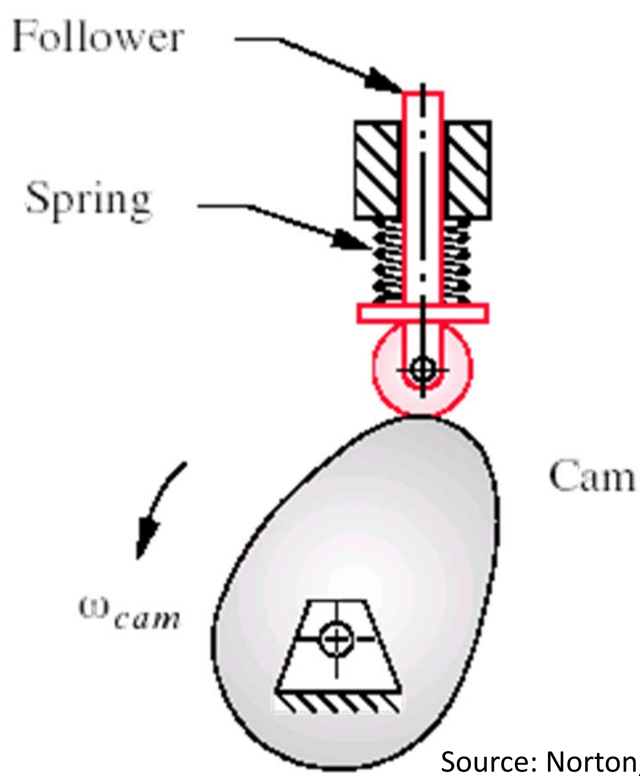


Source: Norton, Design of Machinery

Introduction to Cam Design

At the end of this video, you should be able to:

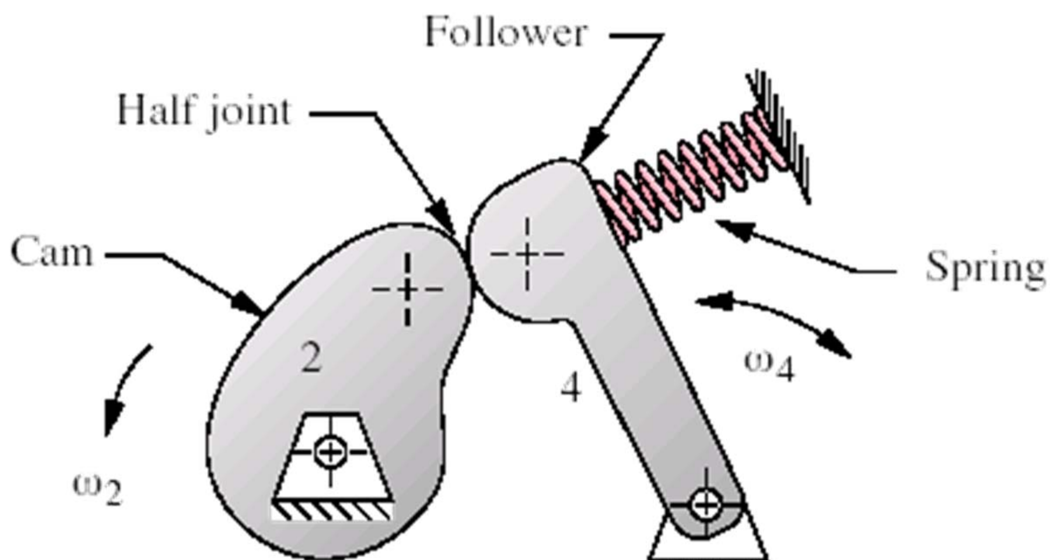
- Explain what a cam is, how it is used, and the typical types of cams
- Identify force closed and form closed followers and explain the benefits and limitations of each
- Describe the primary types of cam motion programs

What is a Cam and Follower?

Cam: specially shaped part designed to move a follower in a controlled fashion

Follower: a link constrained to rotate or translate

- A cam-follower is a degenerate 4-bar linkage

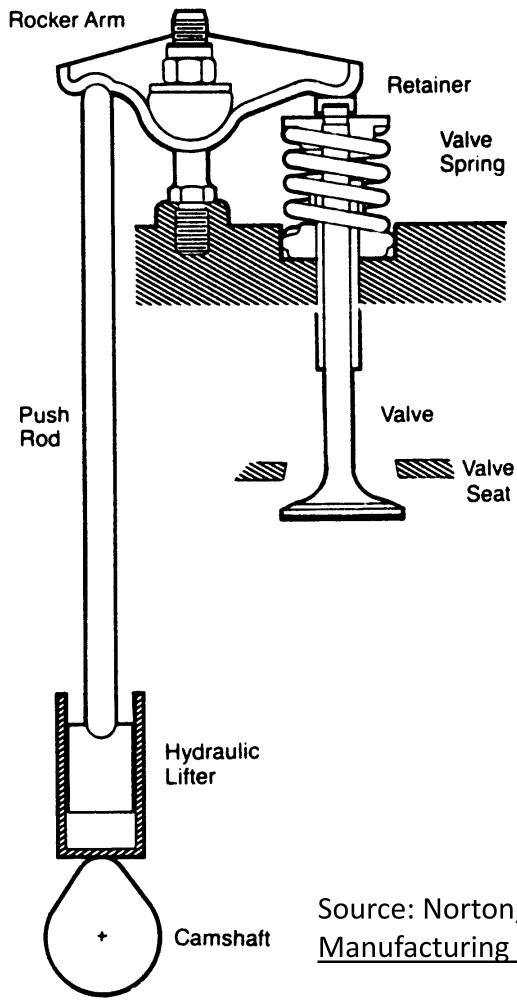


Source: Norton, Design of Machinery

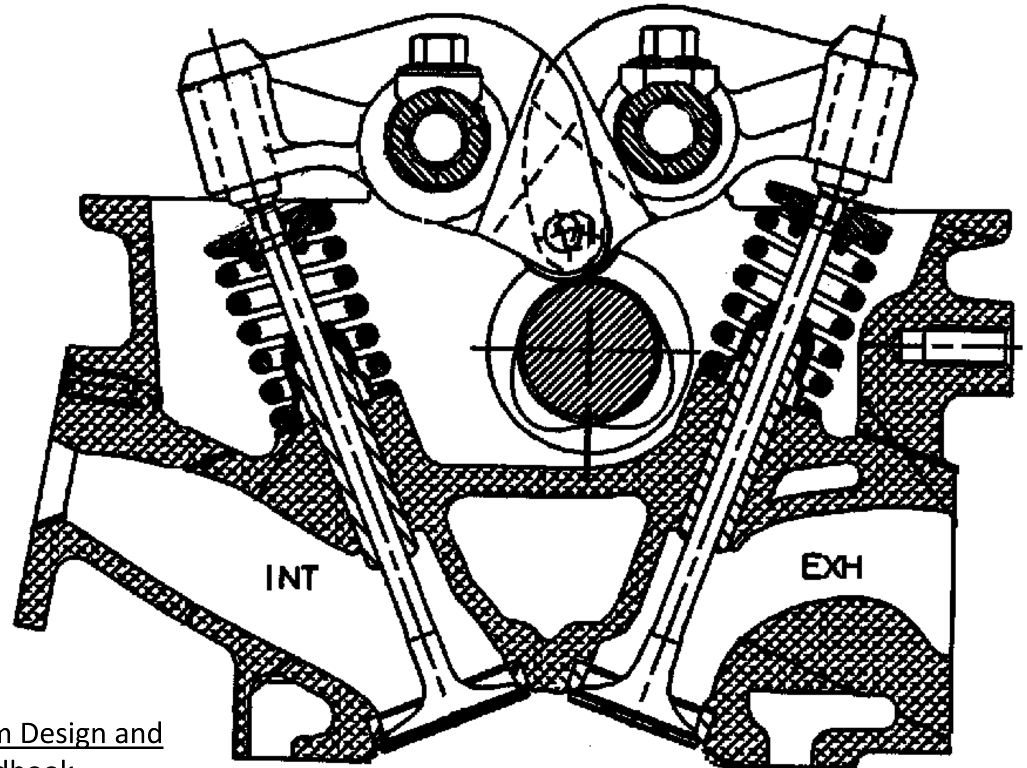
What are Cams Used For?

- Valve actuation in IC engines
- Motion control in machinery
- Force generation
- Precise positioning
- Event timing

Valve Trains



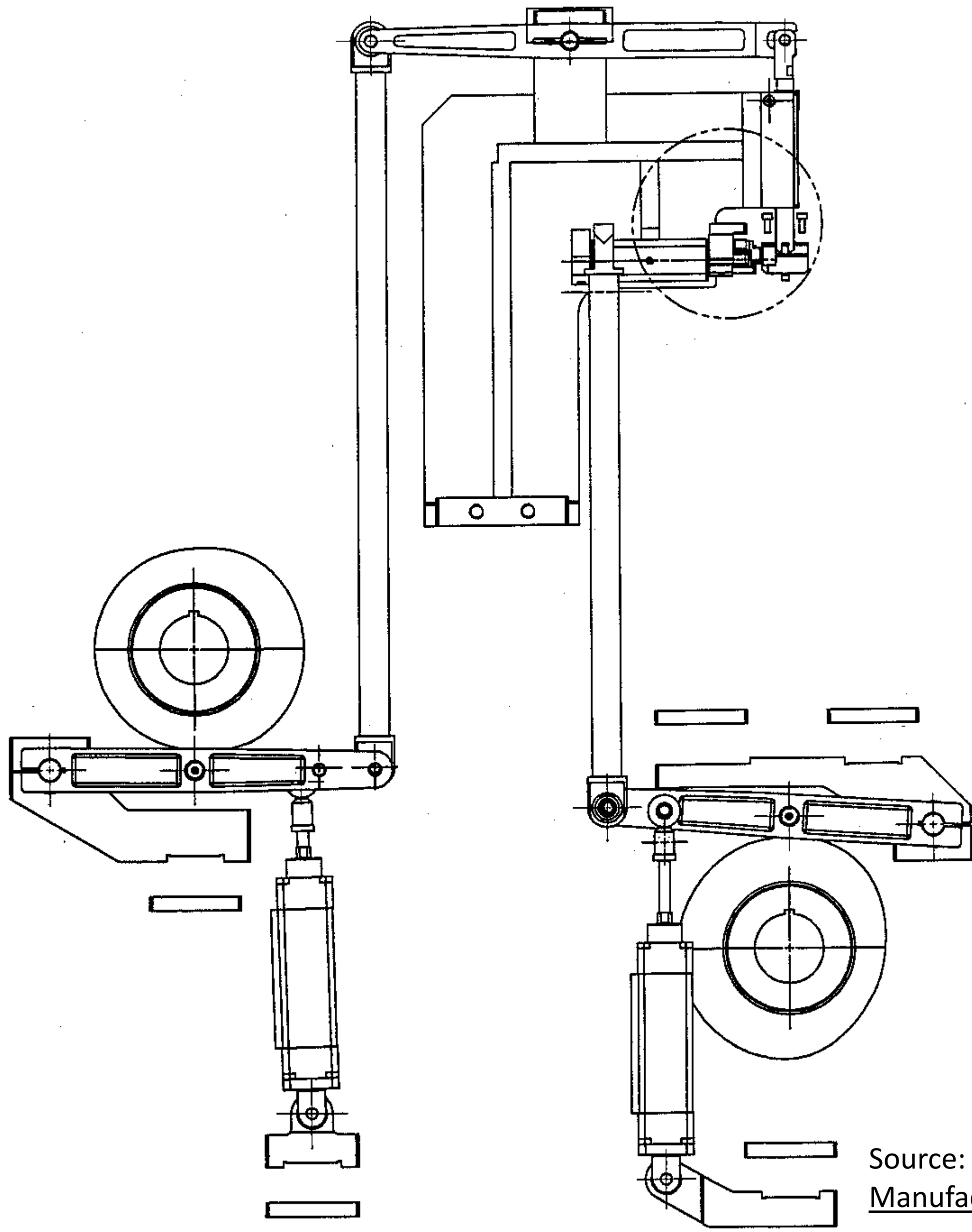
Source: Norton, Cam Design and Manufacturing Handbook



