

CH-7-

* CAMS : كمره عنبر دوار، يملك حركة ثابته او متغيرة عن الكدمات
اخر تدعى بالتابع، واما عن نماذجها واحد ويتولى شرحه التالي

Introduction:
A Cam is rotating machine element, which gives reciprocating or oscillating motion to another element known as follower.

Cam and follower have a line contact and constitute a higher pair, الكمرة تدور بسرعة منتظمة بواسطة الكمرات وتتبع حركتها حركتها

The Cam rotate by engine with uniform speed, but the motion of the follower is predetermined according to the shape of the Cam.

The Cams are widely used for operating the inlet and outlet valves of internal combustion engine, in automatic looms, textile machines, paper cutting machines, etc. حرك الاضراس

* Classification of Followers : تصنيف التتابع

The Followers may classified as discussed below :

I) According to the surface in contact : حسب سطح التماس

1, Knife edge follower : التابع ذات الحافة الحادة

In which the follower has a knife edge in contact, and has a sliding motion in contact and low wear -> as in fig (a).

2 - Roller Follower : التابع ذات الرولة

In which the follower has a roller end, and has a rolling motion in contact, which reduce the wear greatly. It is used mostly in gas and oil engine, and aircraft engine -> fig (b).

3 - Flat face or (mushroom) follower: المشroomي المتبع

In which the follower has a flat face end in contact, it has a sliding motion in contact as shown in fig (c), and reduce the wear mostly, when the the follower has off-set axis with a cam as shown in fig (d).

4) Spherical faced follower: المتبع ذات الوجه الكروي

In which the follower has a spherical face end, it is used to minimise the stresses in the contact surface as shown in fig (e). في اللمس السطحية كالتالي

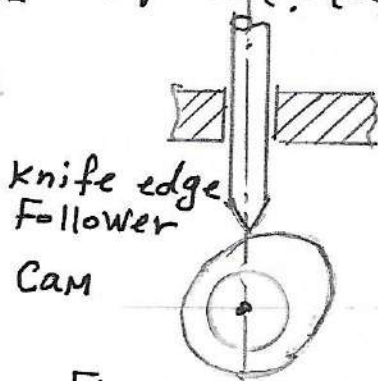


Fig (a)
Cam with knife edge Follower

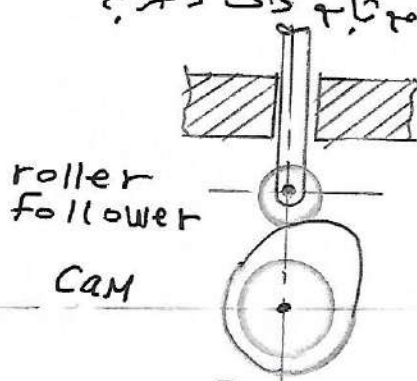


Fig (b)
Cam with roller Follower

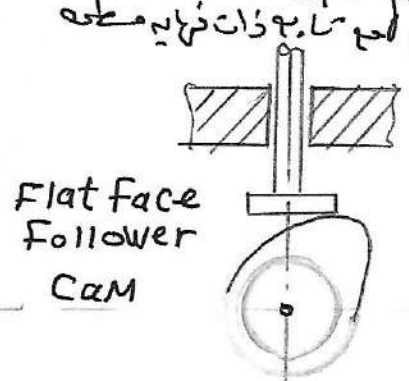


Fig (c)
Cam with flat face Follower

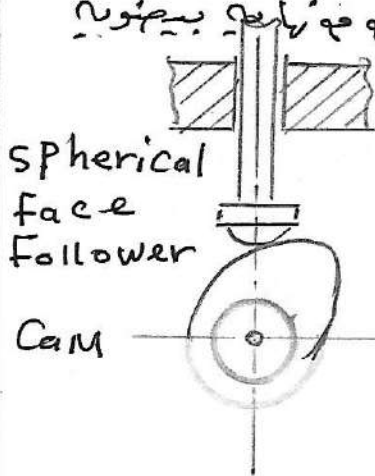


Fig (e)

Cam with spherical face follower

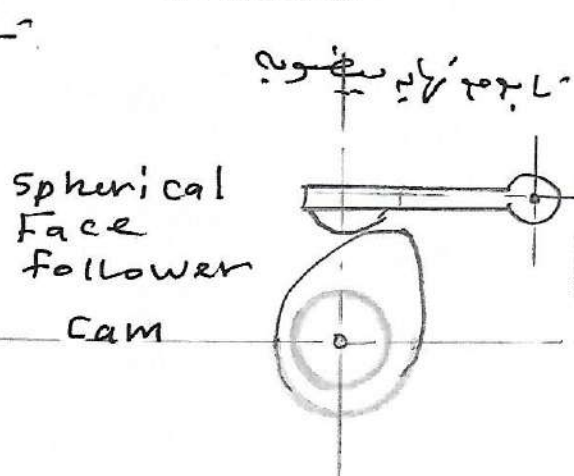


Fig (f)

Cam with spherical face follower

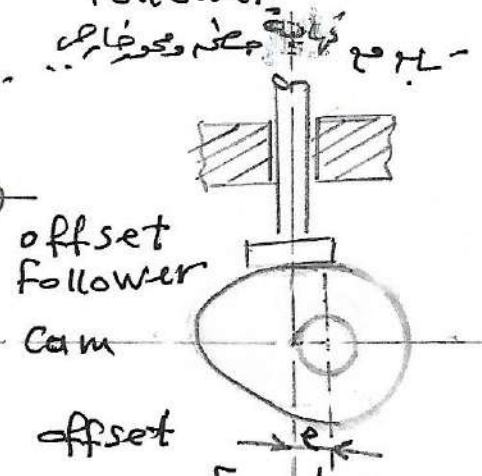


Fig (d)

Cam with offset follower

II) According to the motion of the follower.

a) Reciprocating or translating follower;

ذات الحركة الترددية او الانتقالية

In which the follower reciprocates in guides, as the Cam rotates uniformly, fig (g).

b) Oscillating or rotating follower;

In which the follower is oscillating and the Cam rotating uniformly, fig (h).

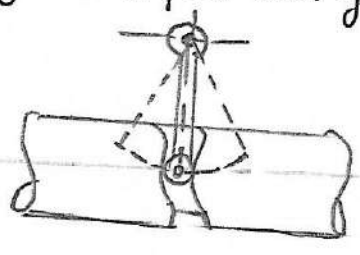
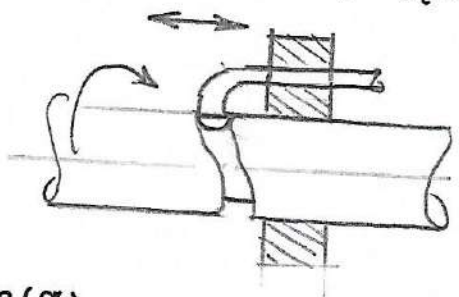


Fig (g) Cylindrical cam with reciprocating follower

Fig (h) Cylindrical cam with oscillating follower

III) According to the bath of motion of the follower:

a) Radial follower;

In which the axis of the follower pass through the center of the Cam. as in fig a, b, c, d)

b) off-set follower;

In which the axis of the follower pass out the center of the Cam. Fig (e).

* Classification of Cams;

1) Radial or disc Cam.

In which the follower reciprocates or oscillates \perp to the Cam axis.

Fig (a, -- f),

2) Cylindrical Cam : الكليات الاسطوانية

In which the follower reciprocates or oscillates in direction parallel to the axis of the Cam, fig (g, h). وفيها التابع يتحرك ترددياً أو تذبذبياً بمحور (g, h) وفيها التابع يتحرك في الاسطوانة.

* Terms of radial Cam : المصطلحات الفنيه لكليه القلبي

1- Base circle ; الدائرة الاساسية

It is the smallest circle Cam be drawn to the Cam profile.

2- Trace point ; النقطة المرجعية

It is the reference point on the follower is used to generat the pitch curve. نقطة مرجعية التتابع تستخدم لتوليد منحنى الخطوة.

3- pressure angle ; زاوية الضغط

It is the angle between the direction of the follower motion and the normal to the pitch curve. الزاوية المحصورة بين محور التتابع والعمود على منحنى الخطوة.

4- pitch point ; نقطة الخطوة

A point on the pitch curve having maximum pressure angle. نقطة على منحنى الخطوة ذات أكبر زاوية ضغط.

5/ pitch circle ; دائرة الخطوة

It is a circle drawn from the center of the Cam through the pitch point. دائرة ترسم من مركز الكلبة خلال نقطة الخطوة.

6- pitch curve ; منحنى الخطوة

It is a curve generated by the trace point of the moving follower. منحنى يتولد بالنقطة المرجعية التتابع المتحرك.

7- Prime circle

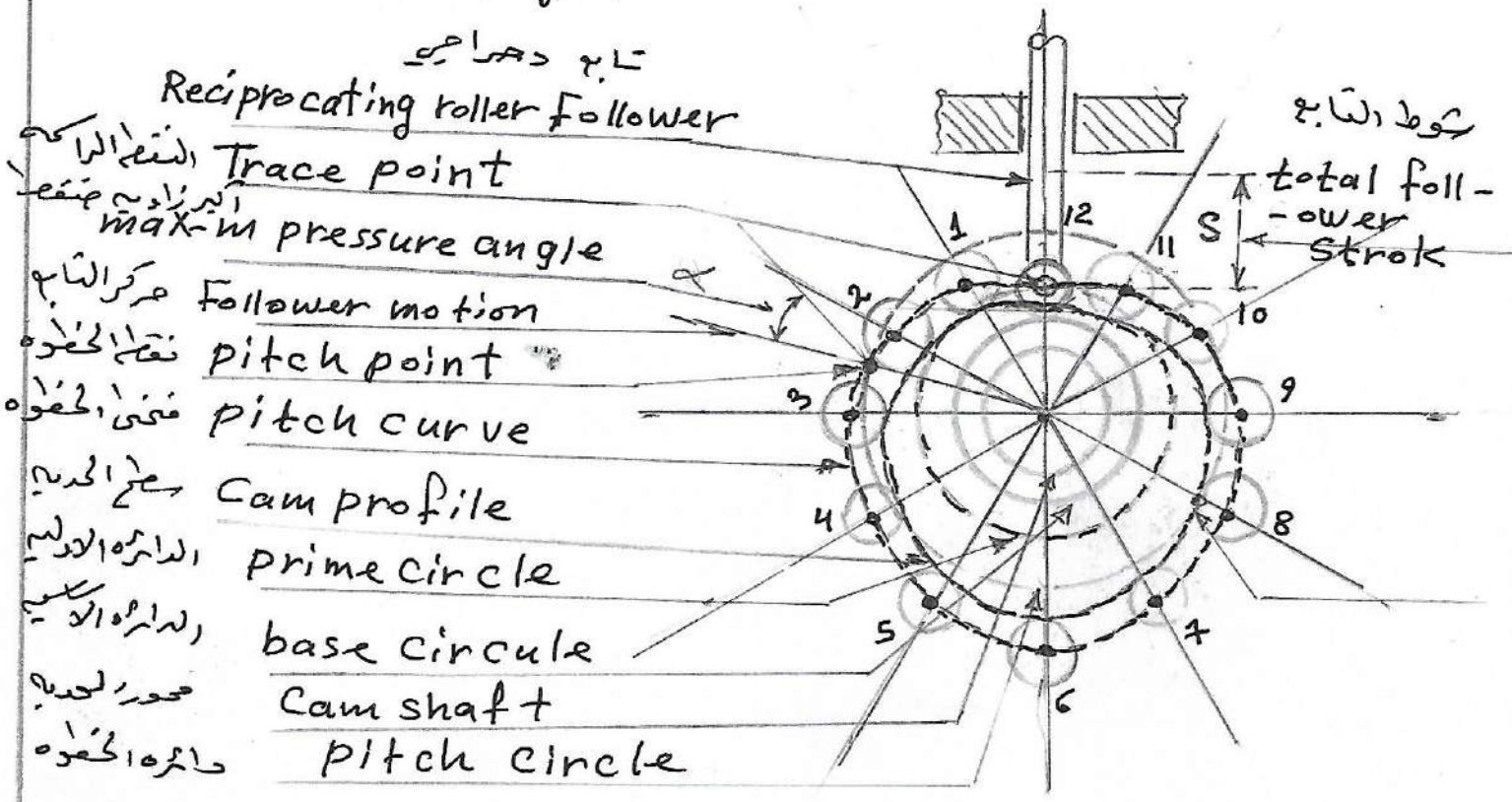
الدائرة الاولى

It is the smallest circle can be drawn from the centre of the Cam and be tangent to the pitch curve.

8- lift or stroke :

هو الارتفاع الذي يتبعه من ادنى الالات موقع له

It is the max-m travel of the follower from the lowest to the top most position, as shown in figure a.



- Reciprocating roller follower
- Trace point
- max-m pressure angle
- Follower motion
- pitch point
- pitch curve
- Cam profile
- prime circle
- base circle
- Cam shaft
- pitch circle

Fig(a) Terms of radial Cams.

Motions of the follower :

- I, uniform velocity
- II, simple harmonic motion.
- III, uniform acceleration and retardation.
- IV, cycloidal motion.

الحركة بسرعة منتظمة
الحركة التوافقية
الحركة بتسارع أو تباطؤ منتظم
الحركة الدائرية

I) Displacement, velocity and acceleration, when the follower moves with uniform velocity

For example, we take knife-edged follower.

1, uniform displacement (motion) ازاحة الحركة المنتظمة
 it is a simple equation of straight-line or uniform motion.

$$y = C \theta \quad \text{--- (1)}$$

where: y - represent follower displacement in mm,
 θ - Cam angle in radians, $\theta_{rad} = \theta_{deg} * \frac{\pi}{180}$,
 C - Constant determined from boundary condition.

If we take:

S_0 = out stroke in (mm) - or total distance to rise,
 θ_0 - Cam angle in rad, when the Cam rotate to effect this rise.

$$\therefore S_0 = C \theta_0 \Rightarrow C = \frac{S_0}{\theta_0} \quad \text{--- (2)}$$

by sub-ing C from (2) in (1) \Rightarrow we get

$$y = \frac{S_0}{\theta_0} \theta \quad \text{--- (3) } \Rightarrow \text{displacement eq-n.}$$

When: $\theta = \theta_0$

$$\therefore \boxed{y_0 = S_0}$$

\rightarrow for out stroke.

and when $\theta = \theta_R$

$$\therefore \boxed{y_R = S_R}$$

\rightarrow displacement for outstroke

\rightarrow displacement for return stroke.

