Chapter 8

Introduction

A **cam** is a specially shaped piece of metal arranged to move a follower in a controls fashion.

A **follower** is a link or linkage train that is

Benefits of Cams

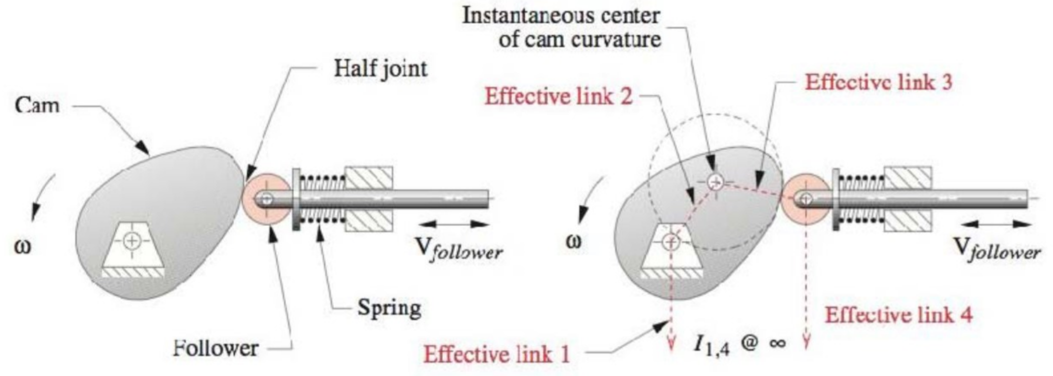
- Function Generation
- A degenerate form of a pure **fourbar linkage (oscillation)** or **fourbar slider-crank (translation)**
- Effective link length could **change** during the motion
- Easier to generate output function than a linkage
- More expensive to make than a linkage

