Feedback Control Systems

“Dampening is what dogs do to fire hydrants, damping is what controllers do to oscillatory systems” –ANONYMOUS VT CONTROLS PROFESSOR

ME 2984

Slack

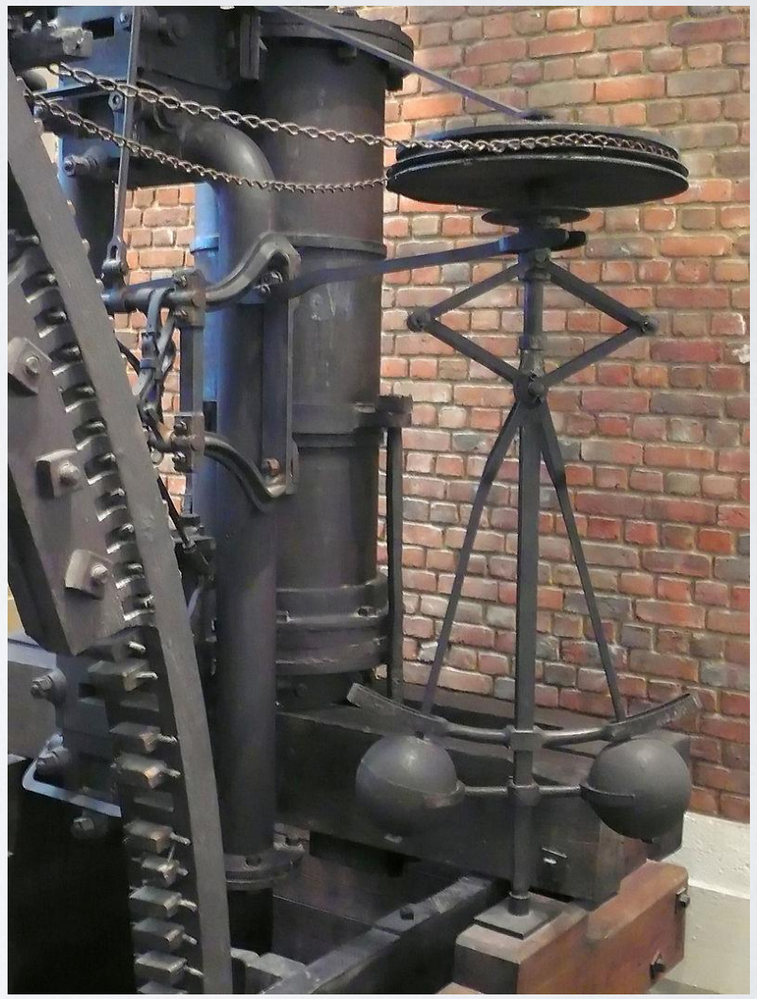
- If you signed up on the sheet and haven’t gotten an invite check your spam.
- Highly recommended that you sign-up

What Is Control Theory?

- Controlling the inputs to a system in order to achieve a desired output
  - Manual
  - Automated
  - Mechanical
  - Analog
  - Digital

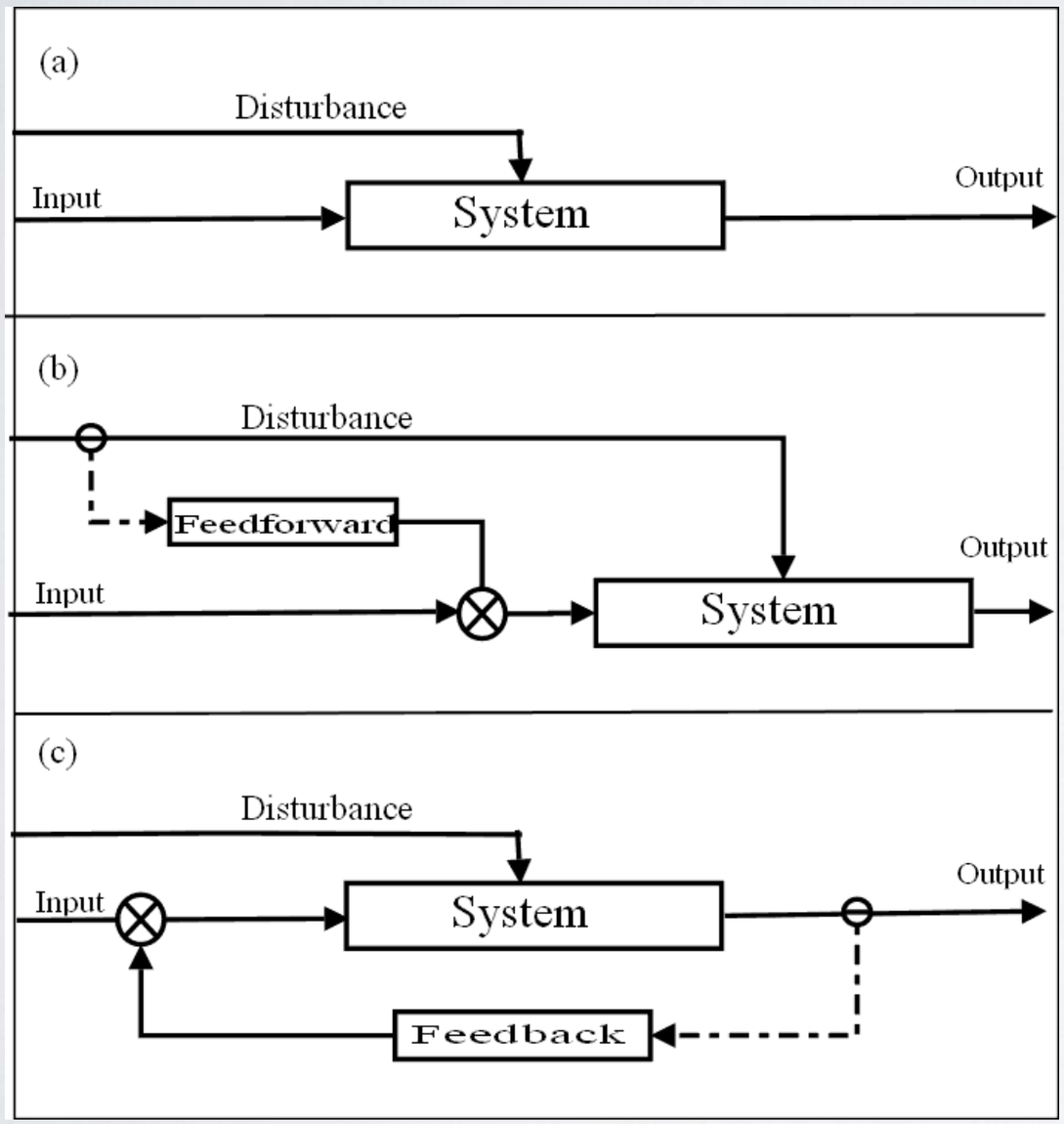
Feedback Control

- Use data to affect your input.
  - Open Loop
    - No output measurement
  - Feedback
    - Use output to affect control signal
  - Feed Forward
    - Predict disturbances to affect controller