2) Velocity of uniform motion السرعة المنتظمة

may be obtain by finding the first derivative with respect to time \Rightarrow for (3)

$$\therefore v = \dot{y} = \frac{d}{dt} \left(\frac{S_0}{\theta_0} \theta \right) = \frac{S_0}{\theta_0} \cdot \frac{d\theta}{dt} = \frac{S_0}{\theta_0} \omega \quad \text{--- (4)}$$

3) Acceleration of uniform motion.

تسارع الحركة المنتظمة

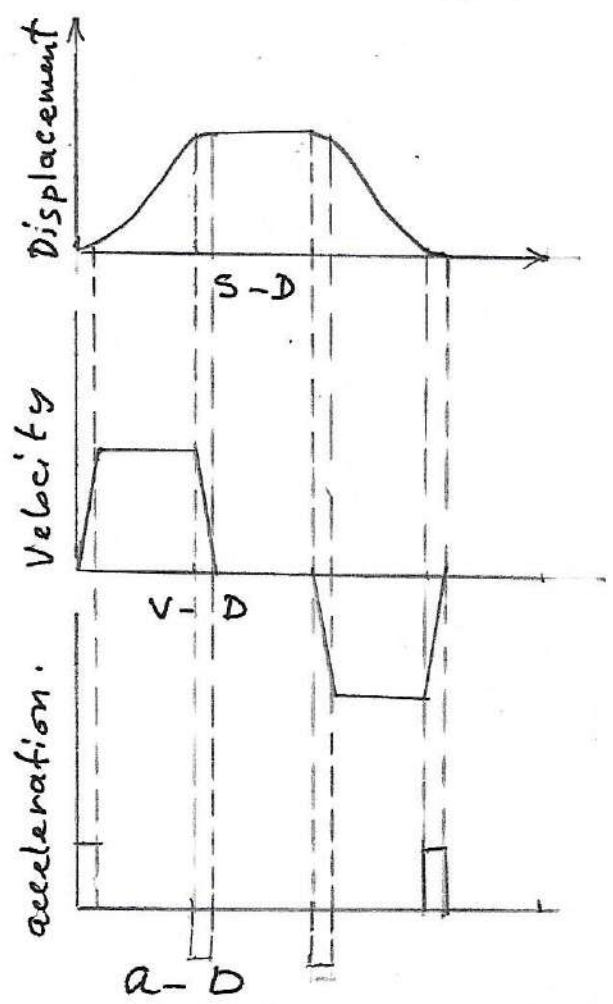
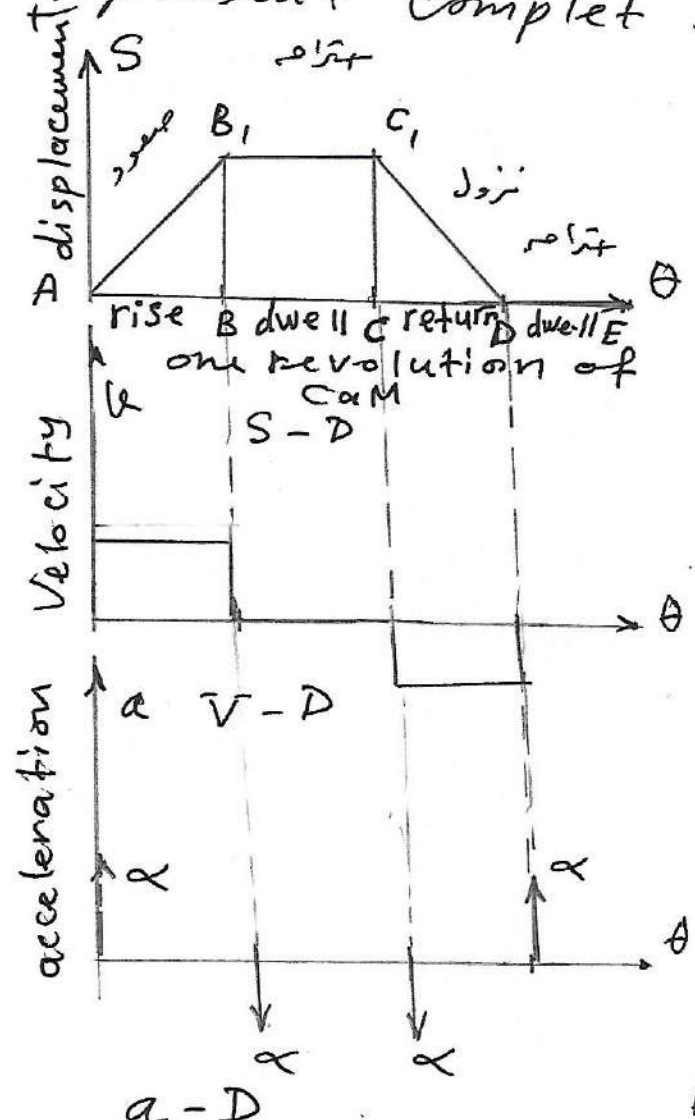
It is obtain by finding the second derivative of Displacement, or first derivative of Velocity.

$$a = \ddot{y} = \frac{d}{dt} \left(\frac{s_0}{\theta_0} \theta \right)$$

$$\text{or } a = \ddot{y} = \dot{v} = \frac{d}{dt} \left(\frac{s_0}{\theta_0} \omega \right) = \frac{s_0}{\theta_0} \left(\frac{d\omega}{dt} \right) = 0 \quad \text{--- (5)}$$

because of $\omega = \text{const} \rightarrow$ angular velocity of cam

The S-diagram, V-diagram and a-diagram are shown in fig (a), They are representing by (x, y) coordinate system, where x-represent one complete revolution of Cam, and y-represent complet stroke of the follower



Fig(b); Modified, S-D, V-D, A-D

From Fig(a) we see that the acceleration of out and return stroke is infinite, because the follower start from rest, and gain velocity with no time, and this is impracticable. therefore we must rounding the sharp corners of the displacement diagram \rightarrow to a parabolic curves in order to get low acceleration of the follower for given strokes, as shown in fig (b)

$$a = \frac{dv}{dt}, dt=0 \rightarrow a = \frac{dv}{0} = \infty$$

* N) Displacement, velocity and acceleration diagrams, when the follower retardation.

* or with parabolic motion.

the equation of motion for parabolic consist of two half (rise and return)

1) equation of parabolic motion for First half of the motion (out stroke)

$$y = C \theta^2 \quad \text{--- (1)}$$

and this equation valid only for inflection point:

where $\begin{cases} y = \frac{S_0}{2} \\ \theta = \frac{\theta_0}{2} \end{cases}$ by sub-in (1) \rightarrow we get

$$\frac{S_0}{2} = C \left(\frac{\theta_0}{2} \right)^2 \Rightarrow C = 2 \frac{S_0}{\theta_0^2} \text{ by sub in (1) } \Rightarrow$$

or $y = 2 S_0 \left(\frac{\theta}{\theta_0} \right)^2$ --- (2)

The velocity and acceleration obtain by finding the first and second derivatives for the equation of the displacement (2) as follow, by taking-

$$2) \begin{cases} S_0 = \text{constant} \\ \theta_0 = \text{constant} \\ \omega = \text{constant} \\ \theta - \text{changeable} \end{cases}$$

2) Velocity :

$$v = \dot{y} = \frac{d}{dt} \left[2 S_0 \left(\frac{\theta}{\theta_0} \right)^2 \right] = 2 \frac{S_0}{\theta_0^2} \frac{d\theta^2}{dt}$$

$$= 2 \frac{S_0}{\theta_0^2} \cdot 2\theta \frac{d\theta}{dt} = \frac{4 S_0 \omega \theta}{\theta_0^2}$$

$$\therefore v = \frac{4 S_0 \omega \theta}{\theta_0^2} \quad \text{--- (3)}$$

3 - acceleration

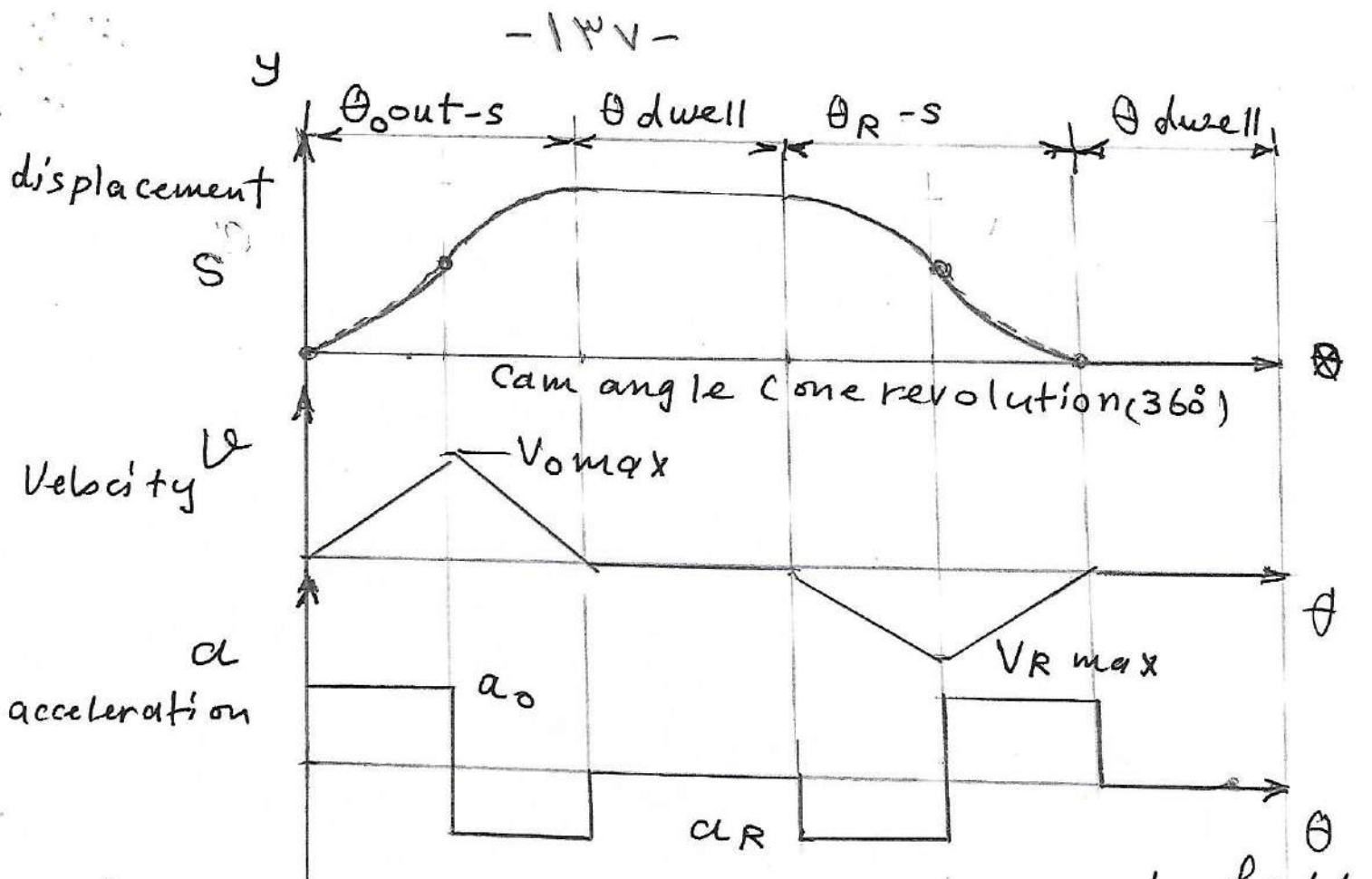
$$a = \ddot{y} = \dot{v} = \frac{d}{dt} \left(\frac{4 S_0 \omega \theta}{\theta_0^2} \right) = \frac{4 S_0 \omega}{\theta_0^2} \times \frac{d\theta}{dt}$$

$$\therefore a = \frac{4 S_0 \omega^2}{\theta_0^2} \quad \text{--- (4)}$$

From eq-n (4) we see that $a = \text{constant}$, and v_{max} occurs at the inflection point, where $\theta = \frac{\theta_0}{2}$ → for out stroke.

$$\therefore v_{\text{max}_0} = \frac{4 S_0 \omega}{\theta_0^2} \left(\frac{\theta_0}{2} \right) = \frac{2 S_0 \omega}{\theta_0}$$

$$\therefore v_{\text{max}_0} = \frac{2 S_0 \omega}{\theta_0} \quad \text{--- (5)}$$



Fig(a): S-D, V-D, a-D for parabolic motion

2 - displacement equation for the second half motion (return stroke) -

$$y = C_1 + C_2 \theta + C_3 \theta^2 \quad \text{--- (6)}$$

For determining the const. C_1, C_2, C_3 may be get by solving these equations. assume that $\theta = \theta_R, y = S_R$

and by sub in (6) we get

$$S_R = C_1 + C_2 \theta_R + C_3 \theta_R^2 \quad \text{--- (7)}$$

When $\theta = \theta_R \rightarrow v = 0$

$$\therefore v = 0 = \dot{y} = \frac{d}{dt} (C_1 + C_2 \theta + C_3 \theta^2) = 0 + C_2 \left(\frac{d\theta}{dt} \right) + C_3 2\theta \left(\frac{d\theta}{dt} \right)$$

$$1. \quad v = 0 = C_2 W + 2C_3 \theta_R W \quad \text{--- (8)}$$

but v_{max} occurs when $\theta = \frac{\theta_R}{2}$ at the inflection point.

$$\text{or } v_{max} = \frac{2SRW}{\theta_R} = C_2 W + 2C_3 W \theta_R \quad \text{--- (9)}$$

by solving equation (7), (8), (9) \rightarrow we get.

$$\left\{ \begin{array}{l} C_1 = SR \quad \rightarrow \text{By sub } C_2, C_3 \text{ in (7)} \rightarrow C_1 \\ C_2 = \frac{4SR}{\theta_R} \quad \rightarrow \text{By sub } C_3 \text{ in (8)} \rightarrow C_2 \end{array} \right.$$

$$C_3 = -2 \frac{SR}{\theta_R^2} \quad \rightarrow \text{By sub } C_2 \text{ in (8) and (9)} \rightarrow C_3$$

By sub these constants in eq-n (6) and obtain the displacement eq-n.

$$1. \quad y = SR \left[1 - 2 \left(1 - \frac{\theta}{\theta_R} \right)^2 \right] \quad \text{--- (10)}$$

$$2. \quad v = \dot{y} = \frac{d}{dt} \left[SR \left(1 - 2 \left(1 - \frac{\theta}{\theta_R} \right)^2 \right) \right]$$

$$\therefore v = \frac{d}{dt} \left[SR - 2SR \left(1 - \frac{\theta}{\theta_R} \right)^2 \right]$$

$$= 0 - 2SR \cdot 2 \left(1 - \frac{\theta}{\theta_R} \right) \times \left(0 - \frac{1}{\theta_R} \cdot \frac{d\theta}{dt} \right)$$

$$= 0 - 4SR \left(1 - \frac{\theta}{\theta_R} \right) \cdot - \frac{1}{\theta_R} W$$

$$v = + \frac{4SRW}{\theta_R} \left(1 - \frac{\theta}{\theta_R} \right) \quad \text{--- (11)}$$

at the inflection point.

$$v \rightarrow v_{max}, \quad \theta \rightarrow \frac{\theta_R}{2}$$

$$\therefore v_{max} = \frac{4SRW}{\theta_R} \left(1 - \frac{\theta_R}{2\theta_R} \right) = \frac{2SRW}{\theta_R}$$

at the inflection point.

