the velocity and acceleration during return stroke are obtained by changing  $\theta_0$  to  $\theta_{r1}$ ).

#### 4.6.3: UNIFORM ACCELERATION AND RETARDATION MOTION [UARM]

The motion of the follower is said to be uniform acceleration and retardation when the follower moves with uniform acceleration during the first half of the follower displacement and moves with uniform deceleration (retardation) during the second half of the follower displacement.

The displacement, velocity and acceleration diagram are shown in the figure 4-8(a)(b)(c).

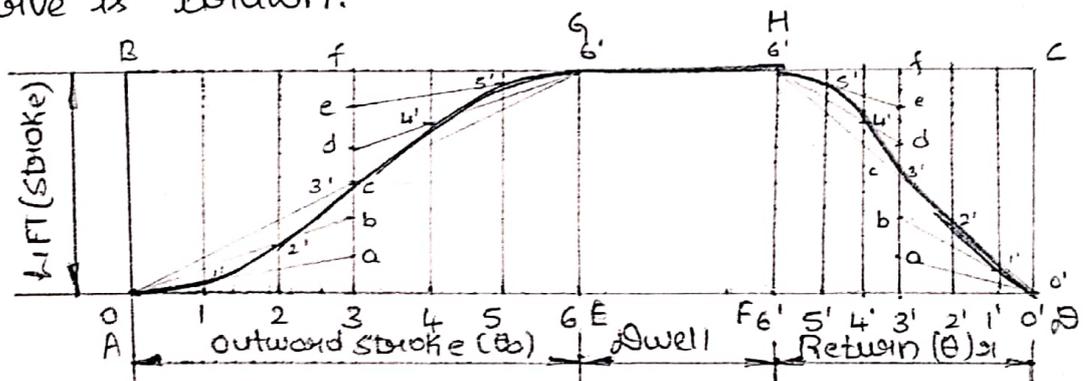
Displacement Diagram: The displacement diagram is drawn according to the methods given below:

- (i) The angular displacements of outward and return stroke are divided into even number of equal parts (say six).
- (ii) The first three intervals represents the follower is accelerated and during next three intervals the follower is retarded.

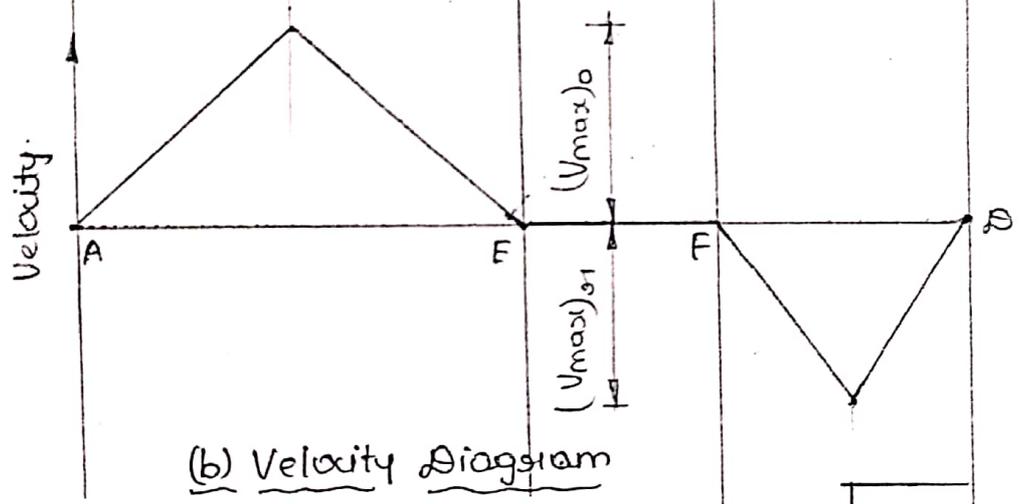
(i) Divide the middle vertical line into same number (say six) and mark a, b, c, d, e, f

(ii) For first three intervals lines are joined from 0 to 1, 0 to 2, 0 to 3 indicating acceleration and for next three intervals lines are joined from 6' to 3, 6' to 4 and 6' to 5 indicating deceleration. Similarly for return stroke.

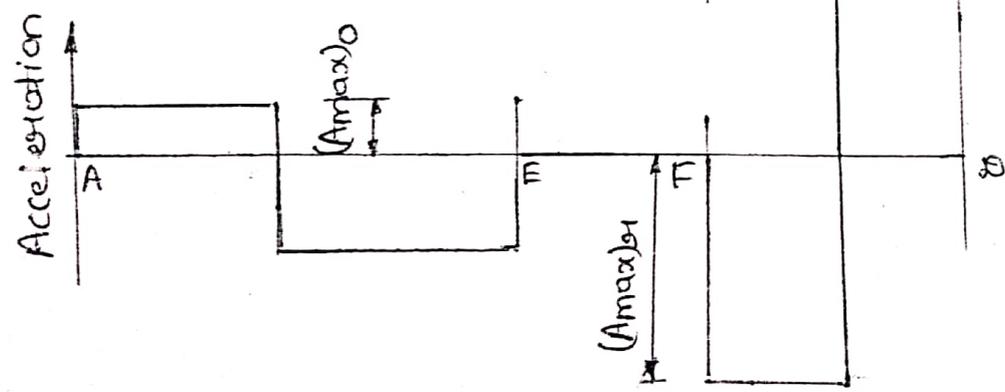
(iii) The intersecting points are numbered as 1', 2', 3'... 5', 6' for outward stroke and 6', 5'... 2', 1', 0' for return stroke and a smooth curve is drawn.



(a) Displacement Diagram.



(b) Velocity Diagram



(c) Acceleration Diagram.

(Figure 4-8).

## MAXIMUM VELOCITY AND MAXIMUM ACCELERATION DURING

### OUTWARD AND RETURN STROKE FOR UARM.

(i) Maximum Velocity during Outward stroke:

$$[V_{max}]_o = 2S \times \frac{\omega}{\theta_o}$$

Similarly for return stroke:  $[V_{max}]_{o1} = 2S \times \frac{\omega}{\theta_{o1}}$

(ii) Maximum Acceleration during Outward stroke:

$$[A_{max}]_o = 4S \times \left[ \frac{\omega}{\theta_o} \right]^2$$

Similarly for return stroke:  $[A_{max}]_{o1} = 4S \times \left[ \frac{\omega}{\theta_{o1}} \right]^2$

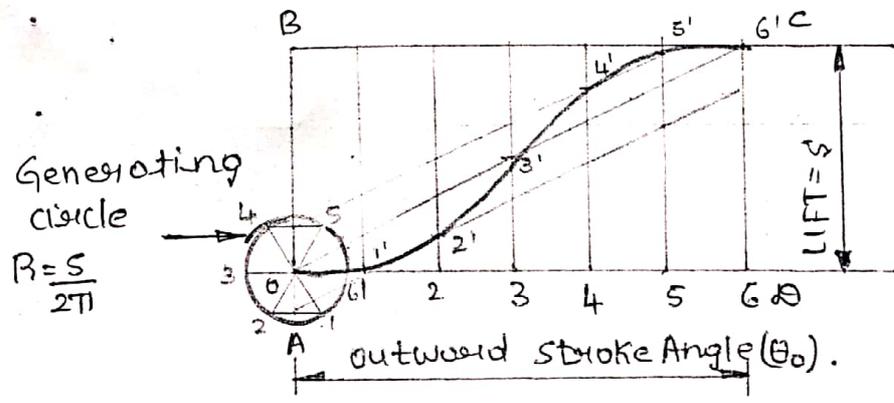
### 4.6.4 Cycloidal Motion:

The cycloid is a curve traced by a point on a circle rolling on a straight line without slipping.

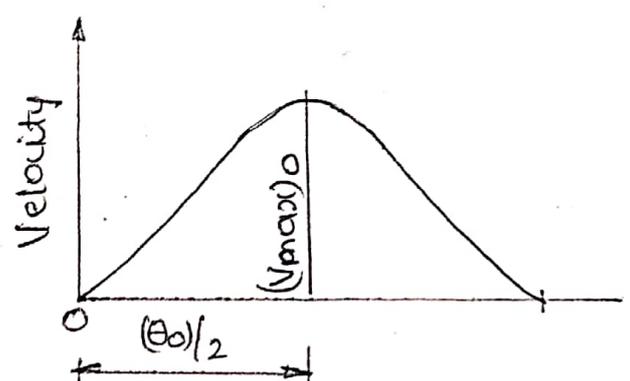
Figure 4.9 (a) (b) (c) shows the displacement, velocity and acceleration diagrams.

The displacement diagram is drawn according to the method given: Fig 4.9(a).

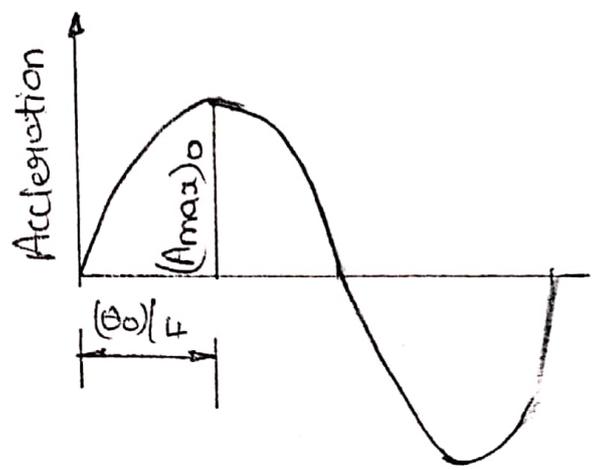
1. Draw the Horizontal line and Vertical line representing Cam angle rotation and displacement respectively with suitable scale
2. Divide the cam rotation (outward and return stroke) into equal number of even parts (say six). Draw Vertical line through these points.
3. Draw a circle of radius  $(S/2\pi)$  with 'O' as centre. This circle is called as generating circle.
4. Divide the circle into six equal parts (60 degrees).
5. Project the circle to its vertical diameter and then draw a line parallel to diagonal OC.
6. Join the intersecting points with a smooth curve which is the required cycloidal path.