Source: Wikipedia

Notation

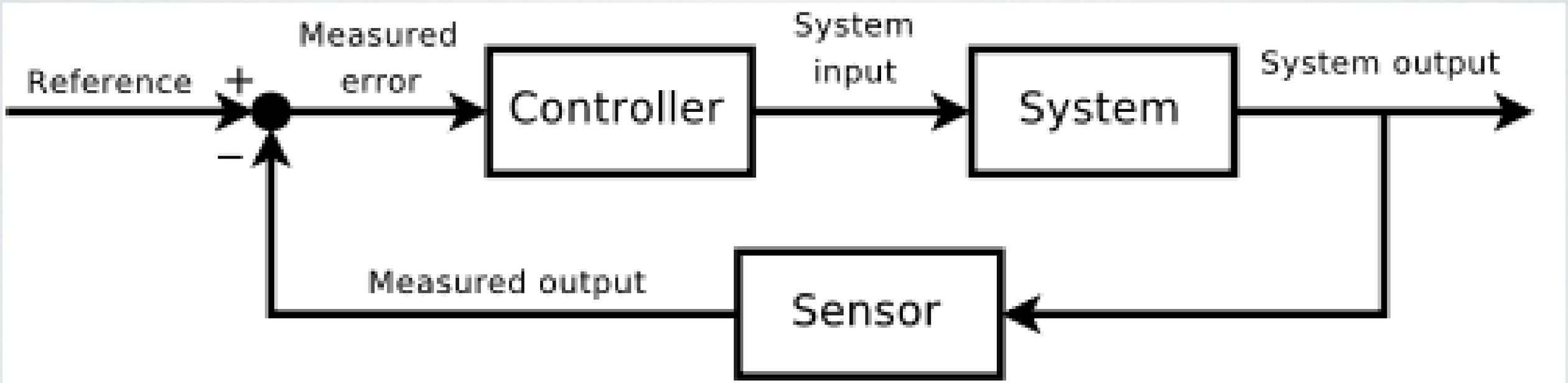


- Block Diagrams used to represent a system
- Single Input, Single Output Systems (SISO)
- Linear time invariant systems

Source: Wikipedia

VirginiaTech
Invent the Future®

Standard Control Loop



VirginiaTech
Invent the Future®

BLOCK DIAGRAMS

Stability

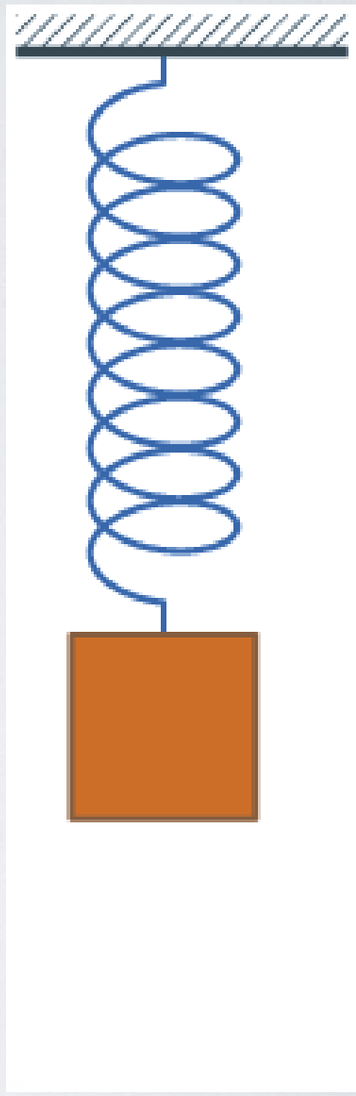
Source: Adrian Pingstone

Source: NASA

- Stable systems naturally reject disturbances
- Will naturally return to an initial condition
- Unstable systems will deviate to infinity from a small input