8) the acceleration be.

$$a = \ddot{y} = \frac{d}{dt} \left(\frac{4SRW}{\theta_R} \left(1 - \frac{\theta}{\theta_R} \right) \right)$$

where $w = \text{const}$, θ - changeable.

$$\therefore a = \frac{d}{dt} \left(\frac{4SRW}{\theta_R} - \frac{4SRW \cdot \theta}{\theta_R^2} \right)$$

$$= 0 - \frac{4SRW}{\theta_R^2} \left(\frac{d\theta}{dt} \right) w = \frac{4SRW^2}{\theta_R^2}$$

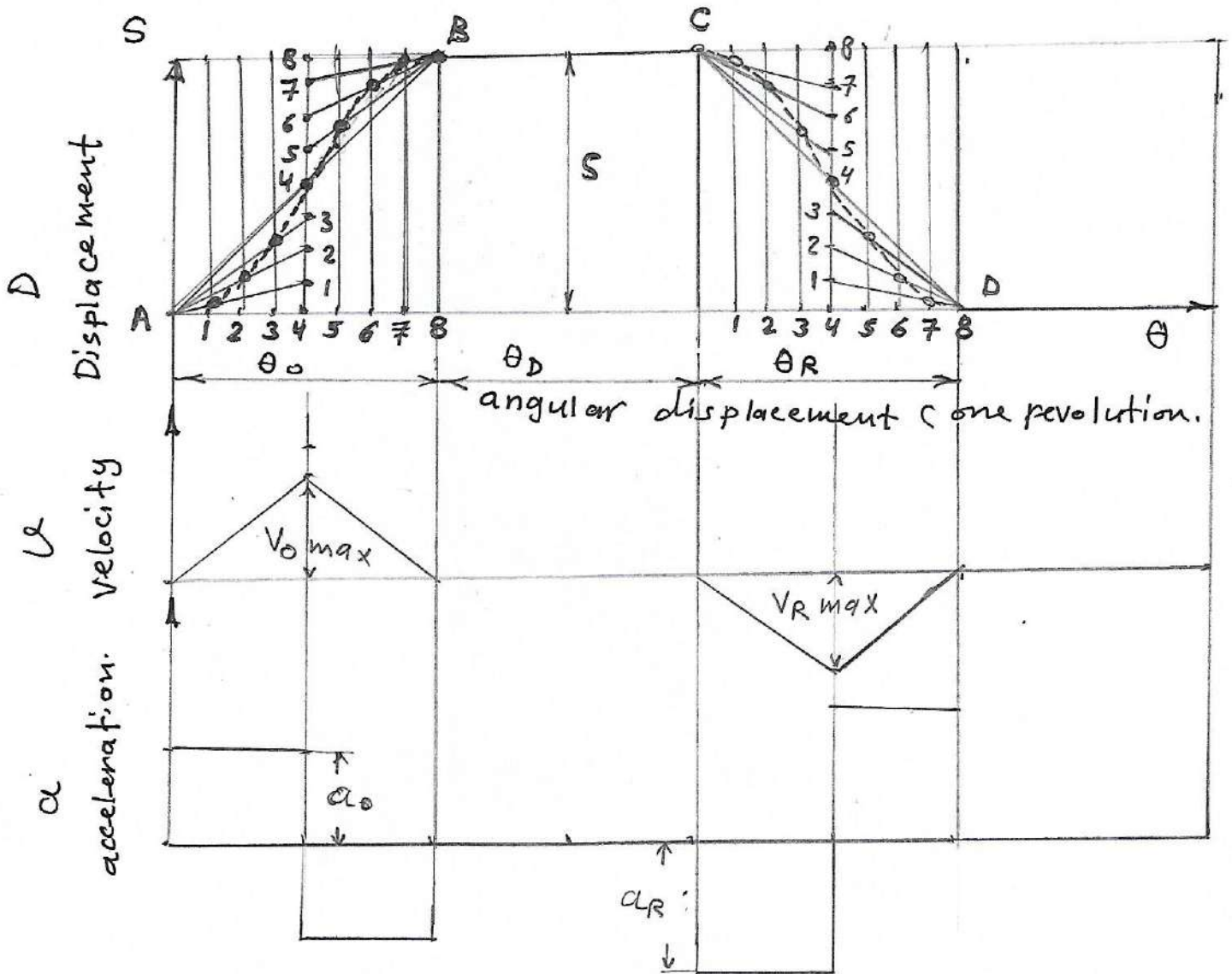
$$\therefore a = \frac{4SRW^2}{\theta_R^2} \quad \text{--- (12)}$$

الطريقة البيانية لتنازح خط الأزام للحركة القطع الأسي

* Graphical Method for drawing displacement, velocity and acceleration, when the follower move with uniform acceleration and retardation \rightarrow (Parabolic-motion), as follow:

- 1- Divide the angular displacement ^{قسم الأزام الزاوية للصفوف إلى عدد متساوي ولكن (٨)} for out stroke (θ_0) into any equal number (say 8).
- 2- Divide the stroke (S_0) into the same equal number of parts (8).
- 3- Join point A with B, C, D, E _{F, G, H, J} with 1, 2, 3, 4, and join point J with 5, 6, 7, 8, then these point to obtain parabolic curve for out stroke.
- 4- By similar way draw parabolic curve for return stroke (θ_R, SR).
- 5) calculate the v_{max} , a_{max} for out stroke, and v_{min} , a_{min} for return stroke as follow: fig (a)

* Graphical Method For drawing parabolic curve



Fig(a) : Graphical Method for drawing, D, V, a diagram as follow :

- 1- Divide θ_0 into equal number, like 1, 2, 3, 4, 5, 6, 7, 8
- 2- Divide S_0 into same equal number, 1, 2, 3, 4, 5, 6, 7, 8
- 3- Join A with 1, 2, 3, 4
- 4- Join B with 5, 6, 7, 8
- 5- Find A cross point
- 6- draw parabolic curve through cross point for out stroke.
- 7- by same way for SR-stroke.
- 8- Find $V_{0\max}$, $V_{R\max}$.

III) Displacement, velocity and acceleration diagrams, when the follower moves with simple harmonic motion.

1) Simple harmonic motion represent with following equation for displacement.

$$y = \frac{S_0}{2} \left(1 - \cos \frac{\pi \theta}{\theta_0} \right) \text{ --- (1) } \rightarrow \text{for out stroke}$$

2) The velocity represent with a first derivative of displacement.

$$\begin{aligned} \therefore v = \dot{y} &= \frac{d}{dt} \left(\frac{S_0}{2} \left(1 - \cos \frac{\pi \theta}{\theta_0} \right) \right) \\ &= \frac{d}{dt} \left(\frac{S_0}{2} - \frac{S_0}{2} \cos \frac{\pi \theta}{\theta_0} \right) = 0 - \frac{S_0}{2} \left(-\frac{\pi}{\theta_0} \right. \\ &\quad \left. \sin \frac{\pi \theta}{\theta_0} \right) \left(\frac{d\theta}{dt} \right) \rightarrow \omega \end{aligned}$$

$$v = + \frac{\pi S_0 \omega}{2 \theta_0} \sin \frac{\pi \theta}{\theta_0} \text{ --- (2) } \rightarrow \text{Sine Curve}$$

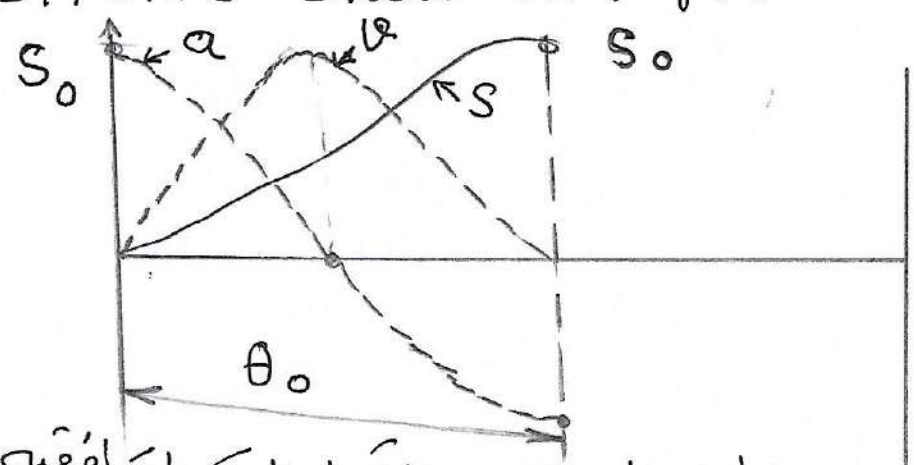
3) acceleration represent second derivative of displacement or first derivative of velocity.

$$\begin{aligned} \therefore a = \ddot{y} = \dot{v} &= \frac{d}{dt} \left(\frac{\pi S_0 \omega}{2 \theta_0} \sin \frac{\pi \theta}{\theta_0} \right) = \\ &= \frac{\pi S_0 \omega}{2 \theta_0} * \frac{\pi}{\theta_0} \cos \frac{\pi \theta}{\theta_0} \left(\frac{d\theta}{dt} \right) \omega \end{aligned}$$

$$a = \frac{\pi^2 S_0 \omega^2}{2 \theta_0^2} \cos \frac{\pi \theta}{\theta_0} \text{ --- (3) } \rightarrow \text{Cosine Curve}$$

* For return stroke by same way

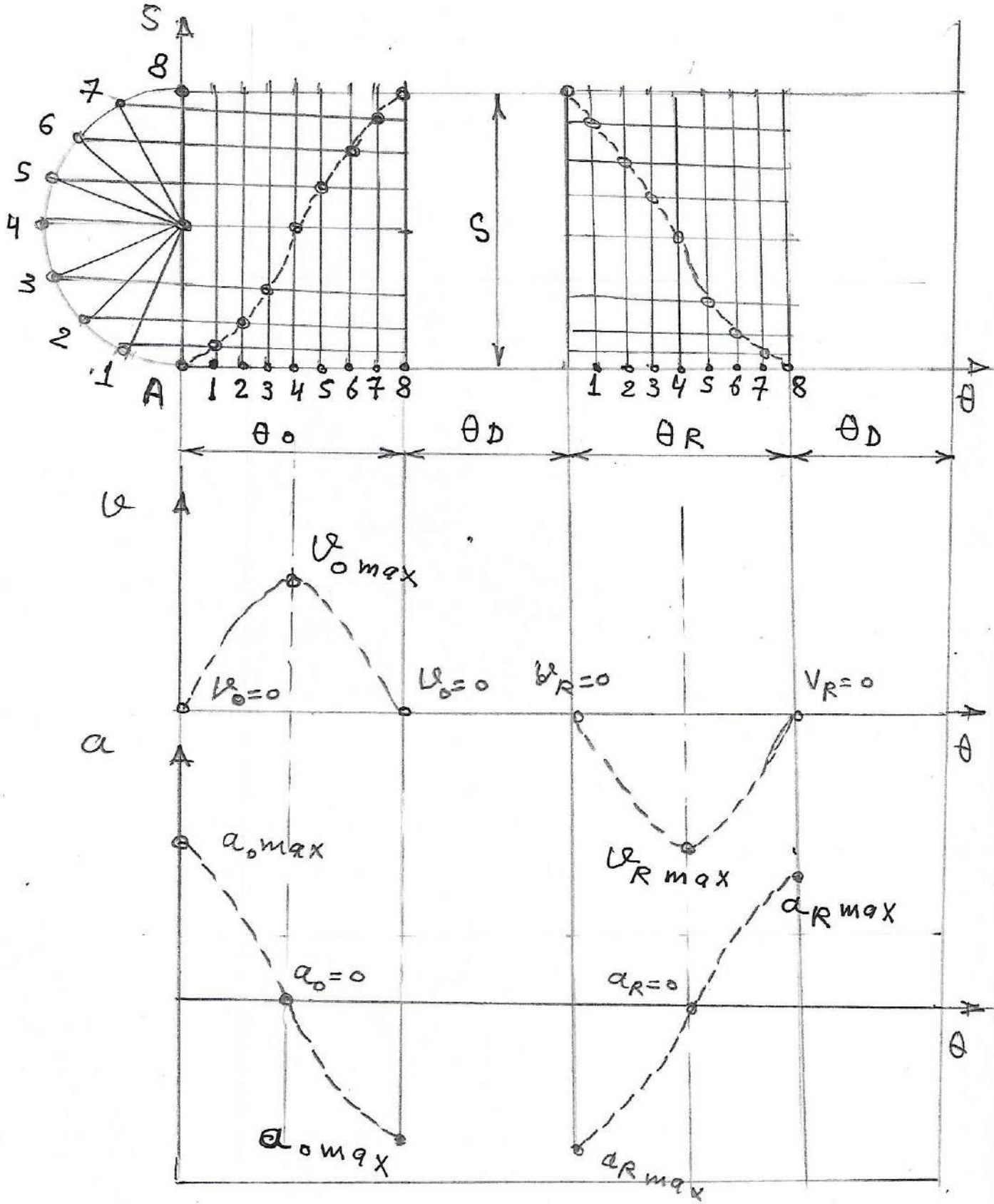
representation of simple harmonic motion for out stroke show in fig(a).



* Graphical Method for drawing the displacement, velocity and acceleration when the follower move with simple harmonic motion: as follow

- 1- draw semi circle with diameter (S_0)
- 2- Divide the semi circle into any equal parts, for example (8 parts)
- 3- Divide the angular displacements of the cam into the same number of equal parts.
- 4- Displacement diagram is obtained by the projected points, as bellow.
- 5- velocity diagram consist of sine curve, at beginning and end $\rightarrow V_0 = 0$, at midpoint $\rightarrow V_0 = \text{max}$
- 6- acceleration diagram consist of cosine curve. at beining and end $\rightarrow a = a_{\text{max}}$, and at midpoint $\rightarrow a_0 = 0$ as shown in fig(b),

Fig (b), Graphical Method.



