Theory of machine

If you have a smart project, you can say "I'm an engineer"

Lecture 5

Instructor

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Theory of machine
MDP 234

- **Lecture aims:**
  - Learn fundamental concepts and terminology
  - Learn how to design a cam and follower set to achieve a desired output motion.

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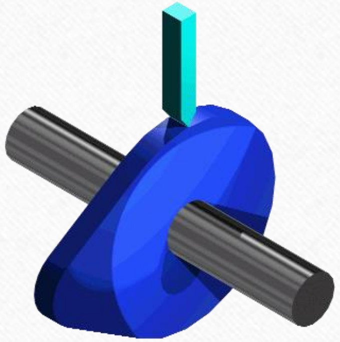
Introduction

1.1 CAM - Definition

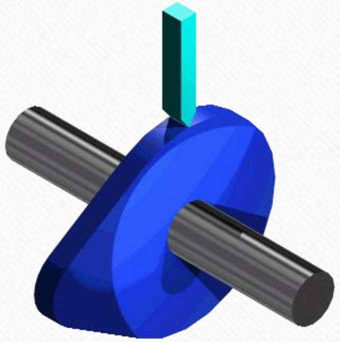


- Cams are used to convert rotary motion into reciprocating motion.
- Necessary **elements** of a cam mechanism are
  - A **driver** member known as the *cam*
  - A **driven** member called *the follower*
  - A **frame** which supports *the cam and guides the follower*

Introduction

1.1 CAM - Definition

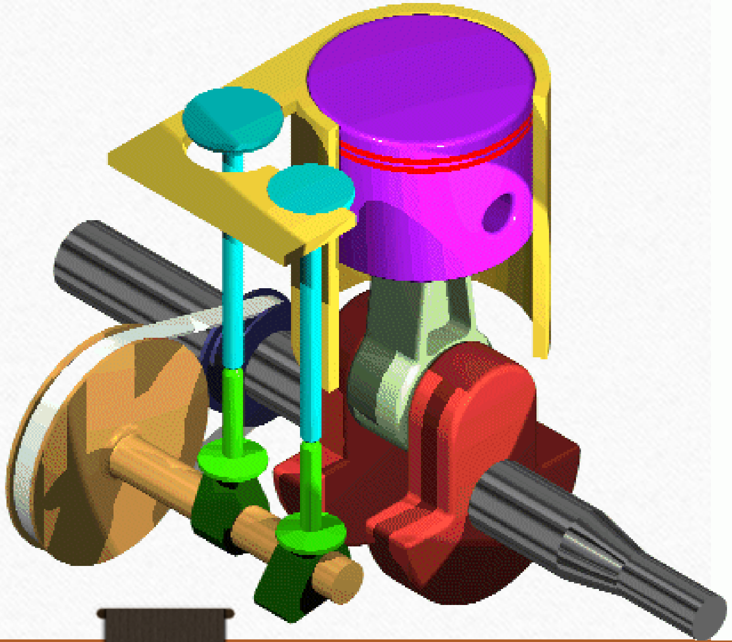
- Cams are **widely used** in automatic machines, internal combustion engines, machine tools, printing control mechanisms, and so on.
- They are **manufactured** usually by die-casting, milling or by punch-presses.
- A cam and the follower combination belong to the category of **higher pairs**.

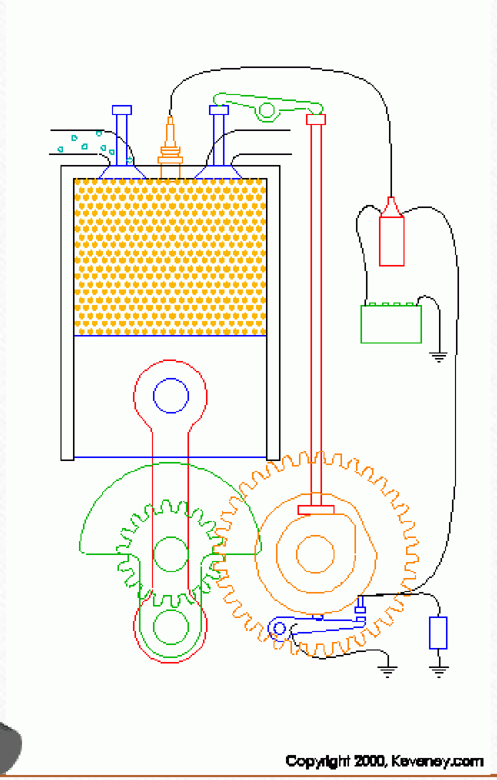


Introduction

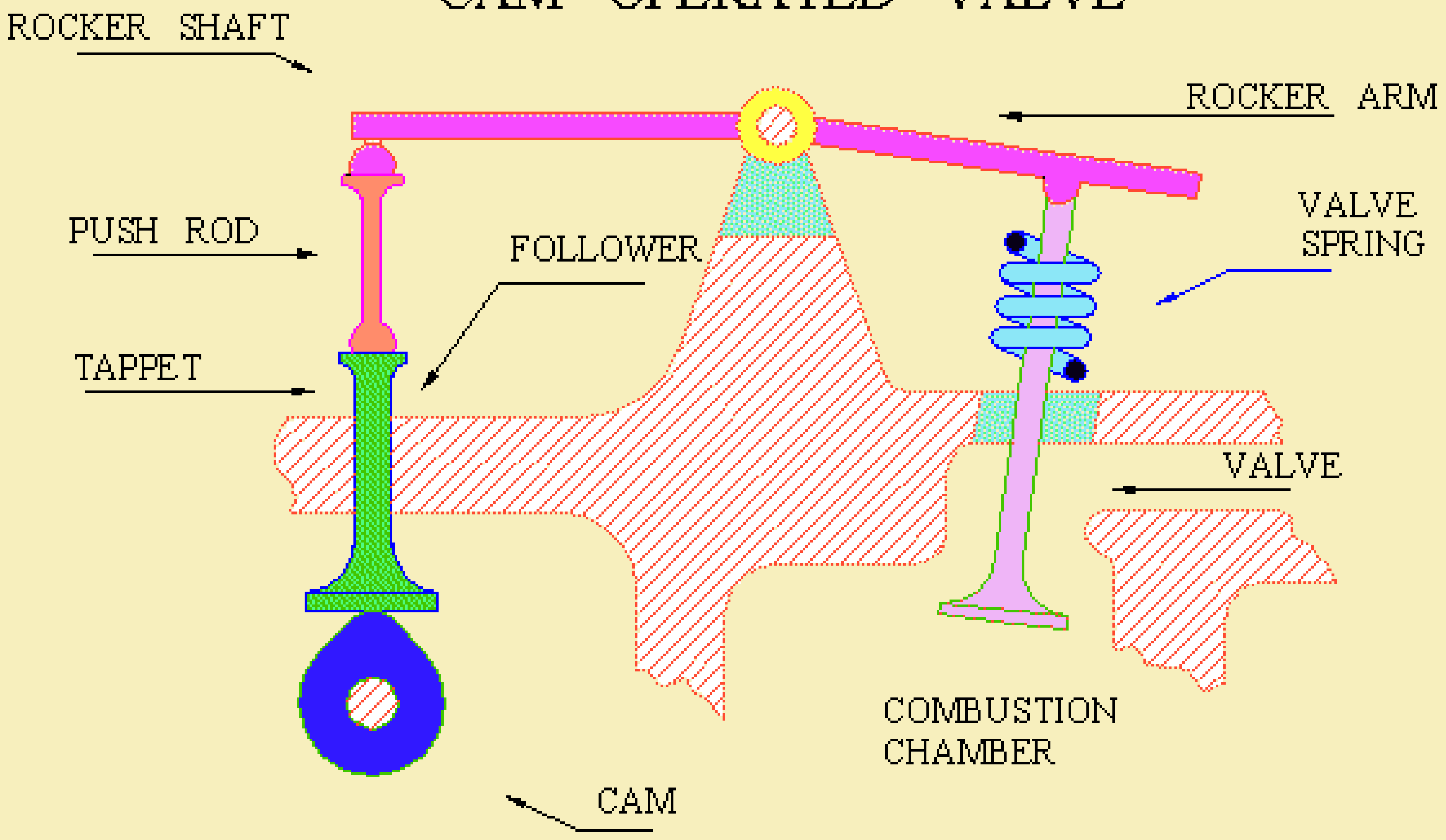
Examples for cam

- In IC engines to operate the inlet and exhaust valves





CAM OPERATED VALVE



Cam Mechanism

1.2 Classification of CAM Mechanism

I. According to modes of Input / Output motion

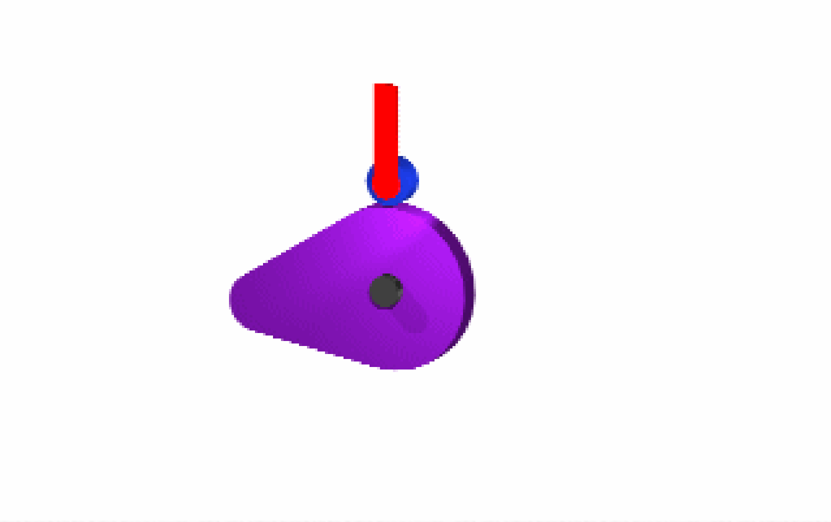
1.2.1 Rotating cam – Translating follower