8.1 Cam Terminology

Classifications of Cam-follower Systems

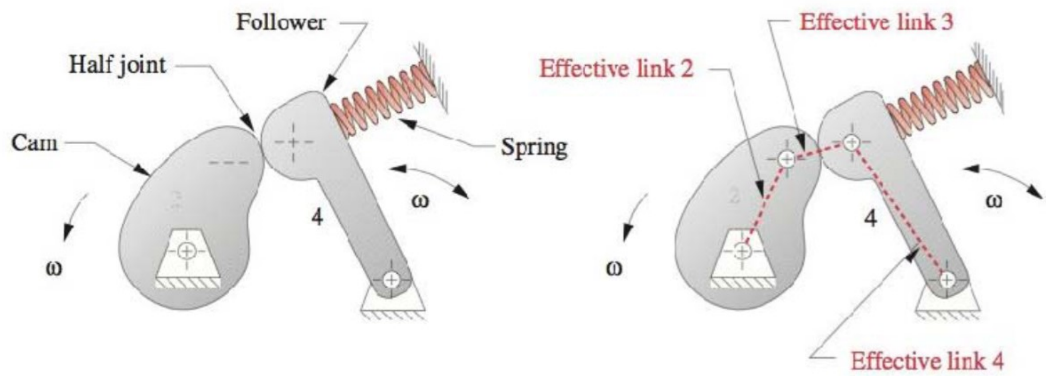
Type of Follower Motion

- translating



(b) A translating cam-follower has an effective fourbar slider-crank equivalent

- rotating



(a) An oscillating cam-follower has an effective pin-jointed fourbar equivalent

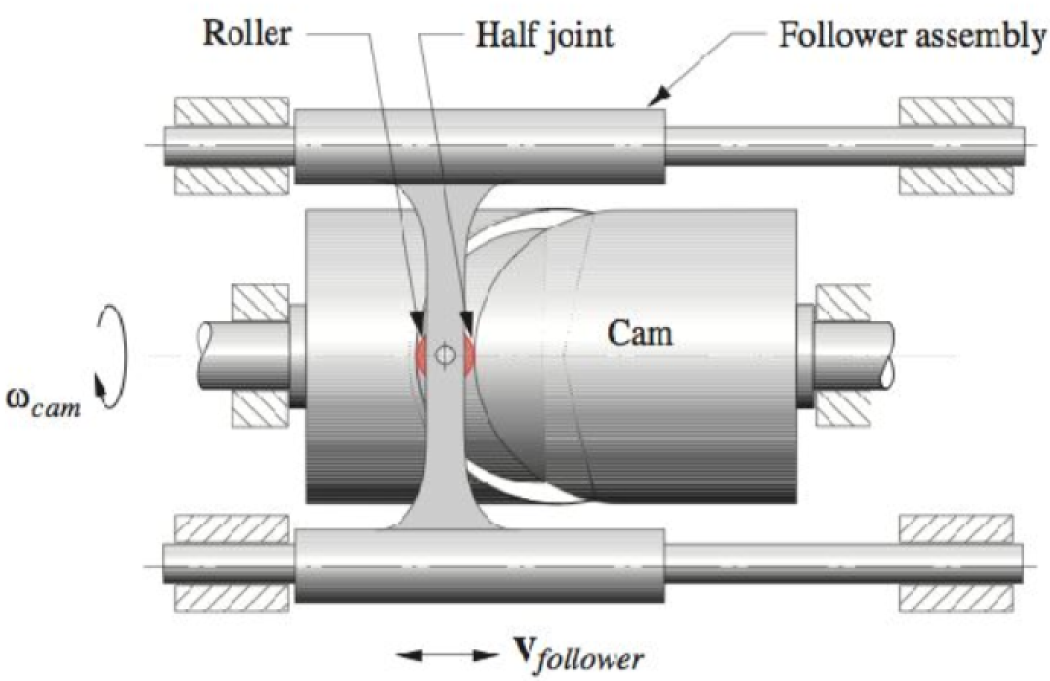
Type of Cam

- radial cam *(the figures above are all radical cams)*

  open radical cams are also called plate cams

- axial cam

  also called a face cam if open(force closed) and a cylindrical or barrel cam if grooved or ribbed(formed-closed)



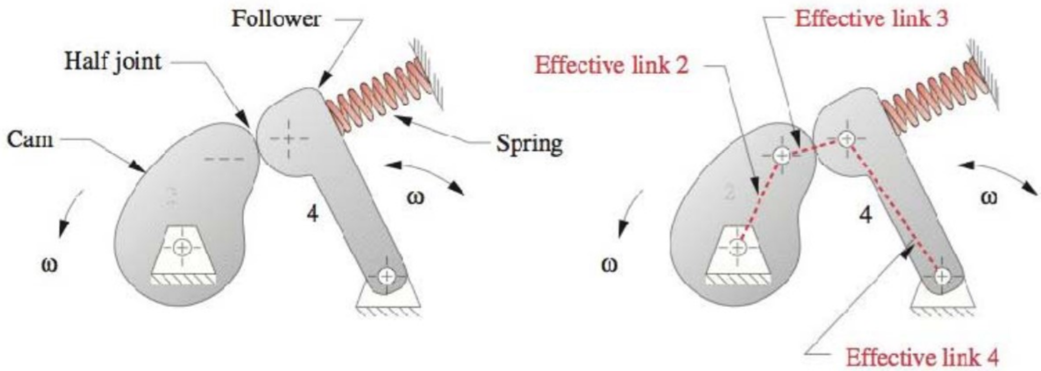
- three-dimensional cam

(c) Three-dimensional cams
Courtesy of The Gillette Co.
Boston, MA

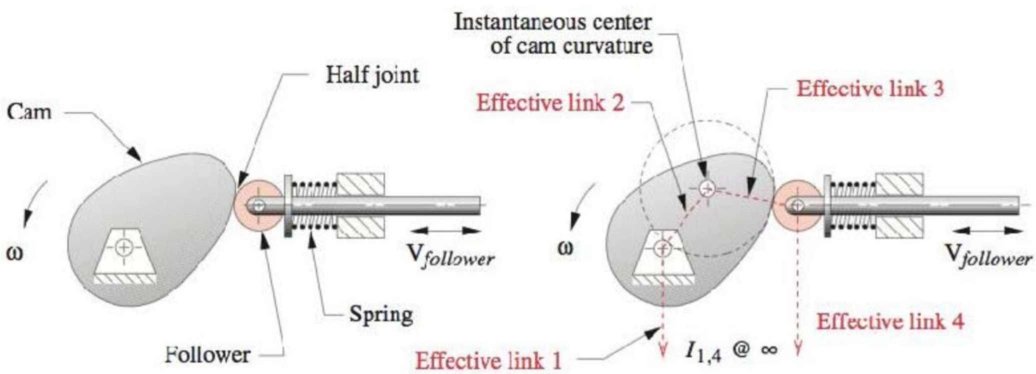
Type of Joint Closure

- force-closed

  requires **an external force** be applied to the joint in order to keep cam and follower physically in contact