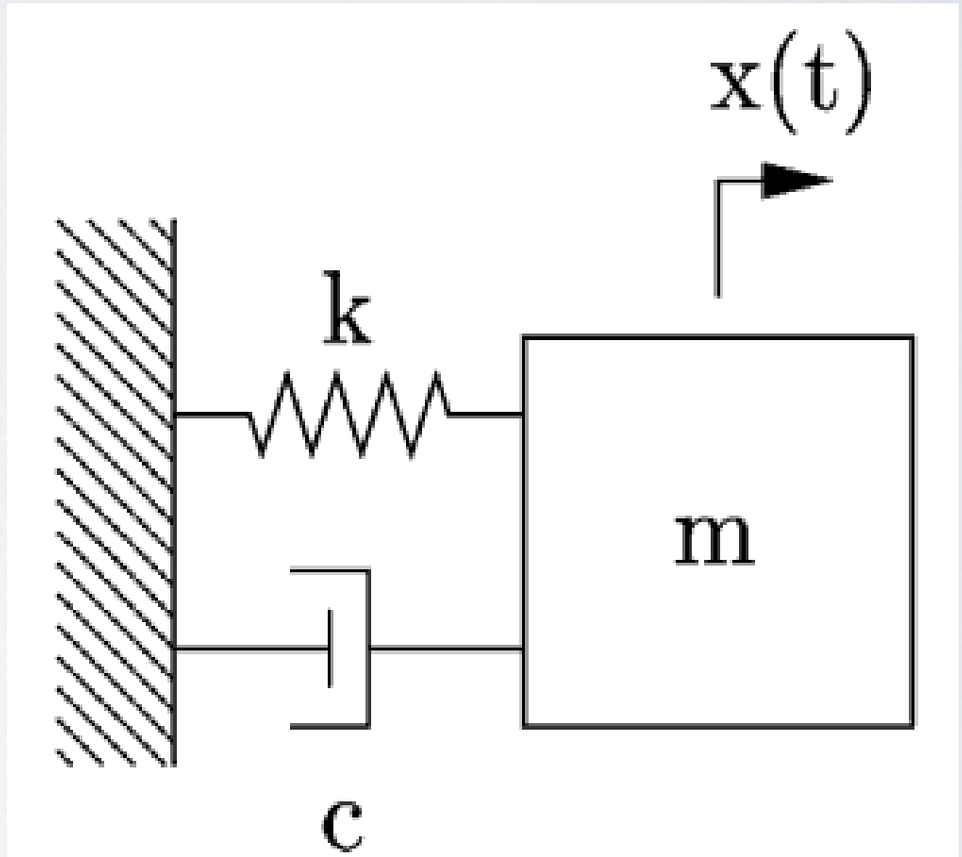
Spring Mass

- Simple easy to model system
  - $m\ddot{x} + kx = 0$
- Unconstrained Oscillation
  - $\omega_0 = \sqrt{k/m}$



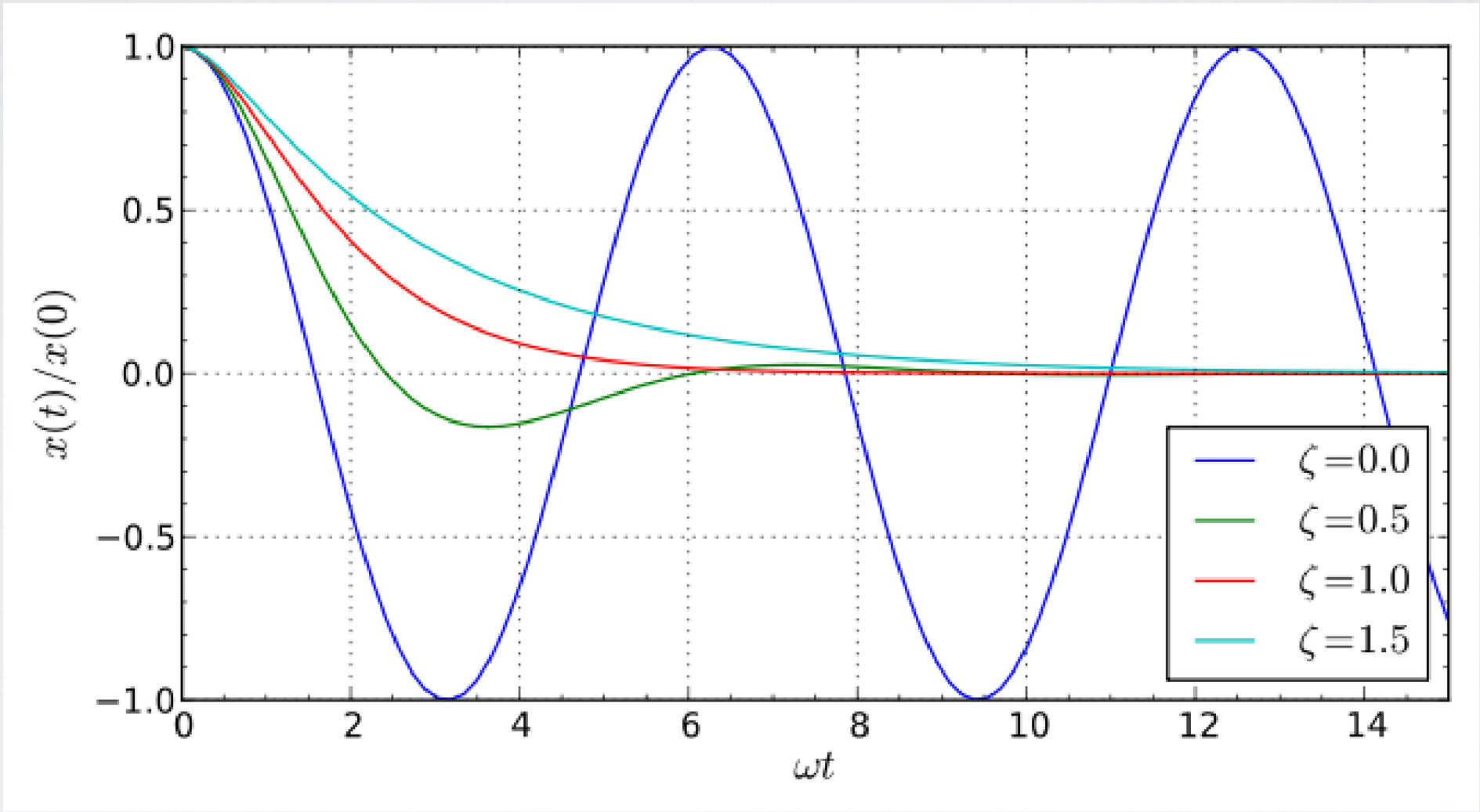
Spring Mass Damper

- Damper is optional
  - $m\ddot{x} + c\dot{x} + kx = 0$
- Produces oscillatory response
  - $\omega_0 = \sqrt{k/m}$
  - $\zeta = \frac{c}{2\sqrt{mk}}$