(a) Displacement Diagram.



(b) Velocity diagram.



(c) Acceleration diagram.

(Figure 4.9)

## MAXIMUM VELOCITY AND ACCELERATION DURING OUTWARD AND

## RETURN STROKE FOR CYCLOIDAL MOTION:

i) Maximum Velocity during outward stroke:

$$(V_{\max})_o = 2S \frac{\omega}{\theta_o}$$

similarly, for return stroke  $(V_{\max})_{r1} = \frac{2S\omega}{\theta_{r1}}$

ii) Maximum Acceleration during outward stroke:

$$(A_{\max})_o = 2\pi S \left[ \frac{\omega}{\theta_o} \right]^2 \quad \therefore \quad =$$

similarly, for return stroke  $[A_{\max}]_{r1} = 2\pi S \left[ \frac{\omega}{\theta_{r1}} \right]^2$

A cam operates on knife edge follower having a lift of 40mm.

The axis of the follower passes through the axis of the cam shaft. Draw the cam profile for the following data.

i) Follower to move outward through 40mm during 60° of cam rotation.

ii) Follower to dwell for next 45°.

iii) Follower to return to its original position during next 90°.

iv) Follower to dwell for the rest of the cam rotation.

The displacement of the follower is to take place with simple Harmonic Motion during both the outward and return strokes.

The least radius of the cam is 40mm. If cam rotates at 300 r.p.m., determine the maximum velocity and acceleration of the follower during the outward stroke and return stroke.

Soln: Given: Knife Edge follower passing through axis of cam.

$$\text{lift } (s) = 40\text{mm.}$$

$$\text{Angle of Outward stroke (Rise) (or) outstroke } = [\theta_o] 60^\circ \text{ [S.H.M]}$$

$$\text{Angle of Dwell after outward stroke } [\theta_d]_o = 45^\circ$$

$$\text{Angle of return (or) Fall } [\theta_r] = 60^\circ \text{ [S.H.M]}$$

$$\text{Angle of dwell after return (or) Fall stroke } = 360^\circ - [60^\circ + 45^\circ + 60^\circ]$$

$$[\theta_d]_r = 360^\circ - 165^\circ = 195^\circ$$

$$\text{Least radius of cam} = 40\text{mm.}$$

$$\text{speed of cam (N)} = 300 \text{ r.p.m.}$$

$$\therefore \text{Angular Velocity of cam} = \omega = \frac{2\pi N}{60} = \frac{2\pi \times 300}{60}$$

$$\omega = 31.415 \text{ rad/Sec.}$$

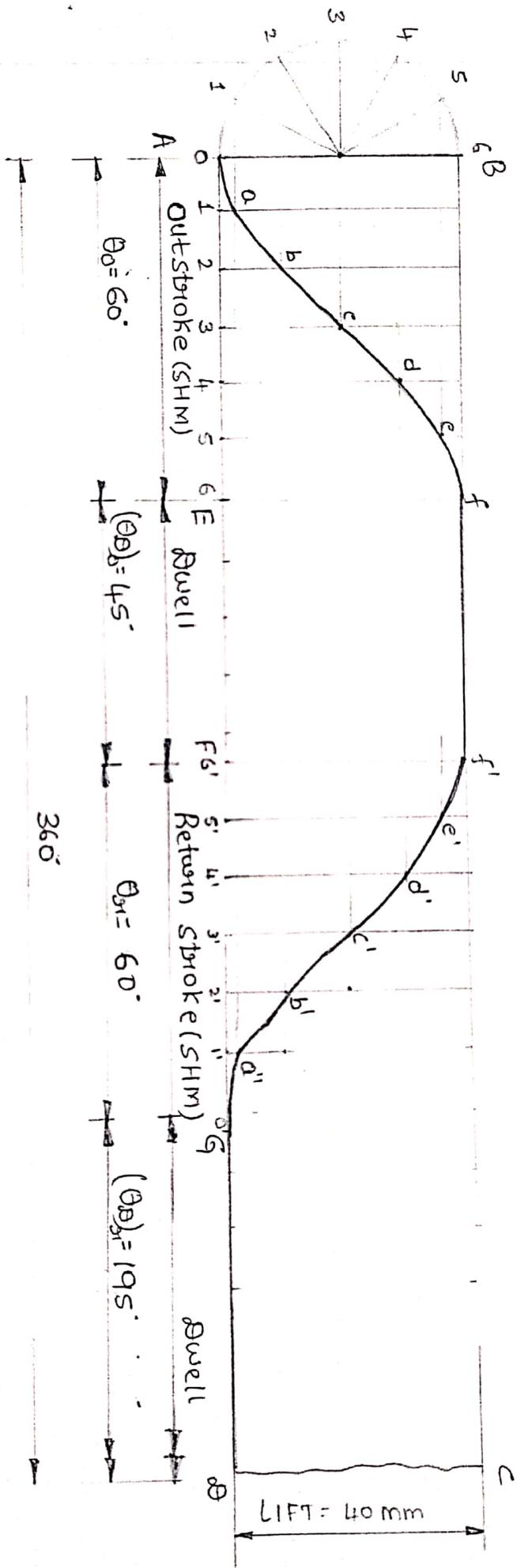


Fig 4.1(a) : Displacement Diagram.

Scale:  
 Horizontal scale 1 cm = 10 degrees  
 Vertical scale = 1 cm = 10 mm  
 OR (1:1)



The displacement diagram is drawn as per the procedure given below: Fig 4.1(a)

- (i) with suitable scale for displacement diagram, mark  $60^\circ$  for outward stroke,  $45^\circ$  for dwell,  $60^\circ$  for return stroke and remaining  $195^\circ$  for dwell.
- (ii) From point 'A' draw a vertical line 'AB' of distance 40mm indicating lift or stroke of the follower.
- (iii) Now draw a semicircle with 'AB' as diameter and divide it into equal number of even parts (06 parts).
- (iv) Mark the points 1, 2, 3, 4, 5, 6 on semicircle.
- (v) Divide the line AE and FG into six equal parts marked as 1, 2, 3, 4, 5, 6 for outward stroke and  $6', 5', 4', 3', 2', 1'$  for return stroke.
- (vi) Draw vertical lines from outward and return stroke points which intersect the horizontal lines drawn from 1, 2, 3, 4, 5, 6 of semicircle at a, b, c, d, e, f for outward stroke and  $f', e', d', c', b', a'$  for return stroke.
- (vii) Join the points a, b, c, d, e, f and  $f', e', d', c', b', a', o, B$  by a smooth curve indicating simple Harmonic motion curve. This is required displacement diagram.

The cam profile shown in figure (4.1 b.) is drawn as per the procedure given below:

- (i) with 'O' as centre and radius equal to 40mm [the least radius of the cam] draw the prime circle.
- (ii) Mark angles of  $60^\circ$ ,  $45^\circ$  and  $60^\circ$  on the prime circle representing outward stroke, dwell and return stroke respectively. such that  $\hat{AOF} = 60^\circ$ ,  $\hat{EOF} = 45^\circ$  and  $\hat{FOG} = 60^\circ$ .
- (iii) Now divide the angles  $\hat{AOF} = 60^\circ$  and  $\hat{FOG} = 60^\circ$  into six equal parts in compare with displacement diagram.

- 1) From 'o' draw radial lines  $01, 02, 03 \dots$  for outward stroke and  $o1', o2', o3' \dots$  for return stroke and extend these lines beyond the prime circle as shown in figure.
- 2) Transfer the distance  $1-a, 2-b, 3-c \dots$  for outward stroke and  $6'-f', 5'-e', 4'-d', \dots$  for return stroke from displacement diagram.
- 3) Join  $A-a-b-c-d-e-f$  for outward stroke and  $f'-e'-d'-c'-b'-a'-o$  for return stroke with the help of smooth curve which is desired cam profile.

Maximum Velocity and Maximum Acceleration during Outward and return stroke:-

Maximum Velocity during Outward stroke:

$$[V_{max}]_{outward} = \frac{\pi s}{2} \times \frac{\omega}{\theta_{outward}} \quad \left[ \theta_{outward} \text{ in radians} \right]$$

$$[V_{max}]_{outward} = \frac{\pi \times 40}{2} \times \frac{31.415}{60 \times \frac{\pi}{180}}$$

$$\therefore [V_{max}]_{outward} = 1884.9 \text{ mm/sec} = 1.89 \text{ m/sec}$$

Maximum Acceleration during Outward stroke:

$$[A_{max}]_{outward} = \frac{\pi^2 s}{2} \times \frac{\omega^2}{(\theta_{outward})^2} \quad \left[ \theta_{outward} \text{ in radians} \right]$$

$$[A_{max}]_{outward} = \frac{\pi^2 \times 40}{2} \times \frac{(31.415)^2}{\left[60 \times \frac{\pi}{180}\right]^2}$$

$$[A_{max}]_{outward} = 177642.405 \text{ mm/sec}^2$$

$$= 177.64 \text{ m/sec}^2$$

### Maximum Velocity during return stroke.

$$\begin{aligned} [V_{max}]_{\text{return}} &= \frac{\pi S}{2} \times \frac{\omega}{\theta_{\text{return}}} \\ &= \frac{\pi \times 40}{2} \times \frac{31.415}{\left[60 \times \frac{\pi}{180}\right]} \end{aligned}$$

$\theta_R$  should be in radians.

$$[V_{max}]_{\text{return}} = 1884.9 \text{ mm/sec (or) } 1.8849 \text{ m/sec}$$

### Maximum Acceleration during return stroke

$$\begin{aligned} [A_{max}]_{\text{return}} &= \frac{\pi^2 S}{2} \times \frac{\omega^2}{\theta_{\text{return}}^2} \\ &= \frac{\pi^2 \times 40}{2} \times \frac{(31.415)^2}{\left[60 \times \frac{\pi}{180}\right]^2} \end{aligned}$$

$$[A_{max}]_{\text{return}} = 177642.40 \text{ mm/sec}^2 = 177.642 \text{ m/sec}^2$$

### Example 4.2

Referring to previous problem 4.1 Keeping all other data same, draw the cam profile when the axis of the follower is not passing through the axis of the shaft but is offset by 20mm from the axis of the cam shaft.