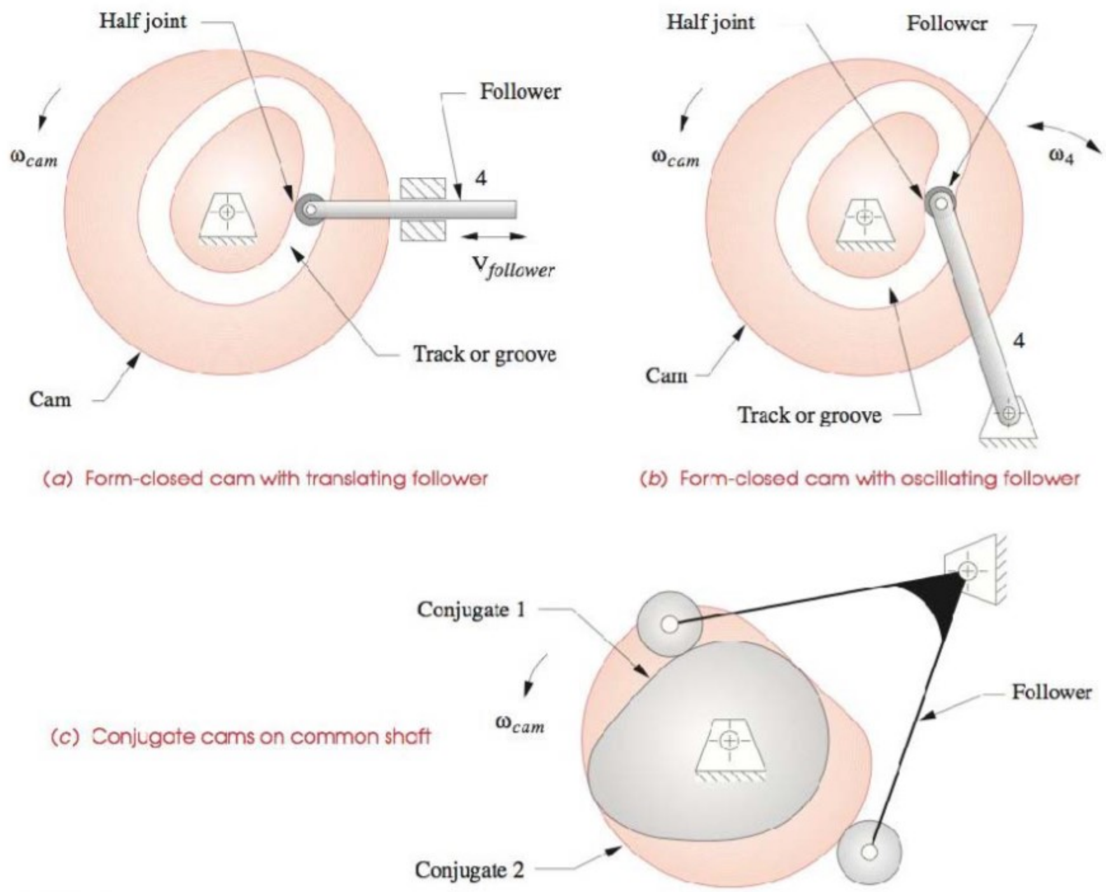
(a) An oscillating cam-follower has an effective pin-jointed fourbar equivalent



(b) A translating cam-follower has an effective fourbar slider-crank equivalent

- form closed

  closes the joint by geometry



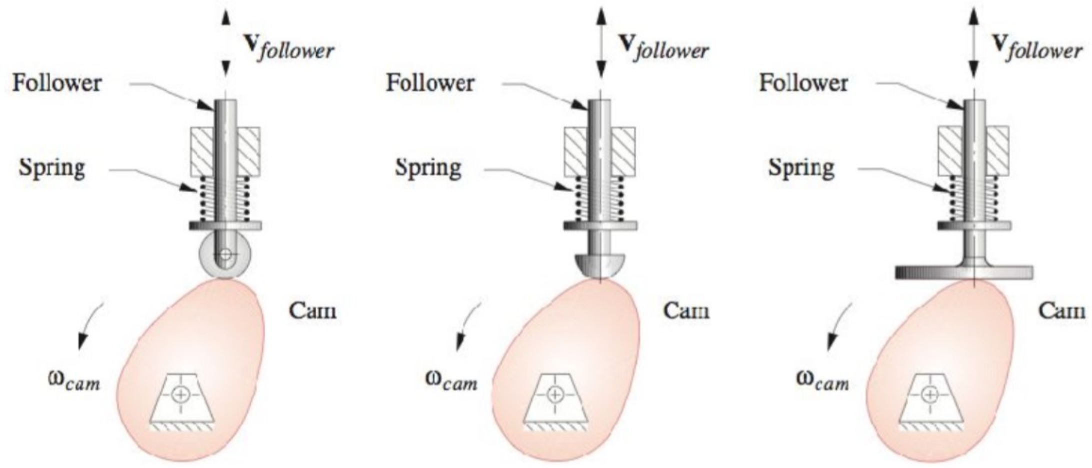
(a) Form-closed cam with translating follower