1.2.2 Rotating cam – Oscillating follower

1.2.3 Translating cam – Translating follower

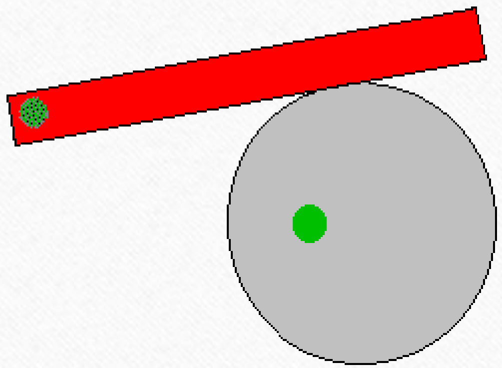
Cam Mechanism

1.2.1 Rotating cam – Translating follower



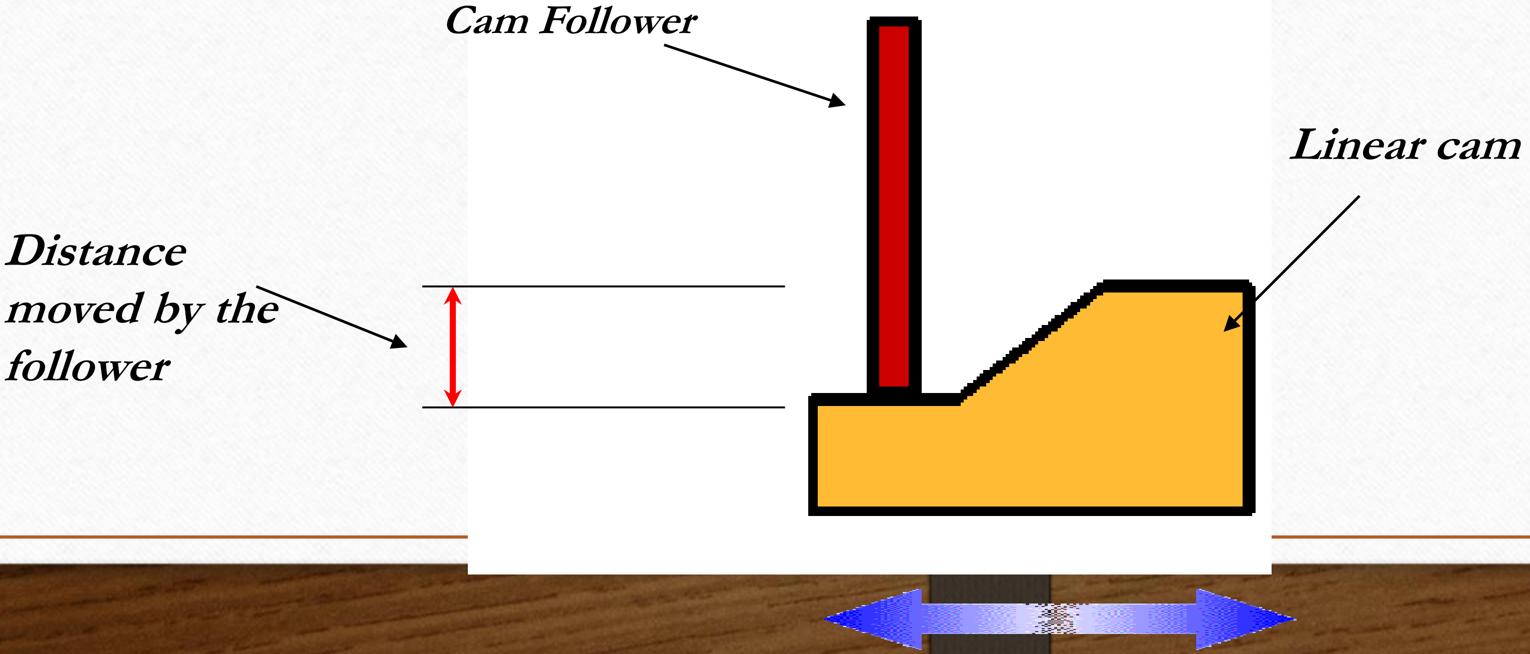
Cam Mechanism

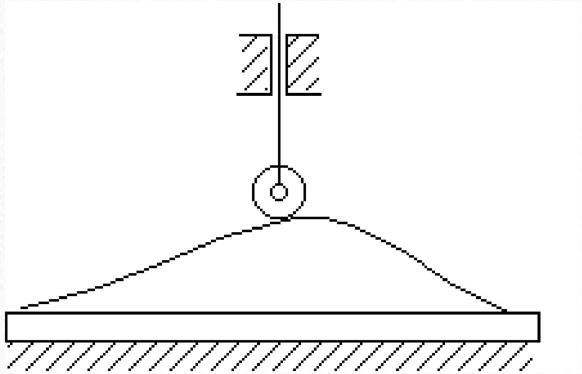
1.2.2 Rotating cam – oscillating follower



Cam Mechanism

1.2.3 Translating cam – Translating follower





Followers Types

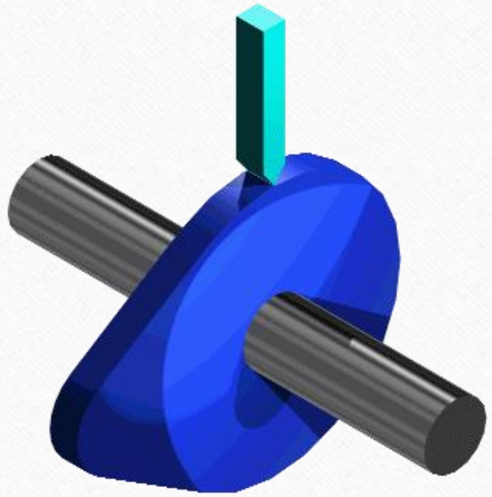
1.3 Classification of followers

1.3.1 According to the shape of follower

- Knife edge follower
- Roller follower
- Flat faced follower
- Spherical faced follower