Soln Given data: Lift (S) = 40mm

$[\theta_o] =$  Angle of outward stroke =  $\theta_{\text{outward}} = 60^\circ$  [S.H.M.]

$[\theta_p]_o =$  Angle of dwell after outward stroke =  $45^\circ$

$[\theta_r] =$  Angle of return (or) Fall =  $\theta_{\text{return}} = 60^\circ$  [S.H.M.]

$[\theta_d]_r =$  Angle of dwell after return =  $360^\circ - [60 + 45 + 60]$   
 $= 360 - 165 = 195^\circ$

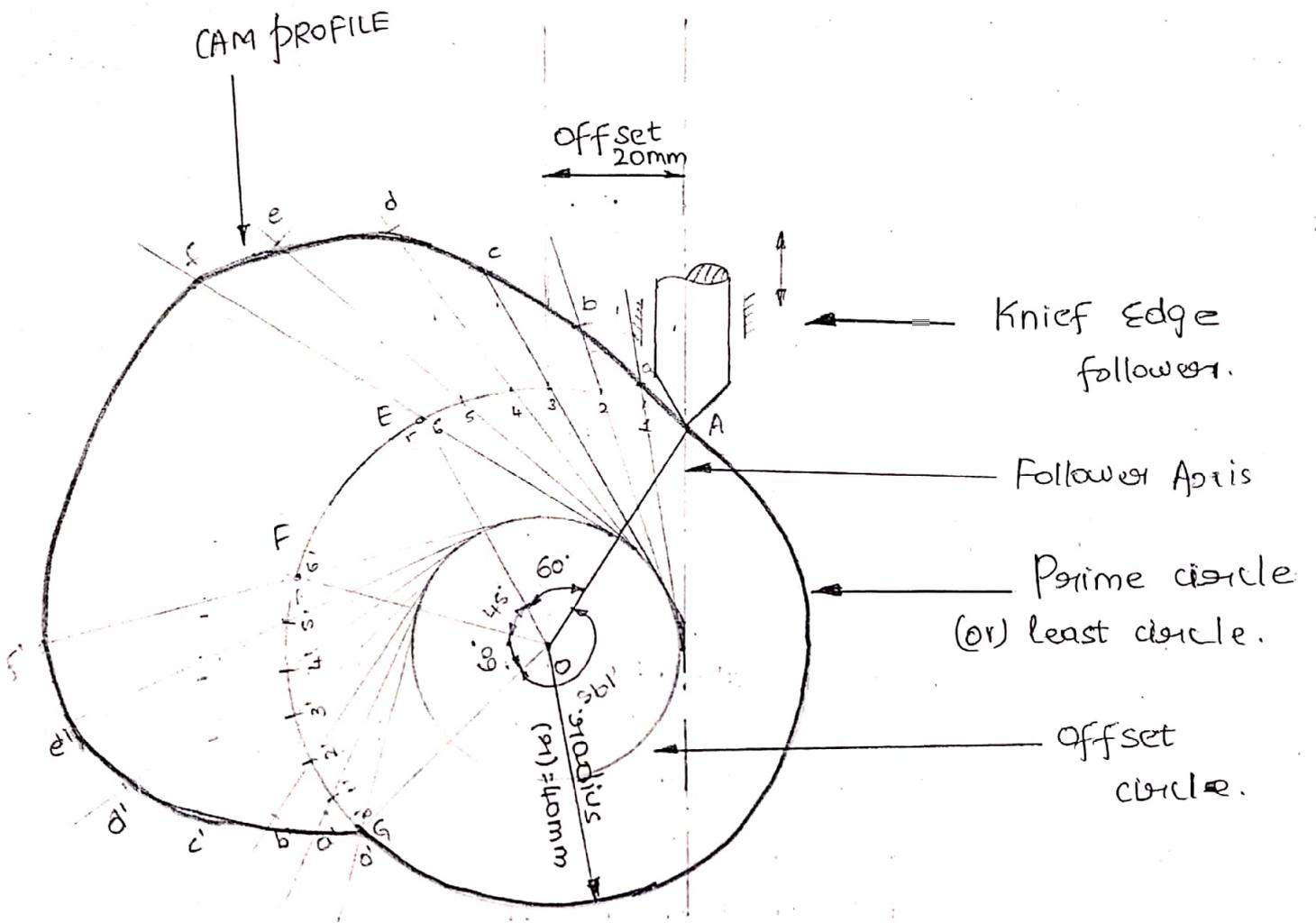


Fig 4.2 (a) Cam profile diagram.

Firstly draw the displacement diagram following the same procedure as shown in (fig 4.1(a)).

### CAM profile Construction: [Fig 4.2 a]

- i) with 'O' as the centre and radius equal to 40mm [the least radius of the cam] draw the prime circle.
- ii) At a distance of 20mm from the axis of the cam, draw the axis follower which intersects the prime circle at 'A'.
- iii) Join O to A.
- iv) With 'O' as centre and radius equal to 20mm draw an offset circle.
- v) Mark the angles  $\hat{A}OE = 60^\circ$  to represent outward stroke,  $\hat{EOF} = 45^\circ$  to represent dwell and  $\hat{FOG}$  to represent return stroke.
- vi) Now divide the angles  $\hat{A}OE = 60^\circ$  and  $\hat{FOG}$  into six equal parts in compare with displacement diagram.
- vii) From 1, 2, 3, 4, 5, 6 for outward stroke and 6', 5', 4', 3', 2', 1' for return stroke draw tangents to the offset circle from the prime circle and extend these tangents beyond the prime circle as shown in figure. 4.2(a).
- viii) Transfer the distance 1-a, 2-b, 3-c, ... for outward stroke and 6'-f', 5'-e', 4'-d' ... for return stroke from the displacement diagram.
- ix) Join A-a-b-c-d-e-f for outward stroke and f'-e'-d'-c'-b'-a'-O for return stroke with the help of a smooth curve which is the required cam profile.
- x) Since the follower remain at rest for remaining revolution, this portion is represented by the curve GA coinciding with the prime circle.

### Example 4-3

Draw the cam profile with 40mm as the minimum radius of the cam and rotating in clockwise wise direction with an uniform speed of 600rpm operating through a roller follower of 10mm in diameter passing through axis of the cam. The follower motion are:

i) Follower to complete outward stroke of 37.5mm during 120° of cam rotation with uniform acceleration and retardation motion (UARM)

ii) Follower to dwell for 60° in the lifted position.

iii) Follower to return to its initial position during 120° of cam rotation with equal uniform acceleration and retardation motion.

iv) Follower to dwell for remaining cam rotation. Determine maximum velocity and maximum acceleration during outward & return stroke.  
soln: Roller follower diameter = 10mm passing through the axis of the cam.

$$\text{Lift (S)} = 37.5\text{mm.}$$

a) Angle of outward stroke (rise) or outstroke = 120° [UARM]

b) Angle of dwell after outward stroke = 60°

c) Angle of return or fall = 120° [UARM]

d) Angle of dwell after fall or return stroke =  $360^\circ - (120^\circ + 60^\circ + 120^\circ)$   
 $= 360^\circ - 300^\circ = 60^\circ$

Minimum radius of cam = 40mm

Cam speed (N) = 600rpm.

∴ Angular velocity of the cam =  $\omega = \frac{2\pi N}{60} = \frac{2\pi \times 600}{60} = 62.83 \text{ rad/sec}$