(b) Form-closed cam with oscillating follower

(c) Conjugate cams on common shaft

Type of Follower

- curved (mushroom)
- flat
- rolling
- sliding



(a) Roller follower

(b) Mushroom follower

(c) Flat-faced follower

Type of Motion Constraints

- critical extreme position
  - end points of motion are critical
  - path between endpoints is not critical
- critical path motion

- the path between endpoints is critical
- displacements, velocities, etc. may be specified
- endpoints usually also critical

Type of Cam Motion Programs

- rise-fall
- rise-fall-dwell
- rise-dwell-fall-dwell

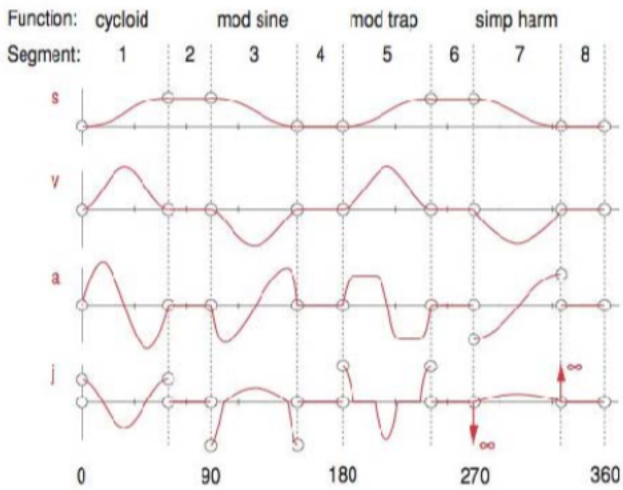
dwell: at zero displacement for 90 degrees (low dwell)

8.2 S V A J Diagrams

$$\theta = \omega t$$

Segment Number	Function Used	Start Angle	End Angle	Delta Angle
1	Cycloid rise	0	60	60
2	Dwell	60	90	30
3	ModSine fall	90	150	60
4	Dwell	150	180	30
5	ModTrap rise	180	240	60
6	Dwell	240	270	30
7	SimpHarm fall	270	330	60
8	Dwell	330	360	30

(*a*) Cam program specifications



(*b*) Plots of cam-follower's *s v a j* diagrams

8.3 Double-Dwell Cam Design Choosing S V A J Functions

The Fundamental Law of Cam Design

Thw cam function must be continuous through the first and second derivatives of displacement across the entire interval

The jerk function must be finite across the entire interval

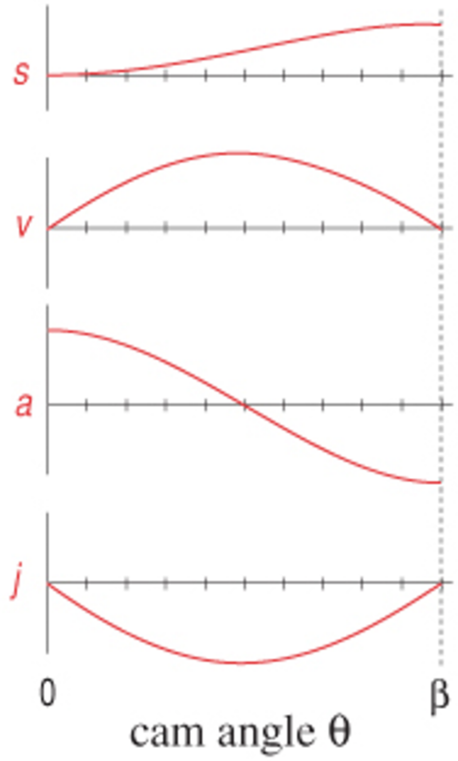
Simple Harmonic Motion (SHM)

