CAM & FOLLOWER MECHANISM

- Cam & Follower mechanism consists of 1) Cam, 2) Follower, 3) Frame.
- This mechanism is an example of higher pair, force closed, completely constrained, open pair.
- In This, the cam is mainly driving element and follower follows it’s motion.
- Generally, the Cam rotates and follower translates or oscillates.
- Cam and Follower mechanism is an exact function generator mechanism.
- For example, In case of moving the valves of an automobile, first in IC engine the valves have to be kept open then kept it open then close it and keep it closed.
- All these timing operations can be easily incorporated by having cam and follower mechanism.

APPLICATION OF CAM & FOLLOWER:

- Cam and follower are widely used for operating inlet and exhaust valves of ICE.
- In Wall clock.
- In feed mechanism of automatic lathe machine.
- In Paper cutting machine.
- In weaving textile machine.
- In food processing machine.

CLASSIFICATION OF FOLLOWERS:

- Knife edge/ Point follower
- Roller Follower
- Flat face follower
- Spherical end follower or Mushroom follower.

1. KNIFE EDGE/ POINT FOLLOWER:

- Reference/ Trace point = Tip of the knife
- It’s simple follower.
- The contacting end is a sharp knife edge, it is called a knife edge follower.
- In this, a considerable side thrust exists between the follower and guide.
- It causes infinitely large contacting stresses and results in high rate of wear. Therefore, it is of very little practical to use.

2. SPHERICAL/ MUSHROOM FACED FOLLOWER:

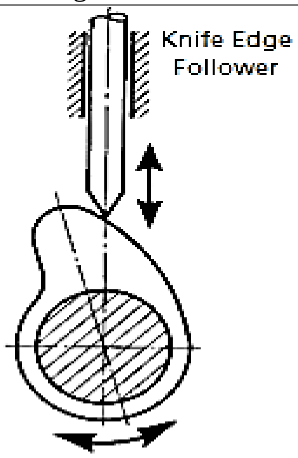
- Trace point = Centre of the roller
- When the contacting end of the follower is of spherical shape, it is called spherical faced follower.
- The centre of the spherical surface is provided on the centre line of the follower.
- It’s used for relatively steep cam and is useful where space may not be adequate.
- It minimises the surface stesses.
- It is used in automobile engines.

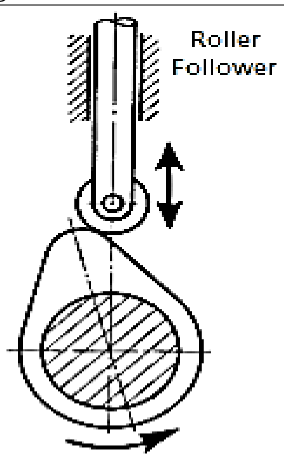
3. ROLLER FOLLOWER:

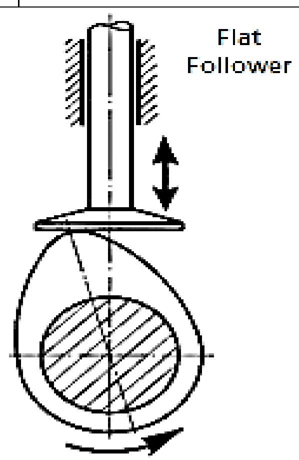
- Trace point = Centre of the roller
- When the contacting end of the follower is a roller, it is called a roller follower.
- Since the rolling motion takes place between the contacting surfaces. Therefore, the rate of wear is greatly reduced but the side thrust exists.
- In case of steep cam, roller follower has a tendency to jam the cam. Therefore, it is not preferable in this situation.
- It’s used in gas and oil engines.
- Roller followers are extensively used where more space is available such as in stationary gas and oil engines and air craft engines.

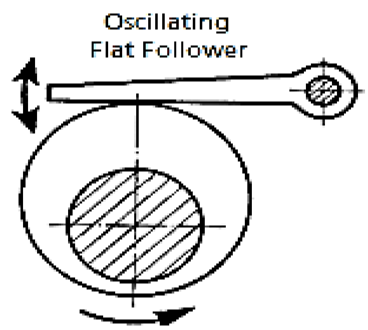
4. FLAT FACE FOLLOWER:

- Trace point = Tip of the flat face.
- When the connecting end is perfectly flat face normal to the stem of follower, it is called as flat face follower.
- The side thrust in it gets reduced w. r. t. roller follower.
- The relative motion is sliding in nature due to which there is more wear of cam surface in it.
- It causes high surface stresses.
- It is used where limited space is available such as in cams which operate the valves of automobile engines.