Overhead Valve

Overhead Camshaft

Industrial Cam Trains



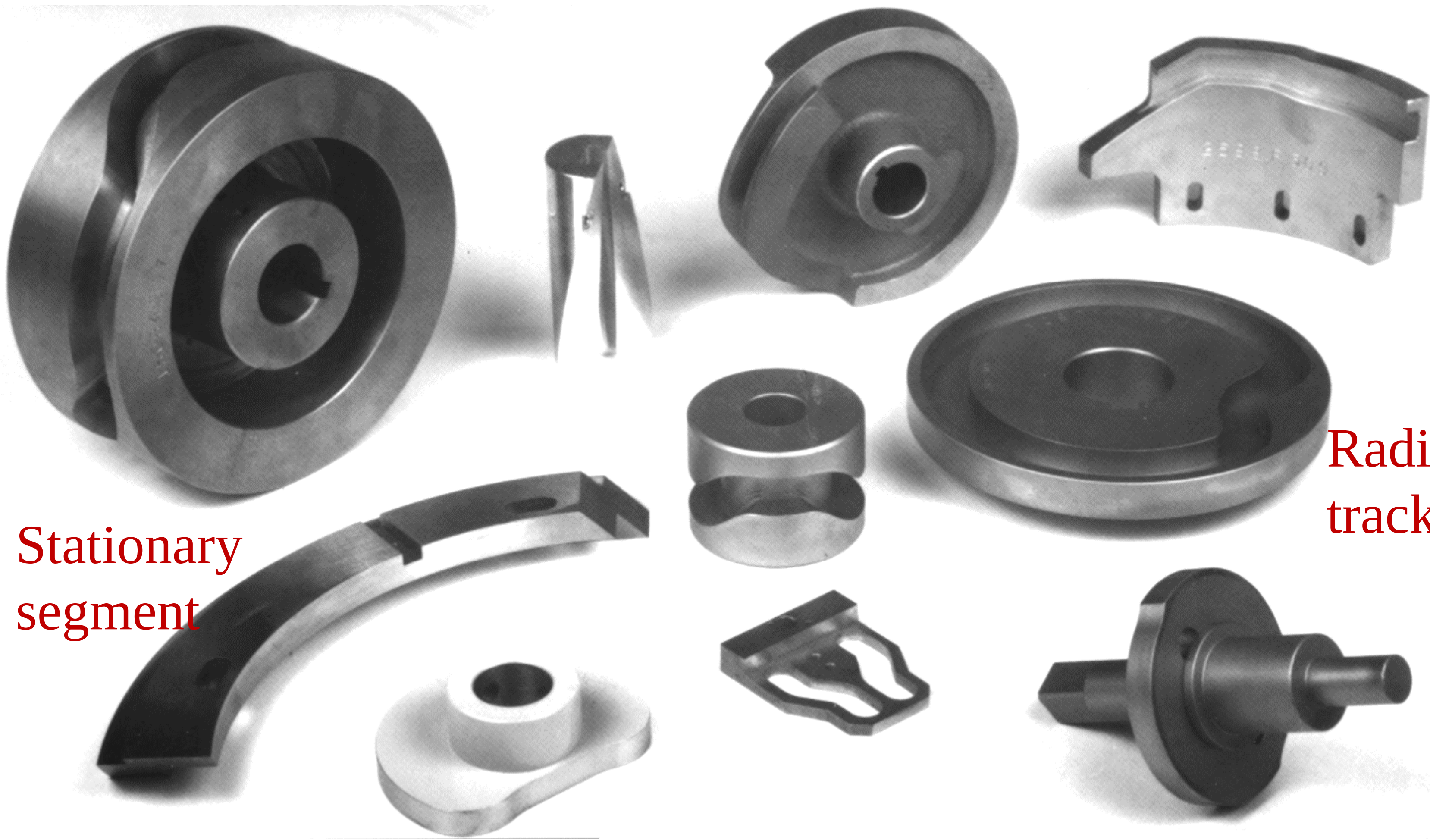
Source: Norton, Cam Design and Manufacturing Handbook

Hydraulic Pump Application

Types of Cams

Barrel or axial - track

Stationary-axial-track



Radial track

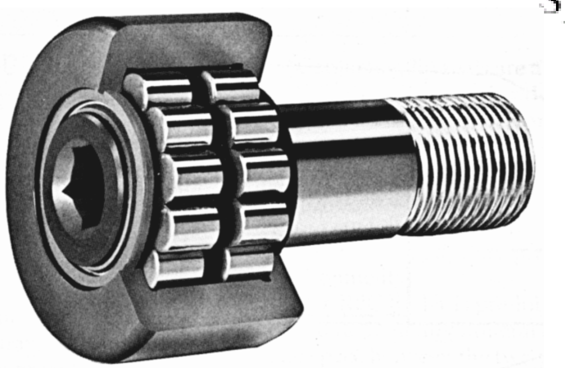
Stationary segment

Radial or plate

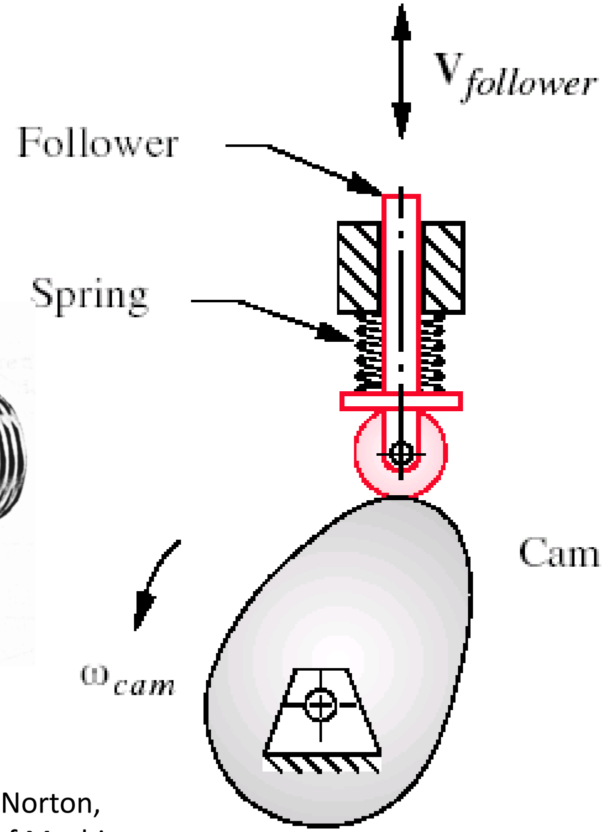
Radial or plate

Source: Norton, Cam Design and Manufacturing Handbook

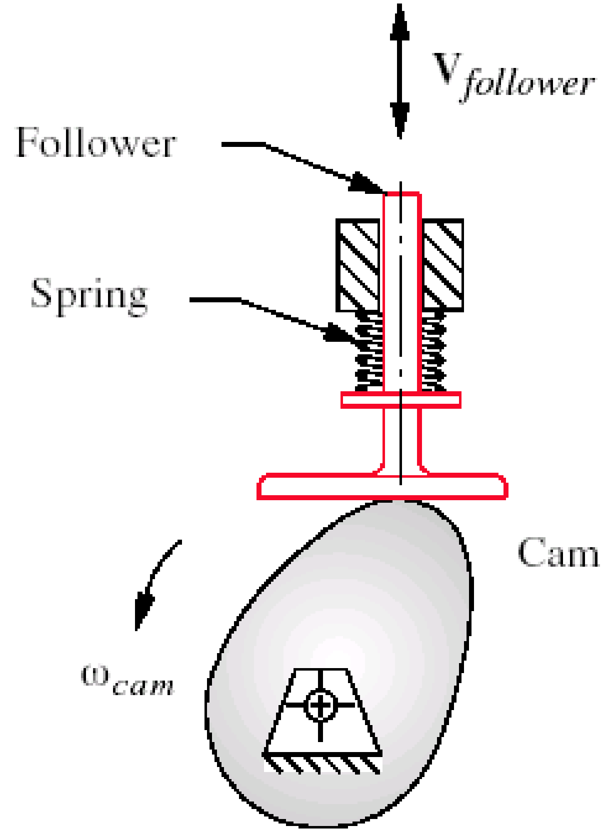
Types of Followers



Source: Norton,
Design of Machinery



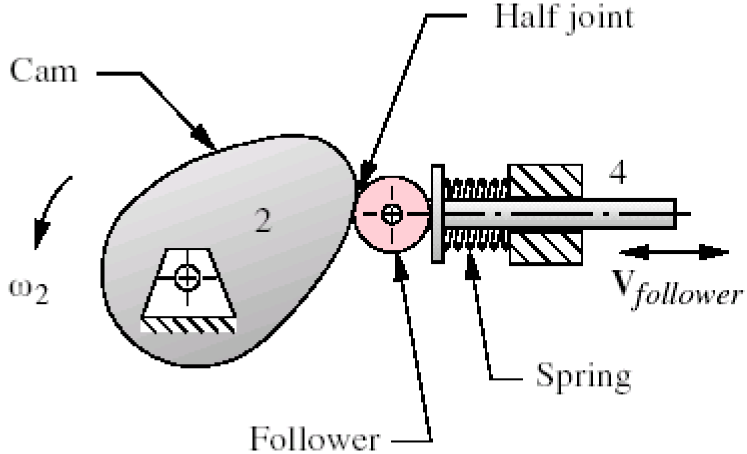
(a) Roller follower

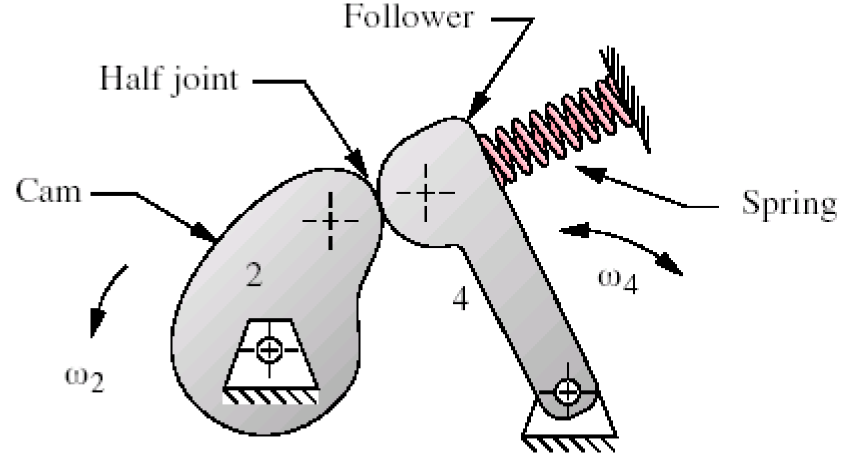


(c) Flat-faced follower

Two Ways to Close Follower Joint

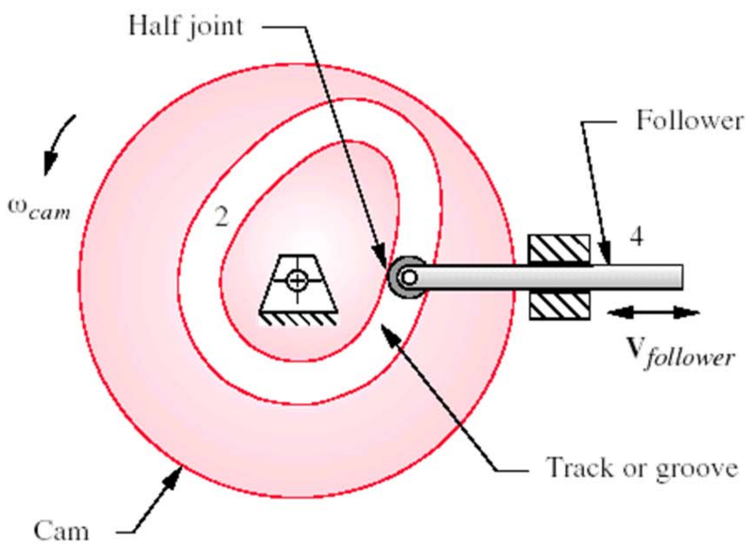
Force Closed:

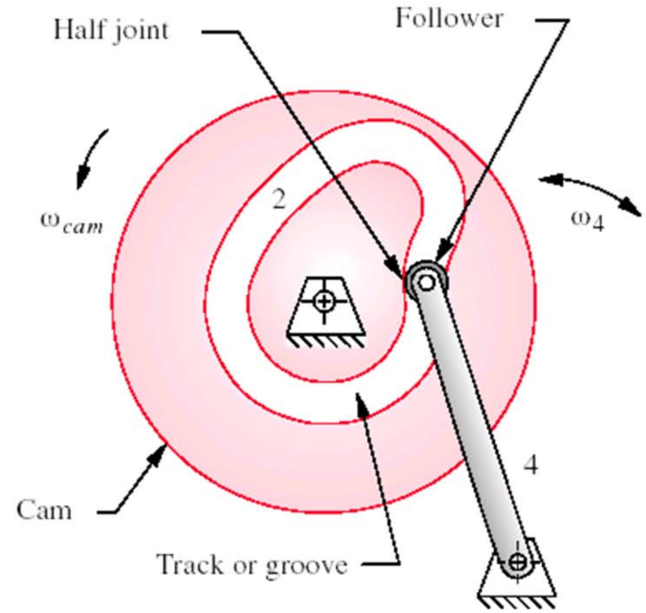




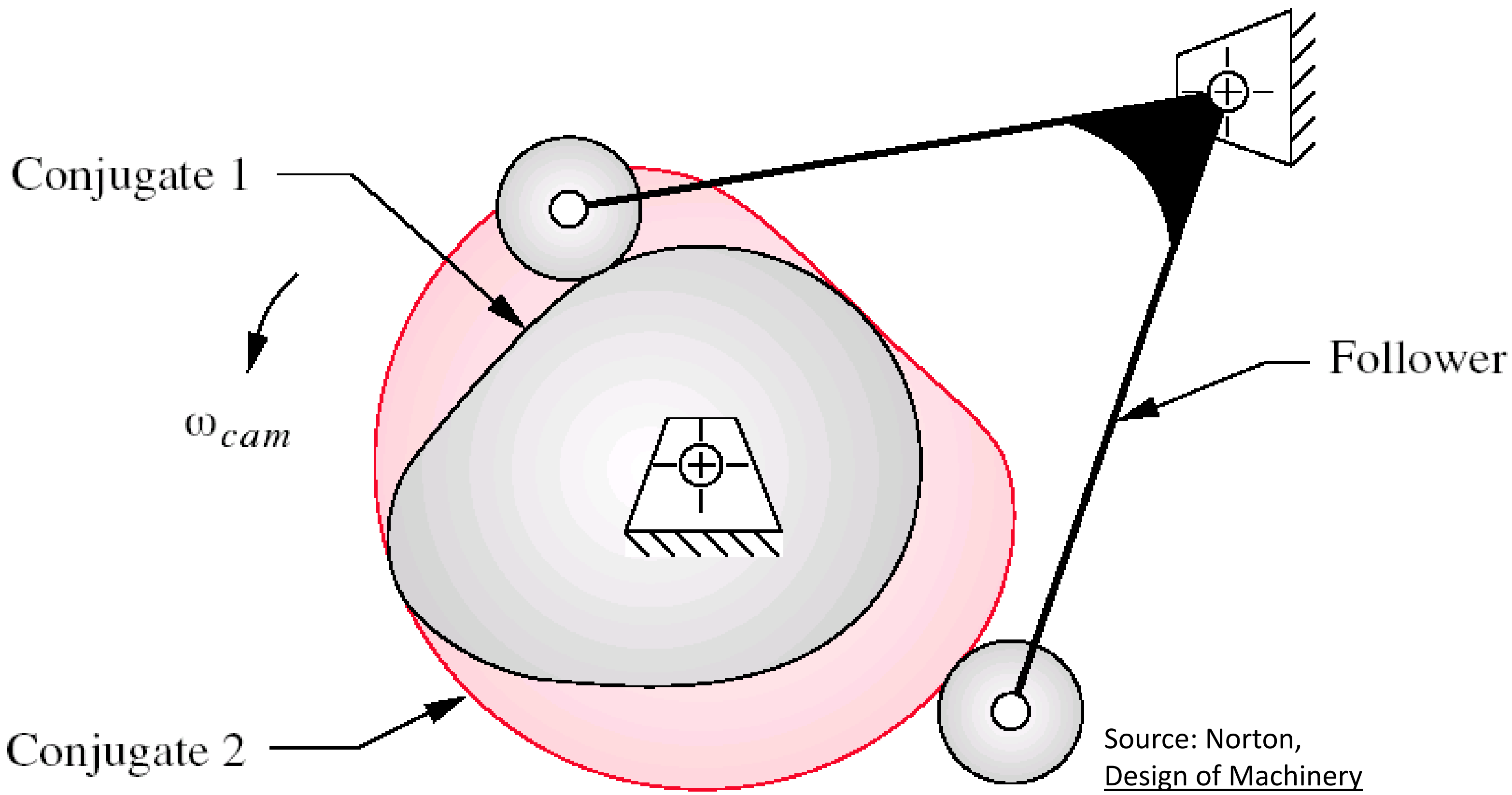
Source: Norton, Design of Machinery

Form Closed:





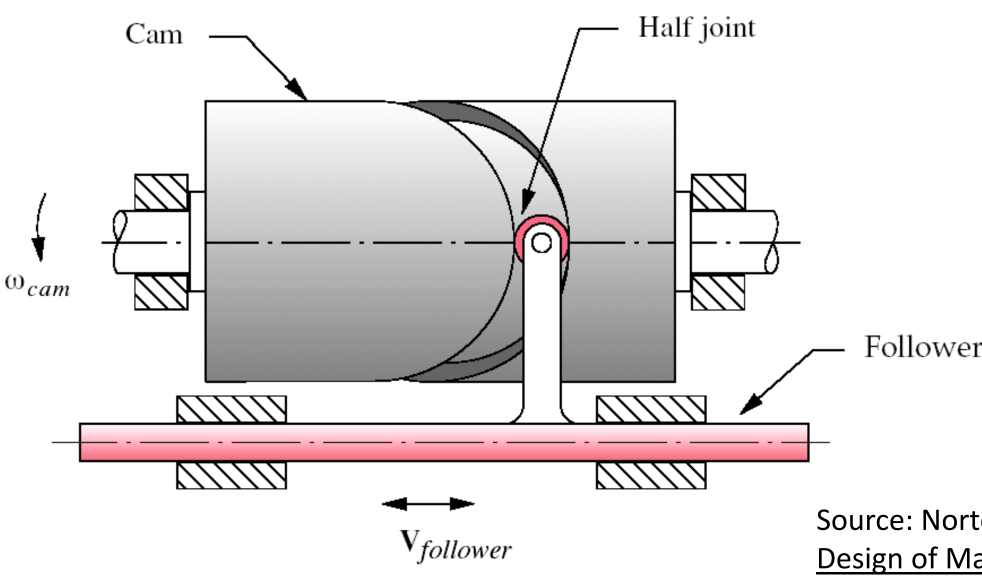
Conjugate Cams



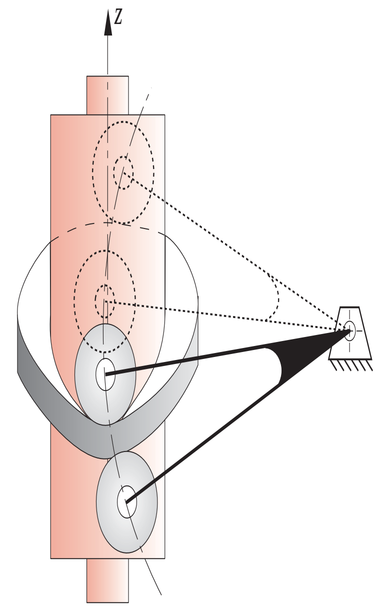
Source: Norton, Design of Machinery

Barrel Cams

Tracked:



Ribbed:

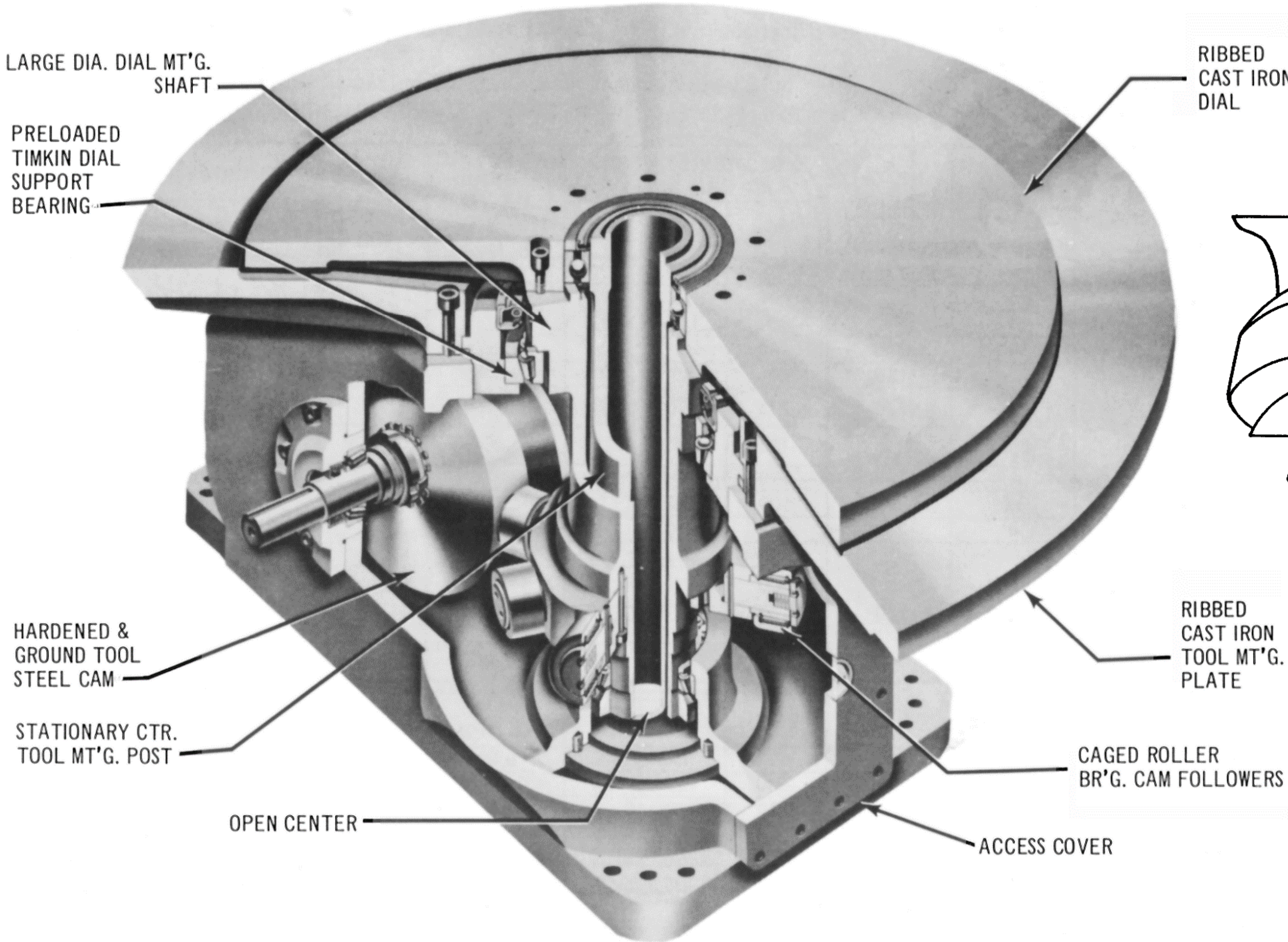


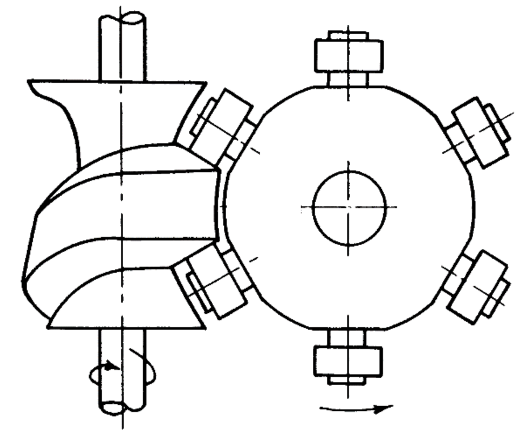
Source: Norton,
<u>Design of Machinery</u>