$$s = \frac{h}{2}[1 - \cos{(\pi\frac{\theta}{\beta})}]$$

$$v = \frac{\pi}{\beta}\frac{h}{2}\sin{(\pi\frac{\theta}{\beta})}$$

$$a = \frac{\pi^2}{\beta^2}\frac{h}{2}\cos{(\pi\frac{\theta}{\beta})}$$

$$j = -\frac{\pi^3}{\beta^3}\frac{h}{2}\sin{(\pi\frac{\theta}{\beta})}$$



- Acceleration discontinuous
- Jerk is infinite

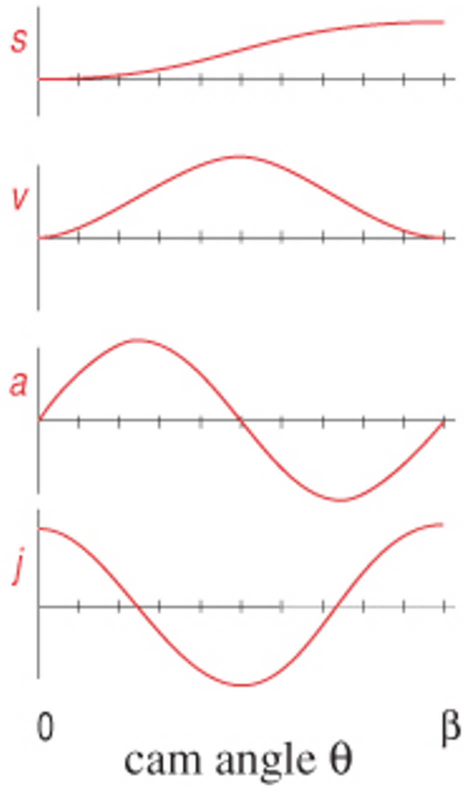
Cycloidal Displacement

$$s = \frac{h}{\beta}\theta - \frac{h}{2\pi}\sin\left(\frac{2\pi\theta}{\beta}\right)$$

$$v = \frac{h}{\beta}\left(1 - \cos\left(\frac{2\pi\theta}{\beta}\right)\right)$$

$$a = \frac{2\pi h}{\beta^2}\sin\left(\frac{2\pi\theta}{\beta}\right)$$

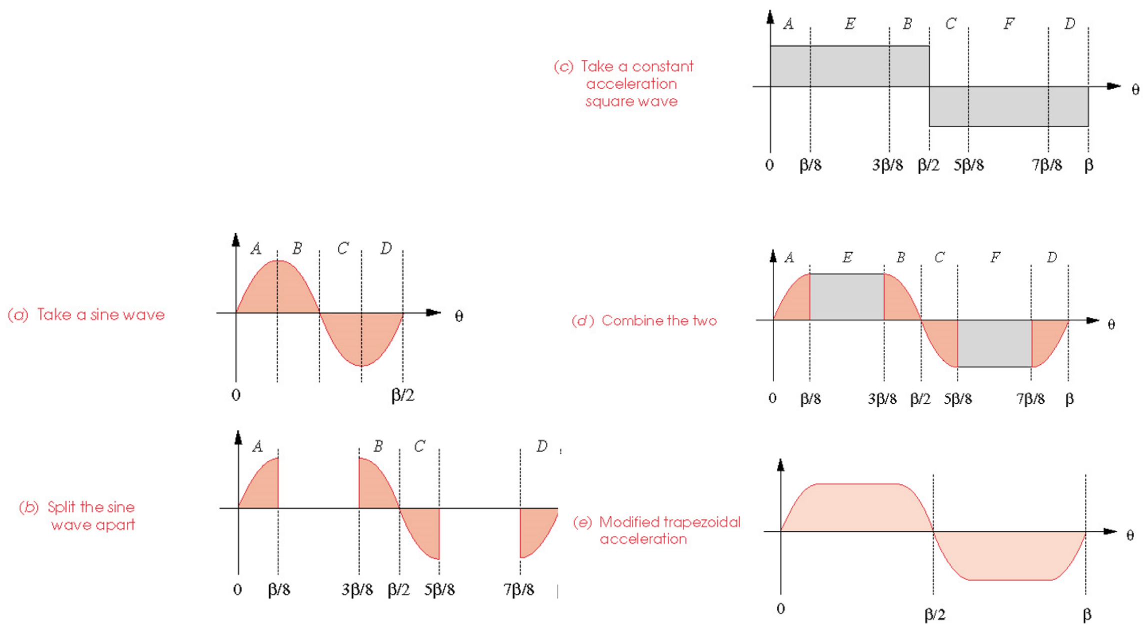
$$j = \frac{h(2\pi)^2}{\beta^3}\cos\left(\frac{2\pi\theta}{\beta}\right)$$



- valid cam design
- acceleration and velocity are higher than other functions
- one may seek to cut off the acceleration