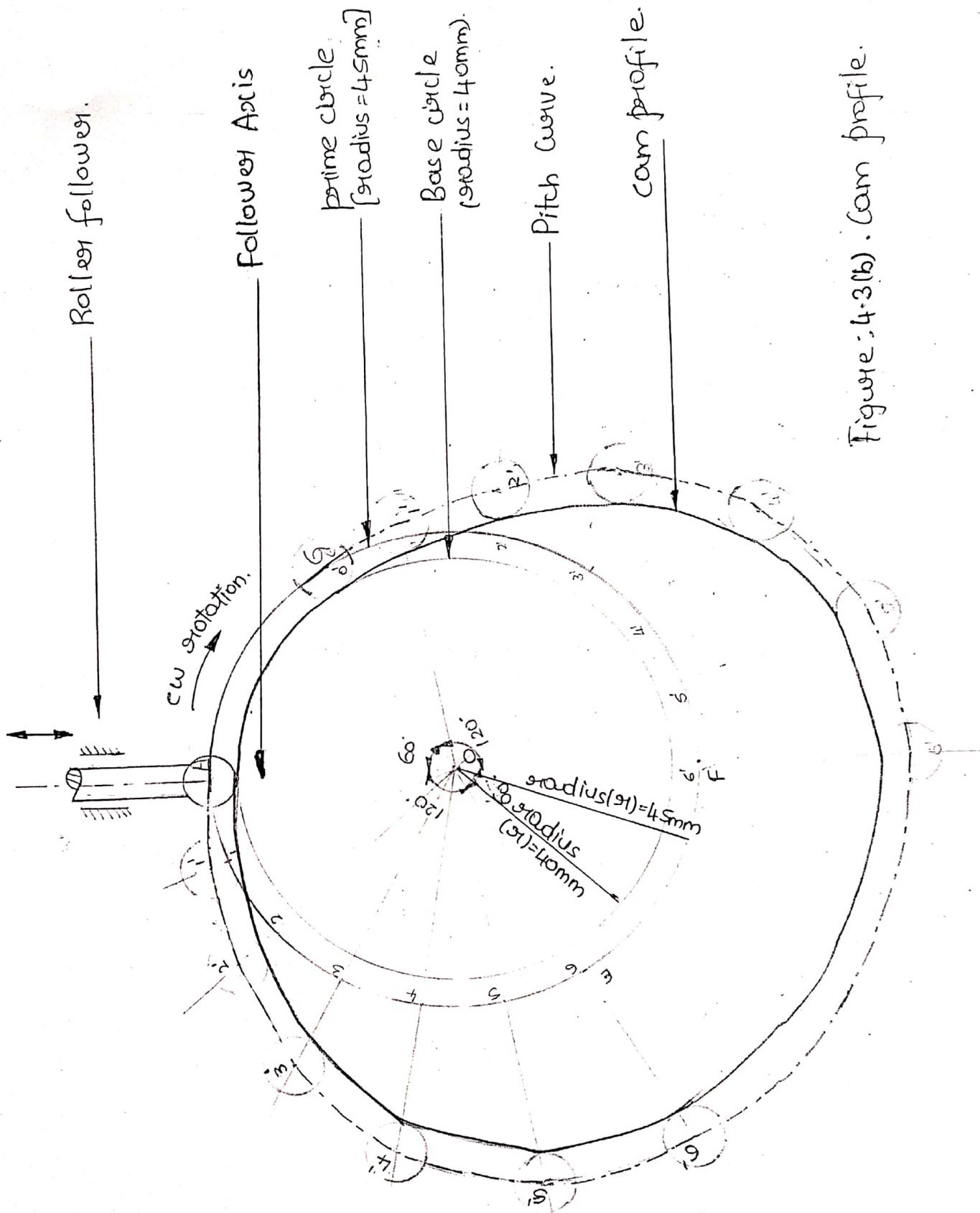


Figure: 4.3(b). Cam profile.

The displacement diagram is drawn as per the procedure given below: Refer fig 4.3(a).

- i) With suitable scale for Horizontal line: mark [AE] 120 for outward stroke, 60 for dwell<sup>[EF]</sup>, 120 for return [FG] and remaining 60 for dwell on a Horizontal line AEF<sub>1</sub>G<sub>1</sub> [G<sub>1</sub>H].
- ii) Divide AE and FG into six number of Equal Even parts.
- iii) Draw the vertical lines through points 0, 1, 2, 3, ... 6 for outward stroke and 6', 5', 4', ... 1', 0' for return stroke.
- iv) Join 1', 2', 3', ... 5', 6' for outward stroke and 6', 5', 4', ... 2', 1', 0' for return stroke with a smooth curve.
- v) Complete the displacement diagram as shown in figure. 4.3 a.

Cam profile Construction. Figure 4.3 (b).

- i) With 'O' as centre and radius Equal to Minimum radius [least radius of the circle] draw the base circle.
- ii) With 'O' as the centre and radius Equal to sum of the minimum radius of the cam and roller radius draw a prime circle:  
 $\therefore$  prime circle radius =  $40 + 5 = 45$  mm.
- iii) Mark the angles  $\hat{AOE} = 120^\circ$  to represent outward stroke,  $\hat{EOF} = 60^\circ$  to represent dwell and  $\hat{FOG} = 120^\circ$  to represent return stroke.
- iv) Now divide the angles  $\hat{AOE} = 120^\circ$  and  $\hat{FOG} = 120^\circ$  into six Equal parts in compare with the displacement diagram.
- v) From O, draw radial lines 0-1, 0-2, 0-3, ... 0-6 for outward stroke and 0-6', 0-5', 0-4', ... 0-1' for return stroke and extend these lines beyond prime circle.
- vi) Now transfer the distance 1-1', 2-2', 3-3', ... 6-6' for outward stroke and 6'-6', 5'-5', 4'-4', ... 0'-0' for return stroke in compare with displacement diagram.

vii) Join A-1', 2', 3', 4', 5', 6' and 6', 5', 4', 3', 2', 1', O', A with the help of a curve known as pitch curve.

viii) From the points A, 1', 2', 3', 4', 5', 6' and 6', 5', 4', 3', 2', 1', O', A draw circles of radius equal to the roller radius (i.e. 5mm).

ix) Join the Bottom portions of these circles with a help of a smooth curve which is the required cam profile.

Maximum Velocity and Maximum Acceleration during Outward and return stroke:-

Maximum Velocity during Outward stroke:

$$[V_{max}]_{outward} = \frac{2 \times S \times W}{\theta_0}$$

$$= \frac{2 \times 37.5 \times 62.83}{\left[120 \times \frac{\pi}{180}\right]} \quad (\theta_0 \text{ in radians})$$

$$[V_{max}]_{outward} = 2249.93 \text{ mm/sec} = 2.24 \text{ m/sec}$$

Maximum Acceleration during Outward stroke:

$$[A_{max}]_{outward} = \frac{4 \times S \times W}{(\theta_0)^2} = \frac{4 \times 37.5 \times 62.83}{\left[120 \times \frac{\pi}{180}\right]^2} = 2148.52 \text{ mm/s}^2$$

$$[A_{max}]_{outward} = 2148.52 \text{ mm/sec}^2 = 2.148 \text{ m/sec}^2$$

Maximum Velocity during return stroke:-

$$[V_{max}]_{return} = \frac{2 \times S \times W}{\theta_{s1}} = \frac{2 \times 37.5 \times 62.83}{\left[120 \times \frac{\pi}{180}\right]} = 2249.93 \text{ mm/sec}$$

$$[V_{max}]_{return} = 2.24 \text{ m/sec}$$

\* Maximum Acceleration during return stroke:

$$[V_{max}]_{return} = \frac{4 \times S \times W}{\theta_{s1}^2} = \frac{4 \times 37.5 \times 62.83}{\left[120 \times \frac{\pi}{180}\right]^2} = 2148.52 \text{ mm/sec}^2 = 2.14 \text{ m/sec}^2$$

### Example 4.4

Referring to the previous problem 4.3. Keeping all other data same, draw the cam profile when the axis of the follower is not passing through the shaft but is offset by 10mm from the axis of the cam shaft.

sol<sup>n</sup>: Given data [From previous problem 4.3]

Roller follower diameter = 10mm [radius = 5mm].

Offset distance = 10mm.

$[\theta_o]$  = Angle of Outward stroke (rise) or outstroke =  $120^\circ$  [UARM]

$[\theta_D]_o$  = Angle of dwell after Outward stroke =  $60^\circ$

$[\theta_{s1}]$  = Angle of return (or) Fall =  $120^\circ$  [UARM]

$[\theta_D]_{s1}$  = Angle of dwell after return stroke =  $360^\circ - [120^\circ + 60^\circ + 120^\circ]$   
 $= 360^\circ - 300 = 60^\circ$

Minimum radius of cam = 40mm.

Cam speed (N) = 600 rpm.

Angular Velocity of the cam,  $\omega = \frac{2\pi N}{60} = \frac{2\pi \times 600}{60}$

$$\omega = 62.83 \text{ rad/sec}$$

### Procedure:

(i) Firstly draw the displacement diagram for the given data following the same procedure as shown in fig 4.3(a).

Cam profile construction. [Refer figure 4.4(a)].

(ii) with 'o' as centre and radius equal to minimum radius [least radius of the circle] draw the base circle.

(iii) with 'o' as centre and radius equal to sum of the minimum radius of the cam and roller radius draw a prime circle.