CLASSIFICATION OF CAM (ON THE BASIS OF LINE OF MOVEMENT OF THE FOLLOWER):

1. **Radial Cam:** Line of movement of follower passes through the centre of the rotation of the cam.
2. **Offset Cam:** Line of movement of follower is offset from the centre of the rotation of the cam.

CAM AND FOLLOWER TERMINOLOGY:

In order to discuss the terminology, we have to consider the inversion of mechanism that is we shall assume the cam as fixed element and follower as moving element.

- Base Circle: Base circle is always tangential Cam profile. And it can't interest the Cam profile. Base circle diameter denotes the size of the cam. It's smallest circle.
- Cam Profile: Curved over which the cam is in physically contact with follower.
- Trace Point: Reference point on the follower.
- Pitch Curve: Curved Generated by all trace point. Or locus of the Trace points.
- Prime Circle: Curved which Concentric to the Base circle and tangential to the Pitch curve.

$$R_{Prime} = R_{Base} + R_{Roller}$$

- Lift/Stroke: Maximum Displacement of Cam over one cycle.
- Angle of Ascent: Angle of Rising of Follower.
- Angle of Decent: Angle of Lowering of Follower.
- Angle of Dwell: Angle through which the cam remains stand still.

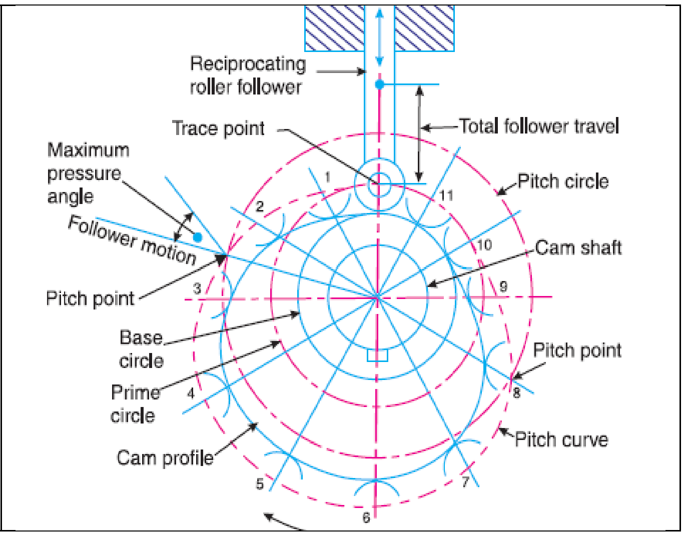
For Knife Edge follower, Pitch Curve = Cam Profile. & Prime Curve = Base Circle

PRESSURE / DEVIATION ANGLE ($\boldsymbol{\beta \leq 90°}$):

- It's the angle included between common normal to the pitch curve through trace point and the line of action of follower motion.
- It's compliment of transmission angle and it is an index of merit/ effectiveness of the mechanism.
- It measures the steepness of the cam profile.
- Pressure angel varies in magnitude at all instants of the follower motion. The point where it is maximum is known as pitch point.
- The locus of the pitch point known as pitch circle.

$$\boldsymbol{\beta_{max} \leq 30° - 40°}$$

From the Fig., $F_x = F \sin\beta$ will try to bed the stem of follower. And $F_y = F \cos\beta$ is balanced by spring force.
Normal thrust between Guide and follower, $N = F_x$



IF $\boldsymbol{\beta}$ INCREASES,

1. Spring force (F_y) Decreases. Hence, the chance of losing contact between cam and follower increases.
2. Normal thrust between Guide and follower (F_x) increases. Hence, chances of Bending of follower increases.
3. Friction between Guide/ Cam and follower $(f = \mu N)$ increases. Hence, Wear of the follower increases.

DERIVATION OF $\boldsymbol{\beta}$ EQUATION: For knife Edge follower,

$V_{I23} = I_{12}I_{23}\omega_2 = V_3 = V_{Follower}(From\ angular\ Velocity\ theorem, When\ I_{23}\ is\ point\ on\ link\ 2)$	
$V_{Follower} = (O_2P)\ \omega_2$	$\tan\beta = O_2P/(R_B + y)$
$\boldsymbol{\tan\beta = \dfrac{V_{Follower}}{(R_B + y)\omega_2} = \dfrac{dy/d\theta}{(R_B + y)}}$	$V_{Follower} = \dfrac{dy}{dt} = \dfrac{dy}{d\theta}\dfrac{d\theta}{dt} = \omega_2 \dfrac{dy}{d\theta} (\because y = f(\theta))$

Here, $dy/d\theta$ is slope of $y\ vs.\theta$ diagram (Displacement diagram).