Combined Functions

cut a sine wave into three pieced and recombine them with a square wave



- lowest magnitude of peak acceleration of standard cam functions

Polynomial Functions

3-4-5 Polynomial

$$s = C_0 + C_1(\frac{\theta}{\beta}) + C_2(\frac{\theta}{\beta})^2 + C_3(\frac{\theta}{\beta})^3 + C_4(\frac{\theta}{\beta})^4 + C_5(\frac{\theta}{\beta})^5$$

$$v = \frac{1}{\beta}[C_1 + 2C_2(\frac{\theta}{\beta}) + 3C_3(\frac{\theta}{\beta})^2 + 4C_4(\frac{\theta}{\beta})^3 + 5C_5(\frac{\theta}{\beta})^4]$$

$$a = \frac{1}{\beta^2}[2C_2 + 6C_3(\frac{\theta}{\beta}) + 12C_4(\frac{\theta}{\beta})^2 + 20C_5(\frac{\theta}{\beta})^3]$$

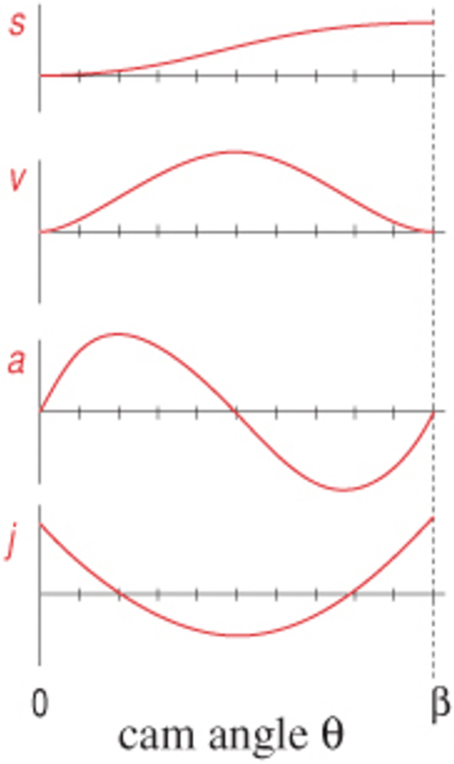
$$\theta = 0 \qquad s = 0 = C_0 \qquad v = 0 = \frac{C_1}{\beta} \qquad a = 0 = \frac{2C_2}{\beta}$$

$$\theta = \beta \qquad s = h = C_3 + C_4 + C_5$$

$$v = 0 = 3C_3 + 4C_4 + 5C_5$$

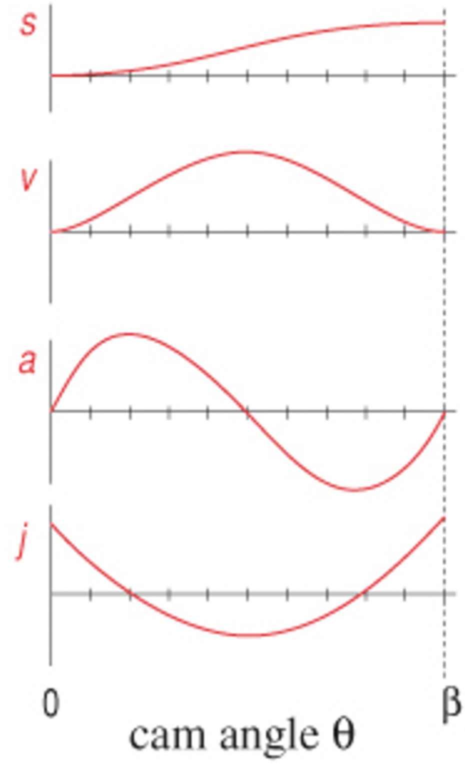
$$a = 0 = 6C_3 + 12C_4 + 20C_5$$

$$\Rightarrow \qquad s = h[10(\frac{\theta}{\beta})^3 - 15(\frac{\theta}{\beta}^4) + 6(\frac{\theta}{\beta})^5]$$