Source: MIT

Output

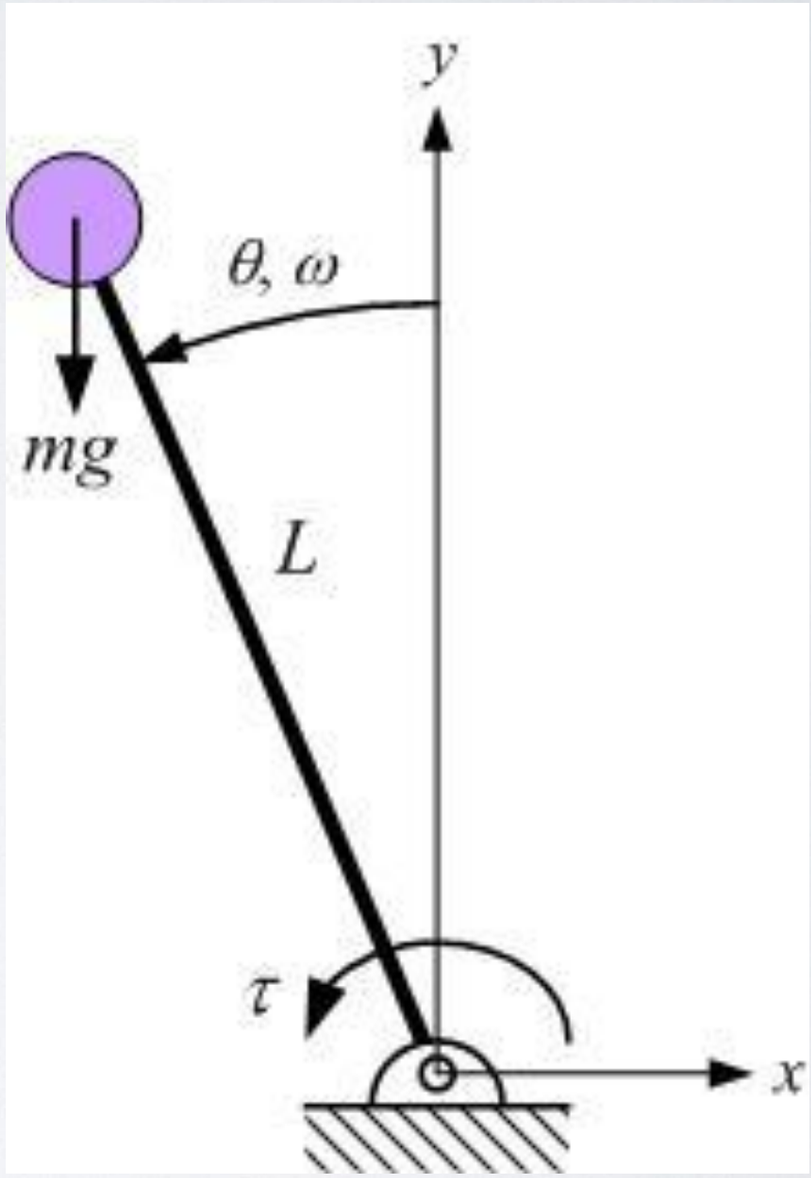

1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
12
14
$x(t)/x(0)$
ωt
$\zeta=0.0$
$\zeta=0.5$
$\zeta=1.0$
$\zeta=1.5$