$$\therefore \text{prime circle radius} = 40 + 5 = 45 \text{ mm.}$$

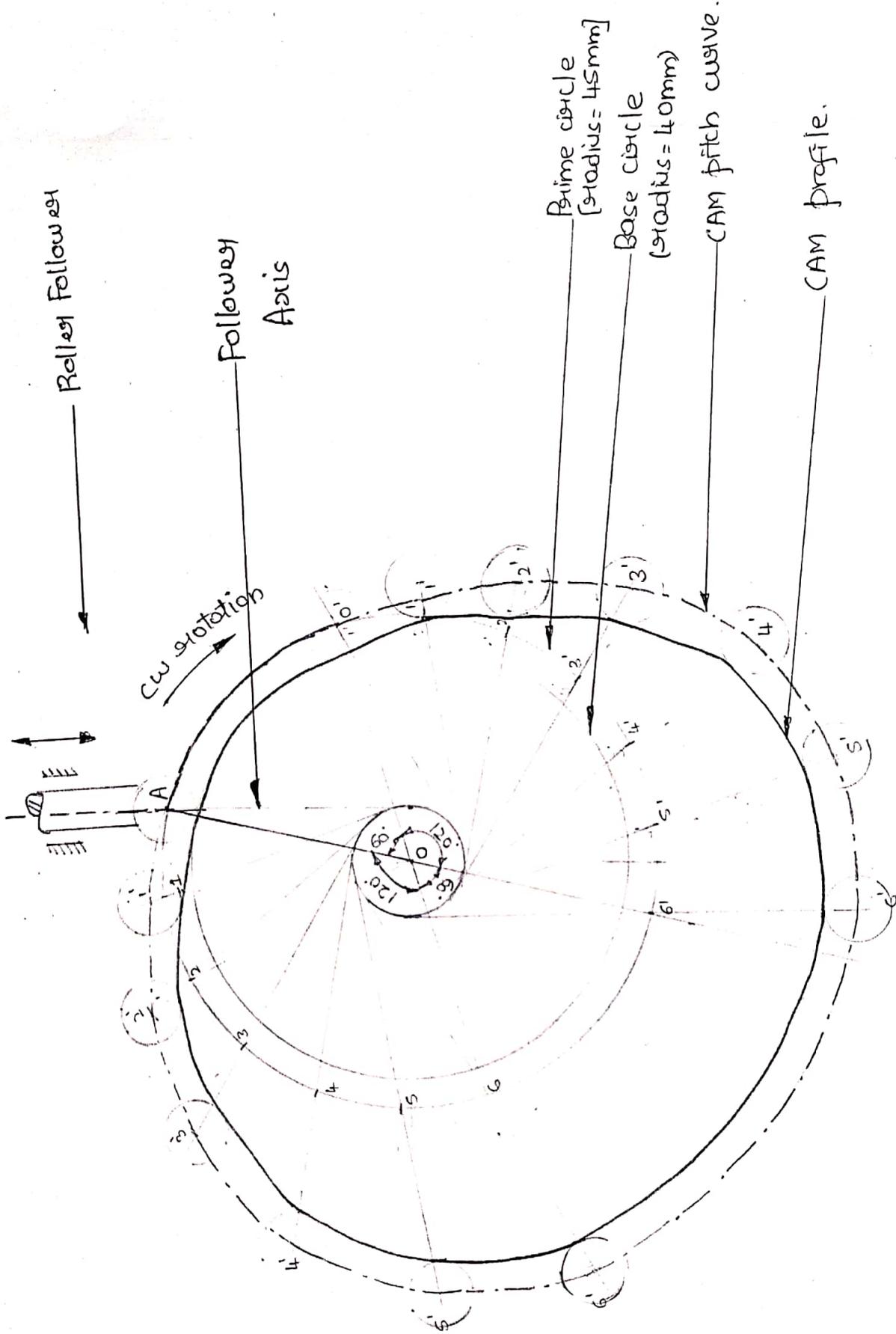


Figure: 4.4(b) Cam profile.

- iii) At a distance of 10mm from the axis of the cam, draw the axis follower (offset follower) which intersects the prime circle at 'A'.
- iv) Join O to A.
- v) With 'O' as centre and radius equal to 10mm (offset distance) draw an offset circle.
- vi) Mark the angles  $\hat{AOE} = 120^\circ$  to represent outward stroke and  $\hat{EOF} = 60^\circ$  to represent dwell, and  $\hat{FOG} = 120^\circ$  to represent return stroke.
- vii) Now divide the angles  $\hat{AOE} = 120^\circ$  and  $\hat{FOG} = 120^\circ$  into six equal parts in compare with displacement diagram.
- viii) From points 1, 2, 3, ..., 5, 6 for outward stroke and 6', 5', 4', ..., 2', 1' for return stroke draw tangents to the offset circle and extend these tangents beyond the prime circle as shown in figure 4.4(a).
- ix) Transfer the distance 1-1', 2-2', 3-3', ..., 6-6' for outward stroke and 6-6', 5-5', 4-4', ..., 1-1', 0-0' for return stroke from the displacement diagram. The points 1', 2', 3', ..., 6' and 6', 5', 4', ..., 1' represents the positions of the roller centre.
- x) From points A, 1', 2', ..., 5', 6' and 6', 5', ..., 1', 0' draw circles with radius equal to roller.
- xi) Join the bottom portions of these circles with the help of a smooth curve which is the required cam profile.

### Example 4.5

Draw the cam profile in which follower moves with simple harmonic motion [S.H.M] during ascent while it moves with uniformly accelerated and decelerated motion during descent.

The follower motion are:

Angle of ascent =  $48^\circ$ . Angle of descent =  $42^\circ$ .

Angle of dwell between ascent and descent =  $60^\circ$

The lift of the follower is 40mm and minimum radius of the cam = 50mm. The follower is operating on a roller follower of roller diameter = 30mm and is offset at a distance of 20mm from the cam axis.

If the cam operates at 360 rpm clockwise, find the maximum velocity and acceleration of the follower during ascent and descent.

Soln Given data: Angle of Ascent (outward stroke or out stroke or rise)  $\theta_o = 48^\circ$  [S.H.M]

Angle of descent [return stroke or Fall]  $\theta_{st} = 42^\circ$  [UADM (or) UARM]

Angle of dwell between ascent and descent =  $[\theta_D]_o = 42^\circ$

$\therefore$  Angle of dwell after return stroke =  $[\theta_D]_{st} = 360^\circ - [48^\circ + 42^\circ + 60^\circ]$   
 $= 360^\circ - 150^\circ$

$$[\theta_D]_{st} = 210^\circ$$

Lift of follower (s) = 40mm

Minimum radius of cam = 50mm.

Roller follower of roller diameter = 30mm [radius = 15mm]

offset distance = 20mm.

Speed (N) = 360 rpm. (clockwise).



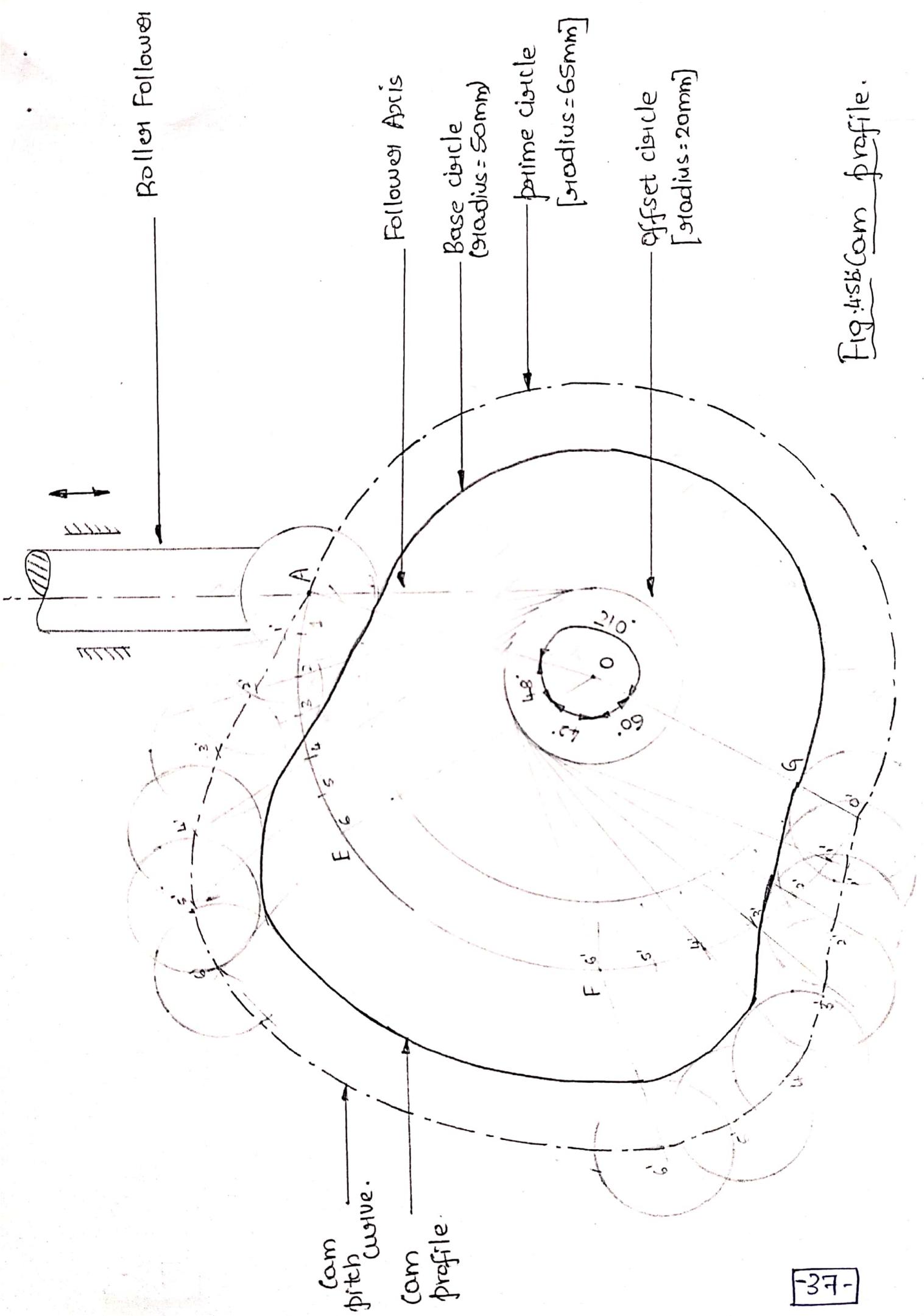
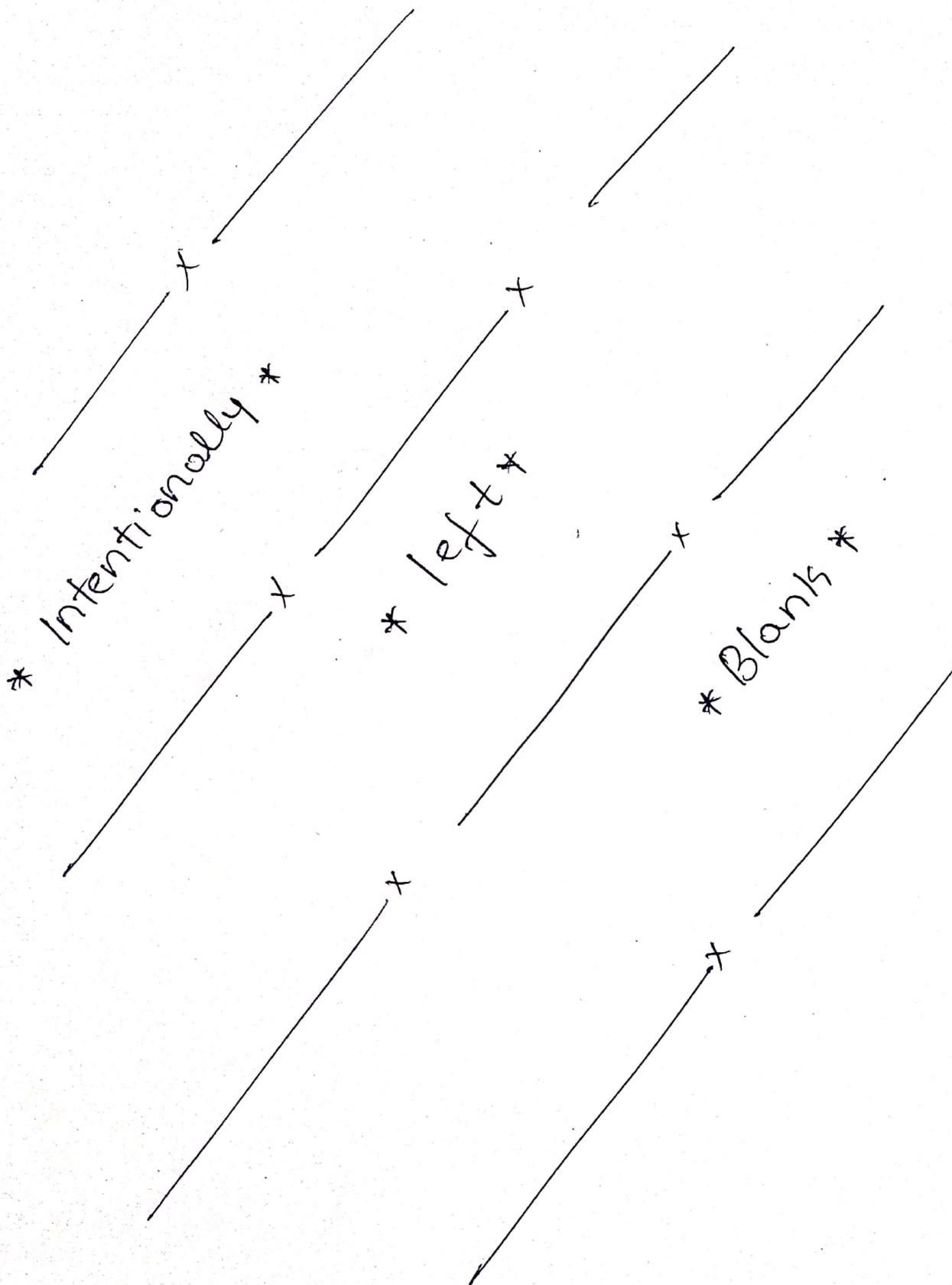