* Construction of Cam profile for a radial Cam
 بناء على الحركة الدائرية

Construction of Cam profile for different types of followers, with different types of motions, as discussed by the following examples:

بناء على الحركة الدائرية للاشكال المختلفة من التتابع وللأنواع المختلفة من الحركات
 سوف نتناولها بالتفصيل التاليه - اتم - Draw - بناء = design

Example (1)

A Cam is to be designed for a knife edge follower moves with uniform velocity for both strokes, and with the following data:

- 1- outstroke during 60° of Cam rotation;
- 2- Dwell for next 30° of Cam rotation;
- 3- Return stroke during next 60° of C.R;
- 4- Dwell for the remaining 210° of C.R;
- 5- stroke of the follower 40 mm; and
- 6- minimum radius of the Cam is 50 mm.

Draw the profile of the Cam when:
 1) The axis of the follower passes through the axis of the Cam shaft; and

2) The axis of the follower is offset by 20 mm of the axis of the Cam shaft.
 3) determine the max-M velocity and acceleration when the Cam

Solution: rotate with 100 r.p.m and draw S-D, V-D, a-D diagram for 1 complete revolution.
 4- Speed of Cam 2000 r.p.m.

1) Draw displacement diagram as follows:

- 1- draw horizontal line $AX = 360^\circ$ and mark $AS = 60^\circ$, $ST = 30^\circ$, $TP = 60^\circ$, $PX = 210^\circ$,

- 2 - draw vertical line $Ay = S = 40 \text{ mm}$, and complete the rectangle.
 - 3 - divide the angular displacement for out and return stroke into any equal number (say 6) and draw vertical line through each number with suitable scale.
 - 4) since the follower moves with uniform velocity then the displacement for out and return stroke are straight lines (AG, HP), and the S-D be complete, as shown below.
- 5)* take scale $\rightarrow 2^\circ = 1 \text{ mm}$, fix as

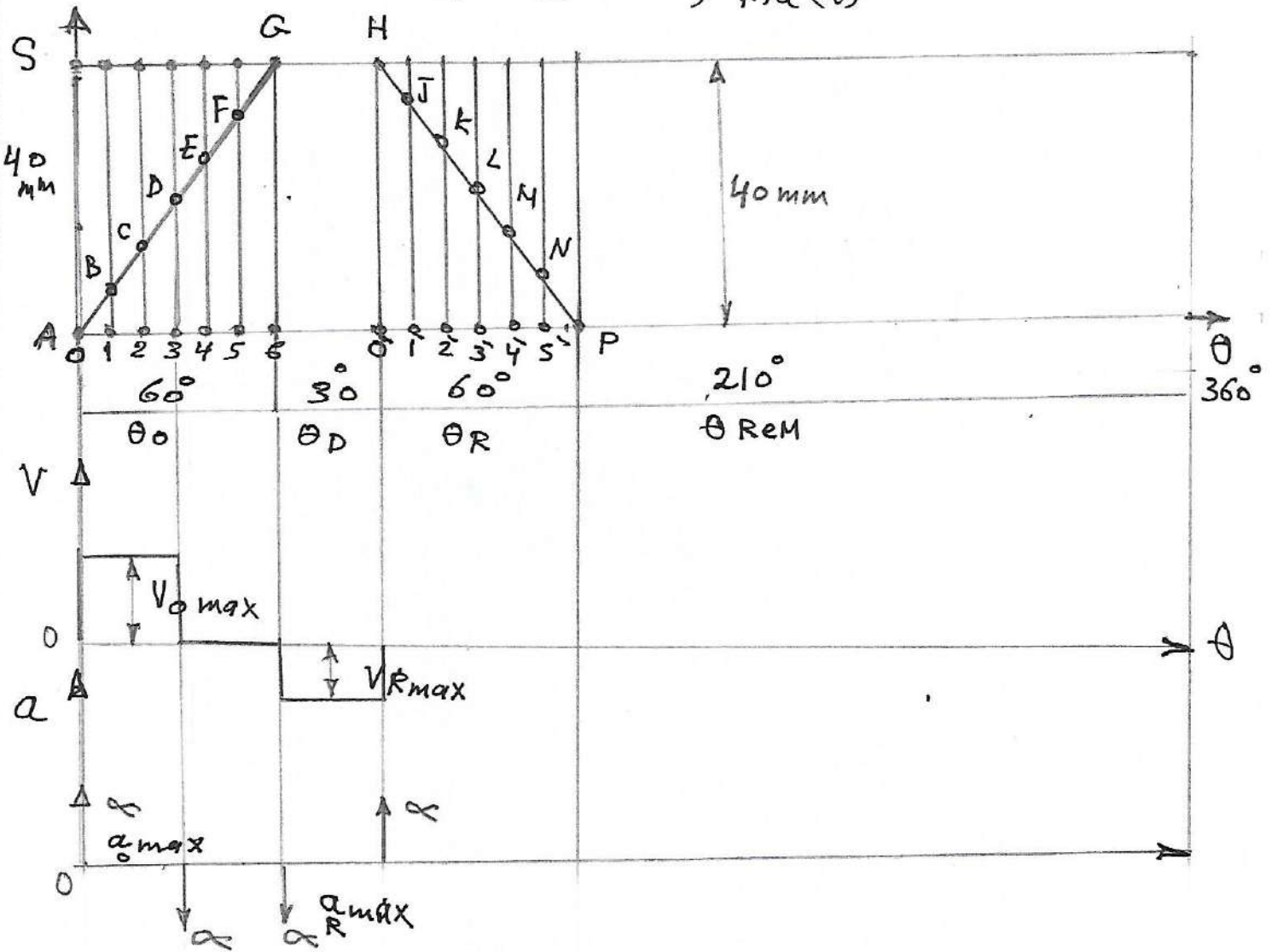
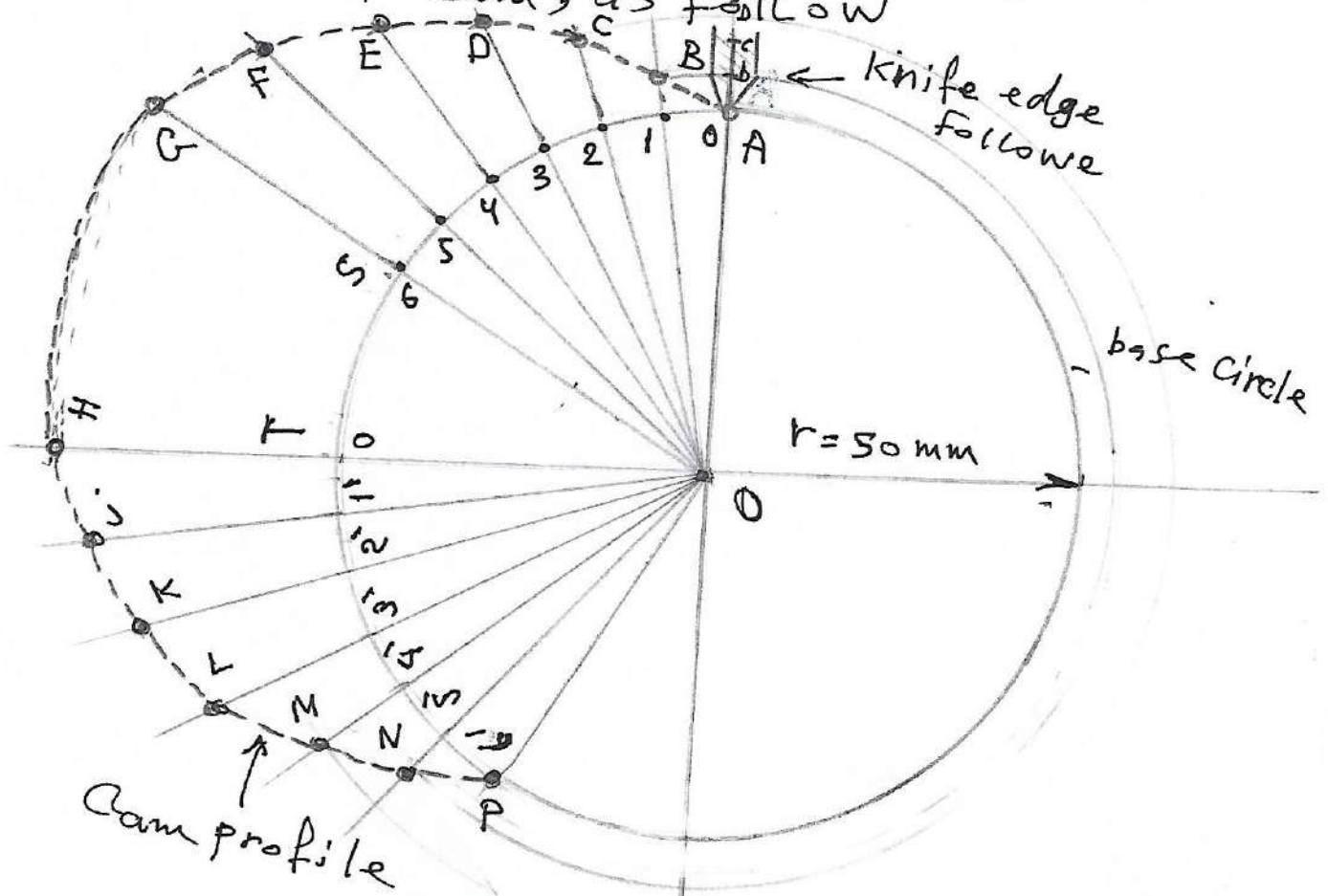


Fig (a) show: S-D, V-D, a-D.

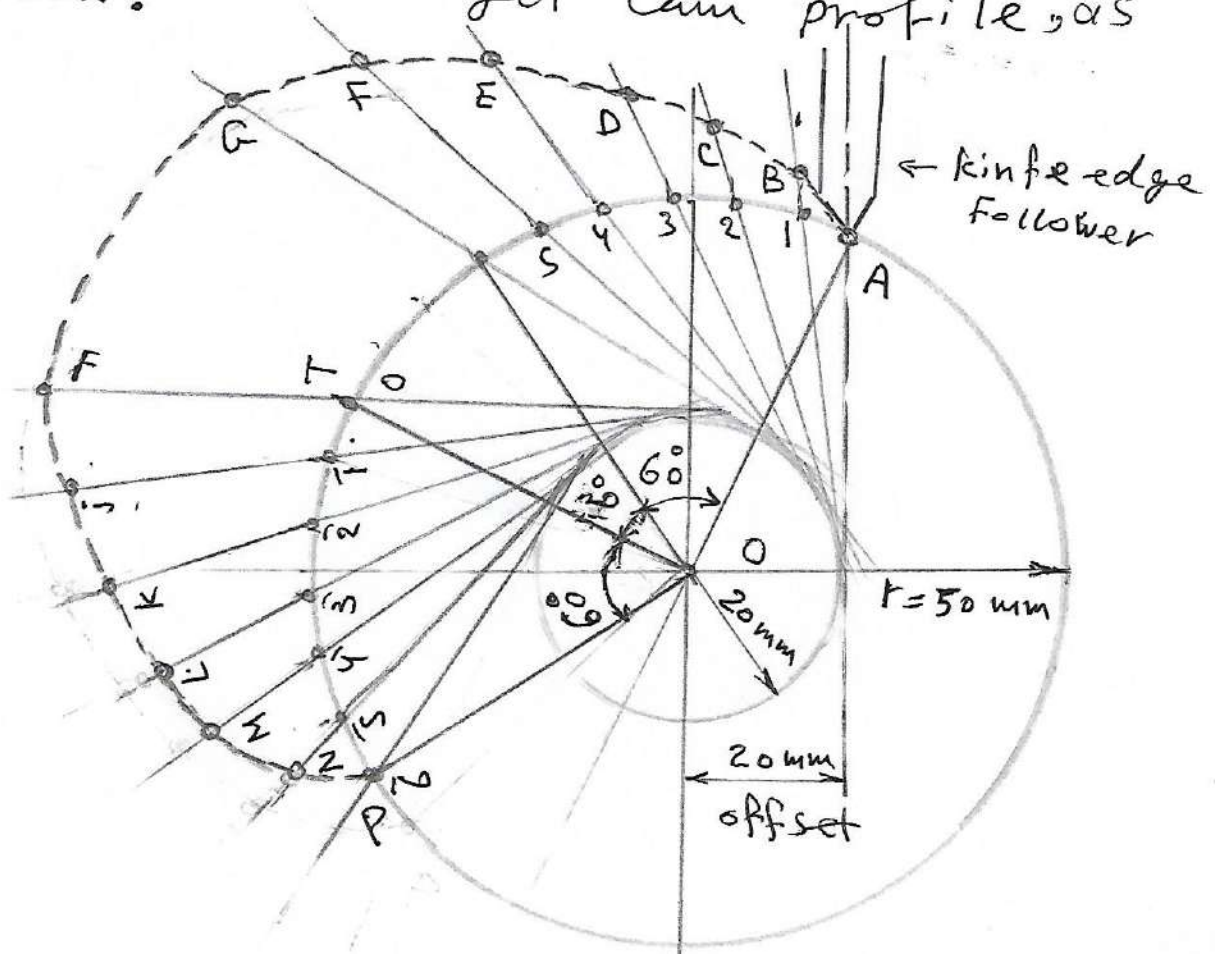
ii) Draw Cam profile, when the axis of the follower pass through the center of cam, as follow

- 1) draw base circle with ($r = 50 \text{ mm}$) and center o.
- 2) Mark point A, and from oA mark angle $\text{AOS} = 60^\circ$ for out stroke, ang $\text{SOT} = 30^\circ$ for dwell, ang $\text{TOP} = 60^\circ$ for return stroke.
- 3) divide the angle of out and return stroke into the same equal number of parts, as in the displacement diagram.
- 4) Join the point 1, 2, 3, and $\hat{1}, \hat{2}, \hat{3}$, - With the center of cam o.
- 5) Added the lengths 1B, 2C, --6G to $\text{O}_1, \text{O}_2, \dots \text{O}_6$ on the cam for out stroke, and by same way added $\text{OH}, \dots \text{OP}$ for return stroke.
- 6) Join the point A, B, C, --N, P to get the profile of cam, as follow



III) Draw Cam profile, when the axis of the follower is offset by 20 mm from the axis of the cam shaft, as follow

- 1- draw base circle with $r = 50 \text{ mm}$.
- 2, draw the axis of the follower with offset 20 mm.
- 3, draw offset circle with radius $r = 20 \text{ mm}$
- 4, from OA mark, angle $\angle AOS = 60^\circ$, $\angle SOT = 30^\circ$
 $\& \text{HOP} = 60^\circ$ for out and return stroke and dwell.
- 5, divide these angles in the same equal parts
- 6, to the offset circle. S-D, and draw from 1, 2, 3, tangents to the offset circle.
- 7, by same way add the lengths from S-D and mark point, A, B, C, ..., P, Joine bellow:



→ max-m velocity for outstroke and return stroke

$$V_{o\max} = \frac{S_o}{\theta_o} \omega = \frac{0,04}{\frac{60 \times \pi}{180} \times \frac{2\pi}{60}} \times \frac{2\pi \times 240}{60} = 1,2 \text{ m/s}$$

$$V_{R\max} = \frac{S_R}{\theta_R} \omega = \frac{0,04}{\frac{60 \times \pi}{180} \times \frac{2\pi}{60}} \times \frac{2\pi \times 240}{60} = 1,2 \text{ m/s}$$

→ max-m acceleration for out and return stroke.

$$a_{o\max} = \frac{S_o}{\theta_o} \frac{d\omega}{dt} = \infty$$

$$a_{R\max} = \infty, \text{ because } \omega = \text{const}$$

* Example (2) :

A Cam is to be designed for a knife edge follower with the following data :

- 1- Cam lift = 40 mm during 90° of Cam rotation with simple harmonic motion.
- 2- Dwell to the next 30°
- 3- During the next 60° of Cam rotation, the follower returns to its original position with simple harmonic motion.
- 4- Dwell during the remaining 180°.