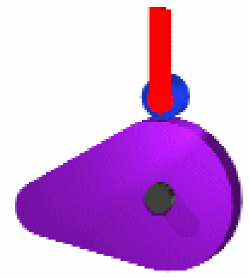
Followers Types

a) Knife edge follower



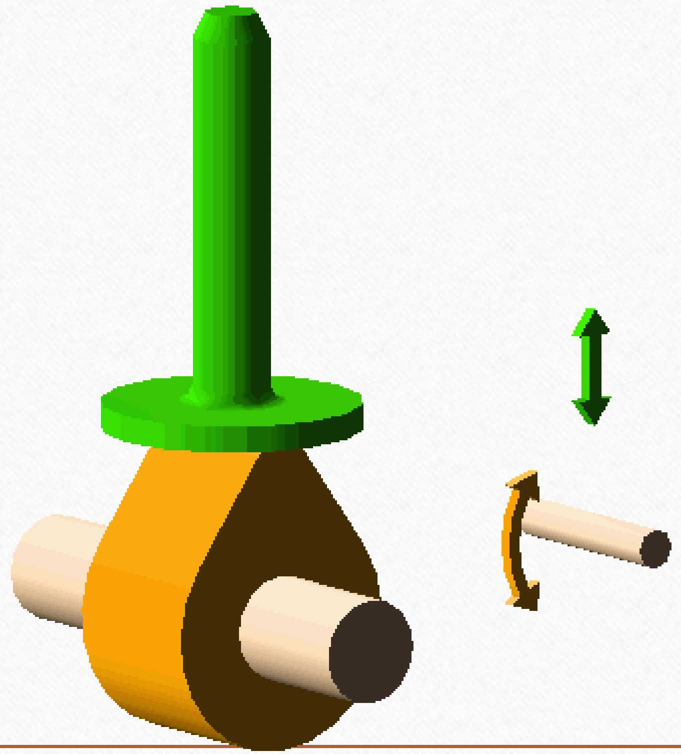
Followers Types

b) Roller follower



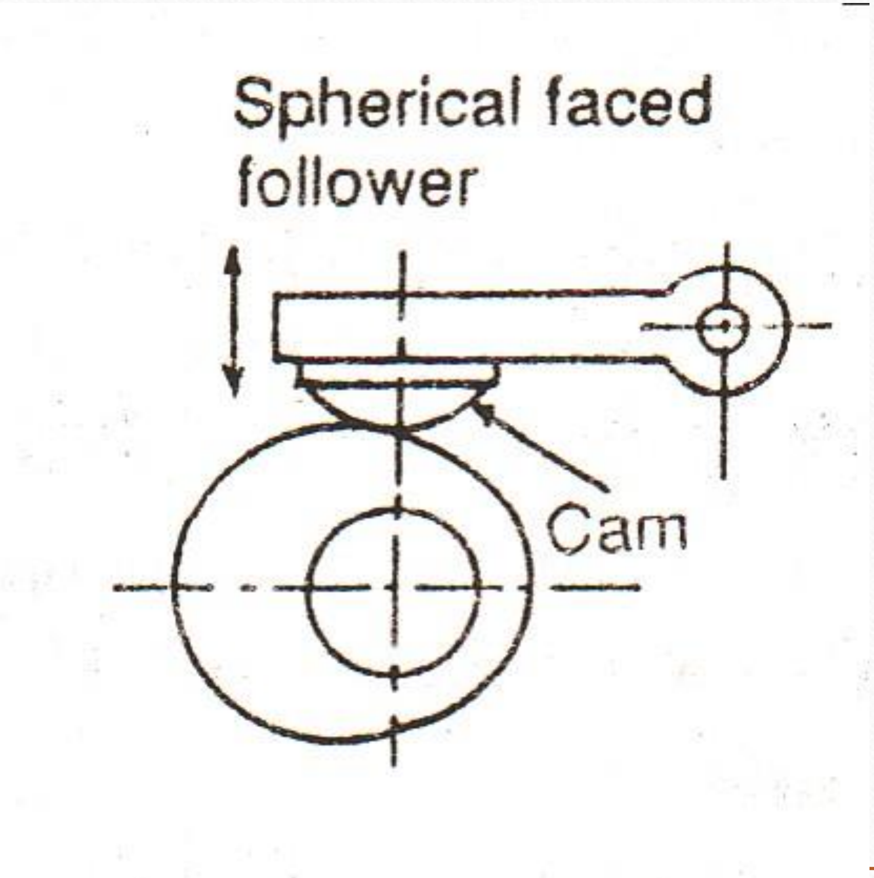
Followers Types

c) Flat faced follower



Followers Types

d) Spherical faced follower

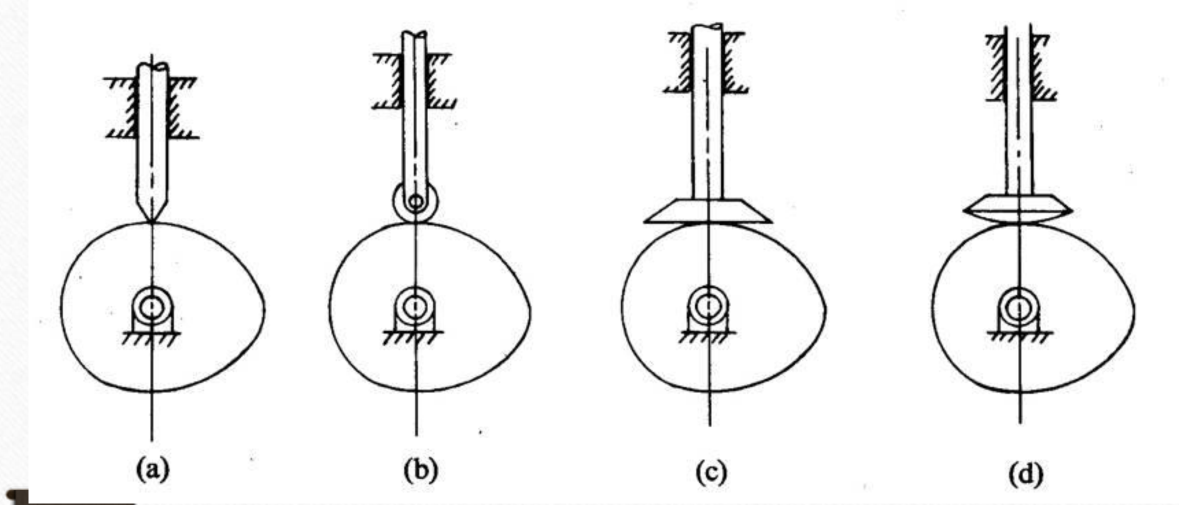


Followers Types

1.3.2 According to the path of motion of follower

a) Radial follower

- When the motion of the follower is along an axis passing through the centre of the cam, it is known as radial followers. Above figures are examples of this type.

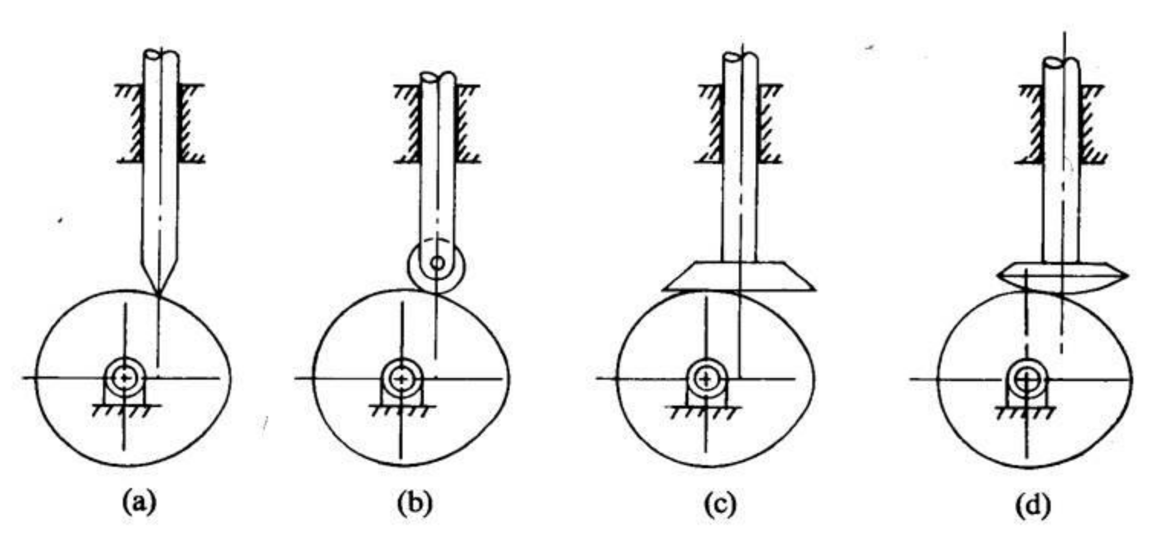


Followers Types

1.3.2 According to the path of motion of follower

b) Offset follower

When the motion of the follower is along an axis away from the axis of the cam centre, it is called off-set follower. Above figures are examples of this type.



Cam-follower Mechanism

Motion Of The Follower

As the cam rotates the follower moves upward and downward.

- The upward movement of follower is called rise (Outstroke)
- The downward movement is called fall (Return stroke).
- When the follower is not moving upward and downward even when the cam rotates, it is called dwell.

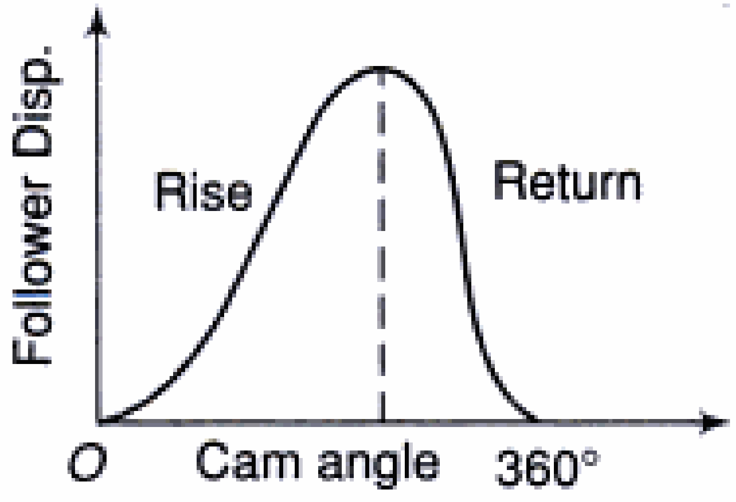
Cam Mechanism

1. Rise-Return-Rise (R-R-R)

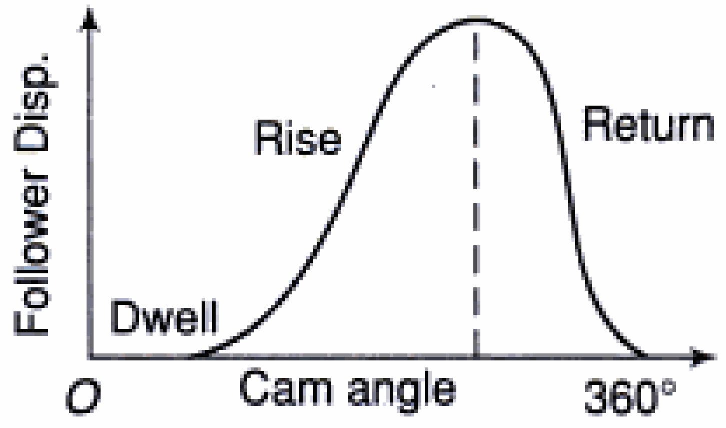
- *In* this, there is alternate rise and return of the follower with no periods of dwells (Fig. a).
- Its use is very limited in the industry.
- The follower has a linear or an angular displacement.