The Inverted Pendulum

- Basic System used for testing controllers

$$\ddot{\theta} - \frac{g}{\ell} \sin\theta = 0$$

- Can be used to model a wide variety of systems



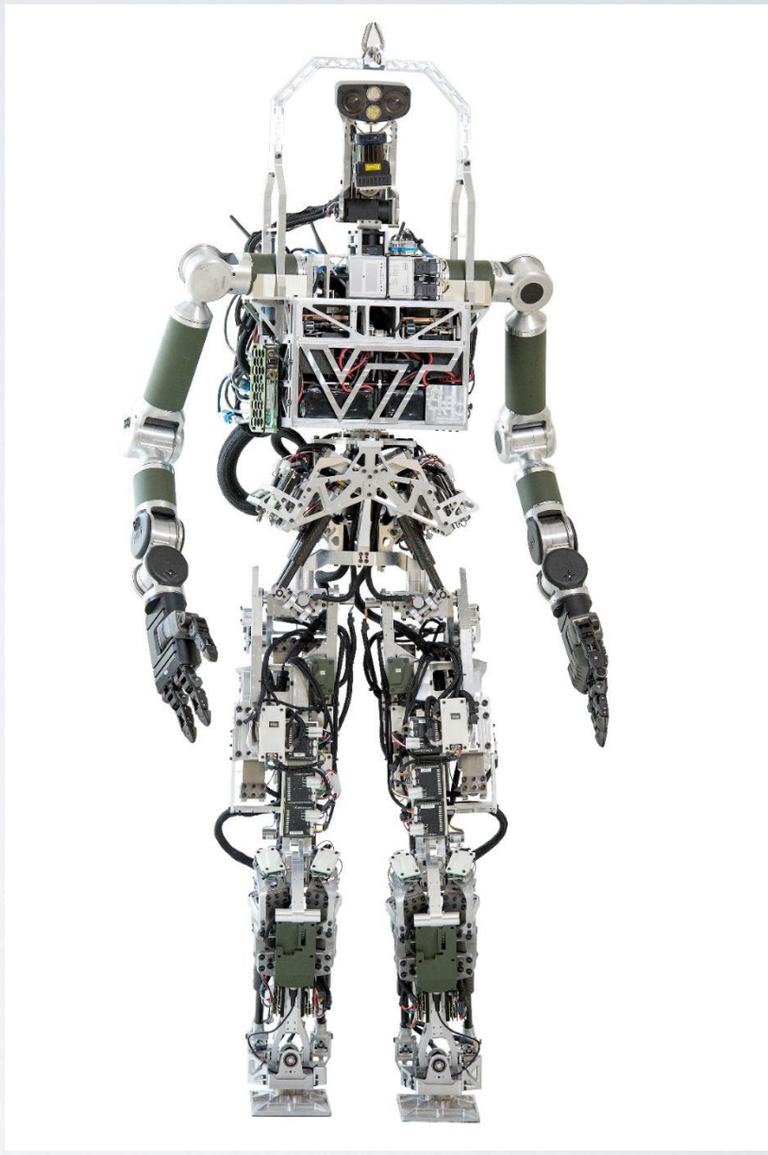
Source: UTPA

VirginiaTech
Invent the Future®

Other Inverted Pendulums

Source: NASA

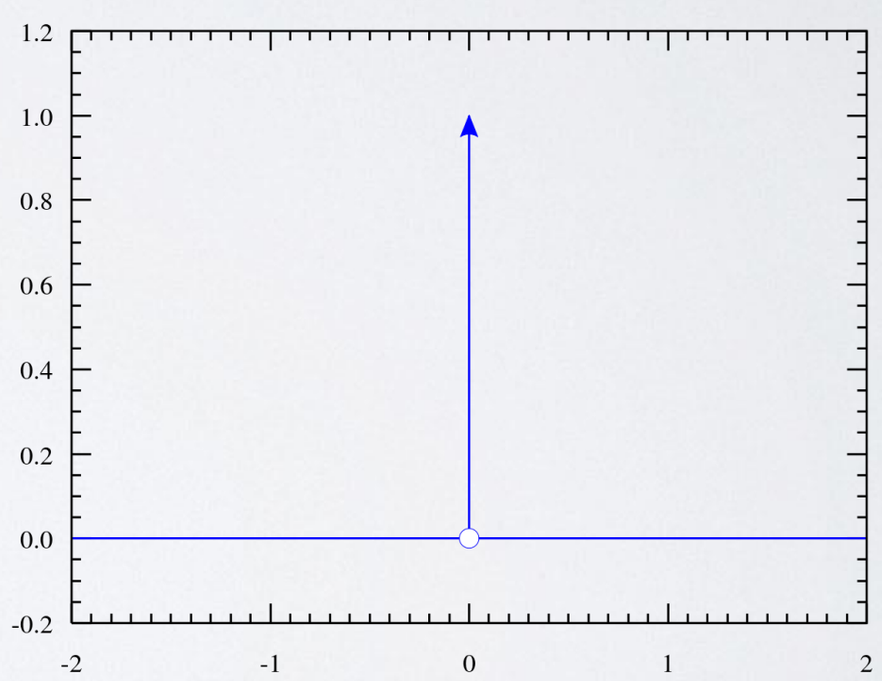
Source: Wikipedia



Source: Logan Wallace

Common Inputs

- Impulse Response / Dirac Delta Function
  - Equivalent to a Hammer Blow
  - Can help determine the Transfer Function

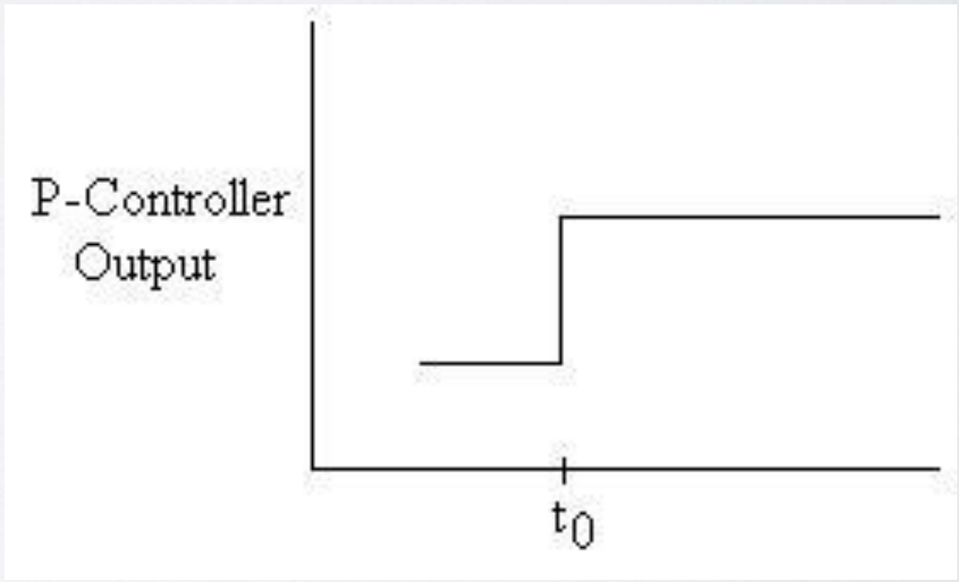


Impulse/Dirac Function

Source: Wikipedia

Common Inputs

- Step Response
  - Constant input starting at time zero
  - Tests the effect on rapid deviations
- Generates common design metrics

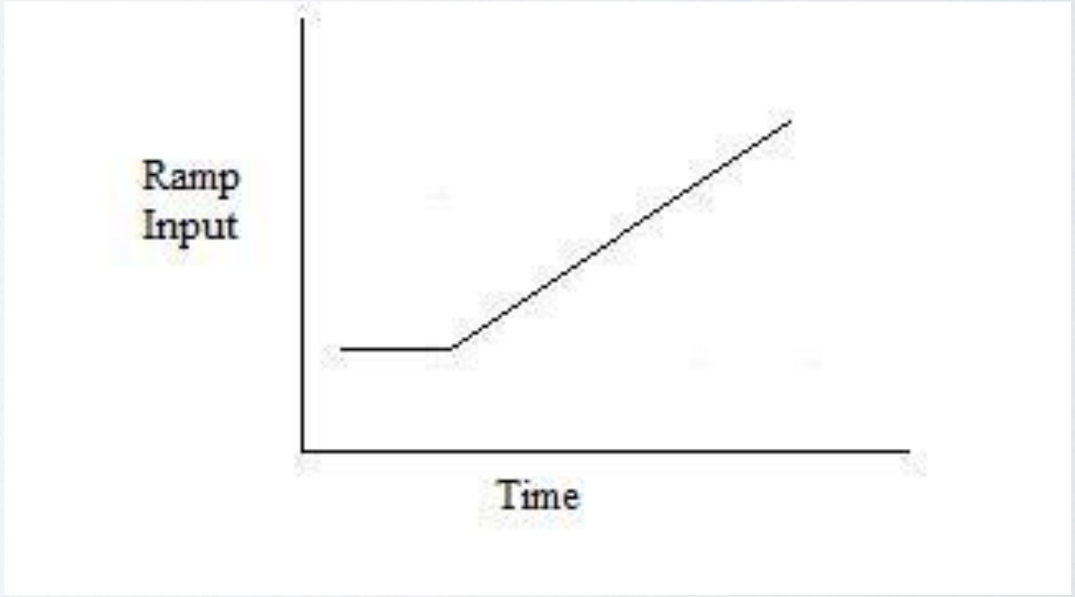


Step Input

Source: U Michigan

Common Inputs

- Ramp function
  - Continually increasing function with set slope
- Used to determine steady state error of certain systems