Fig. 4.56 Cam profile.

-F3-



### Example 4.6

Draw the profile of a cam operating a knife-edge follower when the axis of the follower passes through the axis of the camshaft from the following data.

- (i) Follower to move outward through 30mm with simple Harmonic motion during  $120^\circ$  of cam rotation.
  - (ii) Follower to dwell for next  $60^\circ$ .
  - (iii) Follower to return to its original position with uniform velocity during  $90^\circ$  of cam rotation.
  - (iv) Follower to dwell for the rest of the cam rotation.
- Determine maximum velocity and maximum acceleration during outward and return stroke taking minimum radius of the cam is 20mm rotating at 240 rpm clockwise direction.

Soln: Given data: Knife Edge follower.

Follower passes through the axis of camshaft.

Angle of outward or outstroke (rise)  $= [\theta]_0 = 120^\circ$  [S.H.M]

Angle of dwell after outward stroke  $= [\theta]_0 = 60^\circ$

Angle of return or fall stroke  $= [\theta]_{91} = 90^\circ$  [Uniform Velocity]

Angle of dwell after return stroke  $= [\theta]_{91} = 90^\circ$

Minimum radius of cam = 20mm.

speed (N) = 240 rpm.

$$* \text{ Angular Velocity } (\omega) = \frac{2\pi N}{60} = \frac{2\pi \times 240}{60} = 25.13 \text{ rad/sec.}$$

$$\boxed{\omega = 25.13 \text{ rad/sec}}$$

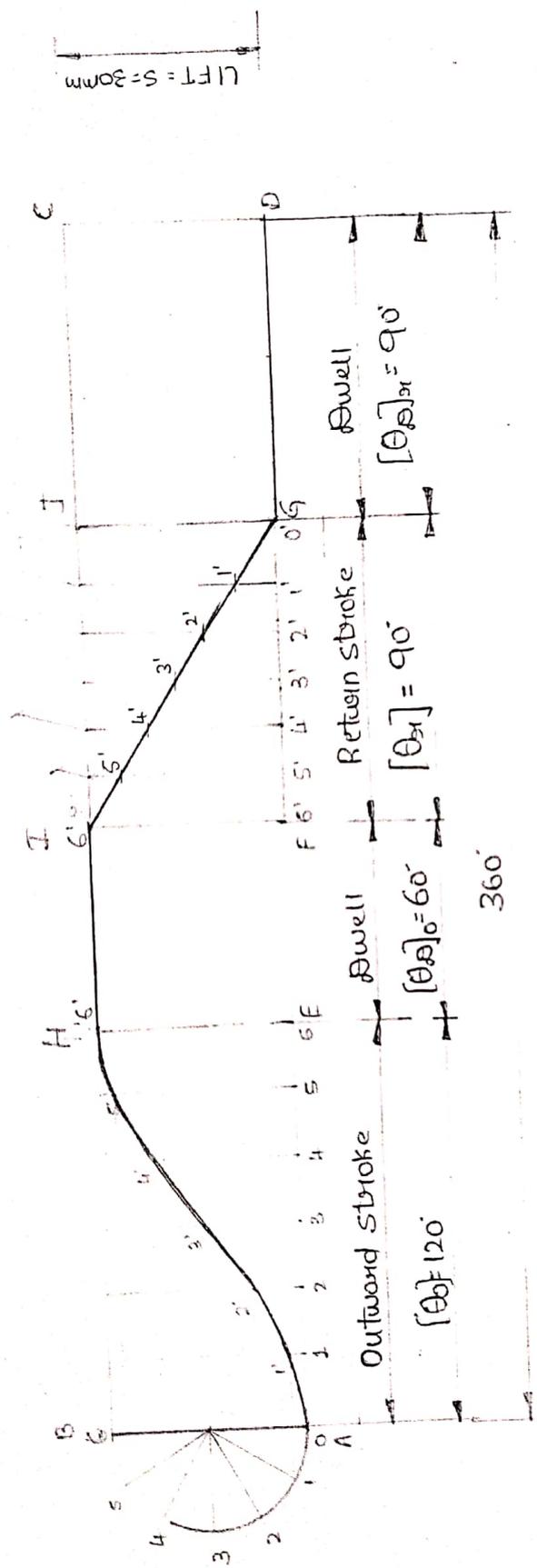


Fig: 4.6a: Displacement diagram.



\* Maximum Velocity and acceleration of the follower during outward stroke.

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### Example 4-7

Draw the profile of the cam when the roller follower moves with cycloidal motion during outstroke and return stroke as given below:

1. Outward stroke with maximum displacement of 31.4mm during  $180^\circ$  of cam rotation.
2. Return stroke for the next  $150^\circ$  of cam rotation.
3. Dwell for the remaining of  $30^\circ$  cam rotation.

The minimum radius of the cam is 20mm and the roller diameter of follower is 10mm. The axis of the follower is offset by 10mm towards the <sup>sight from</sup> axis of the cam shaft.

Soln: Given data. Roller follower with cycloidal Motion.

Angle of Outward stroke (or) outstroke (or) return =  $[\theta_o] = 180^\circ$   
[Cycloidal Motion]

Angle of return stroke (or) Fall (or) descent =  $[\theta_{r1}] = 150^\circ$  [Cycloidal Motion]

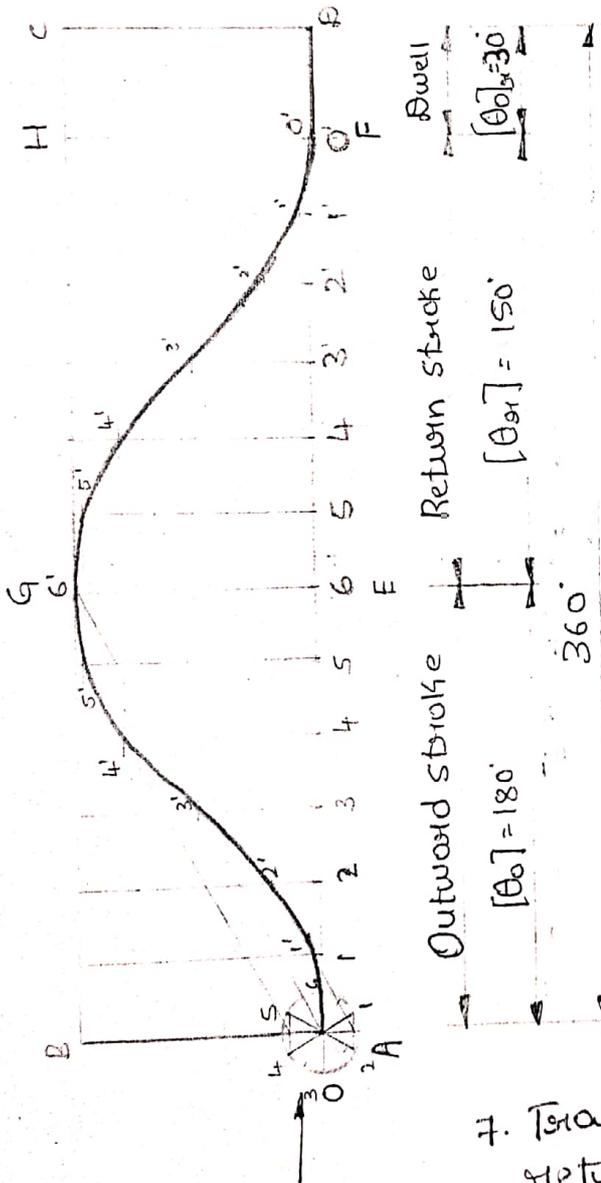
Angle of dwell after return stroke =  $[\theta_{d1}] = 30^\circ$ .