2. Dwell-Rise-Return-Dwell (D-R-R-D)

- *In such a type of cam, there is rise and return of the follower after a dwell Fig.(b).*
- *his type is used more frequently than the* R-R-R *type of cam.*



(a)



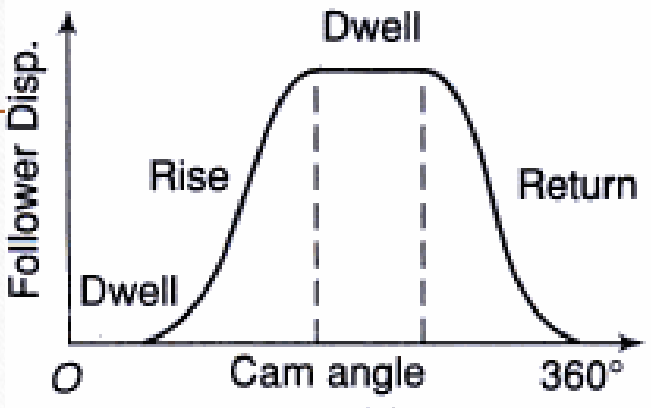
(b)

Cam Mechanism

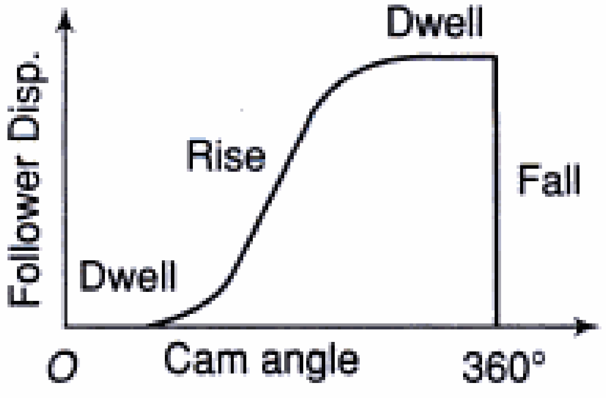
3. Dwell-Rise-Dwell-Return-Dwell (D-R-D-R-D)

It is the most widely used type of cam.

- *The dwelling of the cam is followed by* rise and dwell and subsequently by return and dwell as shown in rig. (c).
- In case the return of the follower is by a fall [Fig.(d)], the motion may be known as Dwell-Rise-Dwell (D-R-D).



(c)

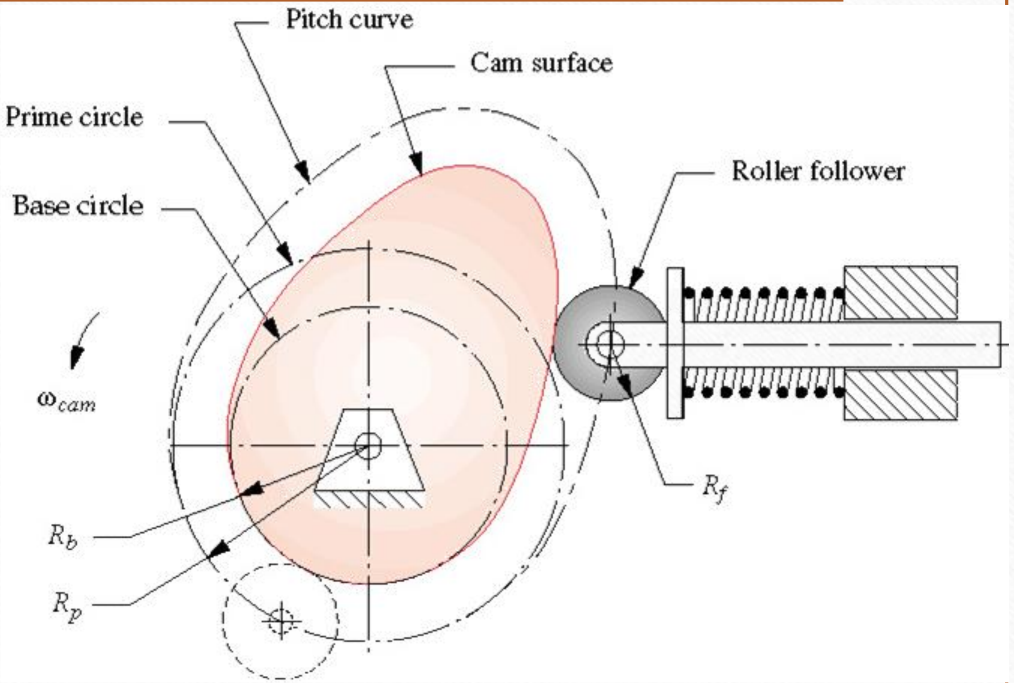


(d)

Graphical layout of cam profiles

Terminology

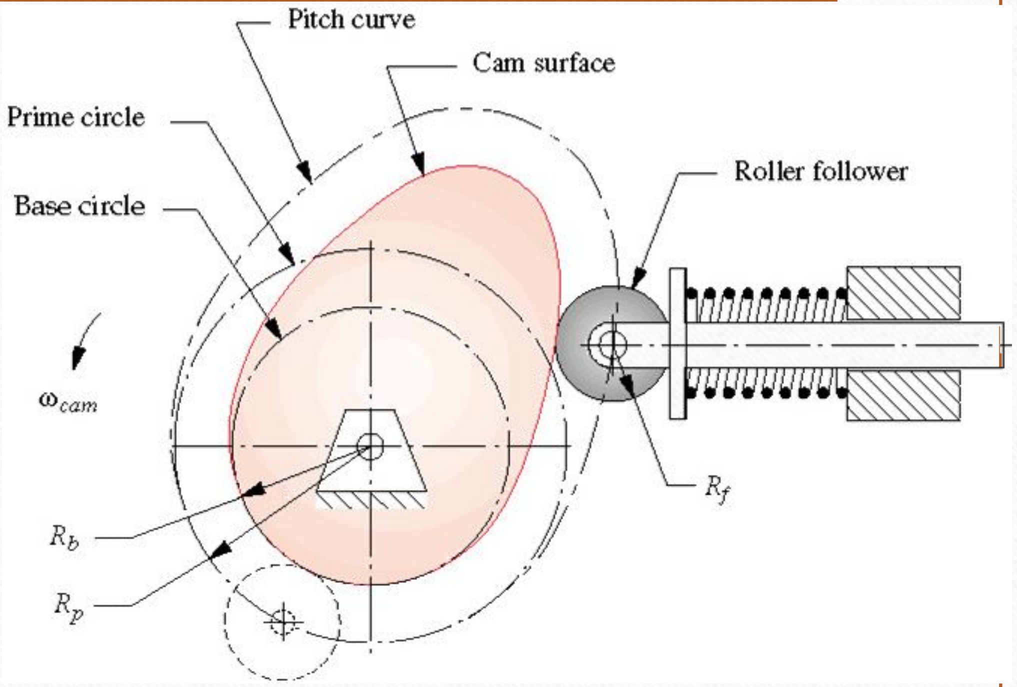
- **Cam profile:** The outer surface of the disc cam.
- **Base circle :** The circle with the shortest radius from the cam center to any part of the cam profile.
- **Trace point:** It is a point on the follower, and its motion describes the movement of the follower. It is used to generate the pitch curve.



Graphical layout of cam profiles

Terminology

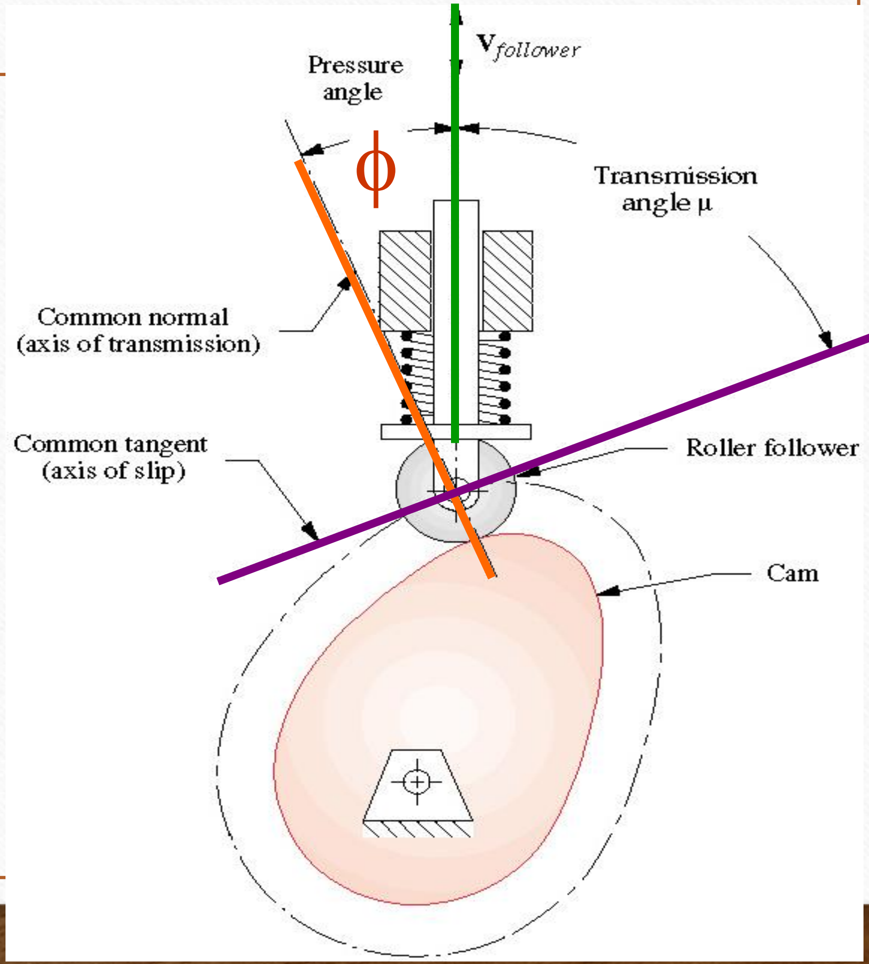
- **Pitch curve :** The path generated by the trace point as the follower is rotated about a stationery cam.
- **Prime circle:** The smallest circle from the cam center through the pitch curve