Draw the profile of the Cam when:

- a) the line of stroke of the follower passes through the center of the Cam shaft, and
- b) the line of stroke is offset 20 mm from the axis of the Cam shaft.

The radius of the base circle of the Cam is 30 mm, Determine the max-m velocity and acceleration of the follower during its out and return stroke, if the Cam rotates at 240 r.p.m.

* Solution :

Solution:

- I, Draw displacement diagram with steps as discussed below:
- 1) Draw horizontal line $Ax = 360^\circ$, with scale $2^\circ = 1\text{mm}$, and mark $AS = 90^\circ$ for outstroke, $SR = 30^\circ$ for dwell, $RP = 60^\circ$, and $PX = 180^\circ$ dwell. Complete the rectangle.
- 2) Draw vertical line $Ay = 40\text{mm}$ stroke, and complete the rectangle.
- 3) Divide the angular displacement and stroke to same equal number of parts (say = 6).
- 4) For simple harmonic motion draw semi circle with diameter (S), and divide into same equal number.
- 5) Locate the intersecting point (A, B, C) for outstroke from the vertical lines (1, 2, 3, 4, 5, 6) and horizontal lines (a, b, c, d, e), by same way for return stroke.
- 6) Join the intersecting points A, B, C with smooth curve to get the required (S-D).

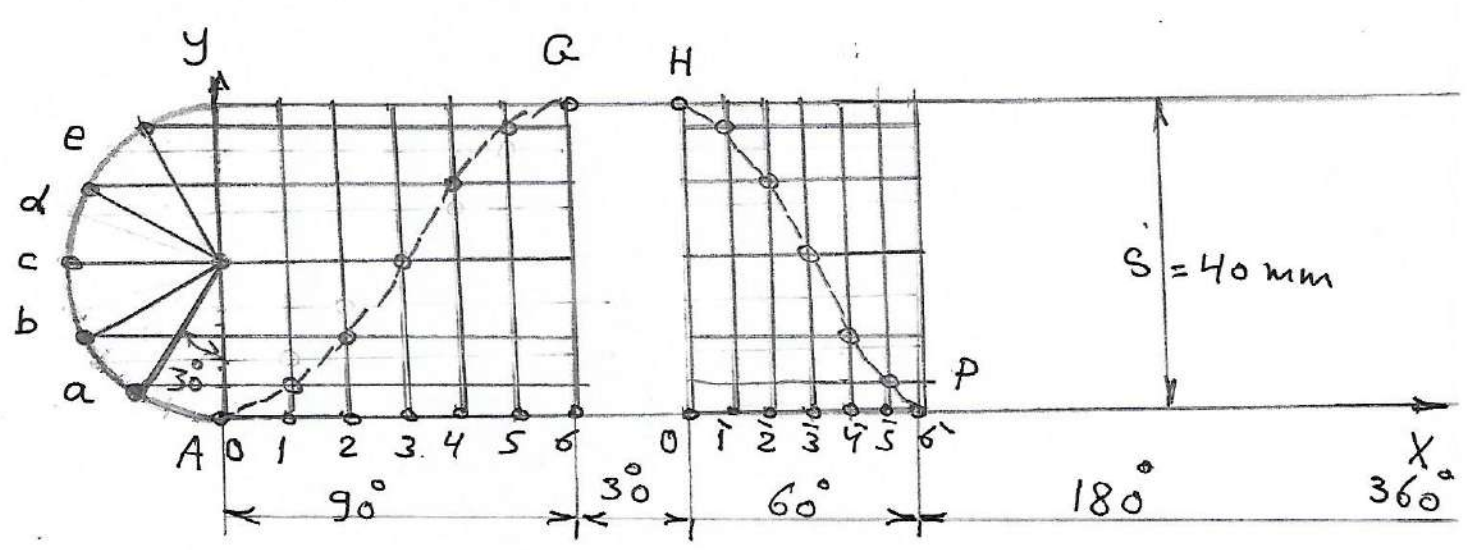
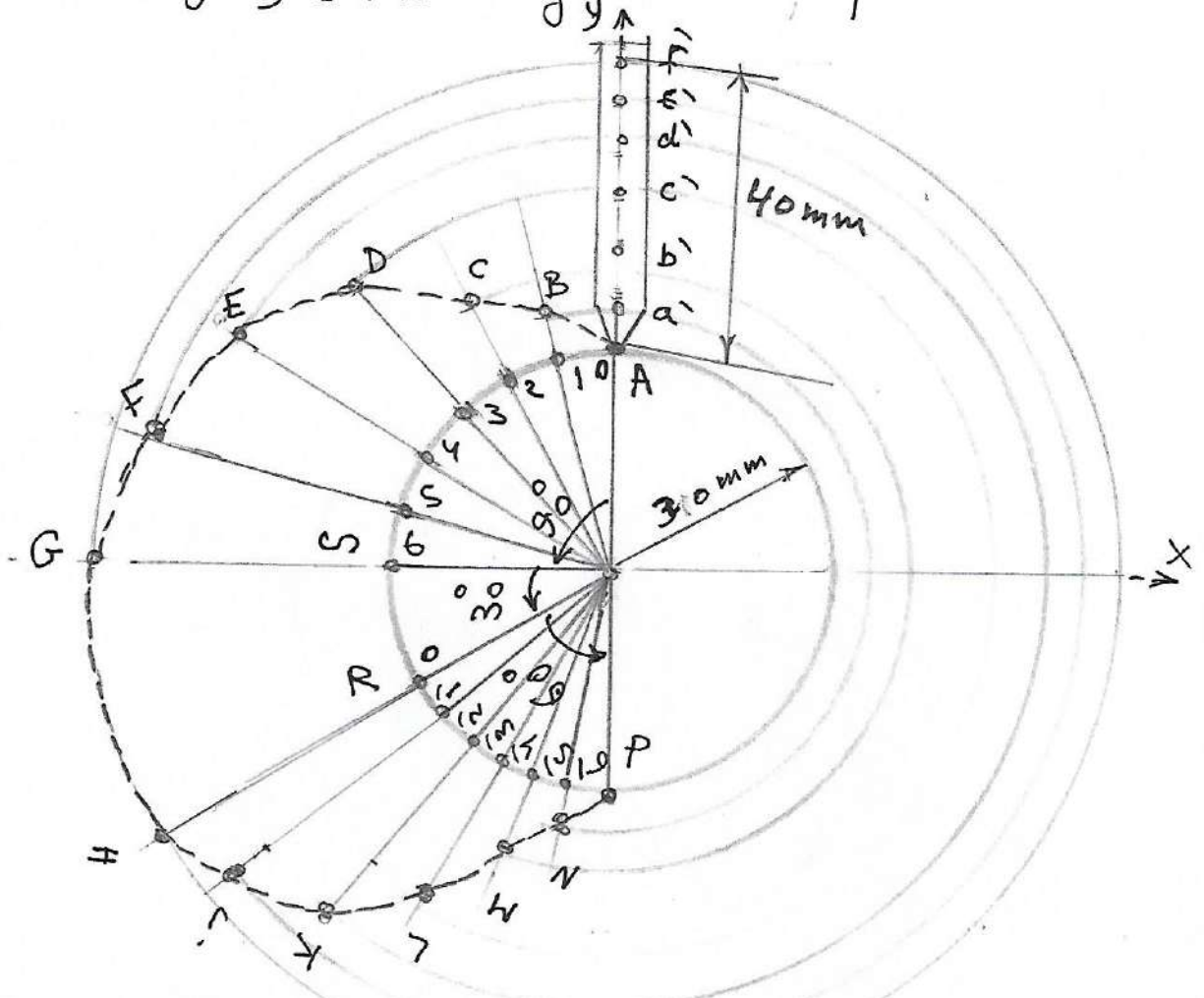
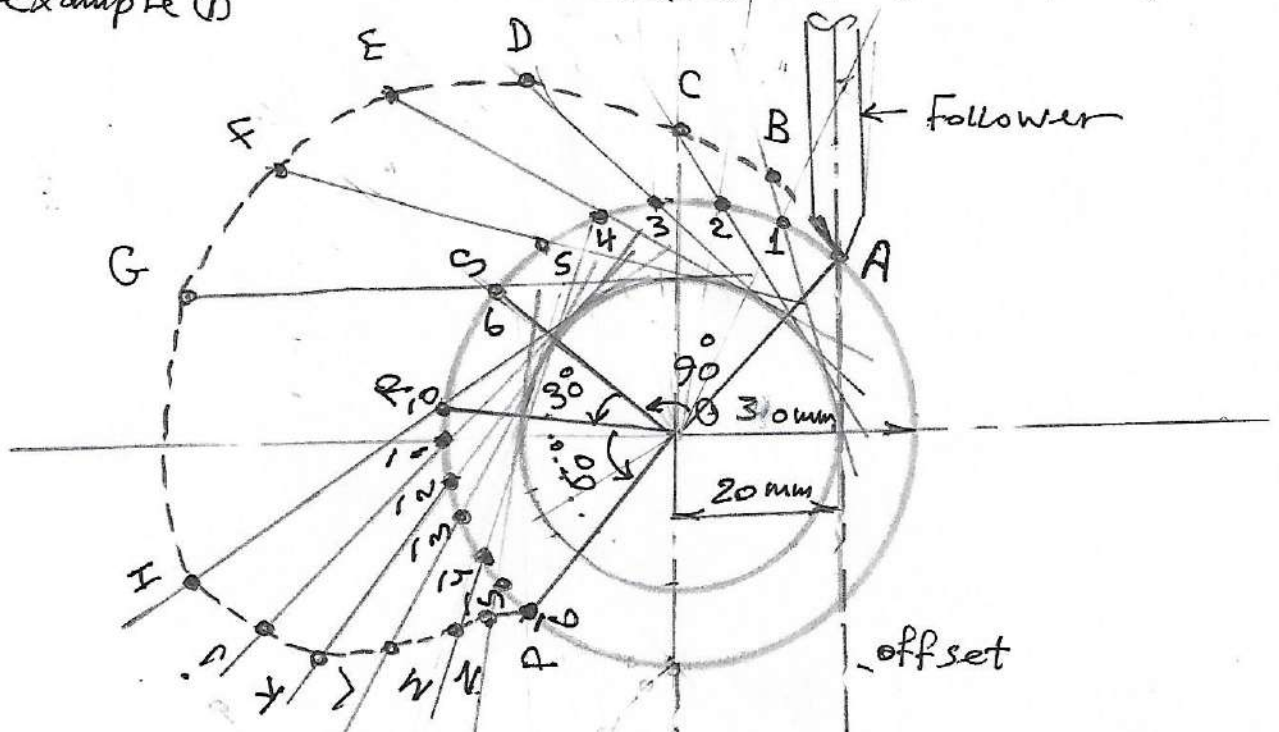


Fig. 10 Displacement diagram.

II, Draw profile of cam, when the axis of follower passes through the center of the cam. This is done by same way as in example (I).



III, Draw Cam profile with offset (20) mm by same way as in example (I)



IV, max-m velocity during out and return stroke

$$V_{O \max} = \frac{\pi \omega S}{2 \theta_O} \quad , \quad V_{R \max} = \frac{\pi \omega S}{2 \theta_R}$$

$$\theta_O = 90^\circ \times \frac{\pi}{180} = 1,571 \text{ rad}$$

$$\theta_R = 60^\circ \times \frac{\pi}{180} = 1,047 \text{ rad}$$

$$\omega = \frac{2\pi n}{60} = \frac{2 \times 3,14 \times 240}{60} = 25,14 \text{ rad/s}$$

$$\therefore V_{O \max} = \frac{3,14 \times 25,14 \times 0,04}{2 \times 1,571} = \underline{1 \text{ m/s}} \quad , \text{ and}$$

$$V_{R \max} = \frac{3,14 \times 25,14 \times 0,04}{2 \times 1,047} = 1,51 \text{ m/s}$$

V, max-m acceleration for out and return stroke.

$$a_{O \max} = \frac{\pi^2 \omega^2 S}{2 \theta_O^2} \quad , \quad a_{R \max} = \frac{\pi^2 \omega^2 S}{2 \theta_R^2}$$

$$\therefore a_{O \max} = \frac{(3,14)^2 \times (25,14)^2 \times 0,04}{2 \times (1,571)^2} = 50,6 \text{ m/s}^2$$

$$a_{R \max} = \frac{(3,14)^2 \times (25,14)^2 \times 0,04}{2 \times (1,047)^2} = \underline{113,8 \text{ m/s}^2}$$

* Example (3)

A cam, with a minimum radius of (25 mm), rotating clockwise at uniform speed, is to be designed to give a roller follower, at the end of a valve rod,

motion described below:

- 1- To raise the valve through (50 mm) during (120°) rotation of the Cam.
- 2- To keep the valve fully raised through next (30°).
- 3- To Lower the valve during next (60°), and
- 4) To keep the valve closed during rest of revolution (150°).

The diameter of the roller (20 mm) and the diameter of the Cam shaft is (25 mm).

Draw the profile of the Cam when :

- a) the line of stroke of the valve rod passes through the axis of the Cam shaft; and
- b) the line of the stroke is offset (15 mm) from the axis of the Cam shaft.

The displacement of the valve, while being raised and lowering, is to take place with simple harmonic motion. Determine the max-m acceleration of the valve, when the Cam shaft rotates at (100 r.p.m).

Draw the displacement, the velocity, and the acceleration diagrams for one complete revolution of the Cam.