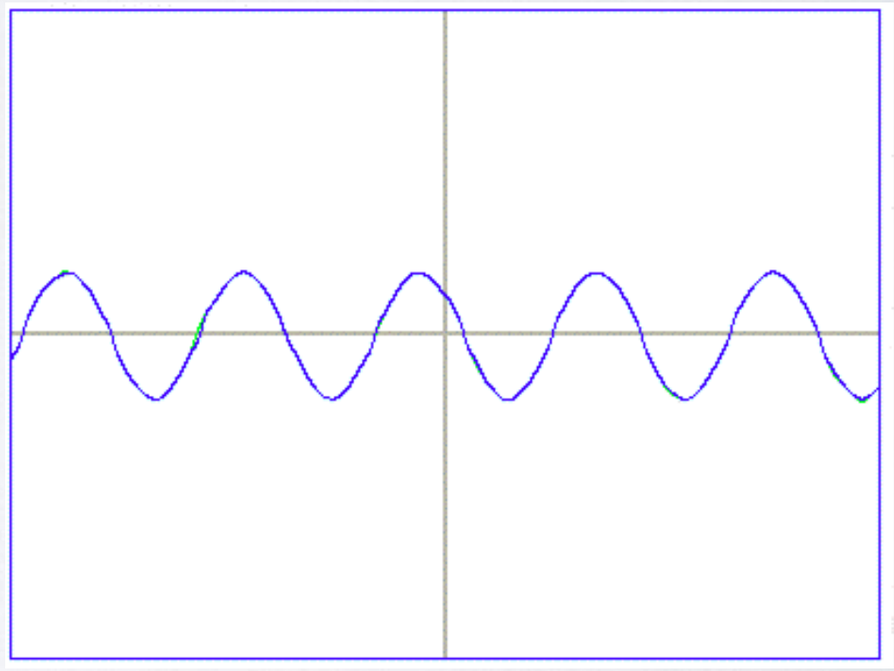


Ramp Input

Source: U Michigan

Common Inputs

- Sinusoidal response
  - Used to determine the response of a system without analysis
- Used in a process called [System ID]

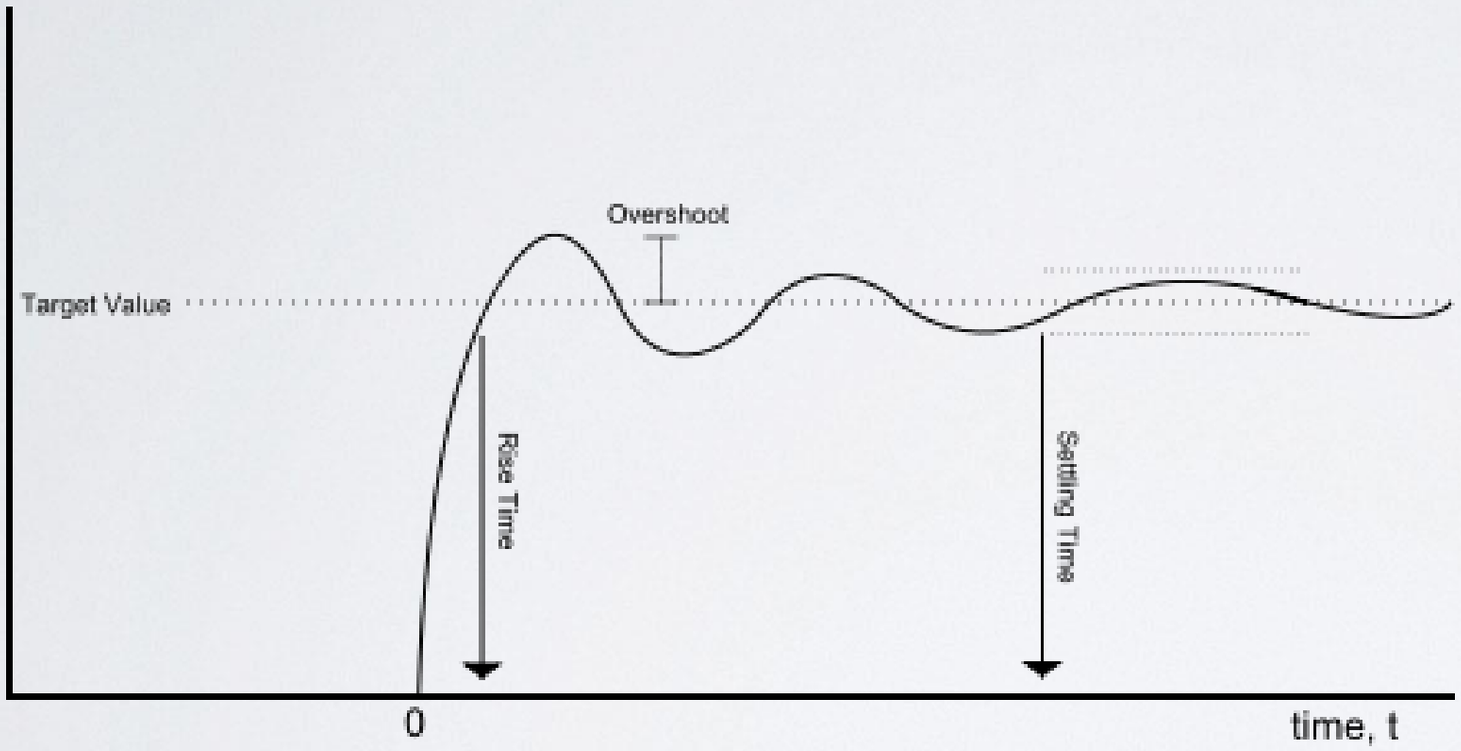


Step Input

Source: Brandeis

Closing The Loop

- Common Design Metrics
  - Rise time
  - Settling Time
  - Percent Overshoot



Types Of Controllers

- Proportional
  - Small error means small change in input
- Can’t deal well with rapid changes