EFFECT OF DIFFERENT PARAMETERS ON $\boldsymbol{\beta}$:

1. Increase in **Size of the Cam** $(\boldsymbol{R_B})$ leads to decrease in β.
2. Increase in **Velocity of follower** $(\boldsymbol{V_{Follower}})$ leads to Increase in β.
3. $\max V_{Follower}|_{\boldsymbol{Cycloidal}} = \max V_{Follower}|_{\boldsymbol{Parabolic}} > \max V_{Follower}|_{\boldsymbol{SHM}} > \max V_{Follower}|_{\boldsymbol{Uniform\ Velocity}}$
4. Since, Cycloidal is best motion but it results in large value of β which is disadvantageous. In order to nullify the increment in β, the Size of the Cam (R_B) increases.

Large $R_B \Rightarrow$ Cycloidal	Medium $R_B \Rightarrow$ SHM	Smallest $R_B \Rightarrow$ Uniform Velocity

5. Increase in Slope in **Displacement diagram or Steepness of cam profile** leads to Increase in β.

CASE-I: If lift or stroke $h = Const.$ & Angle of action(ϕ) increases, Steepness of cam($dy/d\theta$) Decreases. Hence, β will decreases.	**CASE-II:** If Angle of action $\phi = Const.$ & lift or stroke (h) increases, Steepness of cam($dy/d\theta$) Increases. Hence, β will Increases.

6. Effect of eccentricity or offset:

$\tan\beta = \dfrac{(dy/d\theta) - e}{(R_B^2 - e^2 + y)}$	**CASE-I:** During Rise Stroke, Numerator decreases leads to decrease in $\beta. dy/d\theta + ve$ **CASE-II:** During Lowering Stroke, Numerator increases leads to increase in β.

7. Effect of type of follower:

$\tan\beta = \dfrac{V_{Follower}}{(R_B + y)\omega_2} = \dfrac{dy/d\theta}{(R_B + y)} \begin{pmatrix} For\ Kife\ Edge \\ Follower \end{pmatrix}$	$\tan\beta = \dfrac{V_{Follower}}{(R_B + R_R + y)\omega_2} = \dfrac{dy/d\theta}{(R_B + R_R + y)} \begin{pmatrix} For\ other \\ follower \end{pmatrix}$

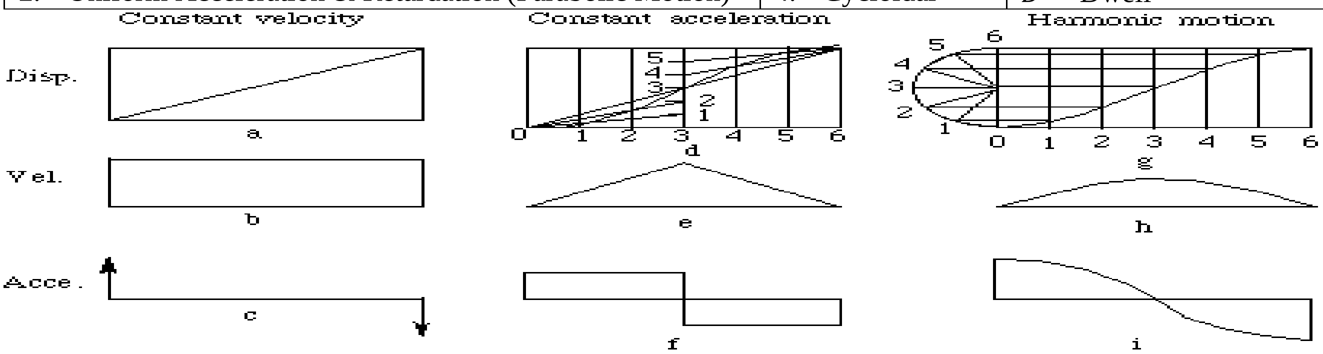
PHYSICAL AND KINEMATIC DERIVATIVES:

$y =$ Displacement of Follower,	$\theta =$ Angular Displacement of Cam	$\omega =$ Angular Speed of Cam