* Solution :

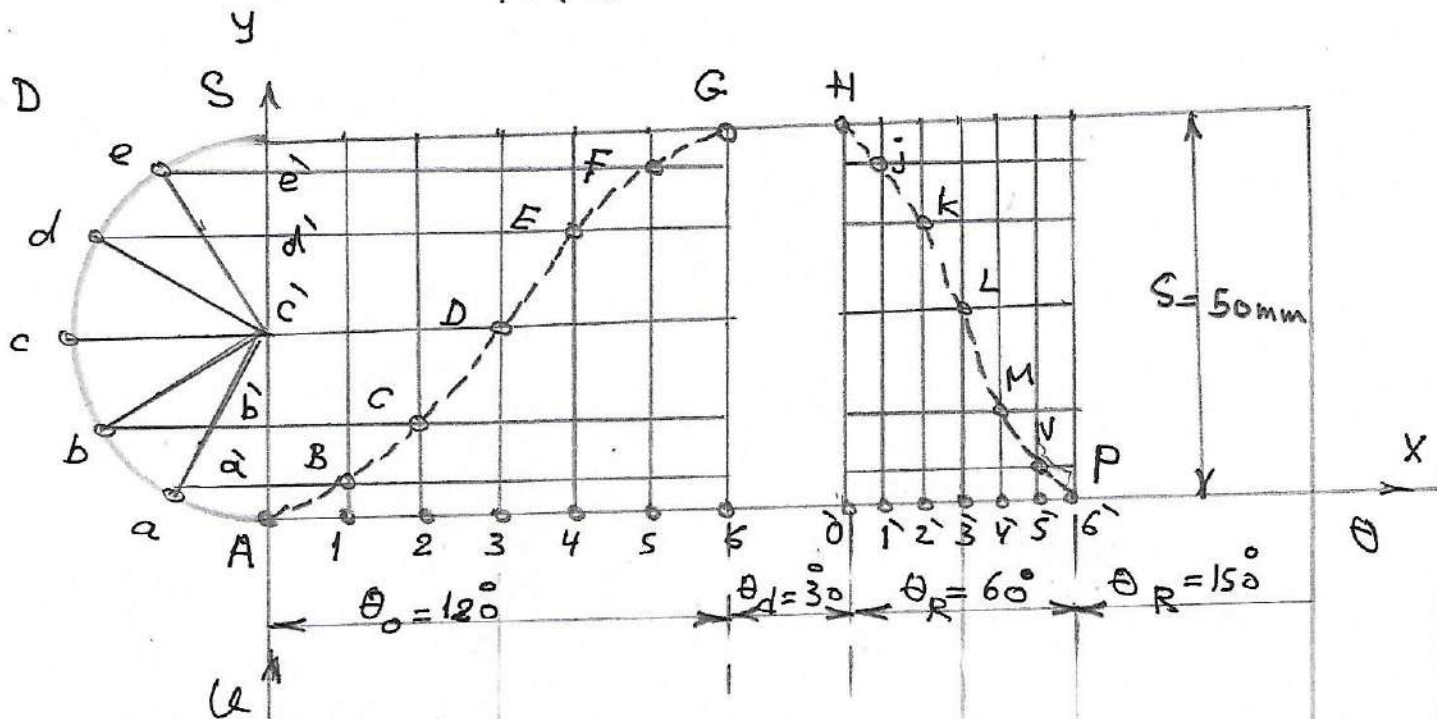
I) Draw displacement diagram by same way, as in example (2) for simple harmonic motion, as shown.

∴ S-D for complete revolution, velocity diagram V-D, and acceleration diagram.

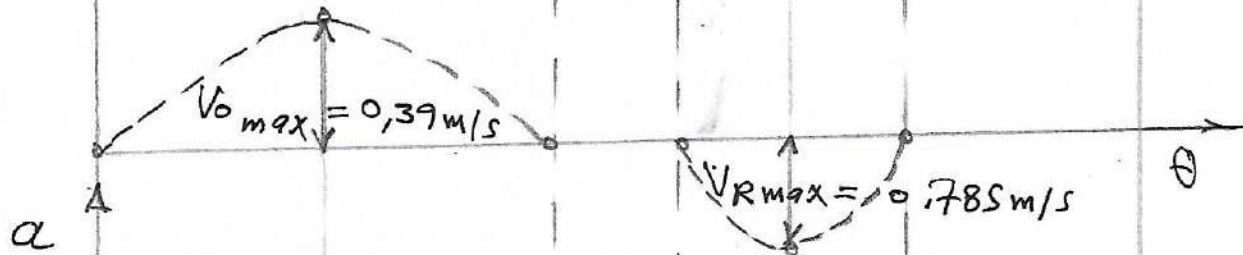
a-D -

Scale: 2° = 1 mm

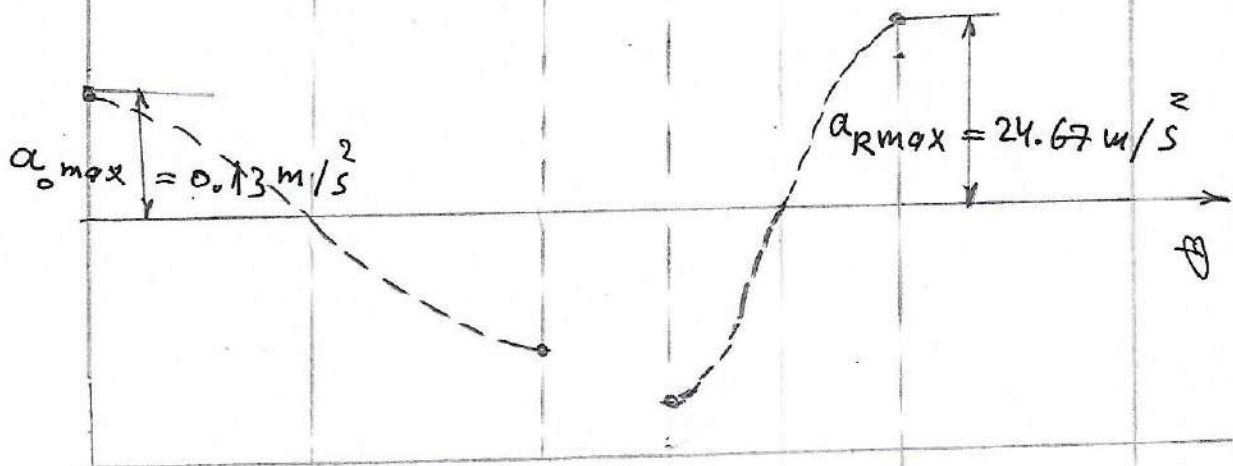
I) S-D



II) V-D



III) a-D



II) Change all angles into radians as follow

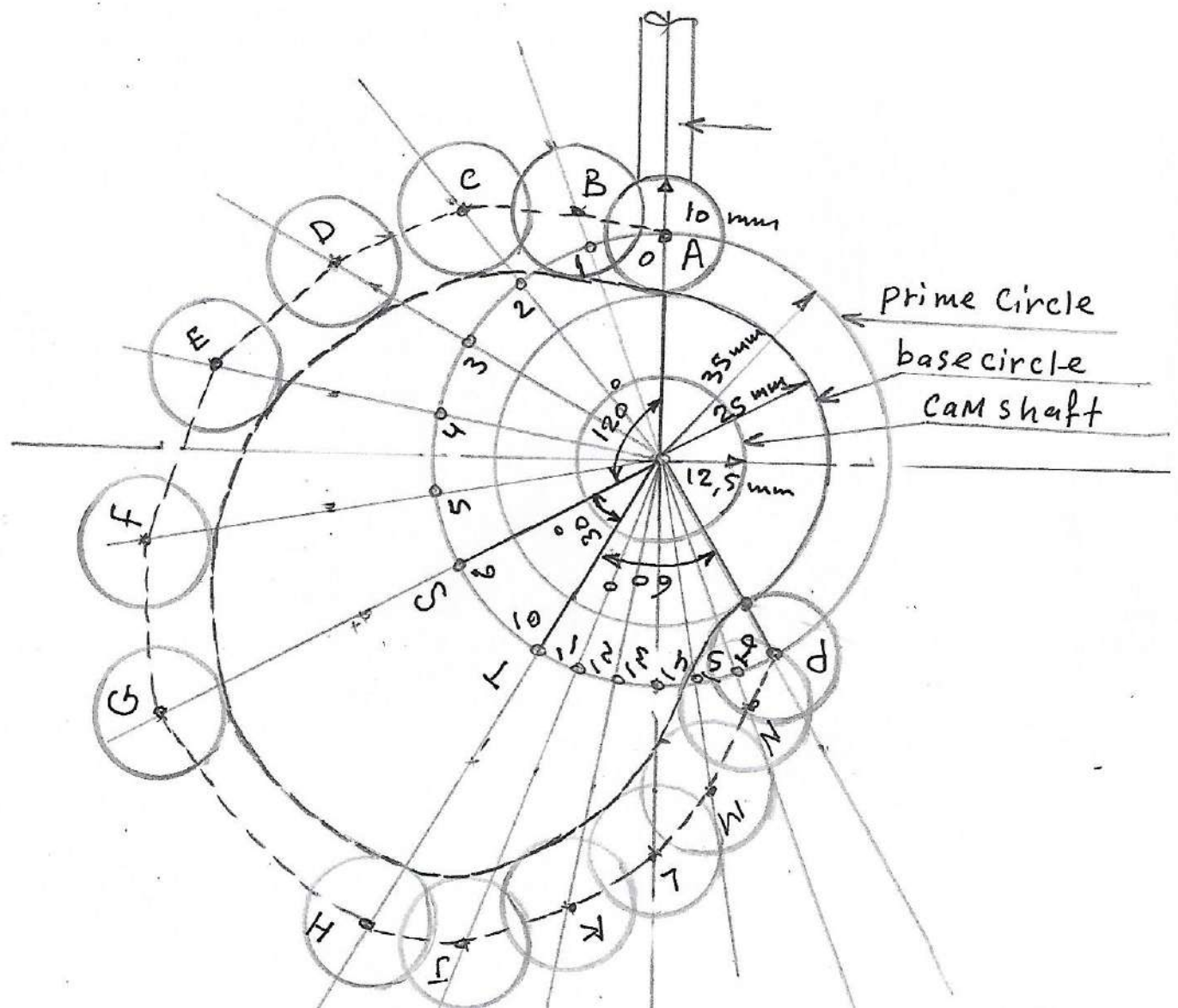
$$\theta_0 = 120^\circ \times \frac{\pi}{180} = 2,1 \text{ rad}$$

$$\theta_R = 60^\circ \times \frac{\pi}{180} = 1,047 \text{ rad.}$$

$$\omega = \frac{2\pi n}{60} = \frac{2 \times 3,14 \times 100}{60} = 10,47 \text{ rad/s.}$$

III) Draw Cam profile with the follower axis passes through the center of cam, with roller follower, as bellow:

- 1) Draw base circle with center O, and radius ($r_b = 25\text{mm}$)
- 2) Draw prime circle with radius $r_p = r_b + \frac{1}{2} D_{\text{roller}}$
 $\therefore r_p = 25 + 10 = 35\text{mm}$.
- 3) on prime circle draw $\theta_o = AOS = 120^\circ$, $SOT = 30^\circ$, $\theta_R = \text{Top} = 60^\circ$,
- 4) divide $\theta_o, \theta_d, \theta_R$ - into same equal number, as in S-D $\rightarrow 1, 2, 3 \rightarrow$ -- Join them with O.
- 5) set off 1B, 2C, 3D from S-D \rightarrow draw circle with r_{roller} from A, B, C --
- 6) Join A, B, C - to get pitch curve.
- 7) Draw tangent curve to the roller from the bottom to get Cam profile, as follow:



IV) Draw Cam profile, when the follower axis passes with offset with cam axis, as follow:

- 1) Draw base circle with radius $r_b = 25 \text{ mm}$,
- 2) Draw prime circle with with radius $r_p = r_b + r_{\text{roller}}$
 $\therefore r_p = 25 + 10 = 35 \text{ mm}$
- 3) Draw off-set circle with center O and radius $r_{\text{off-set}} = 15 \text{ mm}$.
- 4) Join OA and draw the angular displacement for $\theta_o = AOS = 120^\circ$, $\theta_d = SOT = 30^\circ$, and $\theta_R = \text{Top} = 60^\circ$
 $\theta_R = 150^\circ$.
- 5) Divide the angular displacement for out and return stroke in ~~to~~ same equal parts, as in S-D.
- 6) From point $1, 2, 3$ -- and $1', 2', 3'$ draw tangent to the offset circle.
- 7) Set off $1B, 2C$, -- from the displacement diagram
- 8) Join the point A, B, C - to get \rightarrow pitch curve
- 9) From A, B, C , draw circle with r_{roller} .
- 10) Bottom tangent to roller \rightarrow give Cam Curve.
as follow;

The data:

$$r_{\text{cam shaft}} = 12.5 \text{ mm}$$

$$r_{\text{base}} = 25 \text{ mm}$$

$$r_{\text{prime}} = 35 \text{ mm}$$

$$r_{\text{offset}} = 15 \text{ mm}$$

$$\theta_o = 120^\circ$$

$$\theta_R = 60^\circ$$

$$\theta_d = 30^\circ$$

* Example (4)

A Cam, with a minimum radius of (50mm), rotating clockwise at a uniform speed, is required to give a knife edge follower the motion as described below:

- 1- To move outwards through (40mm) during (100°) rotation of the cam.
- 2, To dwell for next (80°) .
- 3) To return to its starting position during next (90°) , and
- 4, To dwell for the rest period of a revolution (90°) .

Draw the profile of the cam.

- 1) when the line of stroke of the follower passes through the centre of the cam, and
- 2) when the line of stroke of the follower is offset by (15mm).

The displacement of the follower is to take place with uniform acceleration, and uniform retardation. Determine the max-m velocity and acceleration of the follower when the cam shaft rotates at (900 r.p.m). Draw the displacement, velocity and acceleration for one revolution.

Solution: change into radians -

$$\theta_o = 100^\circ \times \frac{\pi}{180} = 1.745 \text{ rad.}$$

$$\theta_R = 90^\circ \times \frac{\pi}{180} = 1.571 \text{ rad}$$

$$S = 0.04 \text{ m}$$

$$\omega = \frac{2\pi n}{60} = \frac{2 \times 3.14 \times 900}{60} = 94.26 \text{ rad/s}$$

$$r_b = 50 \text{ mm.}$$

I) Draw displacement diagram, as follow :

1) Draw horizontal line Ax, and locate $\theta_0 = 100^\circ = AS$, $\theta_d = 80^\circ = ST$, $\theta_R = 90^\circ = TP$, and $\theta_{Rem} = PQ = 90^\circ$.