Graphical layout of cam profiles

Terminology

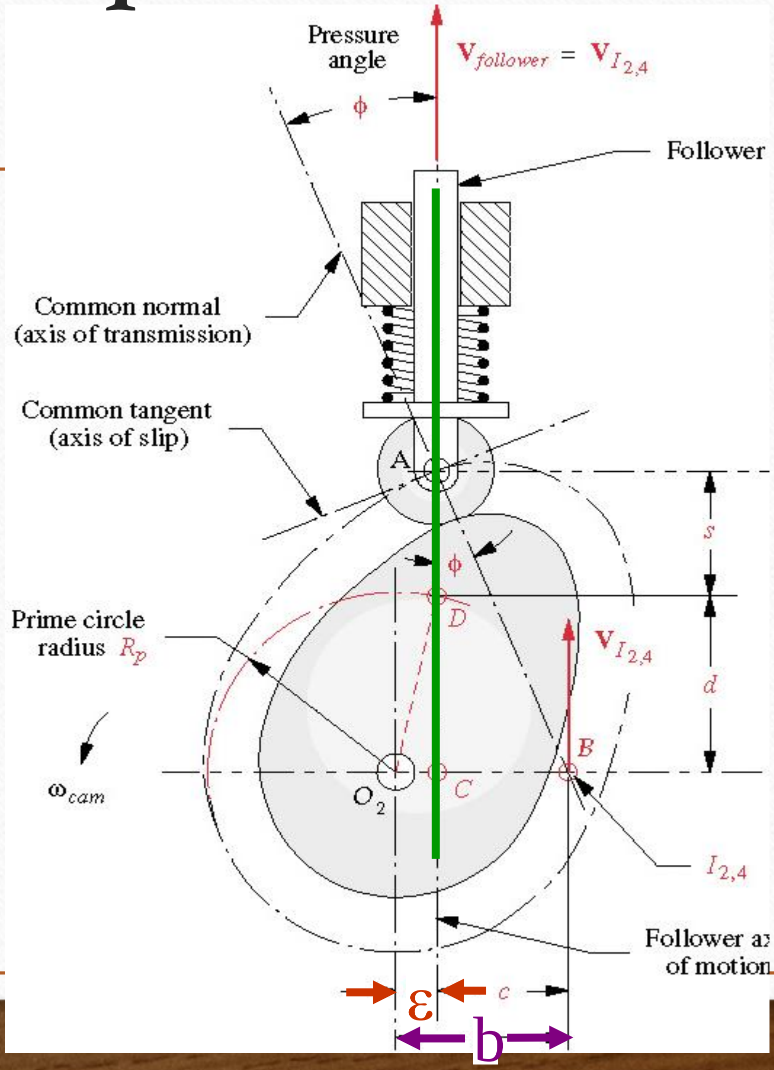
- **Pressure angle:** The angle between the direction of the follower movement and the normal to the pitch curve.
- **Pitch point:** Pitch point corresponds to the point of maximum pressure angle.
- **Pitch circle:** A circle drawn from the cam center and passes through the pitch point is called Pitch circle
- **Stroke:** The greatest distance or angle through which the follower moves or rotates



Graphical layout of cam profiles

Cam Eccentricity

- Eccentricty (ε) – the perpendicular distance between the follower's axis of motion and the center of the cam
- Aligned follower: ε=0



Cam Profile

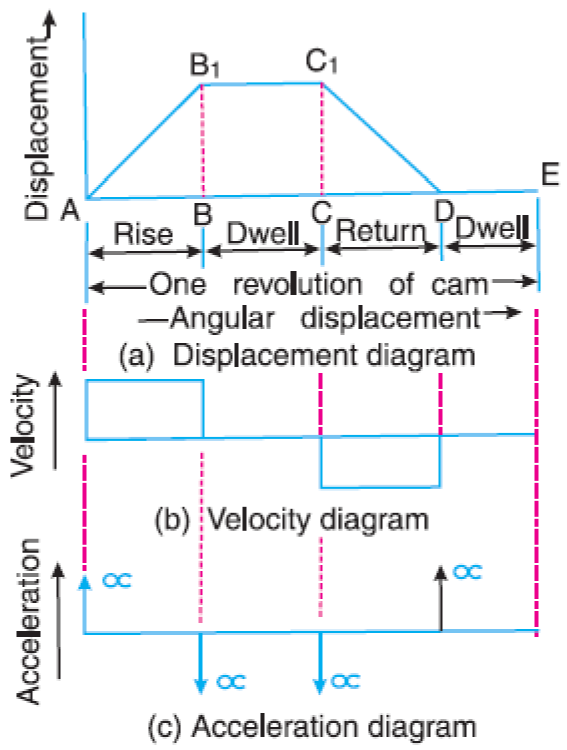
Types of follower motion

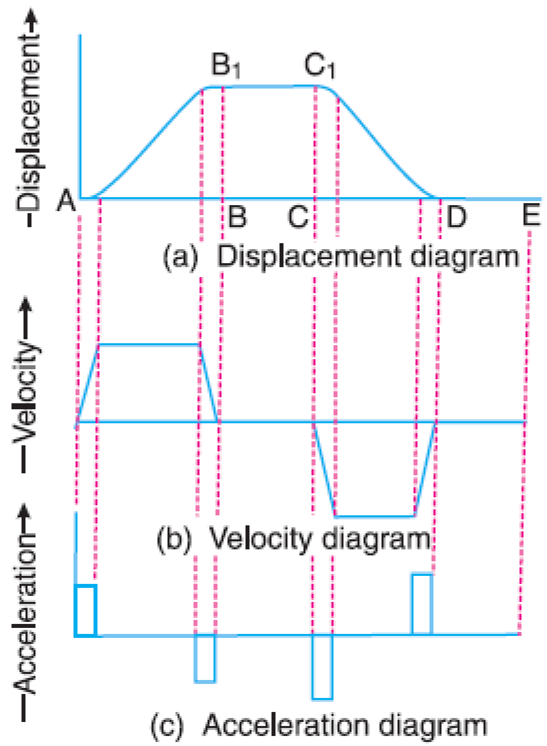
1. Uniform motion (constant velocity)
    - Constant velocity
    - Problem: infinity acceleration at point where dwell portion starts
2. Simple harmonic motion (Sinusoidal)
3. Uniform acceleration and retardation motion
    - Can be shown that acceleration is constant
4. Cycloidal motion

Cam Profile

a) Uniform motion (constant velocity)

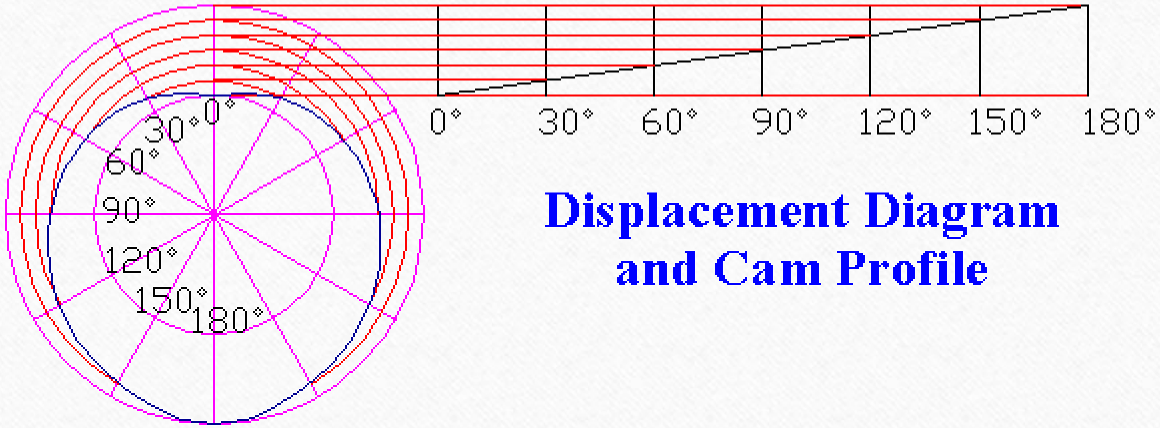
- Displacement diagram: **Displacement is the distance that a follower moves during one complete revolution (or cycle) of the cam while the follower is in contact with the cam.**
- **It is the plot of linear displacement (s) of follower V/S angular displacement (θ) of the cam for one full rotation of the cam.**





Cam Profile

a) Uniform motion (constant velocity)