FIGURE 13-13

Ribbed barrel cam with oscillating roller follower

Rotary Indexers Use Ribbed Barrel Cams





Types of Cam Motion Programs

- No-Dwell or Rise-Fall (RF)
- Single-Dwell or Rise-Fall-Dwell (RFD)
- Double-Dwell (RDFD)
- Multi-Rise-Multi-Dwell-Multi-Fall

- Different Motion Programs Needed for Each

A Cam Timing Diagram

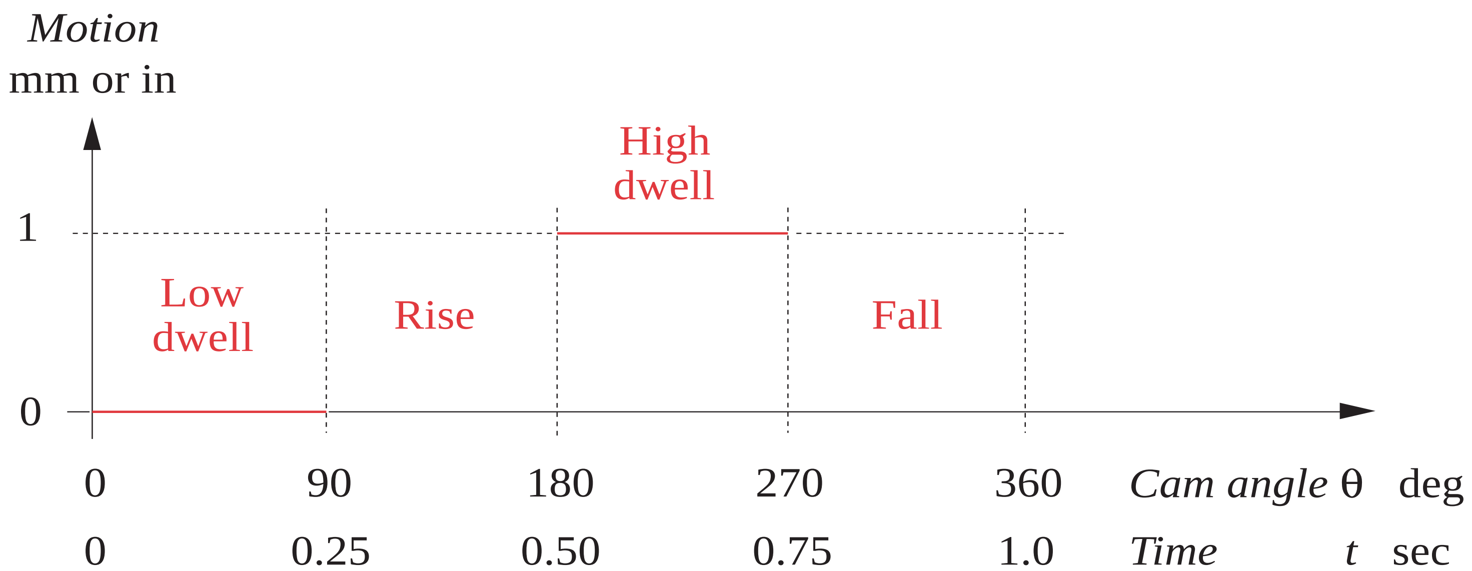
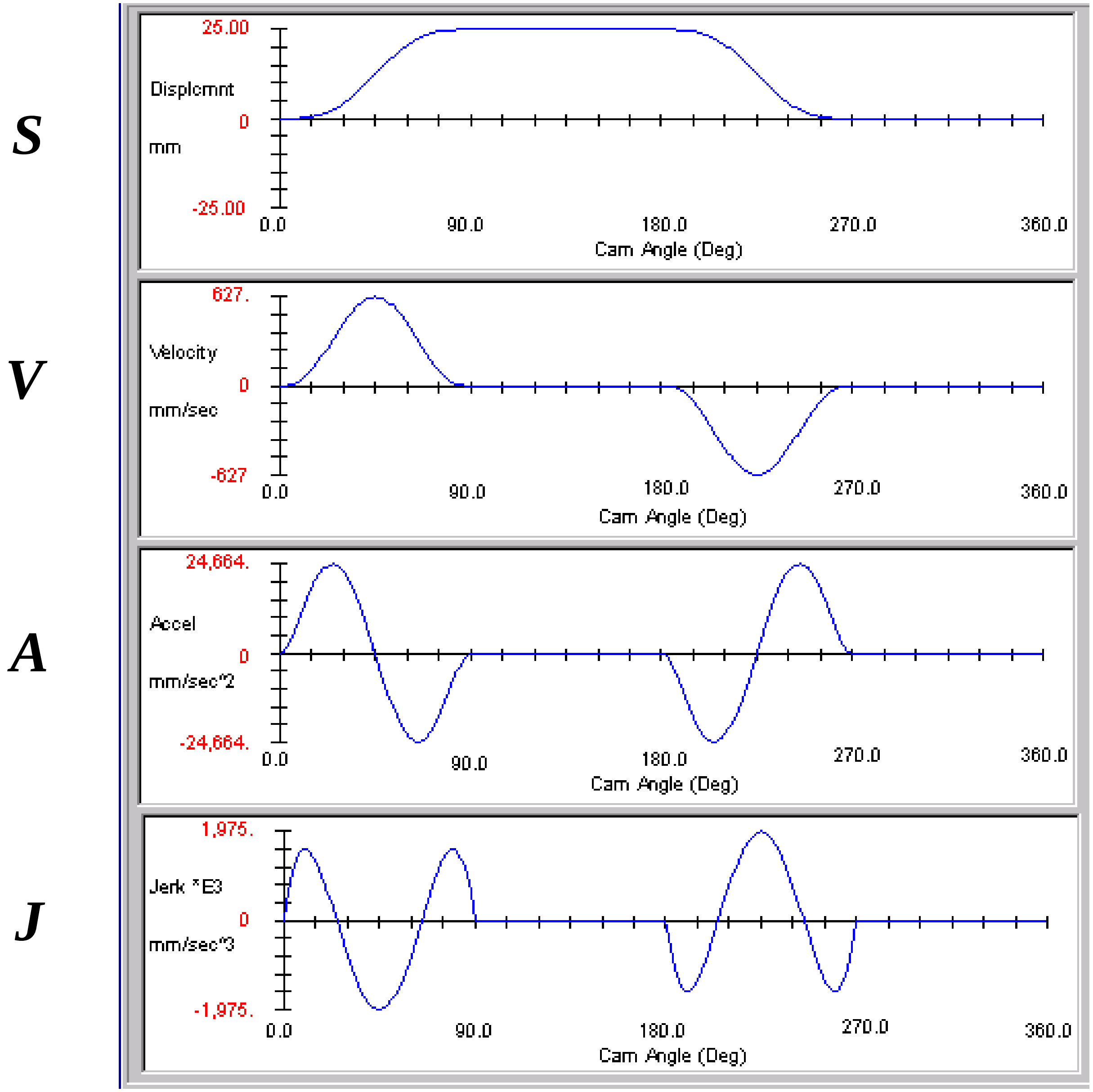
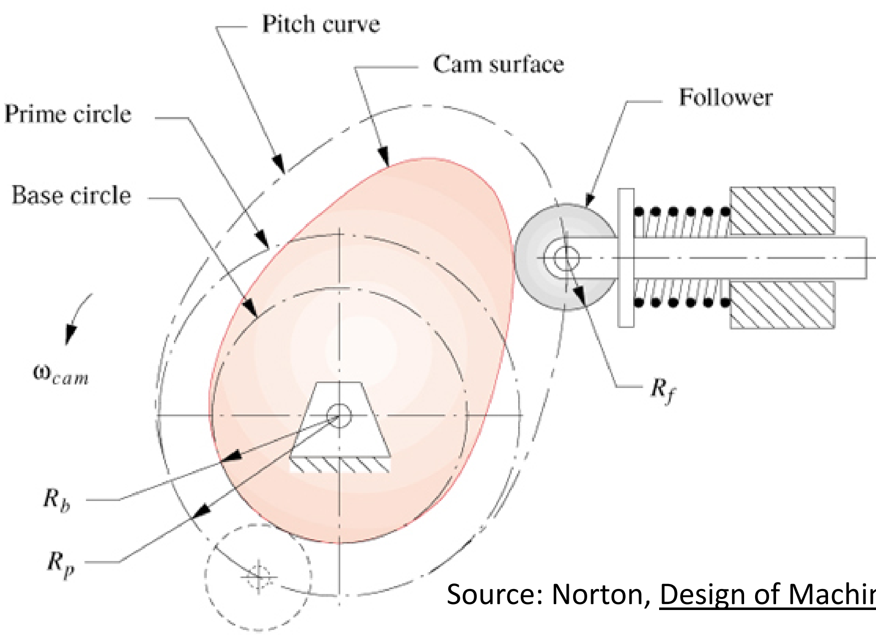