PHYSICAL DERIVATIVES (W. R. T. TIME)	KINEMATIC DERIVATIVES (W. R. T. SPACE)
Velocity of Follower, $V_{Follower} = \dfrac{dy}{dt} = \dfrac{dy}{d\theta}\dfrac{d\theta}{dt} = \omega\dfrac{dy}{d\theta}$	Slope of Displacement Profile or Steepness of cam, $\dfrac{dy}{d\theta}$
Acceleration of Follower, $a_{Follower} = \dfrac{dV_{Follower}}{dt} = \dfrac{dV_{Follower}}{d\theta}\dfrac{d\theta}{dt} = \omega\dfrac{dV_{Follower}}{d\theta} = \omega^2\dfrac{d^2y}{d\theta^2} (For\ constant\ \omega)$	$Radius\ of\ Curvature = \left(\dfrac{d^2y}{d\theta^2}\right)^{-1}$ If $\frac{d^2y}{d\theta^2} \to \infty$, Radius of Curvature = 0. Hence, sharper the cam and Jerk will be present.
Jerk of Follower, $J_{Follower} = \dfrac{da_{Follower}}{dt} = \dfrac{da_{Follower}}{d\theta}\dfrac{d\theta}{dt} = \omega\dfrac{da_{Follower}}{d\theta} = \omega^3\dfrac{d^3y}{d\theta^3} (For\ constant\ \omega)$	It's difficult to define the significance of third derivative but since it is related to the jerk therefore, it's value should be closely control. $\dfrac{d^3y}{d\theta^3}$

TYPES OF FOLLOWER MOTION:

1. Uniform Velocity 2. Uniform Acceleration & Retardation (Parabolic Motion)	3. SHM 4. Cycloidal	$R =$ Rise $D =$ Dwell



$h =$ Lift of follower	$\phi_a =$ Angle of Ascent or Rise Stroke angel

UNIFORM VELOCITY:

$\tan\gamma = \dfrac{h}{\phi_a}$	$y = \theta\tan\gamma = \dfrac{h\,\theta}{\phi_a}$	
$V_{Follower} = \omega\dfrac{dy}{d\theta} = \omega\dfrac{h}{\phi_a} = C$	$a_{Follower} = \omega\dfrac{dV_{Follower}}{d\theta} = 0$	$J_{Follower} = \omega\dfrac{da_{Follower}}{d\theta} = 0$

UNIFORM ACCELERATION & RETARDATION (PARABOLIC MOTION):

$y = a\theta^2 + b\theta + c$ a, b, c are constants depends on BCs.	$y = \left(\dfrac{2h}{\phi_a^2}\right)\theta^2$	$0 \le \theta \le \dfrac{\phi_a}{2}$
$V_{Follower} = \omega\dfrac{dy}{d\theta} = \omega\left(\dfrac{4h\theta}{\phi_a^2}\right)$	$a_{Follower} = \omega\dfrac{dV_{Follower}}{d\theta} = \omega^2\left(\dfrac{4h}{\phi_a^2}\right)$	$J_{Follower} = \omega\dfrac{da_{Follower}}{d\theta} = 0$

θ	0	$\phi_a/2$	ϕ_a
V	0	$2h\omega/\phi_a$	0
$a_{Follower}$	$Constant$		
$J_{Follower}$	0		

Boundary Conditions:
1. $@\theta = 0 \Rightarrow y = 0 \Rightarrow c = 0$
2. $@\theta = 0 \Rightarrow dy/d\theta = 0 \Rightarrow b = 0$
3. $@\theta = \phi_a/2 \Rightarrow y = h/2 \Rightarrow a = 2h/\phi_a^2$

SHM:

<table>
<tr><td colspan="4">$y=\frac{h}{2}[1-\cos\beta]=\frac{h}{2}\left[1-\cos\left(\frac{\pi\theta}{\phi_a}\right)\right]$</td><td>$V_{Follower}=\omega\frac{dy}{d\theta}=\omega\left(\frac{h}{2}\right)\left(\frac{\pi}{\phi_a}\right)\sin\left(\frac{\pi\theta}{\phi_a}\right)$</td><td>$\frac{\beta}{\theta}=\frac{\pi}{\phi_a}$</td></tr>
<tr><td>θ</td><td>0</td><td>$\phi_a/2$</td><td>ϕ_a</td><td rowspan="2">$a_{Follower}=\omega^2\left(\frac{h}{2}\right)\left(\frac{\pi}{\phi_a}\right)^2\cos\left(\frac{\pi\theta}{\phi_a}\right)$</td><td rowspan="2">$a_{F,max}=\omega^2\left(\frac{h}{2}\right)\left(\frac{\pi}{\phi_a}\right)^2$</td></tr>
<tr><td>V</td><td>0</td><td>$\pi h\omega/2\phi_a$</td><td>0</td></tr>
<tr><td>a</td><td>$a_{F,max}$</td><td>0</td><td>$-a_{F,max}$</td><td rowspan="2">$J_{Follower}=-\omega^3\left(\frac{h}{2}\right)\left(\frac{\pi}{\phi_a}\right)^3\sin\left(\frac{\pi\theta}{\phi_a}\right)$</td><td rowspan="2">$J_{F,max}=-\omega^3\left(\frac{h}{2}\right)\left(\frac{\pi}{\phi_a}\right)^3$</td></tr>
<tr><td>J</td><td>0</td><td>$J_{F,max}$</td><td>0</td></tr>
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CYCLOIDAL:

Radius of the circle Drawn for the generation of cycloid,

$$2\pi R=h$$

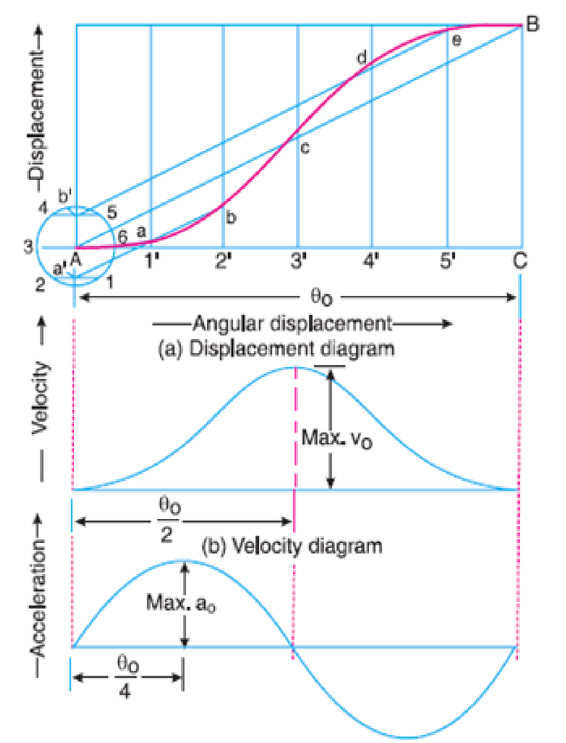
From horizontal divide the circle into equal parts. Find the midpoint of the Parts in vertically opposite point. And from the mid-point draw parallel line to the diagonal (AB)

$$\boldsymbol{y=\frac{h}{\pi}\left[\frac{\pi\theta}{\phi_a}-\frac{1}{2}\sin\left(\frac{2\pi\theta}{\phi_a}\right)\right]}$$

$$V_{Follower}=\omega\frac{dy}{d\theta}=\omega\left(\frac{h}{\phi_a}\right)\left[1-\cos\left(\frac{2\pi\theta}{\phi_a}\right)\right]$$

$$a_{Follower}=\omega^2\left(\frac{h}{\phi_a}\right)\left(\frac{2\pi}{\phi_a}\right)\sin\left(\frac{2\pi\theta}{\phi_a}\right)$$

$$J_{Follower}=\omega^3\left(\frac{h}{\phi_a}\right)\left(\frac{2\pi}{\phi_a}\right)^2\cos\left(\frac{2\pi\theta}{\phi_a}\right)$$



θ	0	$\phi_a/4$	$\phi_a/2$	$3\phi_a/4$	ϕ_a
V_F	0	$\omega\left(\frac{h}{\phi_a}\right)$	$2\omega\left(\frac{h}{\phi_a}\right)$	$\omega\left(\frac{h}{\phi_a}\right)$	0
a_F	0	$\omega^2\left(\frac{2\pi h}{\phi_a^2}\right)$	0	$-\omega^2\left(\frac{2\pi h}{\phi_a^2}\right)$	0
J_F	$\frac{4\pi^2 h\omega^3}{\phi_a^3}$	0	$-\frac{4\pi^2 h\omega^3}{\phi_a^3}$	0	$\frac{4\pi^2 h\omega^3}{\phi_a^3}$