Minimum radius of the cam = 20mm.

Roller follower diameter = 10mm  $\therefore$  [radius = 5mm]

Offset distance = 10mm towards sight from the axis of cam shaft.

Lift (s) = 31.4mm



generating circle.

$$\text{Generating Circle Radius} = R = \frac{\text{Stroke}}{2\pi}$$

$$R = \frac{31.4}{2\pi} \approx 5\text{mm}$$

Procedure to draw displacement diagram. (Refer Figure 4-7a).

1. Draw horizontal line AEFB such that AE = 180° representing outward stroke, EF = 150° representing return stroke and FB = 30° representing dwell period after return stroke with suitable scale.

2. Divide AE = 180° and EF = 150° into any number of Even Equal parts (preferably six parts)

3. From horizontal line, draw a vertical lines from points 1, 2, 3, 4 ... etc Equal to the given stroke (lift) length (s = 1.4mm)

4. With O as centre, draw a generating circle of radius  $R = \frac{\text{stroke (lift)}}{2\pi} = \frac{31.4}{2\pi}$

$$R = 4.997 \approx 5\text{mm}$$

5. Divide the generating circle into six Equal parts and draw horizontal lines to meet these vertical lines at mid points.

6. From these midpoints draw a line parallel to AG to get the points 1', 2', 3' ... etc.

7. Transfer the points (1', 2', 3' ...) towards the return stroke.

8. Join A, 1', 2', 3' ... 6' and 6', 5', 4' ... 1', B with smooth curve which is the required displacement wave.

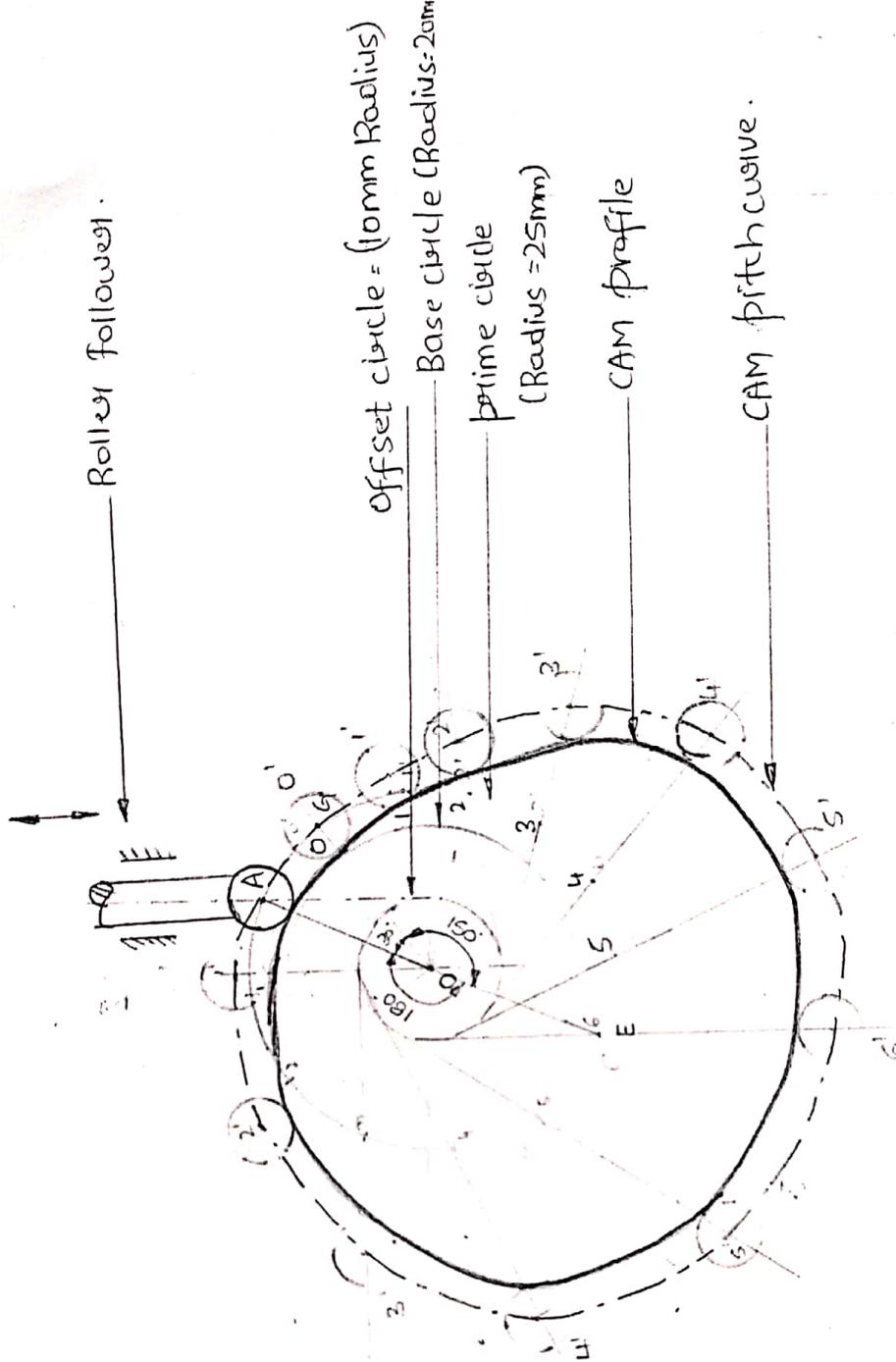


Fig 4.7(b): CAM profile.

Cam profile Construction.

\* Cam profile Fig 4.7(b) is drawn in the similar way as discussed in Example problem.

### Example 4.8

A Flat faced mushroom follower is raised through a distance of 25mm in 120° rotation of the cam, remains at rest for next 30° and is lowered during further 120° rotation of the cam. The raising of the follower takes place with cycloidal motion and falls with uniform acceleration and deceleration. However, the uniform acceleration is  $\frac{2}{3}$  of uniform deceleration. The minimum radius of the cam is 25mm. Draw the cam profile assuming clockwise rotation of the cam.

Soln: Given data: Flat faced mushroom follower  
stroke (or) lift = 25mm.

Angle of rise, outward stroke (or) outstroke (or) rise =  $[\theta_r] = 120^\circ$  [Cycloidal Motion]

Angle of rest (or) dwell after outward stroke =  $[\theta_d]_0 = 30^\circ$

Angle of return, fall or lowered stroke =  $[\theta_f] = 120^\circ$  [UARM or UADM]

Angle of dwell (or) rest after return stroke =  $[\theta_d]_r = 360^\circ - [120^\circ + 30^\circ + 120^\circ]$   
 $= 360^\circ - 270^\circ$

$$[\theta_d]_r = 90^\circ$$

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

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

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

Angular rotation of the cam during deceleration =  $\frac{2}{5} \times 120^\circ = 48^\circ$

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

fall of follower during deceleration =  $\frac{2}{5} \times \text{stroke} = \frac{2}{5} \times 25 = 10\text{mm}$ .

Minimum radius of cam = 25mm.

Generating circle  
 (or) Rolling circle  
 radius (R) = Stroke  
 $\frac{2\pi R}{2\pi}$

$$R = \frac{25}{2\pi} = 3.978 \text{ mm}$$

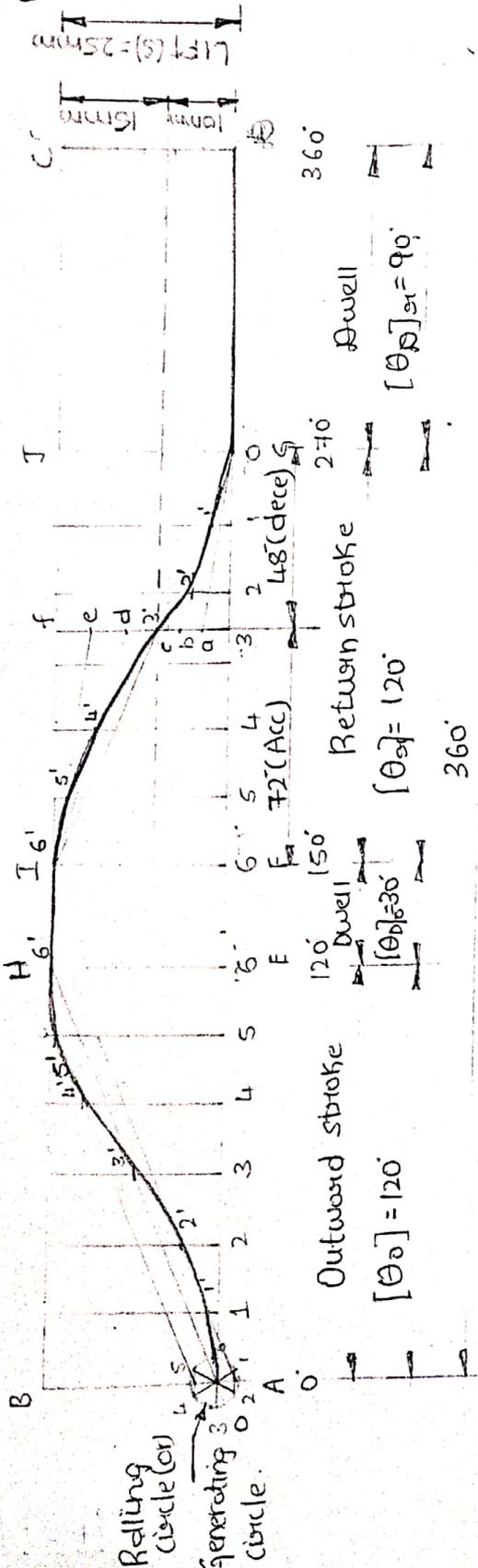


Fig. 4-8(a) Displacement Diagram.