FIGURE 2-2

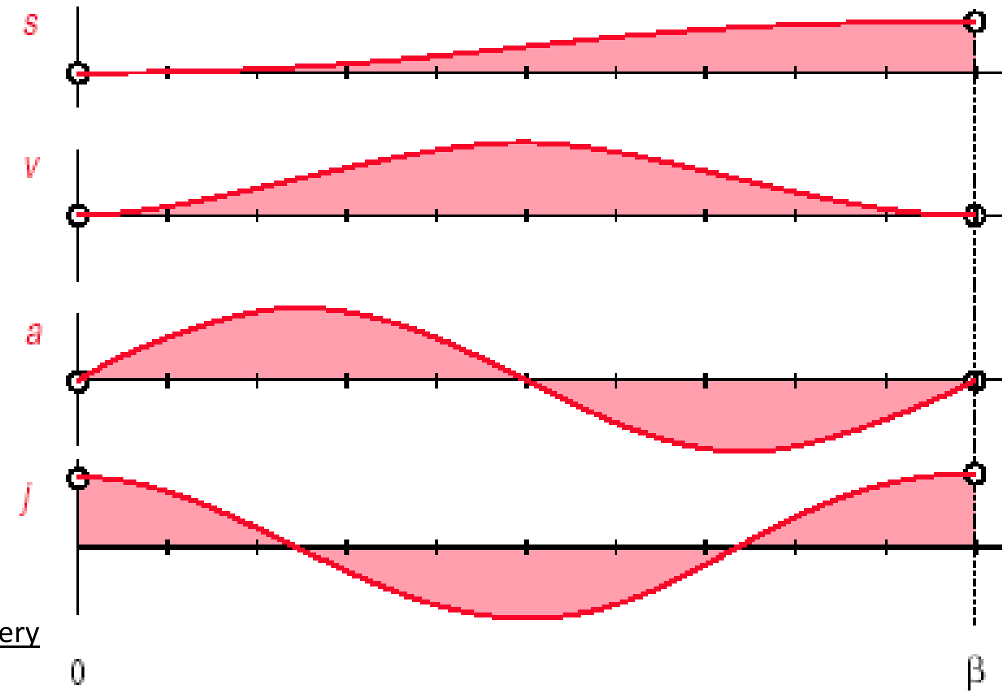
A cam timing diagram

SVAJ Diagrams





Source: Norton, Design of Machinery

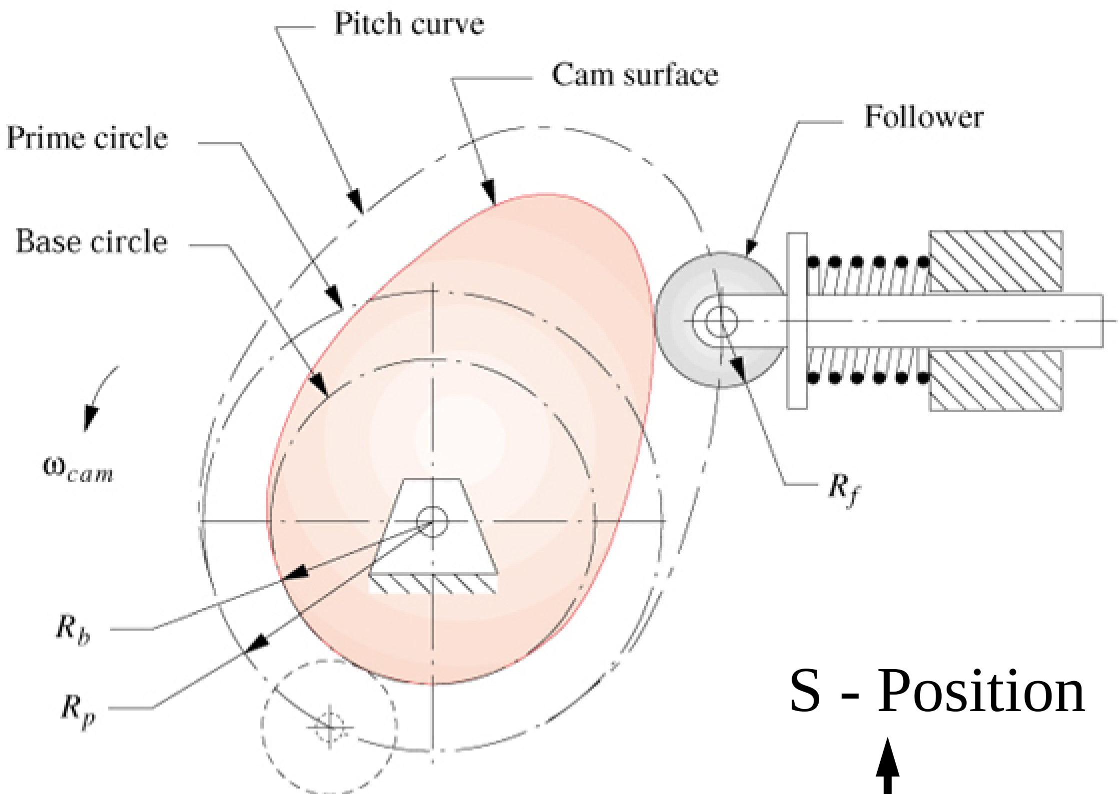


Cam Motion Design: Critical Extreme Position

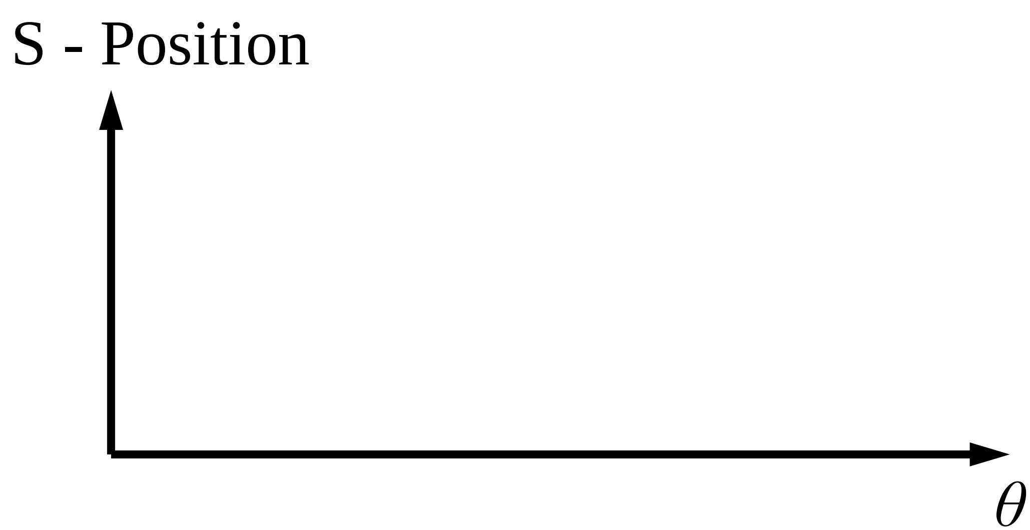
At the end of this video, you should be able to:

- Describe the difference between critical extreme position and critical path motion
- Explain how the fundamental law of cam design applies to selecting an appropriate cam profile
- Design double dwell cam profiles using a variety of motion types

Unwrapping Cam Profile



Source: Norton, Design of Machinery



Type of Motion Constraints

- Critical Extreme Position (CEP)
  - End points of motion are critical
  - Path between endpoints is not critical
- Critical Path Motion (CPM)
  - The path between endpoints is critical
  - Displacements, velocities, etc. may be specified
  - Endpoints usually also critical

Double Dwell Cam Timing Diagram

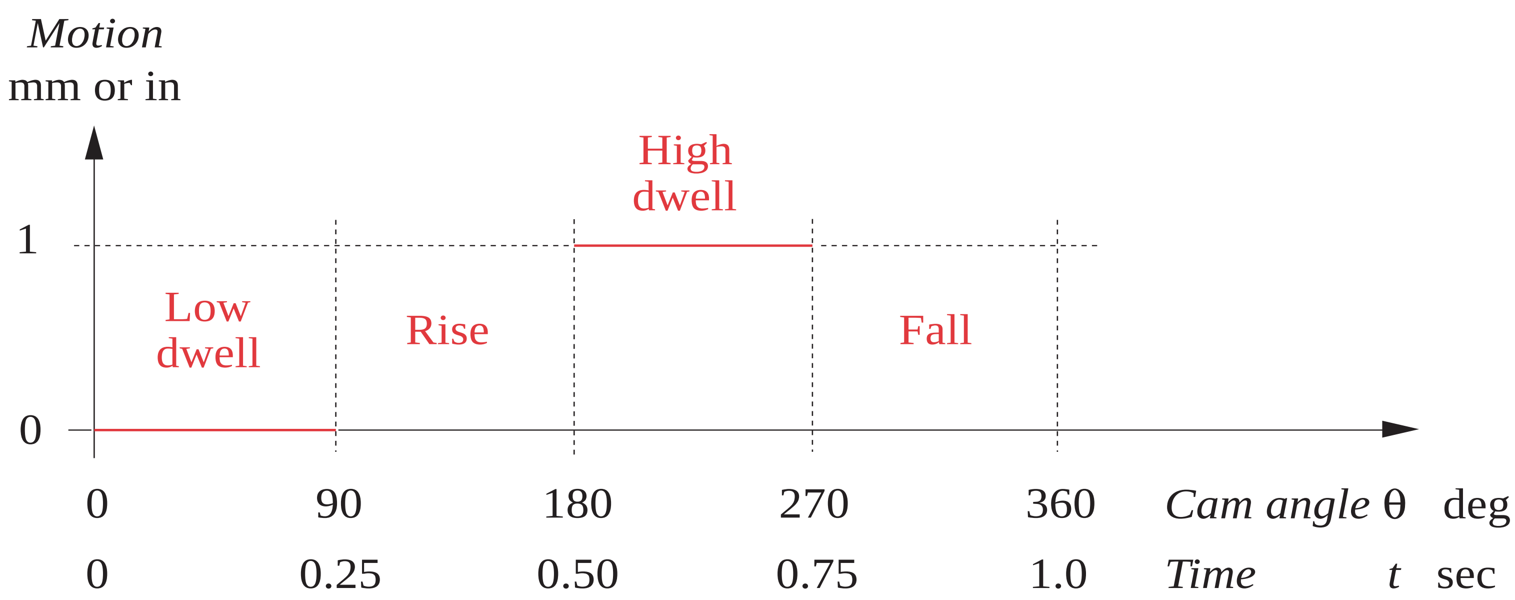
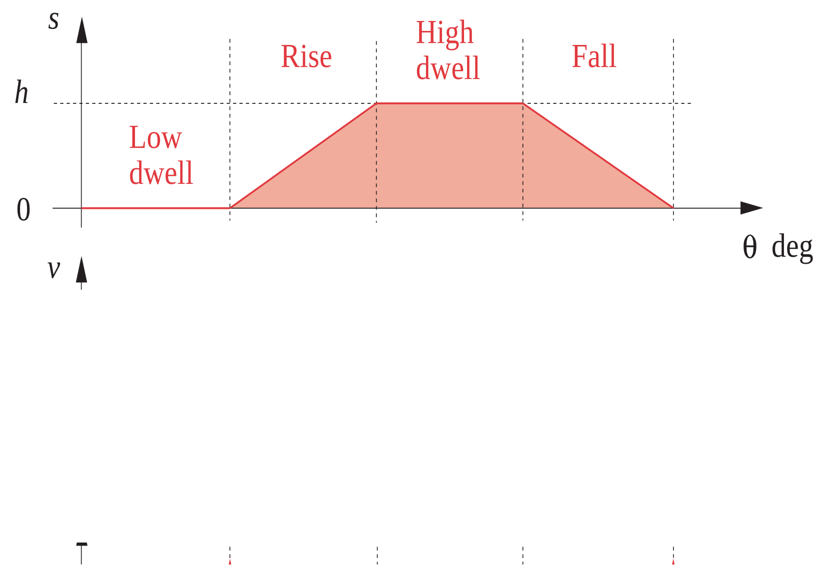


FIGURE 2-2

A cam timing diagram

Naïve and Poor Cam Design: Constant Velocity

(*a*)



Constant Acceleration (Parabolic Displacement)?

Unacceptable

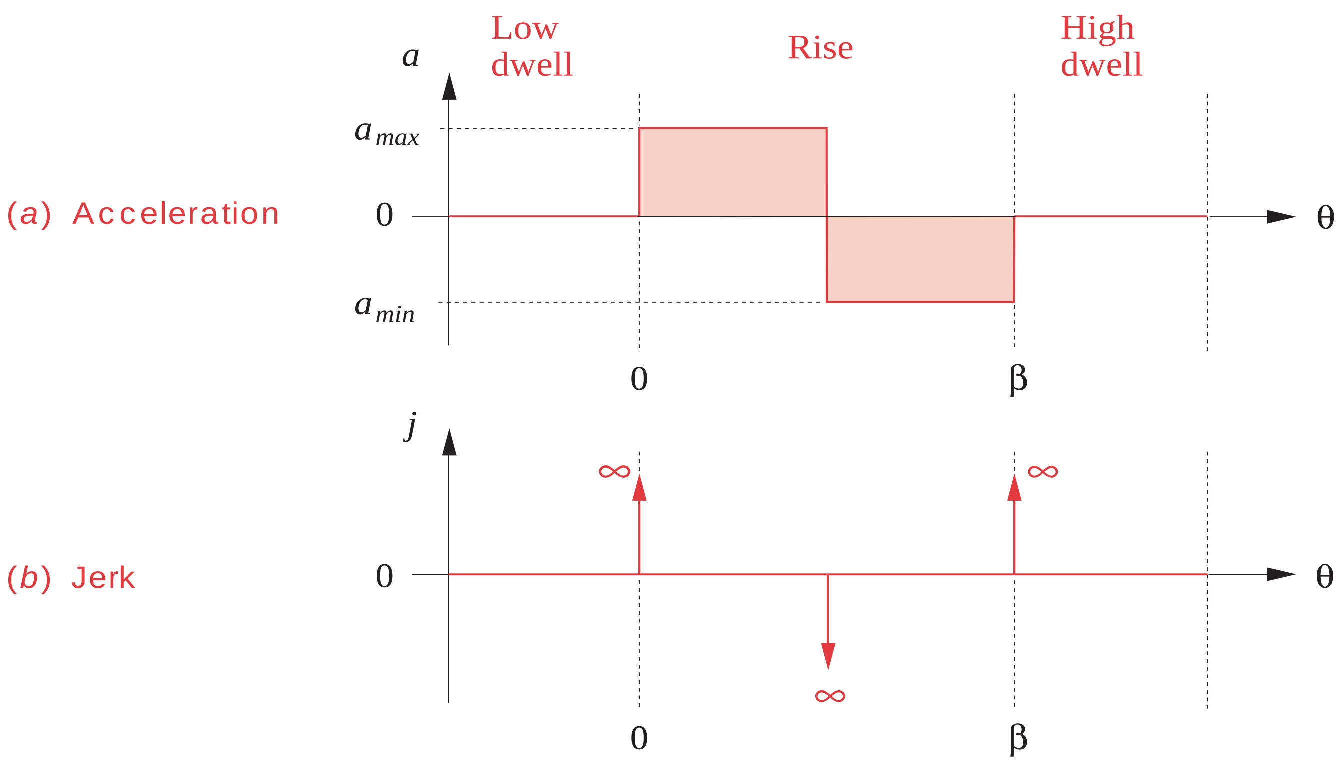


FIGURE 2-6

Constant acceleration gives infinite jerk

Simple Harmonic Motion (SHM)?