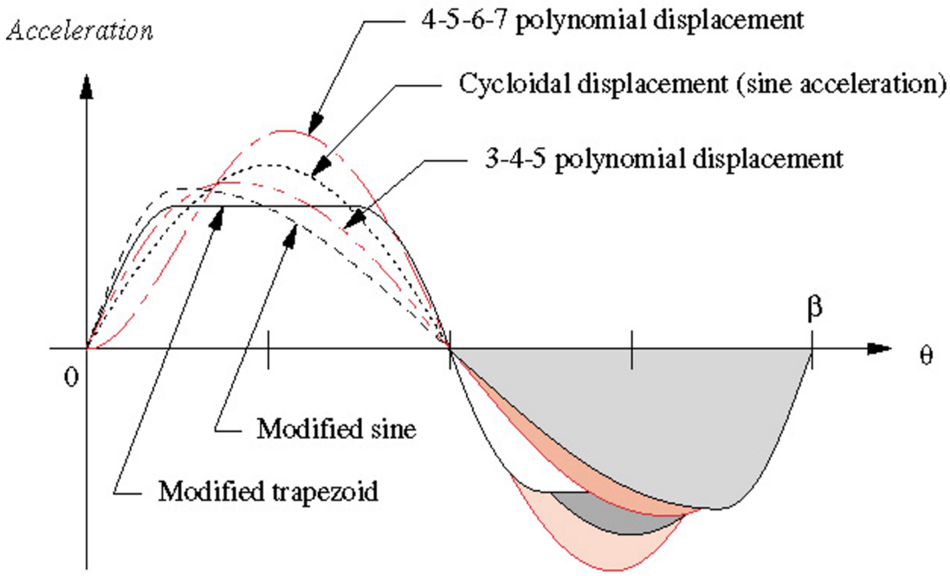


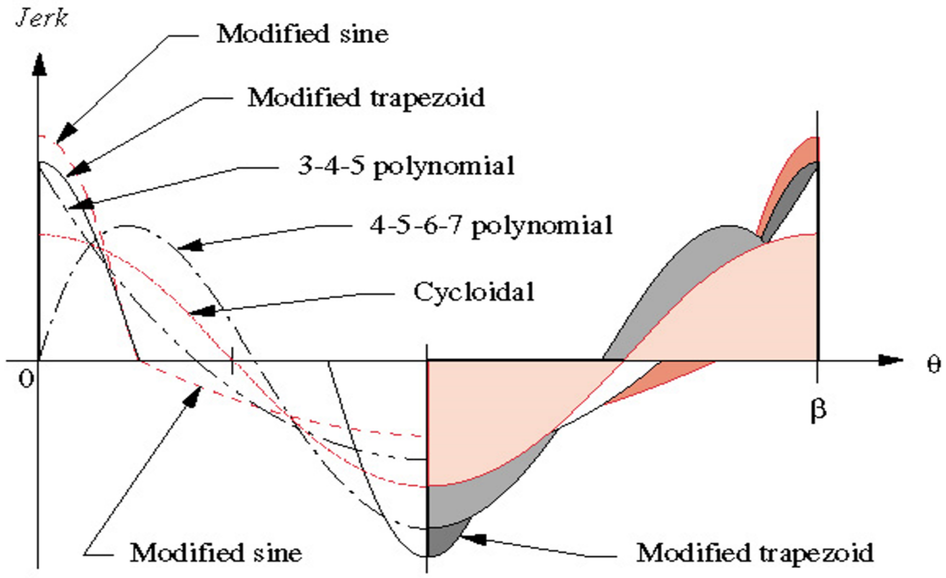
4-5-6-7 Polynomial

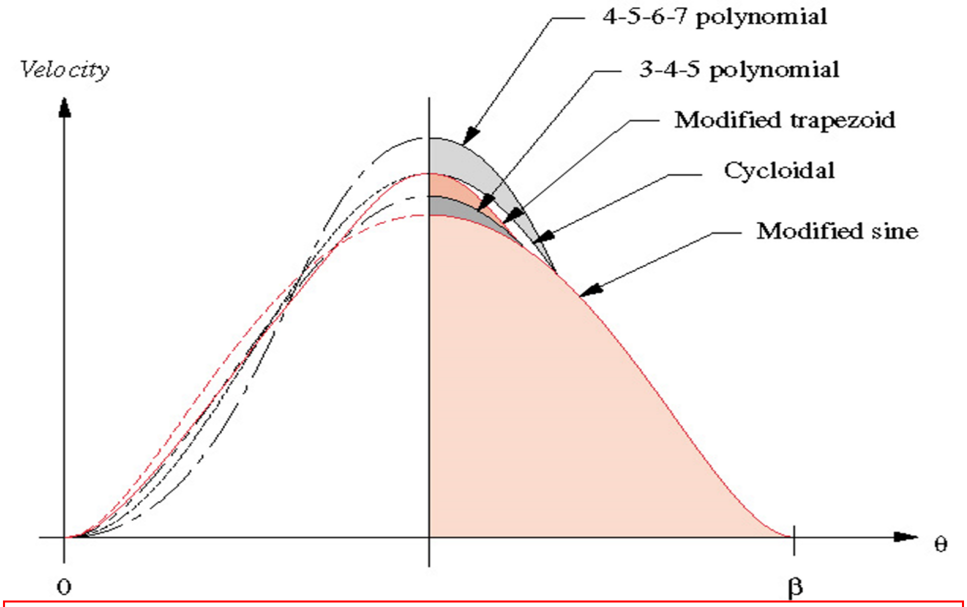
$$s = h[35(\frac{\theta}{\beta})^4 - 84(\frac{\theta}{\beta})^5 + 70(\frac{\theta}{\beta})^5 - 20(\frac{\theta}{\beta})^7]$$