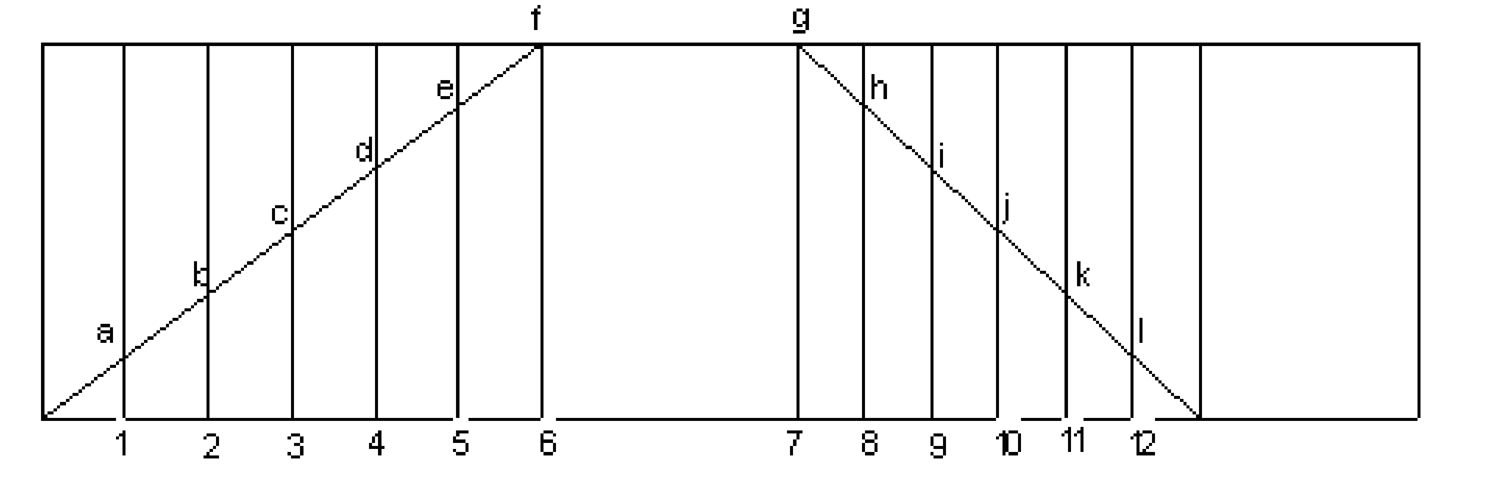
Displacement Diagram and Cam Profile

Cam Profile

a) Uniform motion (constant velocity)

Displacement diagram

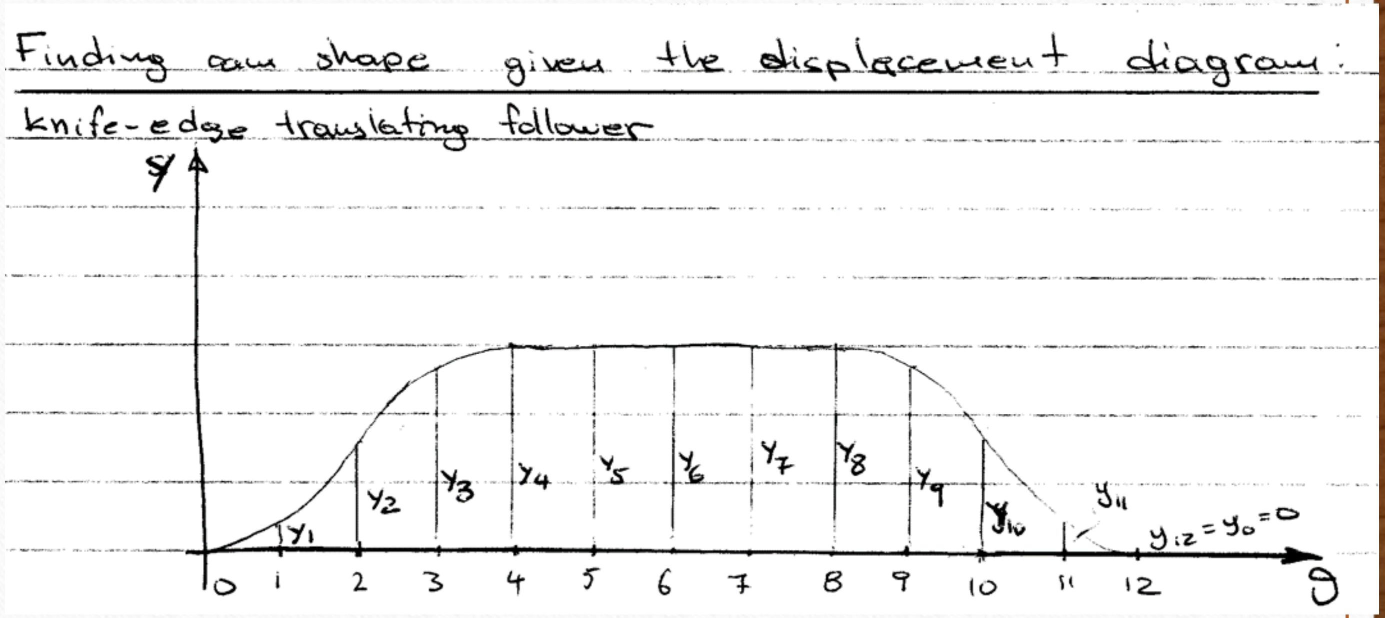
Since the follower moves with uniform velocity during its rise and fall, the slope of the displacement curve must be constant as shown in fig



Constructing cam profile: kinematic inversion principle

Steps:

- Break range of θ in 12 positions
- Measure displacement of follower at each point, y1, y2
- Define base circle of cam
- Divide base circle to 12 equal sectors
- Mark 12 radials in opposite direction of cam rotation
- Mark follower displacements on radials
- Sketch cam



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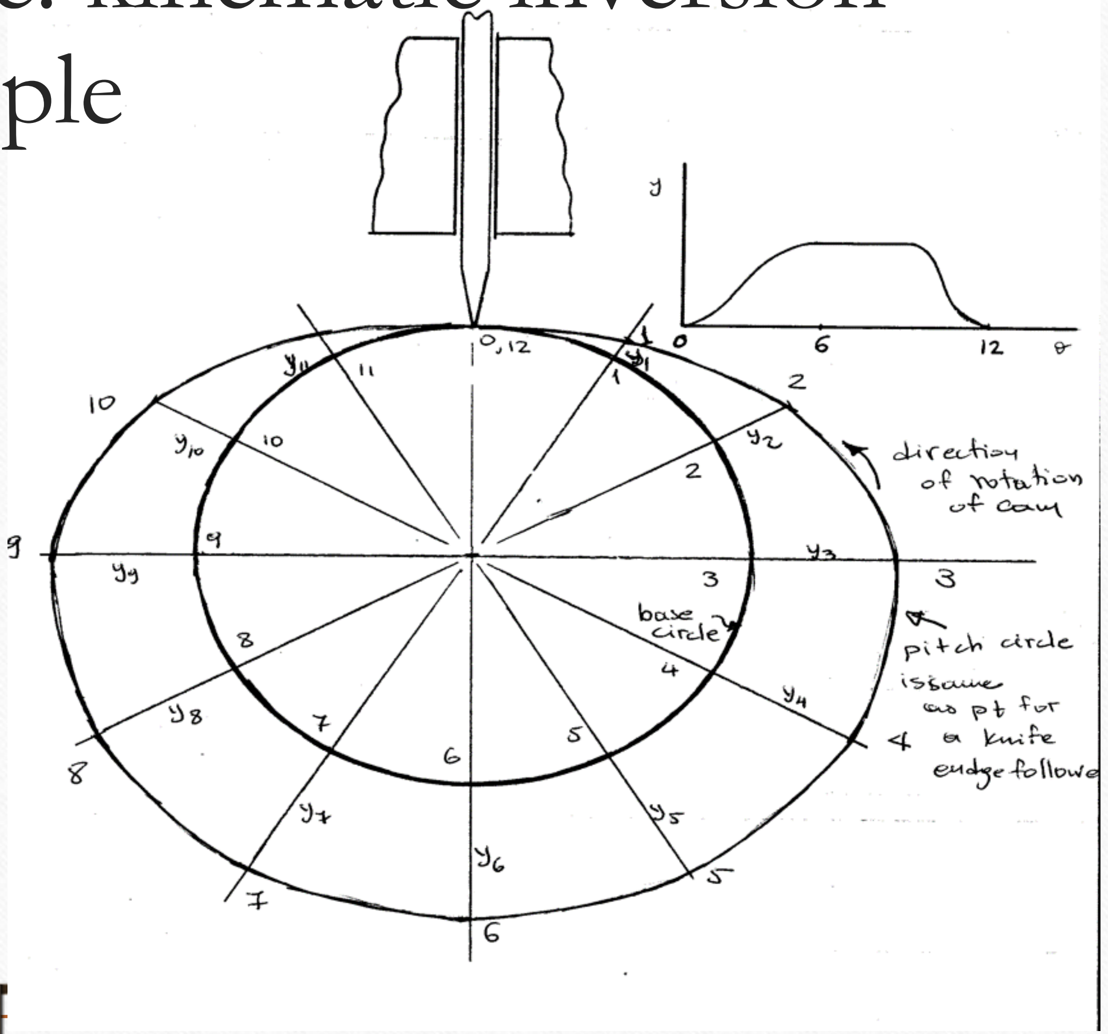
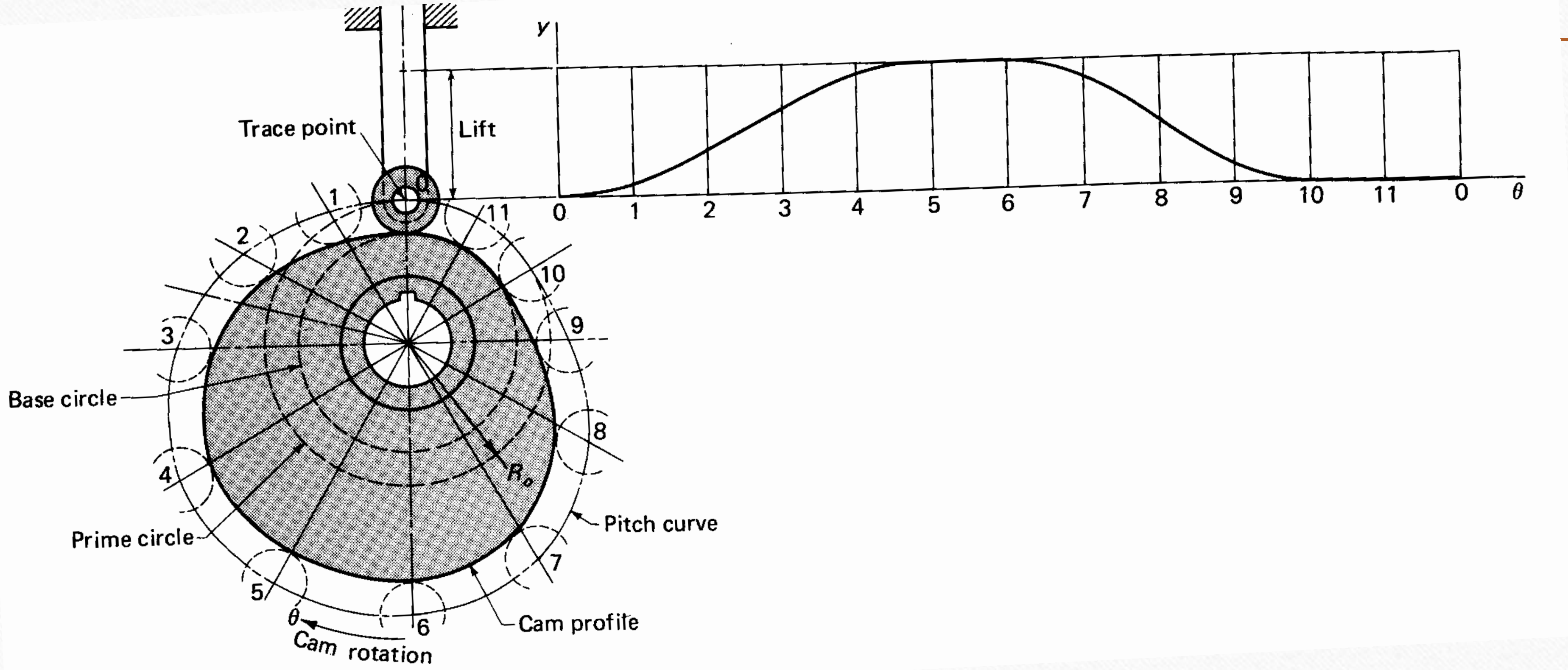