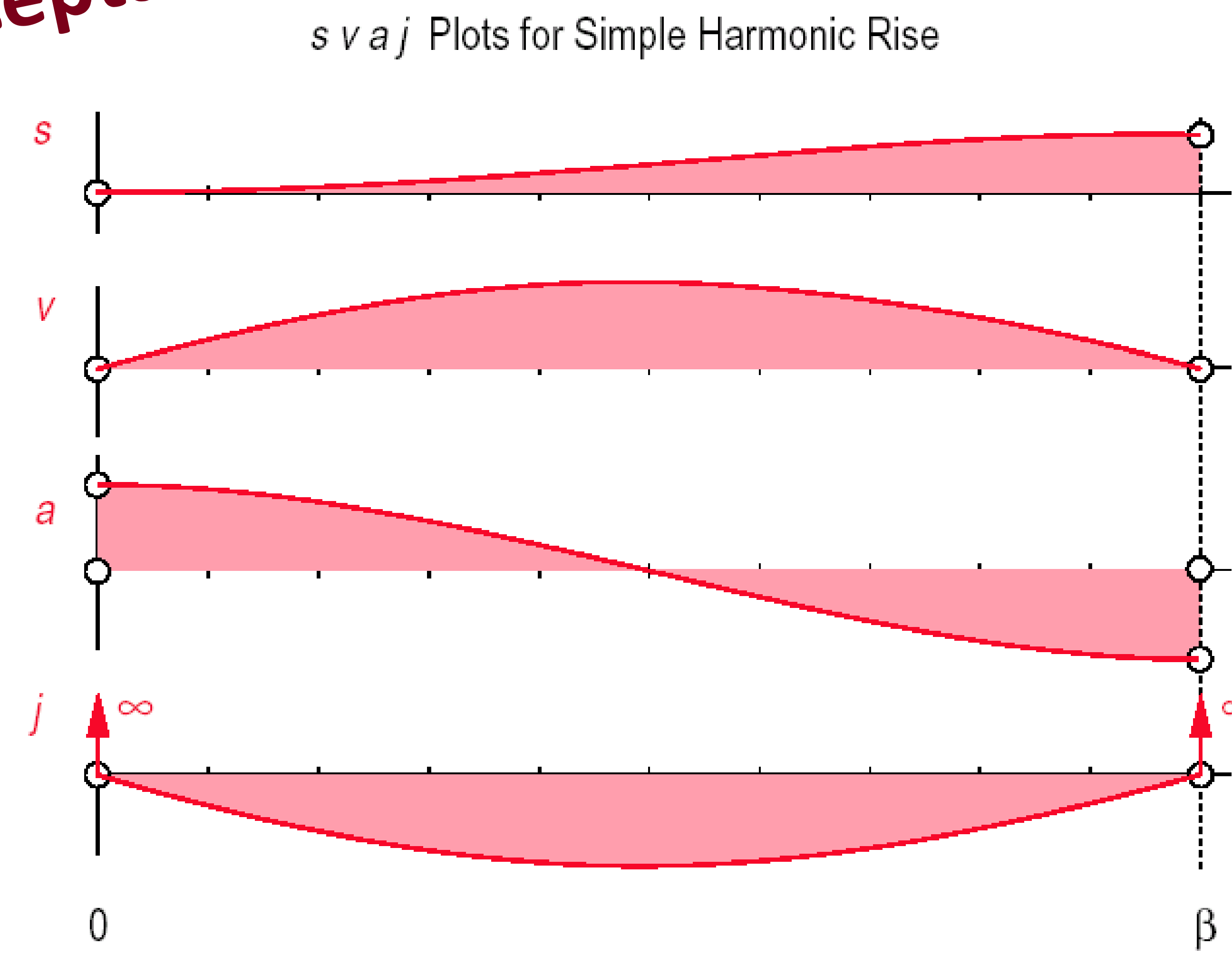
Unacceptable

$$s = \frac{h}{2}\left[1 - \cos\left(\pi\frac{\theta}{\beta}\right)\right] \quad (2.6a)$$

$$v = \frac{\pi}{\beta}\frac{h}{2}\sin\left(\pi\frac{\theta}{\beta}\right) \quad (2.6b)$$

$$a = \frac{\pi^2}{\beta^2}\frac{h}{2}\cos\left(\pi\frac{\theta}{\beta}\right) \quad (2.6c)$$

$$j = -\frac{\pi^3}{\beta^3}\frac{h}{2}\sin\left(\pi\frac{\theta}{\beta}\right) \quad (2.6d)$$



Norton’s Fundamental Law of Cam Design:

The cam-follower function must have continuous velocity and acceleration across the entire interval, thus making the jerk finite.

Choosing Cam Functions

- They must obey the fundamental law
- Lower peak acceleration is better: $F = ma$
- Lower peak velocity lowers $KE = 0.5\ mv^2$
- Smoother jerk means lower vibrations
- Magnitude of jerk is poorly controlled in manufacturing

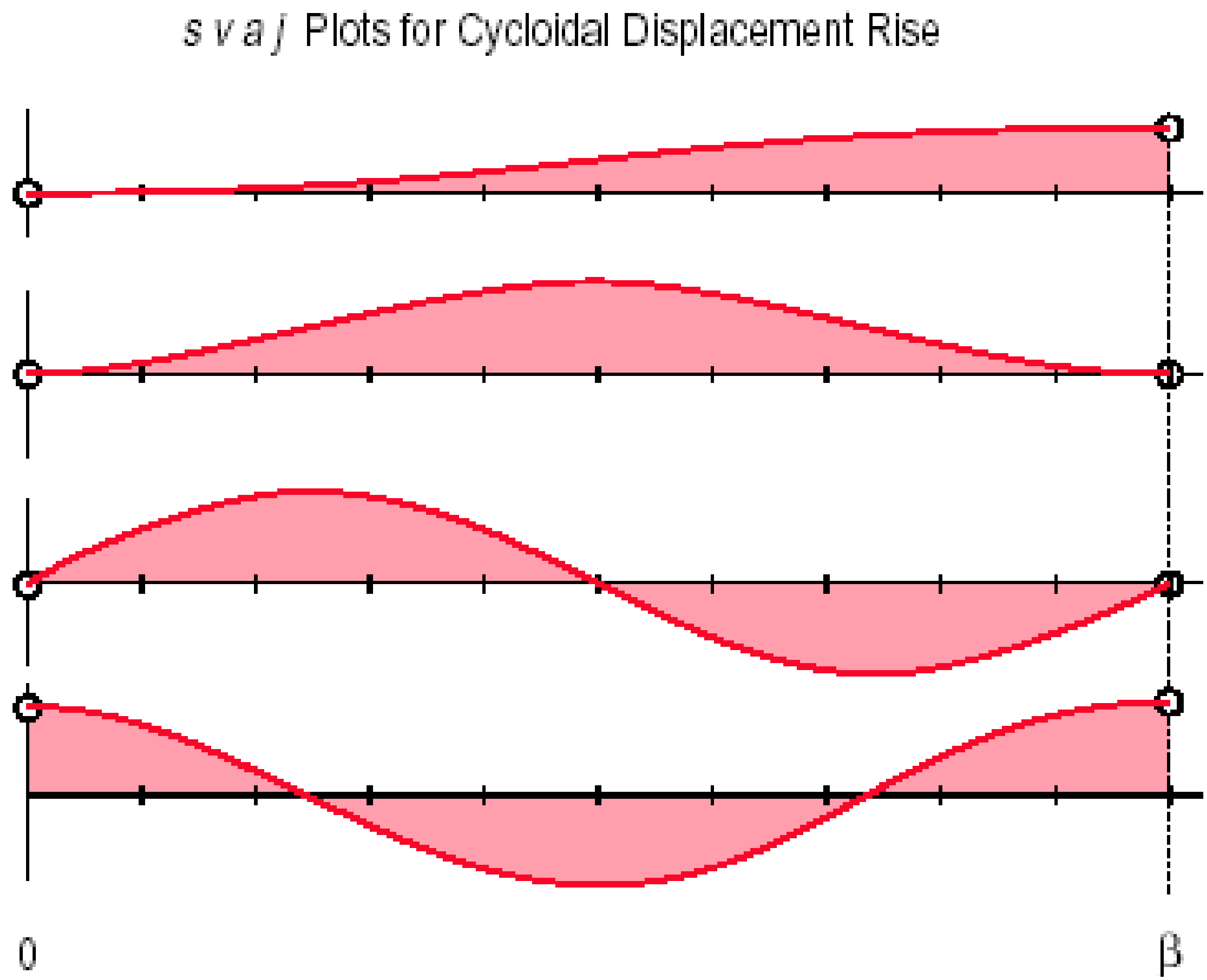
Acceptable Double Dwell Function: Cycloidal Motion

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

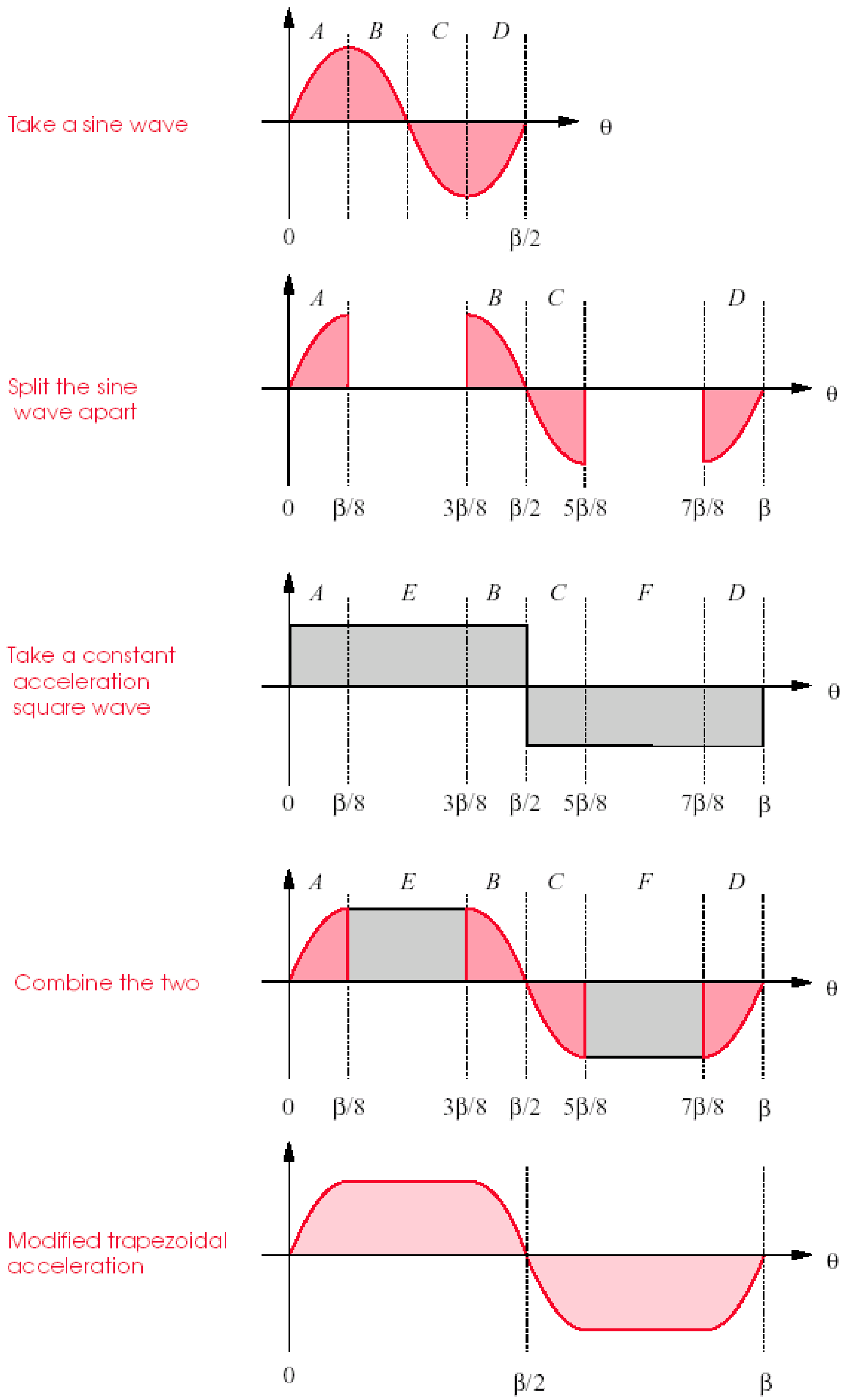
$$v = \frac{h}{\beta}\left[1 - \cos\left(2\pi\frac{\theta}{\beta}\right)\right]$$