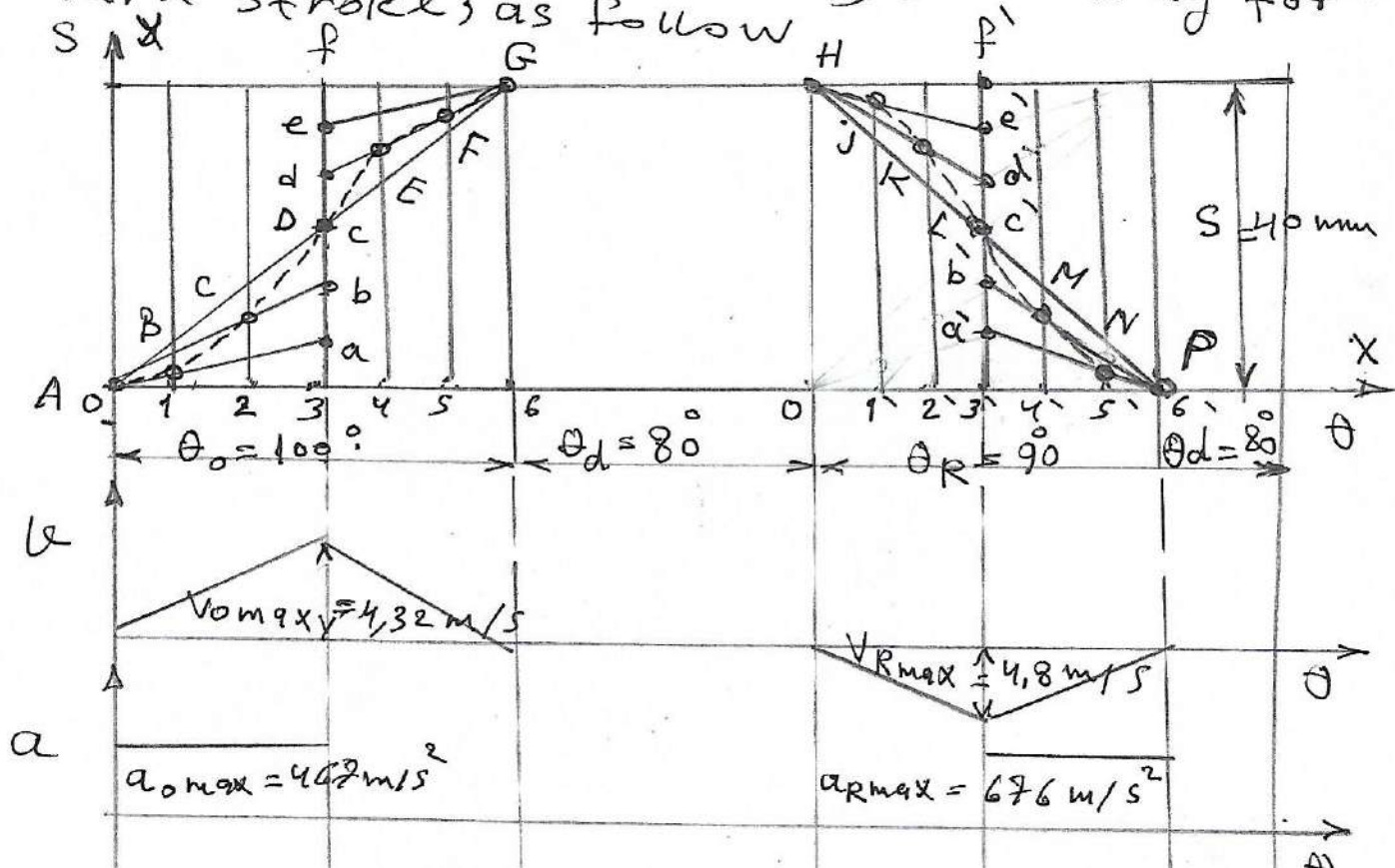
2) Divide AS, TP into equal number with scale $2\dot{C} = 1mm$ say (6) into 1, 2, 3 -- 6

3) Draw vertical line Ay for (stroke = 40mm) and divide into same number (6) \Rightarrow from 3f and 3f' into 1, 2, 3 -- 6.

4) Since the follower move with uniform acc - n and retard - ins, then we have double parabolic curves for out and return stroke.

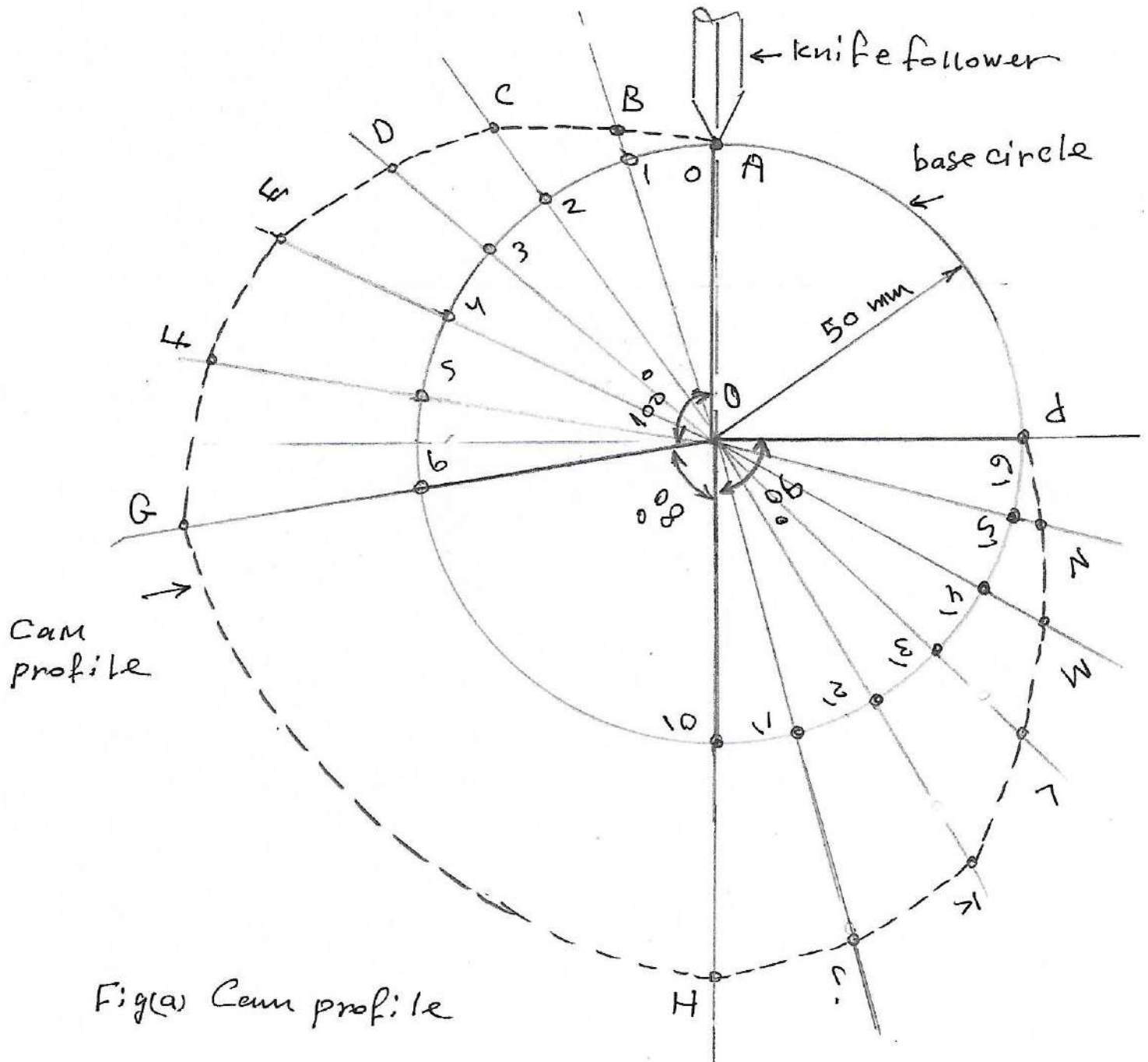
5) Join A with a, b, c -- and locate the intersecting point A, B, C -- with a vertical lines 1, 2, 3 --

6) Join the point A, B, C -- to get the parabolic curve for out stroke, and by same way for return stroke, as follow



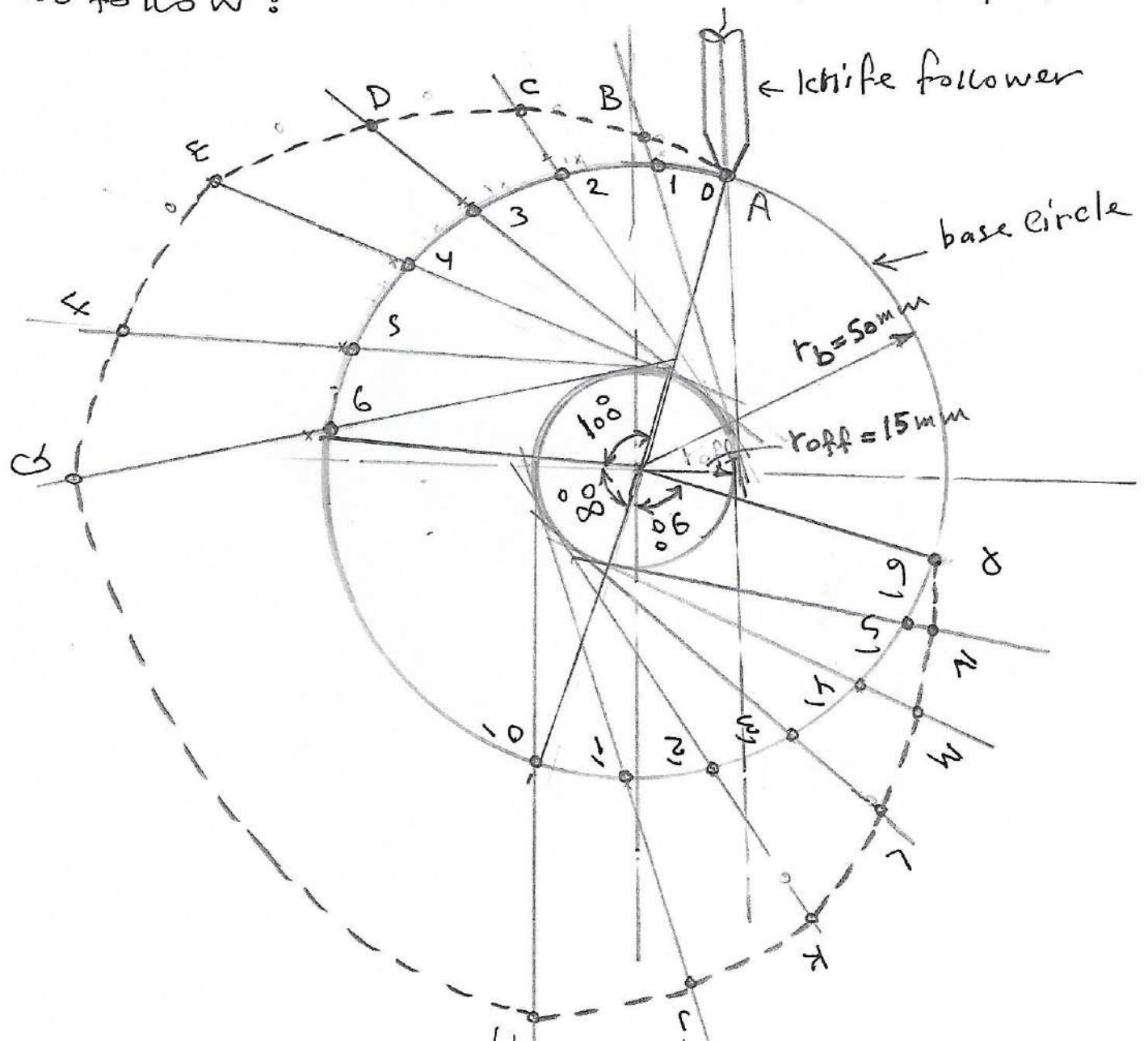
II, Draw profile of Cam, when the follower passes through the center of Cam, as follow:

- 1) Draw base circle with $r_b = 50\text{mm}$
- 2) Divide the base circle into $\theta_o = 100^\circ$, $\theta_d = 80^\circ$, $\theta_R = 90^\circ$, $\theta_{Ret} = 80^\circ$, and divide them into same number as in S-D, $\rightarrow 1, 2, \dots, 6$.
- 3) Join the point, 1, 2, 3 with O
- 4) added the length B_1, C_1 - from S-D
- 5) Join A, B, C \rightarrow to get Cam profile, as follow:



III) Draw Cam profile with the follower passes offset with the Cam Center, as follow.