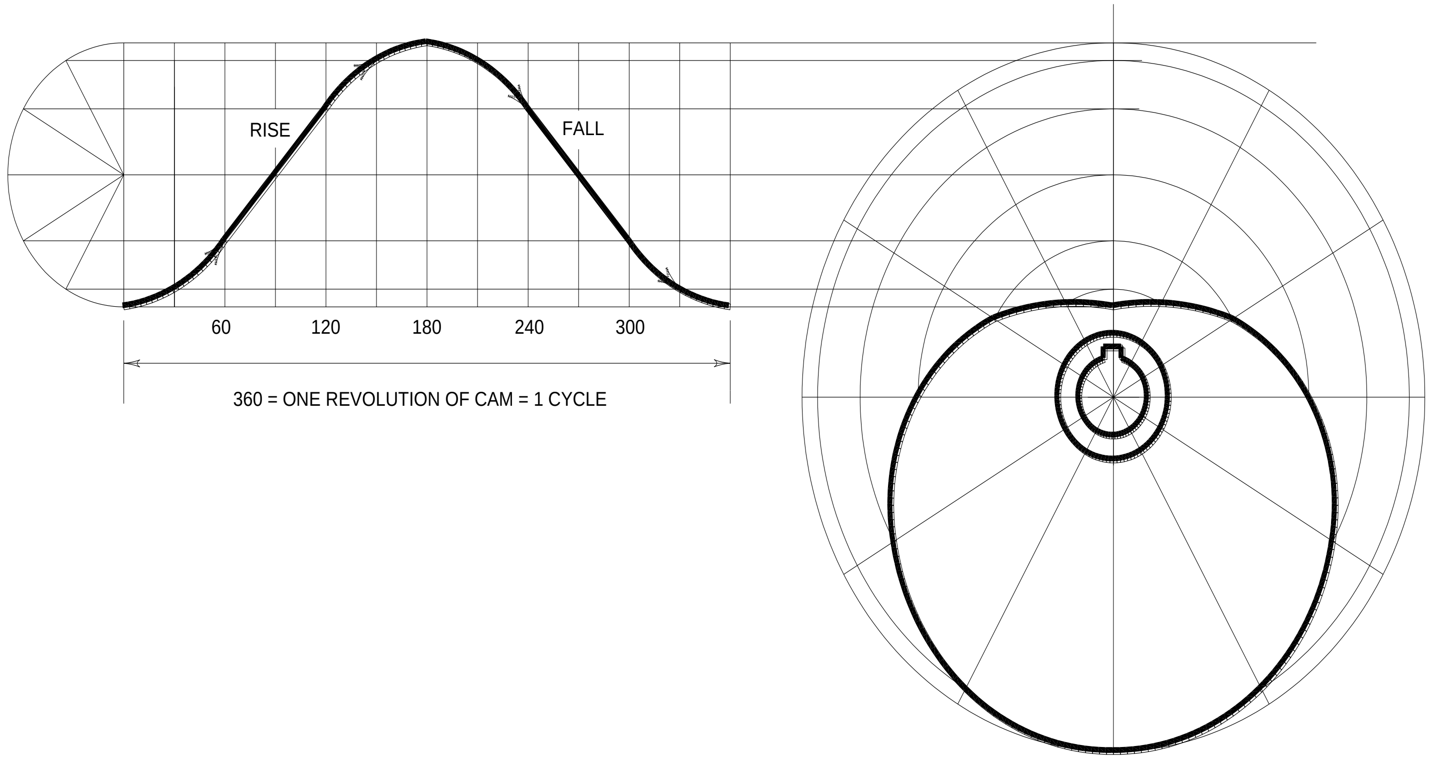
Layout of cam profile: roller follower



Cam Profile

b) Simple Harmonic motion

- Since the follower moves with a simple harmonic motion, therefore velocity diagram consists of a sine curve and the acceleration diagram consists of a cosine curve.



Cam Profile

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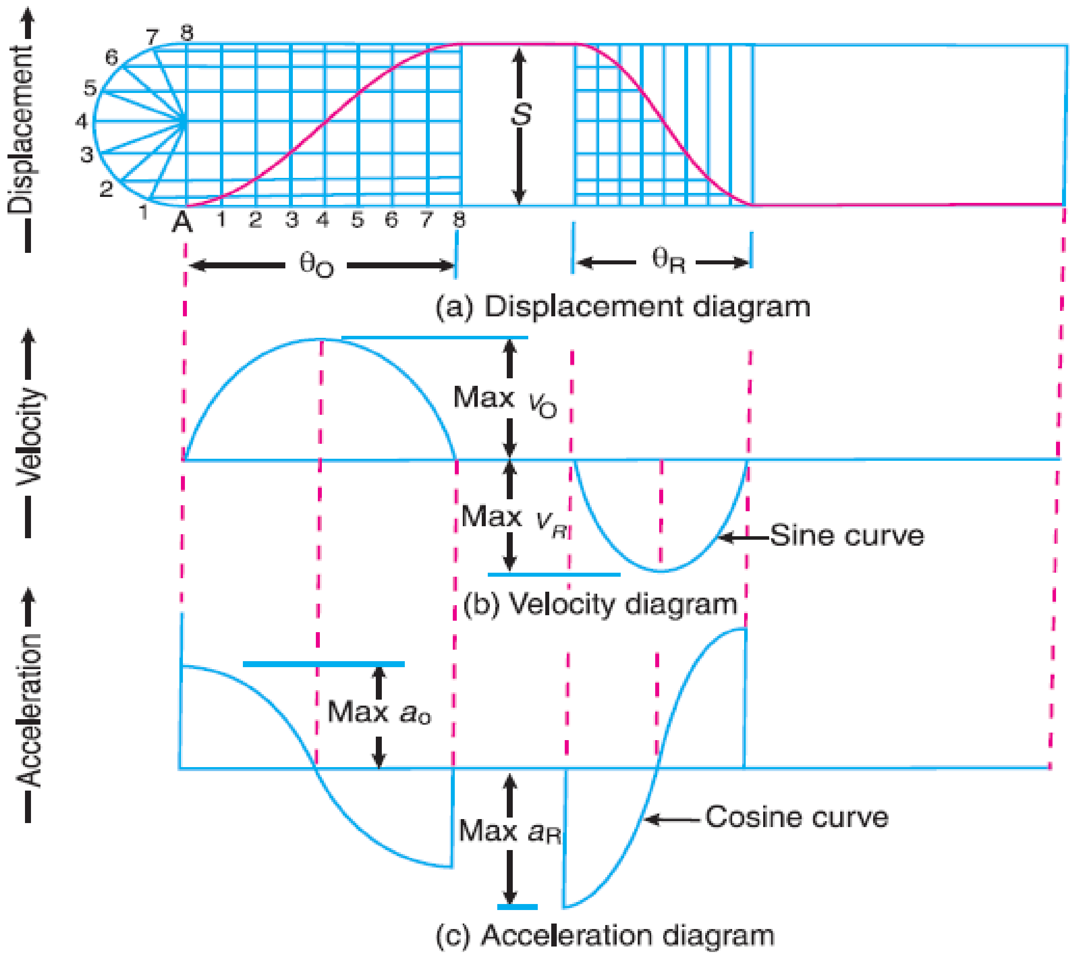