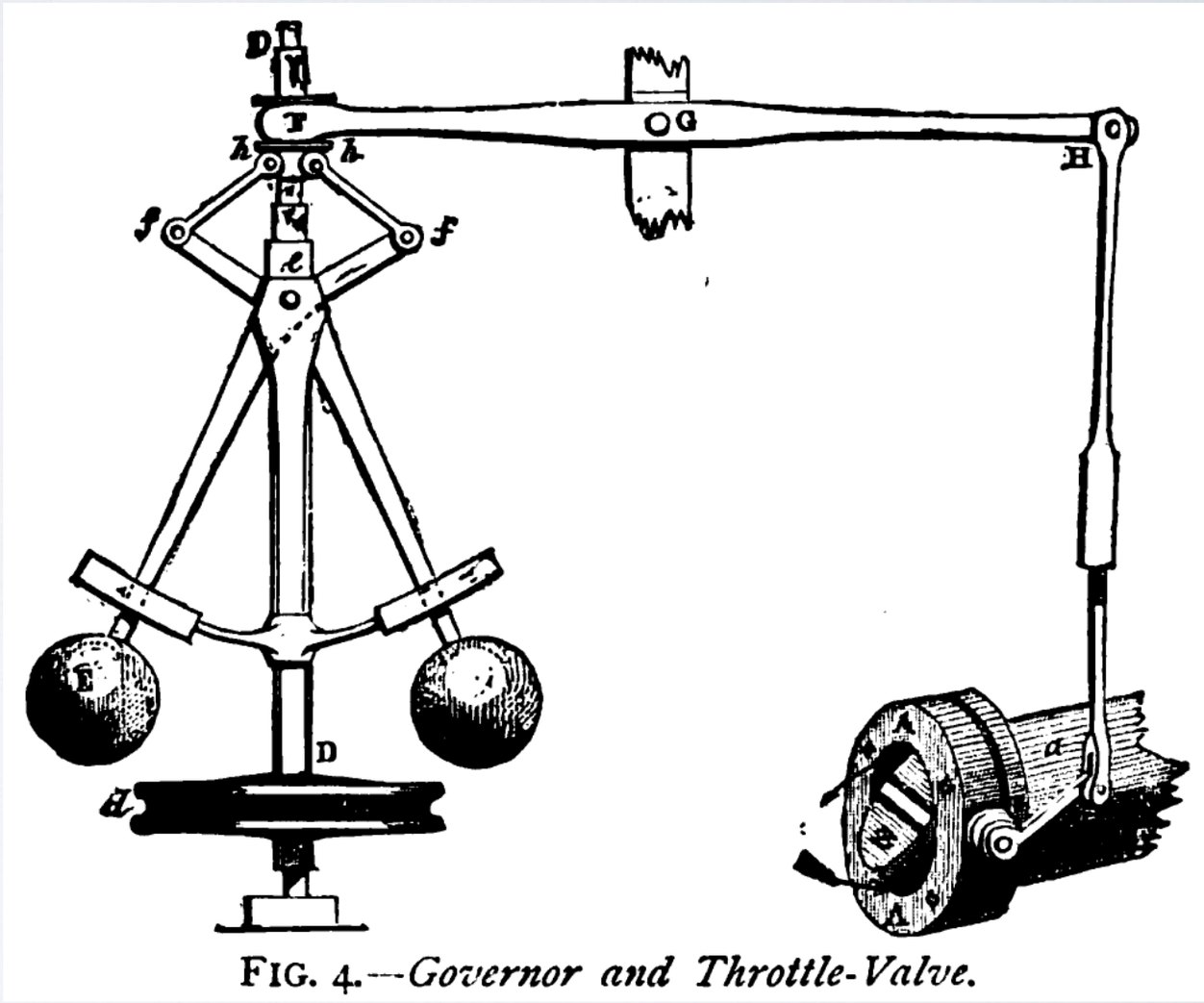
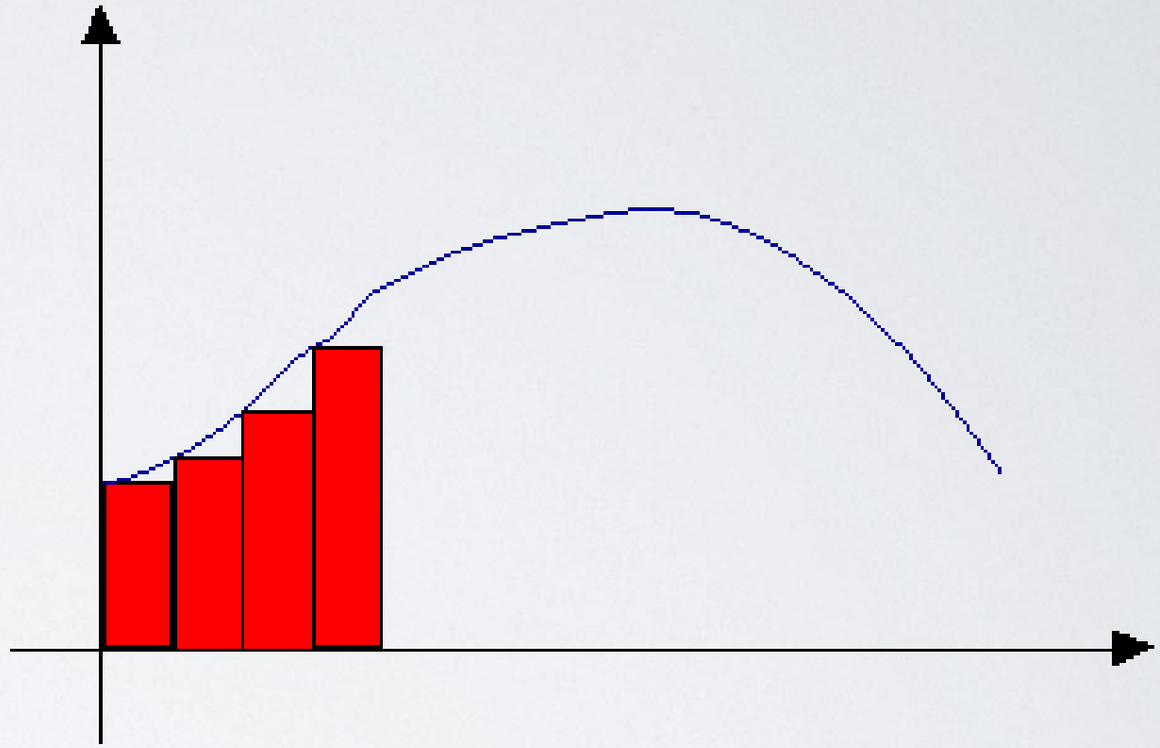


FIG. 4.—*Governor and Throttle-Valve.*

Source: [Wikipedia]