- 1) Draw base circle with radius ($r_b = 50\text{mm}$).
- 2) Draw offset circle with radius ($r_{\text{off}} = 15\text{mm}$).
- 3) Divide the base circle into $\theta_o = 100^\circ$, $\theta_d = 80^\circ$, $\theta_R = 90^\circ$, $\theta_{\text{rem}} = 90^\circ$, and divide θ_o, θ_R into same equal parts (1, 2 -- 6).
- 4) Draw tangent to the base circle passing through (1, 2, -- 6).
- 5) Added the lengths from 3-D and locate the points A, B -- P.
- 6) By joining the point, A, B, -- P \rightarrow we get cam profile as follow:



iv) Max- m velocity for out and return stroke.

$$V_{O \max} = \frac{2\omega s}{\theta_O} = \frac{2 \times 94.26 \times 0.04}{1.743} = 4.32 \text{ m/s}$$

$$V_{R \max} = \frac{2\omega s}{\theta_R} = \frac{2 \times 94.26 \times 0.04}{1.371} = 4.8 \text{ m/s}$$

iv) max- m acceleration for out and return stroke.

$$a_{O \max} = \frac{4\omega^2 s}{(\theta_O)^2} = \frac{4 \times (94.26)^2 \times 0.04}{(1.743)^2} = 467 \text{ m/s}^2$$

$$a_{R \max} = \frac{4\omega^2 s}{\theta_R^2} = \frac{4 \times (94.26)^2 \times 0.04}{(1.571)^2} = 576 \text{ m/s}^2$$

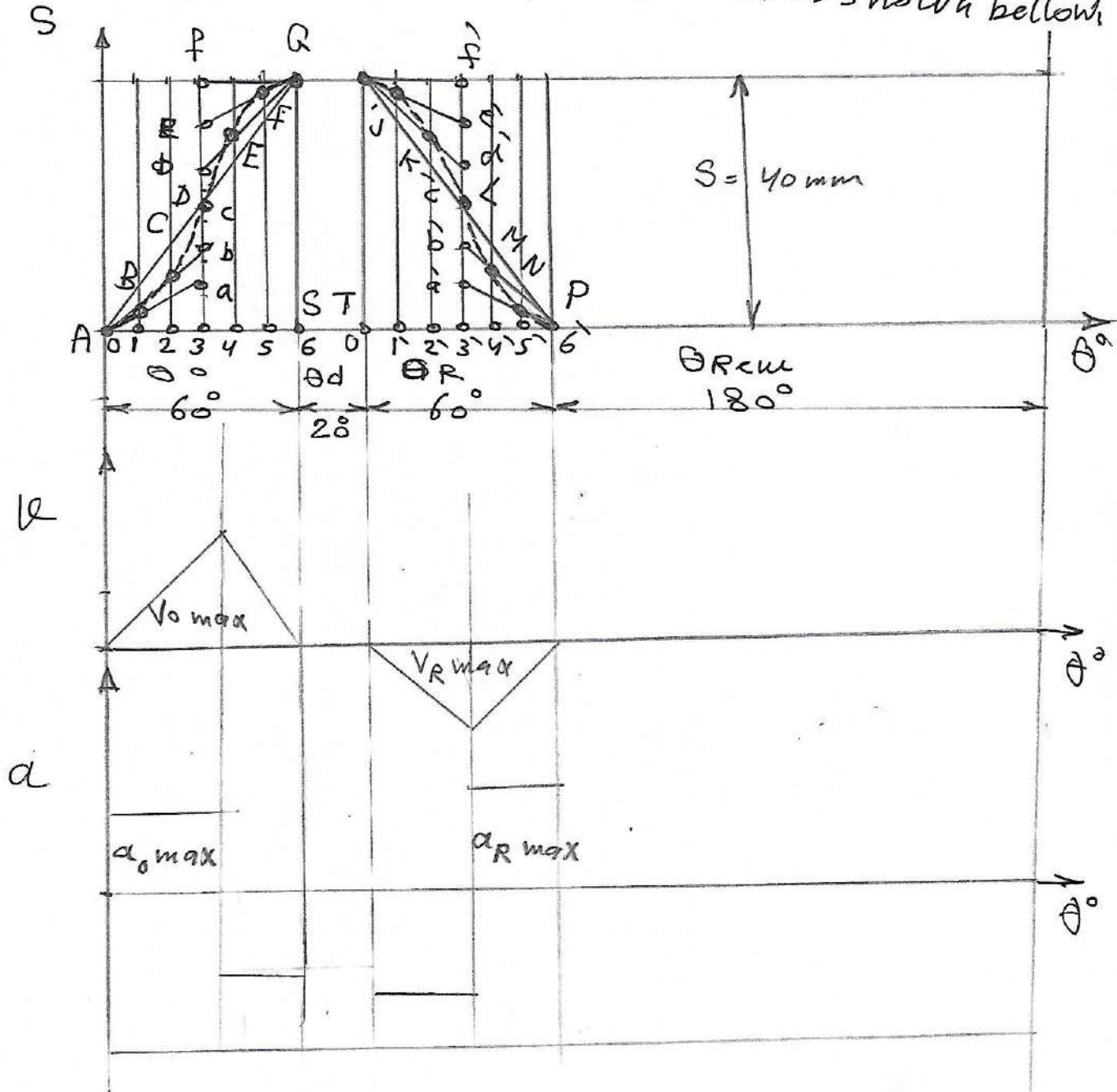
Example (5):

Design a Cam for operating the exhaust valve of an oil engine. It is required to give equal uniform acceleration and retardation during opening and closing of the valve each, of which corresponds with 60° of cam rotation. The valve must remain in the fully open position for 20° of cam rotation. The lift of the valve is (40 mm), and the least radius of the cam is (40 mm). The Follower is provided with a roller of radius (10 mm). Draw cam profile, if: 1) line of stroke passes through the axis of the cam, 2) line of stroke is offset by (20 mm) from the center of the cam.

3 - Determine the max- m velocity and acceleration of the follower, when the cam shaft rotates at 900 r.p.m, 4 - Draw displacement, velocity and acceleration for complete revolution.

I) Draw: S-D, V-D, A-D, as follow:

- 1, Draw horizontal line ASTP represent the angular displacement, with scale ($2^\circ = 1m$), then mark, $\theta_0 = 60^\circ$, $\theta_d = 20^\circ$, $\theta_R = 60^\circ$, $\theta_{Rem} = 180^\circ$.
- 2) Divide AS, TP into same equal parts (as six) and draw vertical lines, 1, 2 -- 6 through them.
- 3- Dived the line of stroke $3f, 3f'$, into same equal parts, a, b, -- f, and complete the S-D.
- 4- Locate the cross points s, A, B -- G, and join them to get double parabolic, as shown below.



II) Draw Cam profile, when when line of stroke passes through the center of Cam, as follow.

- 1) Draw base circle with ($r_b = 40\text{mm}$).
- 2) Draw prime circle with ($r_p = r_b + \frac{1}{2}r_R = 40 + 10 = 50\text{mm}$).
- 3) Locate the angles on the prime circle $\theta_0 = 60^\circ$, $\theta_d = 20$, $\theta_R = 60$, and divide them into same equal parts 1, 2, -- 6, draw lines from O through 1, 2, -- 6,
- 4) Add the length 1B, 2C --
- 5) Join the points A, B -- to get the Cam profile, as follow:

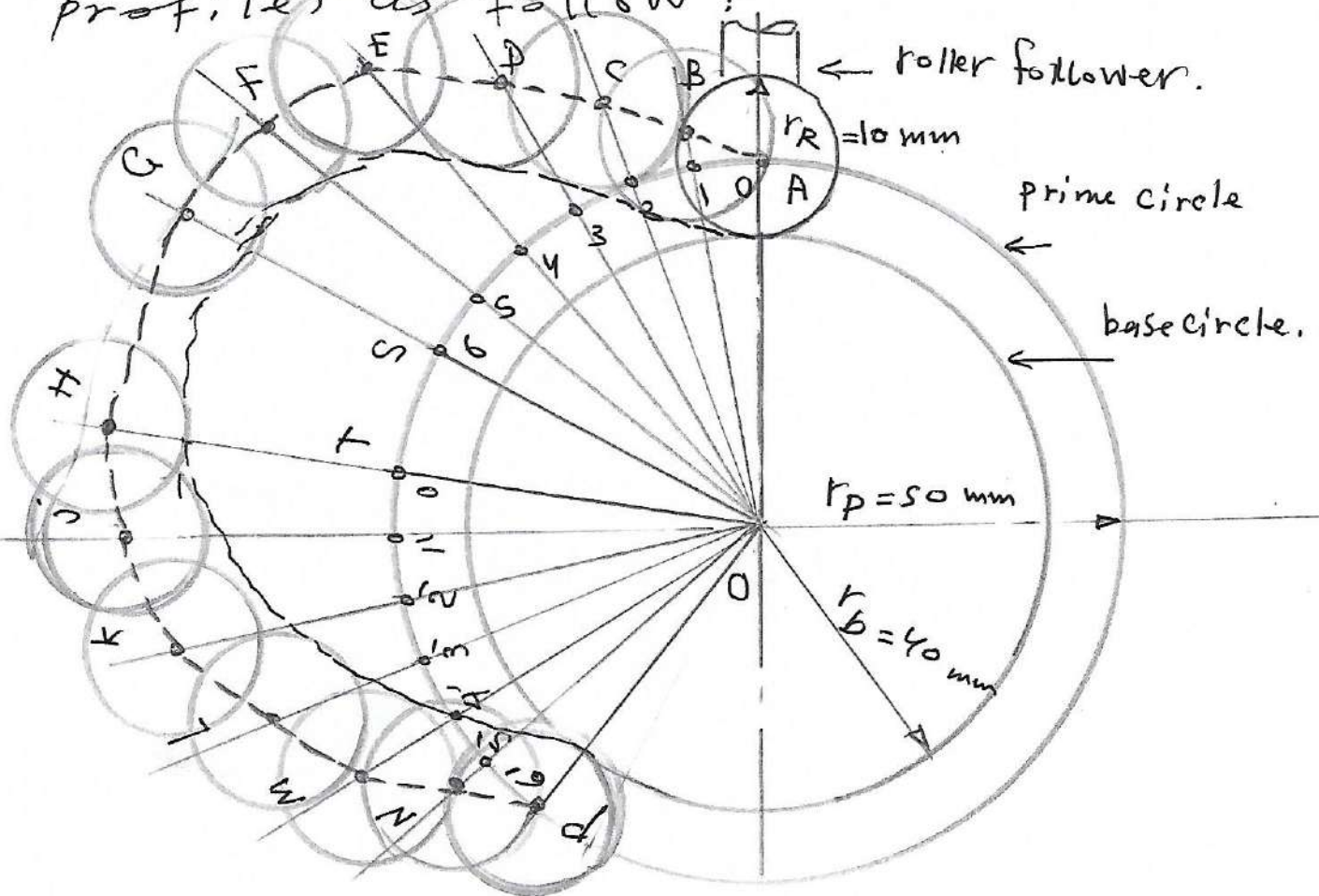


Fig. Cam profile with axis passes through the center of the Cam.

III) Draw Cam profile, when the line of stroke is off-set by 20 mm from the axis of the Cam, as follows:

1. Draw base circle with radius ($r_b = 40 \text{ mm}$) and center O .
2. Draw prime circle with radius ($r_p = r_b + r_r = 40 + 10 = 50 \text{ mm}$ and center O).
3. Draw off-set circle with radius $r_{\text{off}} = 20 \text{ mm}$ and center O .
4. Divide the prime circle into $\theta_o = 60^\circ$, $\theta_d = 20^\circ$, $\theta_R = 60^\circ$, into equal number as in S-D 1, 2, ... 6, ... added.
5. Draw tangent from the off-set circle passing through 1, 2, ... 6, ... and add the lengths to them from S-D, 1B, 1C -
6. Join point A, B, ... 6 to get Cam profile as follow

IV) max-m velocity :

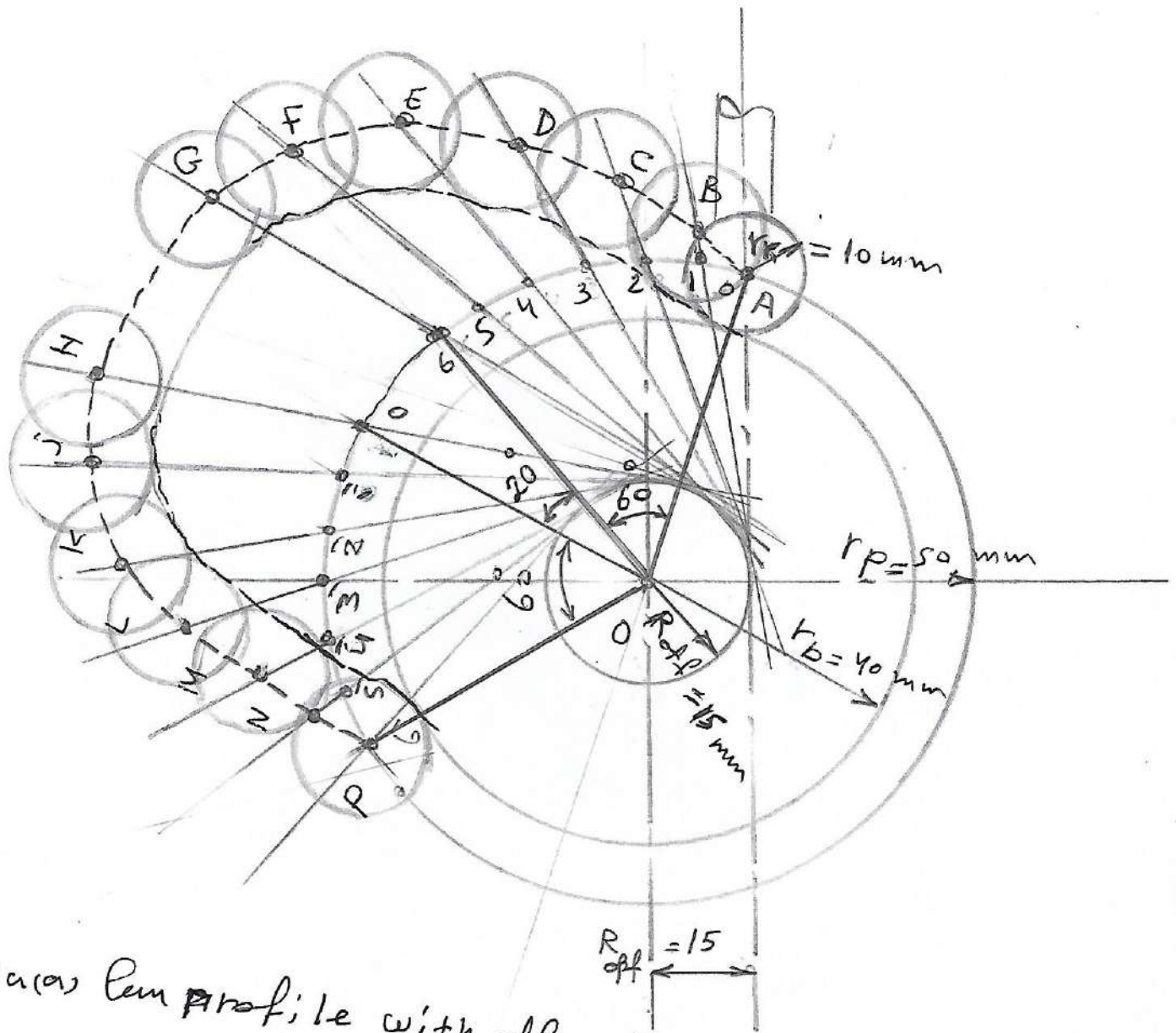
$$V_{o \text{ max}} = \frac{2\omega s}{\theta_o} = \frac{2 \times 942 \times 0,04}{1,047} = 71,977 \text{ m/s}$$

$$V_{R \text{ max}} = \frac{2\omega s}{\theta_R} = \frac{2 \times 942 \times 0,04}{1,047} = 71,977 \text{ m/s}$$

V) max-m acceleration .

$$a_{o \text{ max}} = \frac{4\omega^2 s}{(\theta_o)^2} = \frac{4 \times (942)^2 \times 0,04}{(1,047)^2} = 141978 \text{ m/s}^2$$

$$a_{R \text{ max}} = \frac{4\omega^2 s}{(\theta_R)^2} = \frac{4 \times (942)^2 \times 0,04}{(1,047)^2} = 141978 \text{ m/s}^2$$



Pincas Cam profile with off-set

$$\omega = \frac{2\pi n}{60} = \frac{2 \times 3.14 \times 900}{60} = 94.2 \text{ rad/s}$$

$$\theta_a = \frac{60 \times \pi}{180} = 1.047 \text{ rad}$$

$$\theta_R = 1.047 \text{ rad.}$$