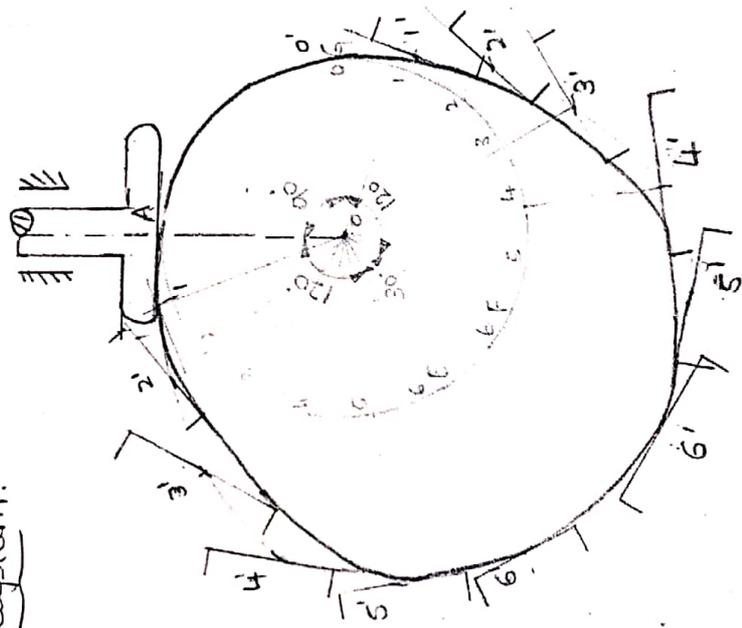


Fig 4-8(b): Cam profile.

Displacement diagram Construction

1. Draw the displacement diagram for the given data shown in figure.
2. For cycloidal motion procedure and UARM (UADM) motion procedure refer the Examples respectively.

## CAM profile Construction. Figure. 4.8(b)

1. Draw the base circle with centre 'O' and radius equal to 25mm.
2. Draw the flat faced follower in the zero(0°) degree position as a tangent to the base circle.
3. Divide the base circle into  $\hat{A}O\hat{E} = 120^\circ$  representing outward stroke,  $\hat{E}O\hat{F} = 30^\circ$  representing dwell,  $\hat{F}O\hat{G} = 120^\circ$  representing return stroke angle and  $\hat{G}O\hat{A} = 90^\circ$  representing dwell angle.
4. Divide the angles  $\hat{A}O\hat{E} = 120^\circ$  and  $\hat{F}O\hat{G} = 120^\circ$  into six equal parts in compare with displacement diagram.
5. Draw radial lines through these points and extend beyond the base circle.
6. Transfer the distance 11', 22', 33' ... from the displacement diagram measuring from base circle.
7. From these points draw a line perpendicular to the radial line indicating follower position.
8. Draw a smooth cam profile tangent to each of the follower position which is the required cam profile.

### Example: 4.9

A vertical spindle supplied with a plane horizontal face at its lower end is actuated by a cam keyed to uniformly rotating shaft. The spindle is raised through a distance of 30mm in one-fourth, remains 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 30mm and 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 centre and the cam rotates in counter clock wise direction.

Soln: Given data: Stroke (lift) =  $S = 30\text{mm}$

Least radius of cam = 30mm

Horizontal face [Flat face follower]

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

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

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

Angle of dwell after return =  $360^\circ - [90^\circ + 90^\circ + 120^\circ]$

$$= 360^\circ - 300^\circ = 60^\circ$$

$$\boxed{[\theta_D]_{\text{ret}} = 60^\circ}$$

During return stroke, the deceleration period is half the acceleration period.

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

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

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

Distance moved by the follower during deceleration =  $30 - 20 = 10\text{mm}$ .

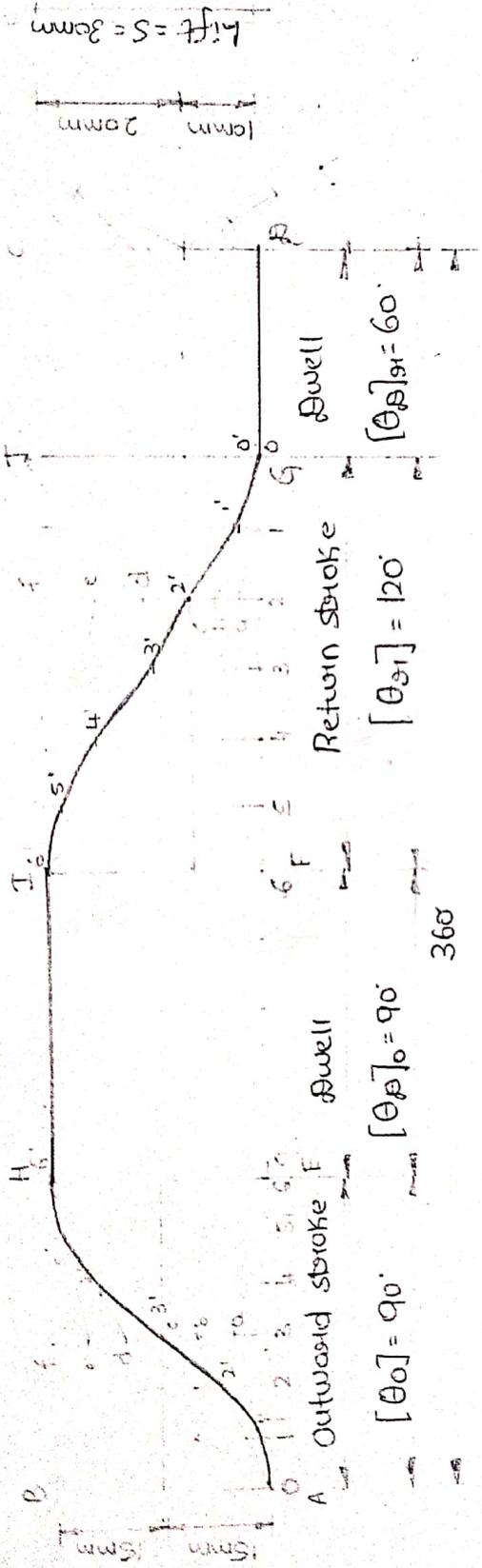


Figure 4.9(a) Displacement diagram

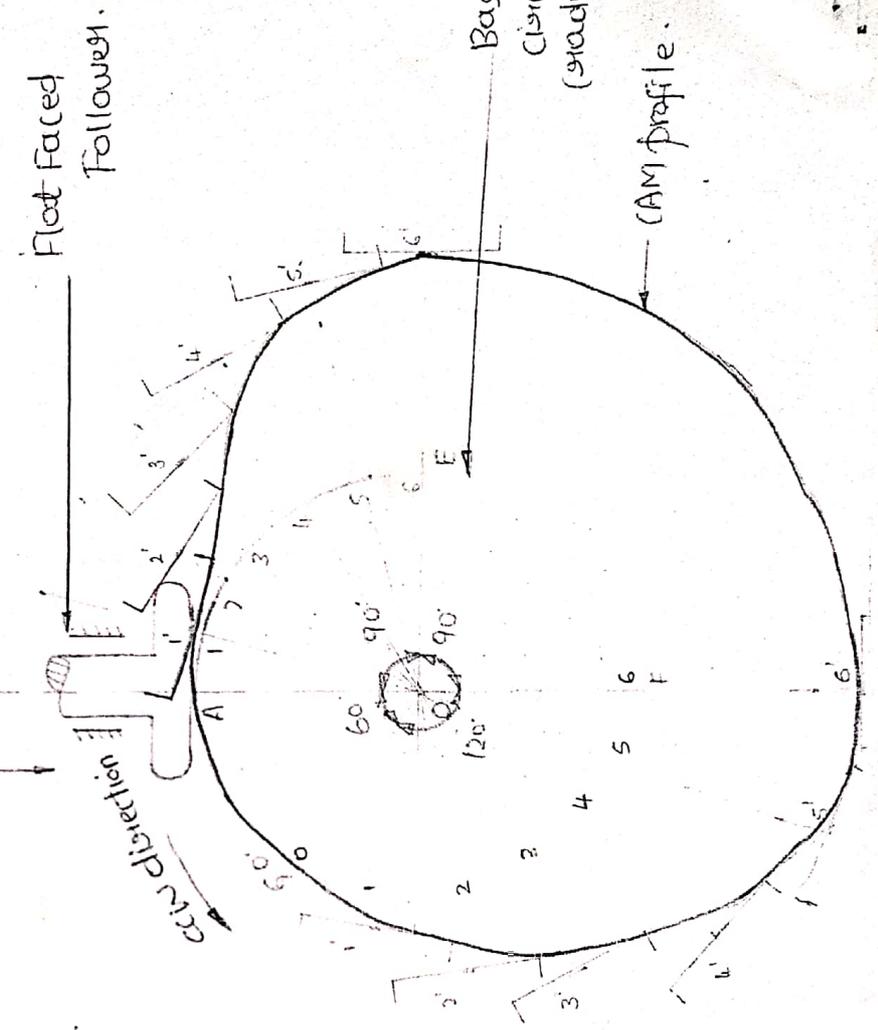


Figure 4.9(b) Cam profile