Cam Profile

b) Simple Harmonic motion

Let S = Stroke of the follower,

θ_O and θ_R = Angular displacement of the cam during out stroke and return stroke of the follower respectively, in radians, and

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

maximum velocity of the follower on the outstroke, $\frac{\pi \omega S}{2\theta_O}$

∴ Maximum acceleration of the follower on the outstroke,

$$a_O = a_P = \frac{\pi^2 \omega^2 . S}{2(\theta_O)^2}$$

Similarly, maximum velocity of the follower on the return stroke,

$$v_R = \frac{\pi \omega . S}{2\theta_R}$$

and maximum acceleration of the follower on the return stroke,

$$a_R = \frac{\pi^2 \omega^2 . S}{2(\theta_R)^2}$$

Cam Profile

c) Uniform acceleration and retardation

- Since the acceleration and retardation are uniform, therefore the velocity varies directly with time.

velocity of the follower during outstroke,

$$v_O = \frac{2\omega.S}{\theta_O}$$

maximum velocity of the follower during return

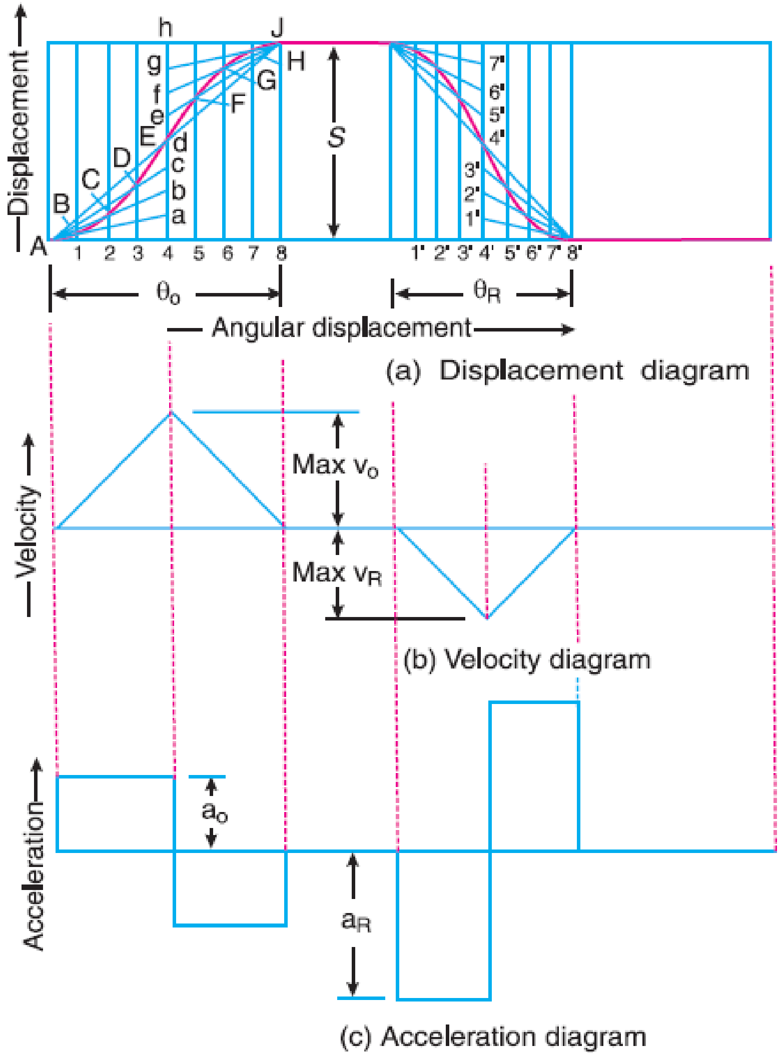
$$v_R = \frac{2\omega.S}{\theta_R}$$

Maximum acceleration of the follower during outstroke,

$$a_O = \frac{4\omega^2.S}{(\theta_O)^2}$$

Similarly, maximum acceleration of the follower during return

$$a_R = \frac{4\omega^2.S}{(\theta_R)^2}$$



Cam Profile

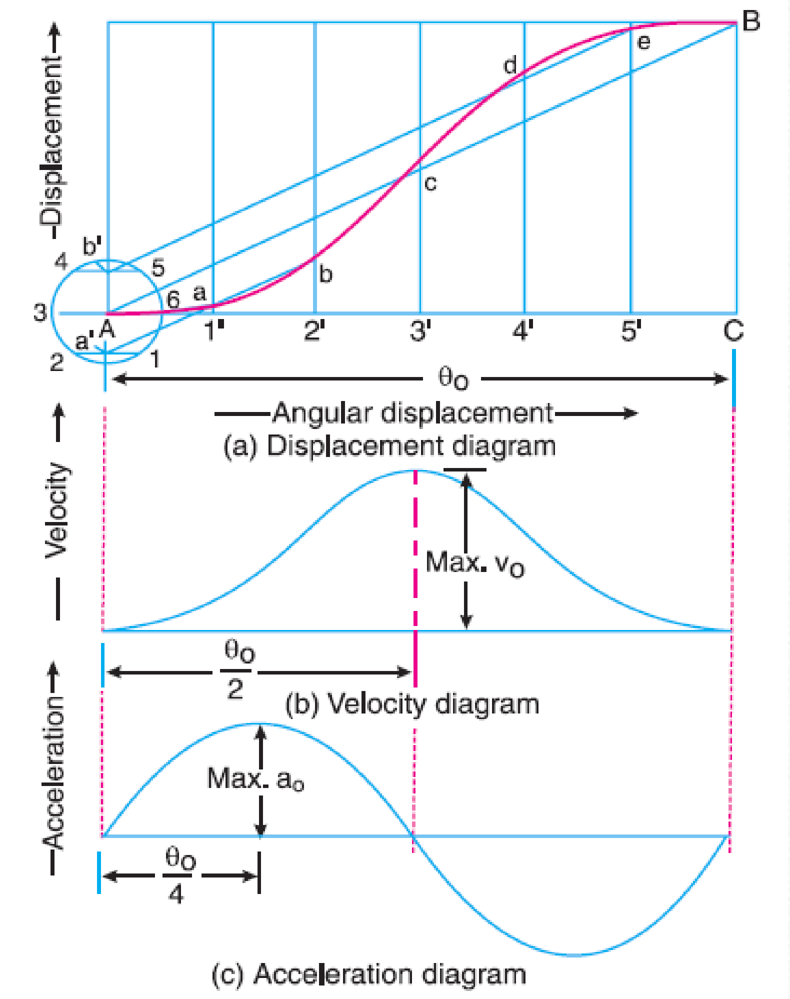
d) Cycloidal motion

$$v_O = \frac{2\omega S}{\theta_O}$$

$$a_O = \frac{2\pi\omega^2.S}{(\theta_O)^2}$$

$$v_R = \frac{2\omega.S}{\theta_R}$$

$$a_R = \frac{2\pi\omega^2.S}{(\theta_R)^2}$$



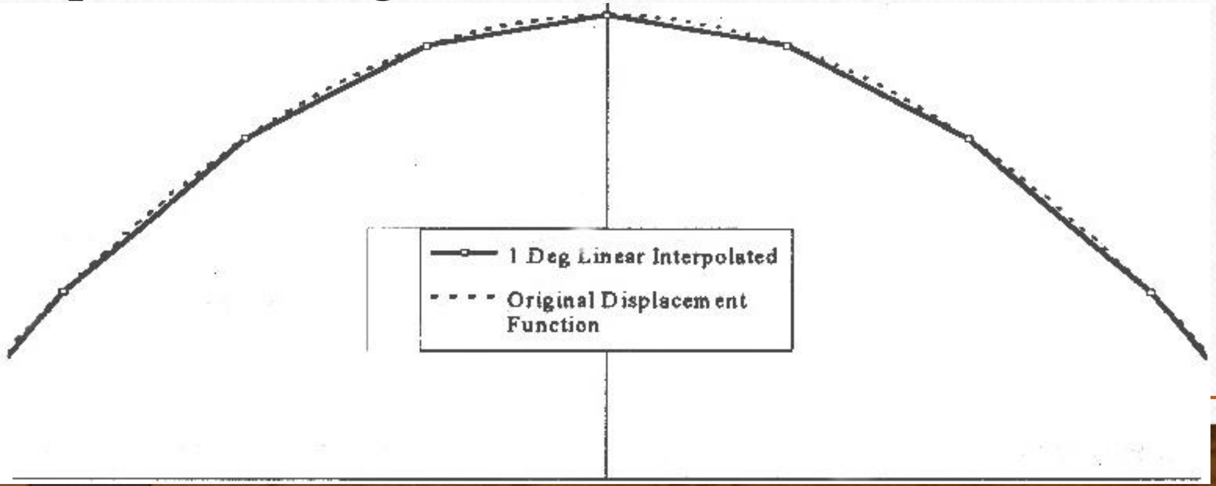
(a) Displacement diagram

(b) Velocity diagram

(c) Acceleration diagram

Cam Manufacturing Considerations

- Medium to high carbon steels, or cast ductile iron
- Milled or ground
- Heat treated for hardness (Rockwell HRC 50-55)
- CNC machines often use linear interpolation (larger accelerations)



SVAJ diagrams: show displacement, velocity, acceleration versus θ