Comparisons




Jerk
Modified sine
Modified trapezoid
3-4-5 polynomial
4-5-6-7 polynomial
Cycloidal
0
θ
β
Modified sine
Modified trapezoid


4-5-6-7 polynomial
Velocity
3-4-5 polynomial
Modified trapezoid
Cycloidal
Modified sine
θ
0
β

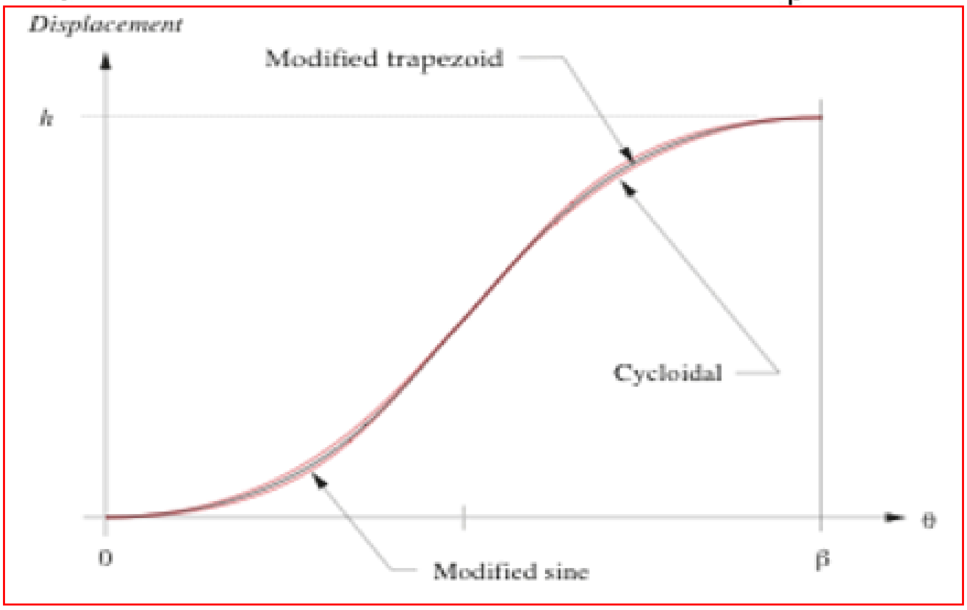

Displacement
Modified trapezoid
h
Cycloidal
θ
0
β
Modified sine

TABLE 8-2 Factors for Peak Velocity and Acceleration of Some Cam Functions

Function	Max. Veloc.	Max. Accel.	Max. Jerk	Comments
Constant accel.	$2.000\ h/\beta$	$4.000\ h/\beta^2$	infinite	∞ jerk - not acceptable.
Harmonic disp.	$1.571\ h/\beta$	$4.945\ h/\beta^2$	infinite	∞ jerk - not acceptable.
Trapezoid accel.	$2.000\ h/\beta$	$5.300\ h/\beta^2$	$44\ h/\beta^3$	Not as good as mod. trap.
Mod. trap. accel.	$2.000\ h/\beta$	$4.888\ h/\beta^2$	$61\ h/\beta^3$	Low accel but rough jerk.
Mod. sine. accel.	$1.760\ h/\beta$	$5.528\ h/\beta^2$	$69\ h/\beta^3$	Low veloc - good accel.
3-4-5 Poly. disp.	$1.875\ h/\beta$	$5.777\ h/\beta^2$	$60\ h/\beta^3$	Good compromise.
Cycloidal disp.	$2.000\ h/\beta$	$6.283\ h/\beta^2$	$40\ h/\beta^3$	Smooth accel. & jerk.
4-5-6-7 Poly. disp.	$2.188\ h/\beta$	$7.526\ h/\beta^2$	$52\ h/\beta^3$	Smooth jerk-high accel.

8.4 Single Dwell Cam Design Using Double Dwell Functions

skipped