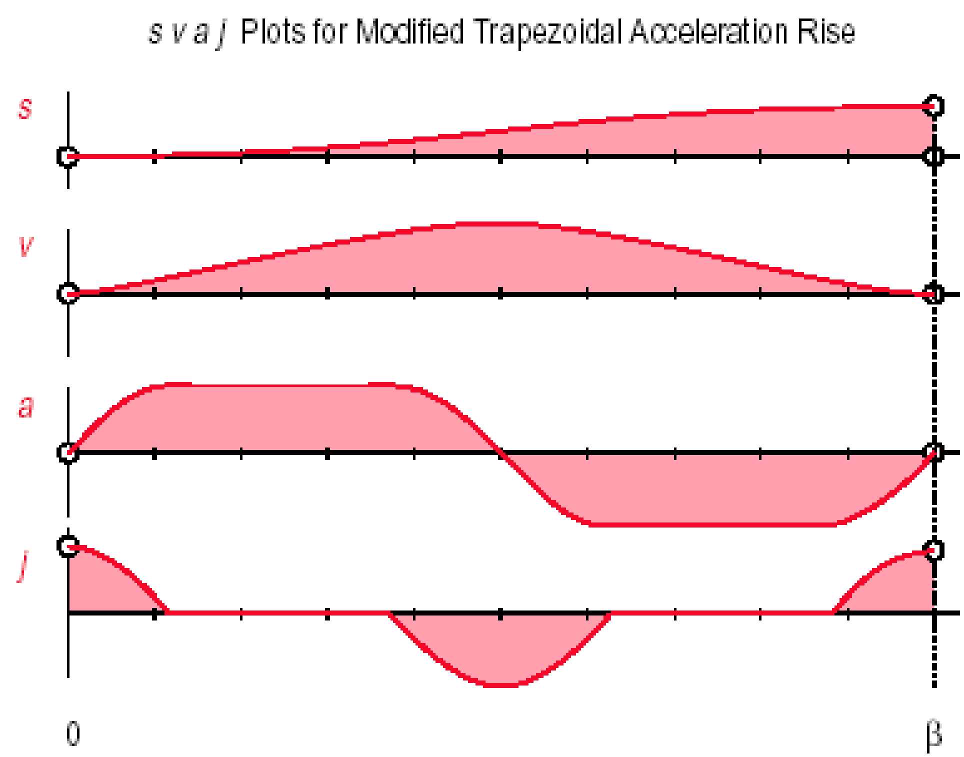
$$a = 2\pi\frac{h}{\beta^2}\sin\left(2\pi\frac{\theta}{\beta}\right)$$

$$j = 4\pi^2\frac{h}{\beta^3}\cos\left(2\pi\frac{\theta}{\beta}\right)$$

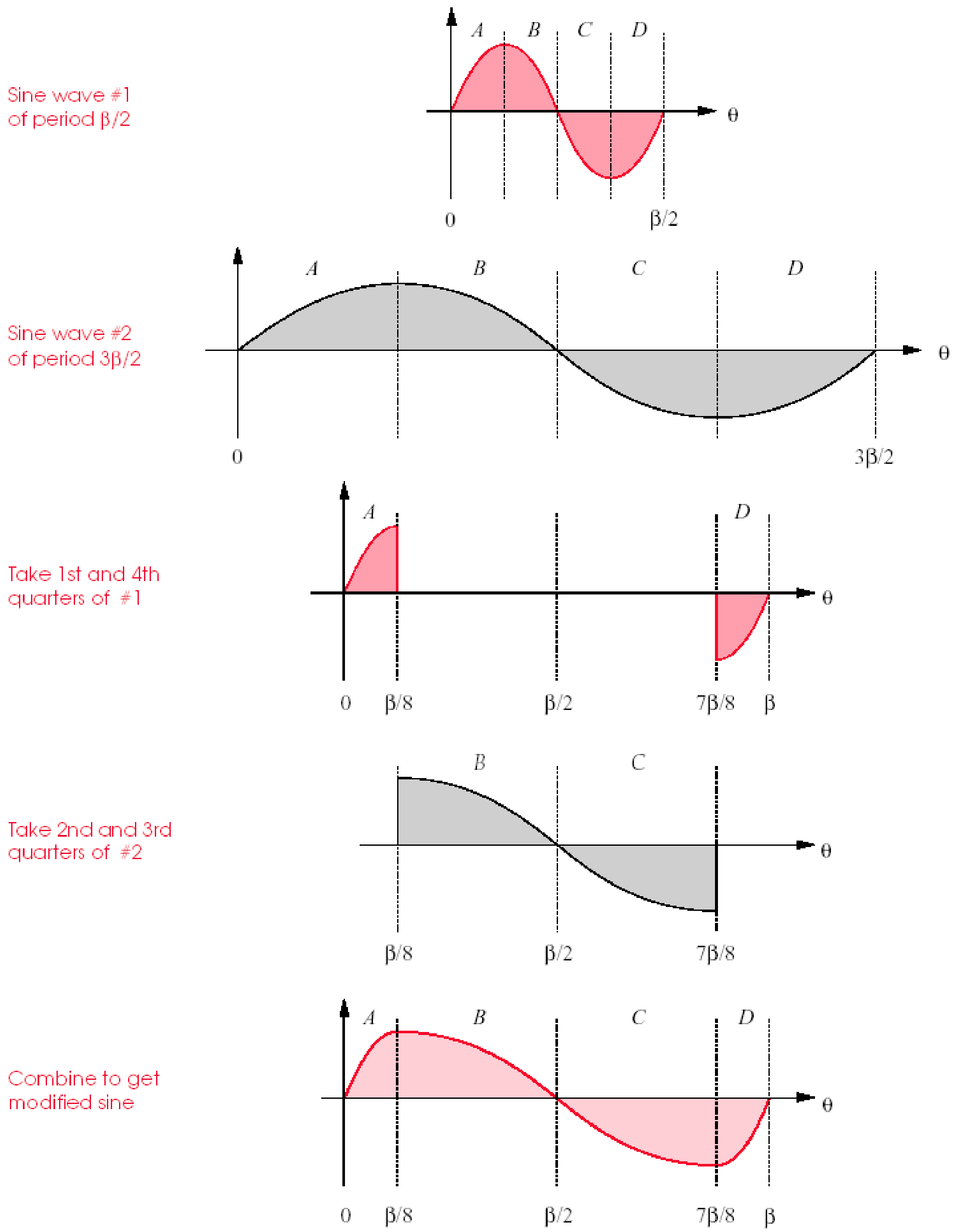


Acceptable Double Dwell Function: Modified Trapezoidal Acceleration





Acceptable Double Dwell Function: Modified Sine Acceleration



Polynomial Functions

$$s = C_0 + C_1 x + C_2 x^2 + C_3 x^3 + C_4 x^4 + C_5 x^5 + C_6 x^6 + \cdots + C_n x^n \qquad (3.19)$$

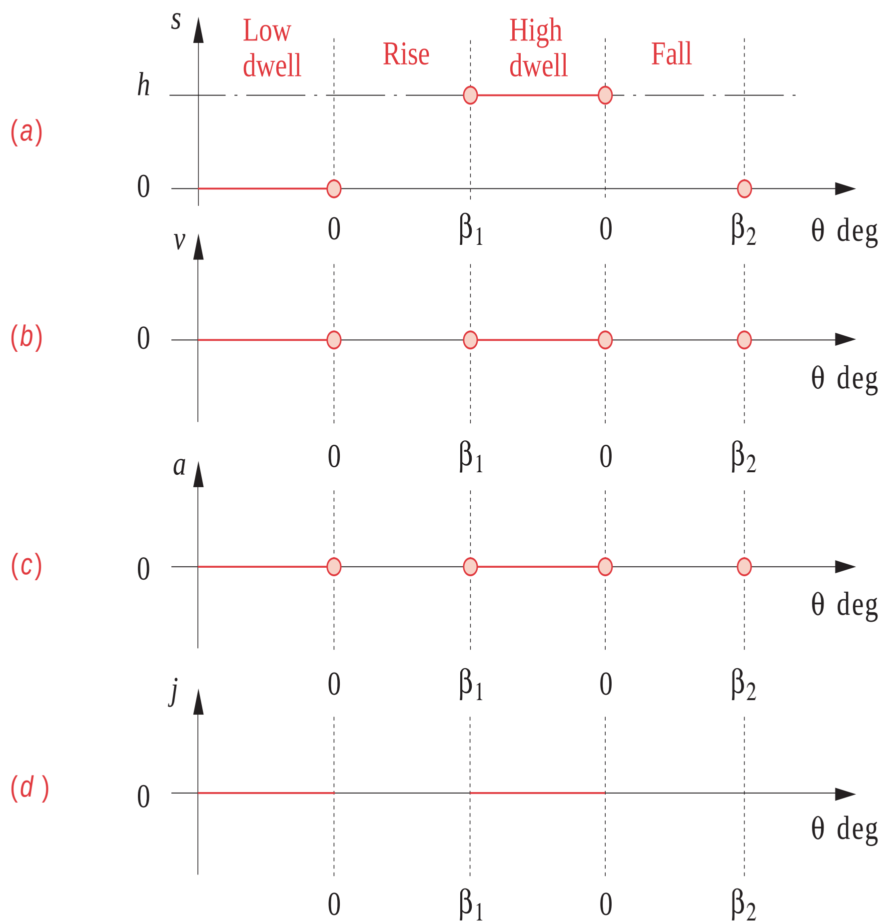


FIGURE 3-13

Minimum boundary conditions for the double-dwell case

$$\text{when} \quad \theta = 0; \quad \text{then} \quad s = 0, \quad v = 0, \quad a = 0$$
$$\text{when} \quad \theta = \beta_1; \quad \text{then} \quad s = h, \quad v = 0, \quad a = 0 \qquad \text{(a)}$$

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

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

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

$$0 = C_0 + 0 + 0 + \cdots$$
$$C_0 = 0 \qquad \text{(f)}$$

$$0 = \frac{1}{\beta}\left[C_1 + 0 + 0 + \cdots\right]$$
$$C_1 = 0 \qquad \text{(g)}$$

$$0 = \frac{1}{\beta^2}\left[C_2 + 0 + 0 + \cdots\right]$$
$$C_2 = 0 \qquad \text{(h)}$$

$$h = C_3 + C_4 + C_5 \qquad \text{(i)}$$

$$0 = \frac{1}{\beta}\left[3C_3 + 4C_4 + 5C_5\right] \qquad \text{(j)}$$

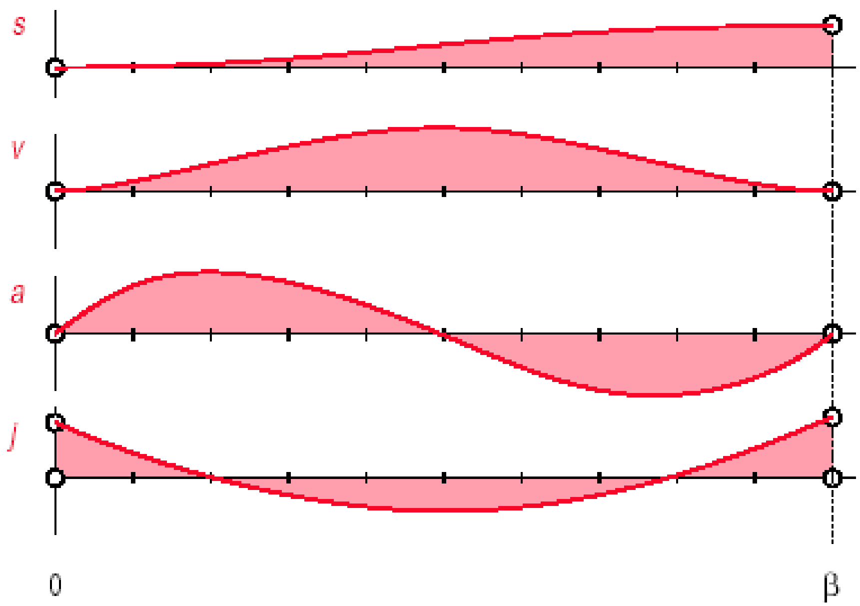
$$0 = \frac{1}{\beta^2}\left[6C_3 + 12C_4 + 20C_5\right] \qquad \text{(k)}$$