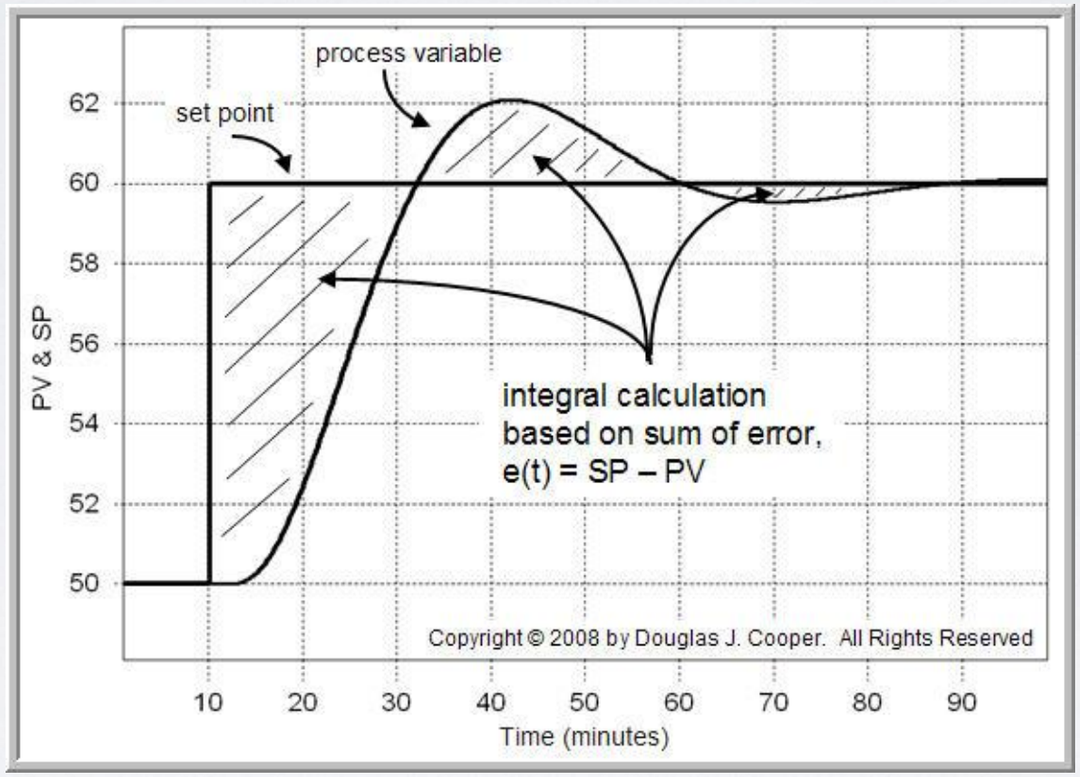
Types Of Controllers

- Integrator
  - Integrates the Error in the system
  - System must be able to get Steady State Error



Types Of Controllers

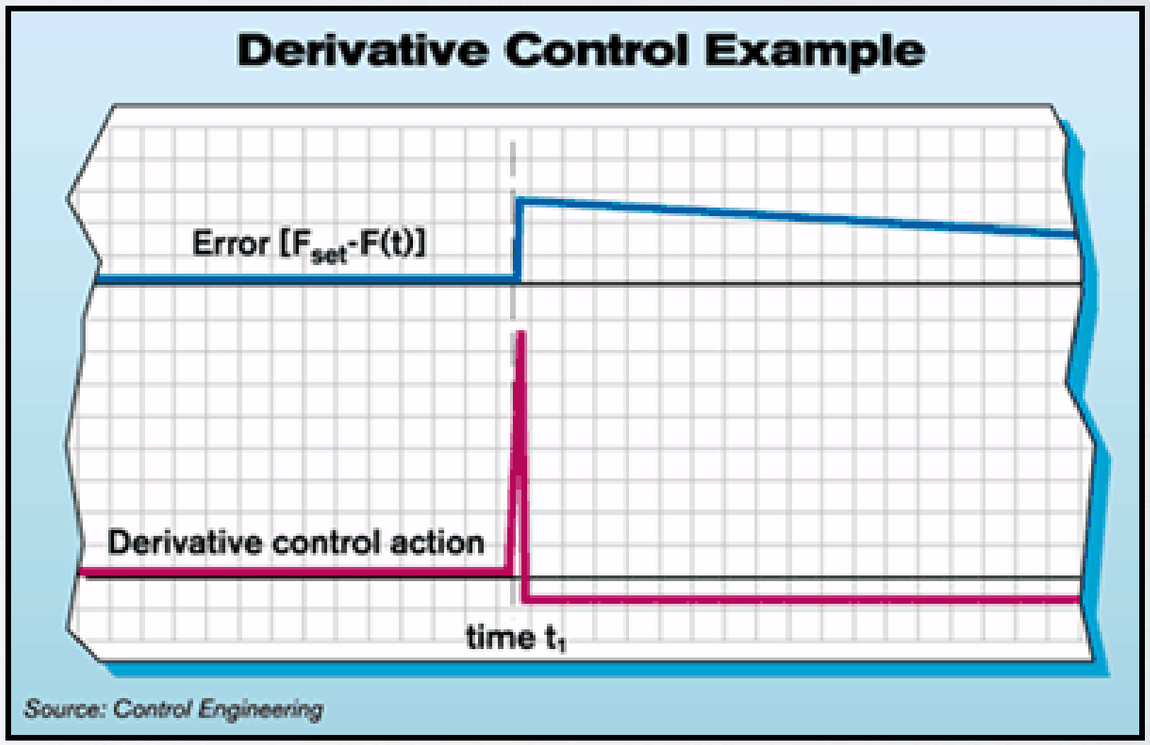
- What happens to the error at Tzero?



- Known as windup, can overload the capacity of your actuators

Types Of Controllers

- Derivative
  - Counteracts P and I
  - Acts very quickly
  - Can be very sensitive to noise
  - Cannot exist by itself



VirginiaTech
Invent the Future®

PID Controllers

- Most common type of controller
- Must be tuned for system performance

What Does A Controls Engineer Do?

- Use analysis to determine the dynamics of a system
- Use a variety of tools to achieve desired system performance
  - Laplace Transforms
  - Pole Zero Plots
  - Bode Plots
  - State Space Analysis

VirginiaTech
Invent the Future®

Homework 2

- Homework 2 is due at 11:55 Tonight
  - Written section must be turned in Digitally via Scholar
  - Code must be submitted via GitHub