$$C_3 = 10h; \qquad C_4 = -15h; \qquad C_5 = 6h \qquad \text{(l)}$$

The 3-4-5 and 4-5-6-7 Polynomials

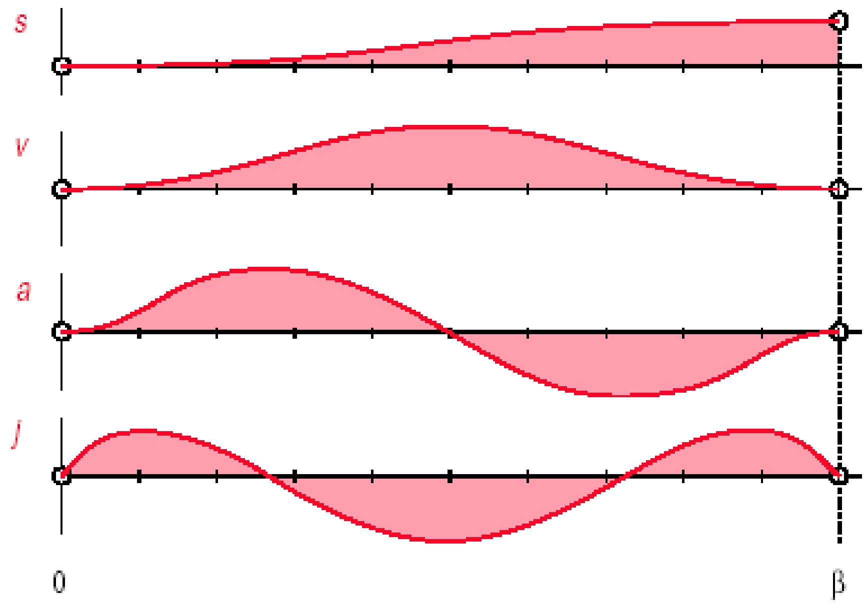
3-4-5 Polynomial

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

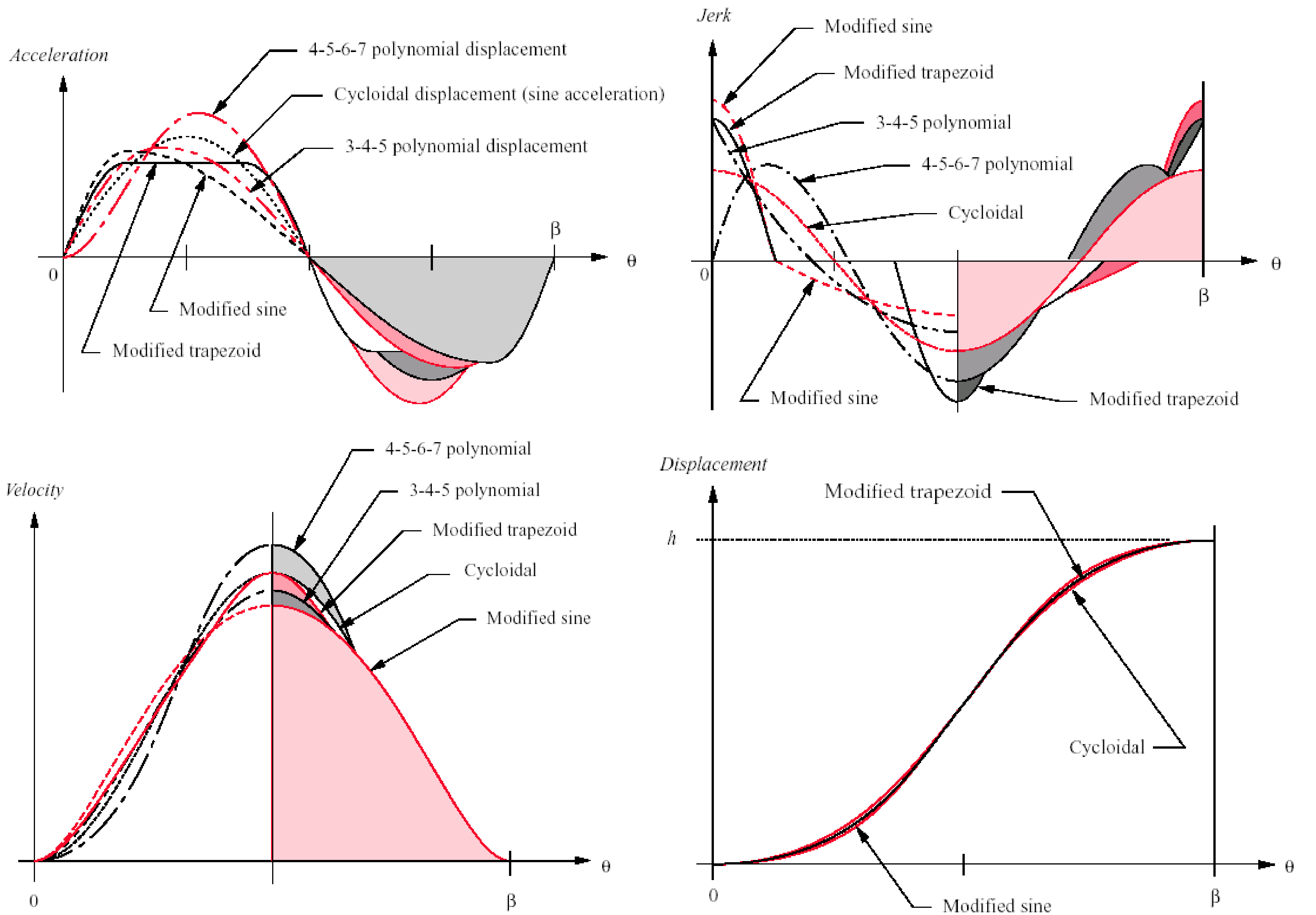


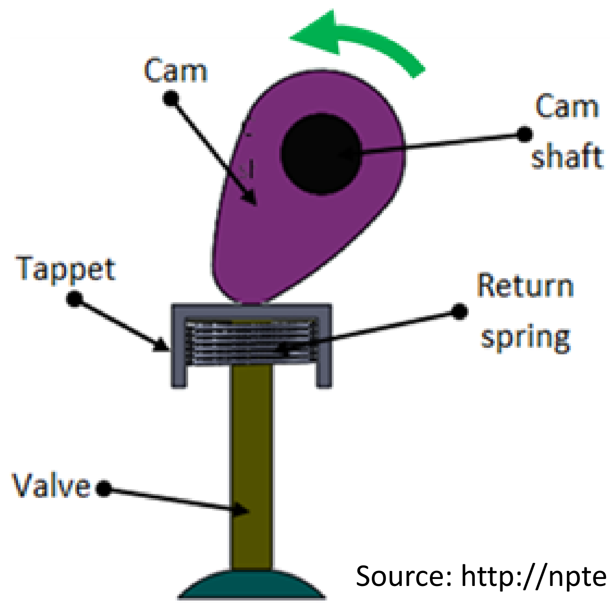
4-5-6-7 Polynomial

$$s = h\left[35\left(\frac{\theta}{\beta}\right)^4 - 84\left(\frac{\theta}{\beta}\right)^5 + 70\left(\frac{\theta}{\beta}\right)^6 - 20\left(\frac{\theta}{\beta}\right)^7\right]$$



Comparison of Five Double-Dwell Fcns





Source: http://nptel.ac.in

Cam Motion Design: Polynomial Deep Dive

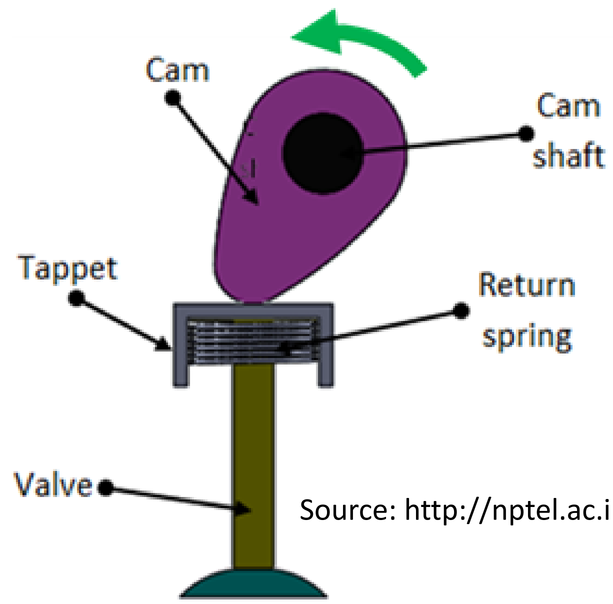
At the end of this video, you should be able to:

- Describe why a double-dwell profile is not ideal for a single-dwell cam
- Construct the boundary conditions for a polynomial cam segment
- Solve for the coefficients of a polynomial cam segment

Task: Rise-Fall-Dwell

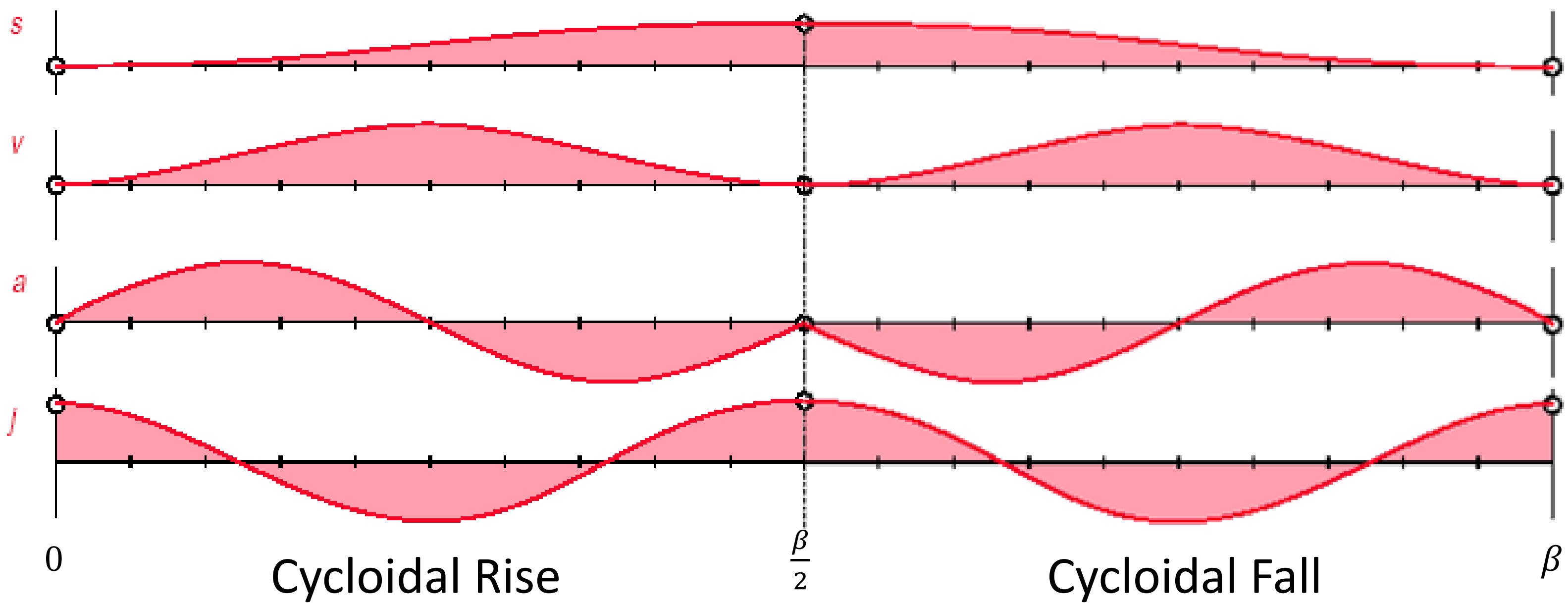
Single Dwell Cam Design

- Rise: 1 inch in 90°
- Fall: 1 inch in 90°
- Dwell: 180°→360°



Source: http://nptel.ac.in

2 Double-Dwell Profiles?



Cycloidal Rise

Cycloidal Fall