Kuwait University
College of Engineering and Petroleum

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ME417 CONTROL OF MECHANICAL SYSTEMS

PART I: INTRODUCTION TO FEEDBACK CONTROL

LECTURE 2: ANALYSIS AND DESIGN

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Ali AlSaibie

Lecture Plan

- Objectives:
  - *Introduce the work cycle of a Control Systems Engineer*
  - *Introduce key concepts of analysis in feedback control*
  - *Overview the control design process*
- Reading:
  - *Nise: 1.4-1.7*

What do Control Systems Engineers do?

- Control Systems Engineers are needed in
  - Manufacturing, Oil & Gas, Automotive, Aerospace, Robotics, Defense, Biomedical, Heavy Machinery, Household goods just to name a few
- They take a top-down design approach
- They often work as systems engineers / integrators
  - *Manufacturing Process Control*

What do Control Systems Engineers do?

- But can also be specialized depending on the field
  - *Advanced Control of Spacecraft*
  - *Autopilot Systems*
- Control Systems Theory extends to biology and economics.
  - Controlling outbreaks
  - Modeling economic behaviors

What do Control Systems Engineers do?

- There are three main components in the world of Control Systems
  1. Modeling
     - All the tools available for a Control Systems Engineer rely on mathematics
     - Any dynamic system must first be modeled mathematically
     - This part was covered in the Systems/Vibration courses.
  2. Analysis
     - The characteristic of a system is studied
     - Evaluating a system to be controlled or examining the effect of a controller on a system
     - Control Systems Engineering has a comprehensive set of tools for analysis
  3. Design
     - It remains a creative process
     - But based on well defined requirements

Modeling

- A model is a mathematical representation of a system
- For Mechanical Systems, we use
  - Newton’s Approach: $F = ma$, or
  - Lagrange’s: $T + V + \delta U = E$,

In order obtain the dynamic relationship, that is often a differential equation

$$\frac{d^m c(t)}{dt^n} + d_{n-1}\frac{d^{m-1}c(t)}{dt^{n-1}} + \cdots + d_0 c(t) = b_m \frac{b^m r(t)}{dt^m} + b_{m-1}\frac{d^{m-1}c(t)}{dt^{m-1}} + \cdots + b_0 r(t)$$

Modeling

- Using the dynamic relationship we can model in the
  1. Frequency Domain via Transfer Function:

$$\frac{C(s)}{R(s)} = G(s) = \frac{(b_m s^m + b_{m-1} s^{m-1} + \cdots + b_0)}{(a_n s^n + a_{n-1} s^{n-1} + \cdots + a_0)}$$

  - *Restricted to Linear, Time-Invariant Systems*
  - *Representation is only for single-input, single-output (SISO)*
  - *However, it is fundamental to learning control system concepts*
- *Covered in detail in ME318 – System Dynamics*

Modeling

- Using the dynamic relationship we can model in the

  2. Time Domain via State Space Representation:

     - General form:

$$\dot{\boldsymbol{x}} = A(t, x) + B(t, x, u)$$
$$\boldsymbol{y} = C(t, x) + D(t, x, u)$$

     - Linear, Time-Invariant form:

$$\dot{\boldsymbol{x}} = A\boldsymbol{x} + B\boldsymbol{u}$$
$$\boldsymbol{y} = C\boldsymbol{x} + D\boldsymbol{u}$$

     - *Can be used to represent any system*
       - *Nonlinear, time-dependent, coupled, multi-input multi-output*
     - *The form used in current research in the area.*
     - *Numerically friendly*
     - *But more abstract than transfer function*
     - *Will be covered later in the course*

Analysis

- *“Analysis is the process by which a system’s performance is determined”*
- How well does the system perform against desired requirements?
- Many different performance criteria in the context of control systems
- We will treat:
  - Transient Response
  - Steady-State Response
  - Stability
- Others:
  - Energy Efficiency, Robustness, Tracking Error, Sensor Error, State Estimation

Analysis – Transient Response

- Whenever a system's equilibrium is disturbed, the response it undergoes until it reaches the new equilibrium, is called transient response
- Desired system performance may require a specific transient response profile
  - Min/Max Speed/Acceleration
  - % Overshoot
  - Rise-Time
  - Tracking Error
- By employing feedback control, we can attain specific transient response behaviors
- *Discuss the importance of transient response in the context of control design*

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Analysis – Steady-State Response

- After the transients have decayed to zero
  - The dynamic system may not have reached the target set-point accurately
  - The difference between the desired target and steady-state value is
    - *Steady-State Error*

  - Steady-State Error is a key design requirement
    - You want an elevator to reach and be level with the floor
    - You want a hard-disk head to position accurately
    - *What other examples can you think of?*

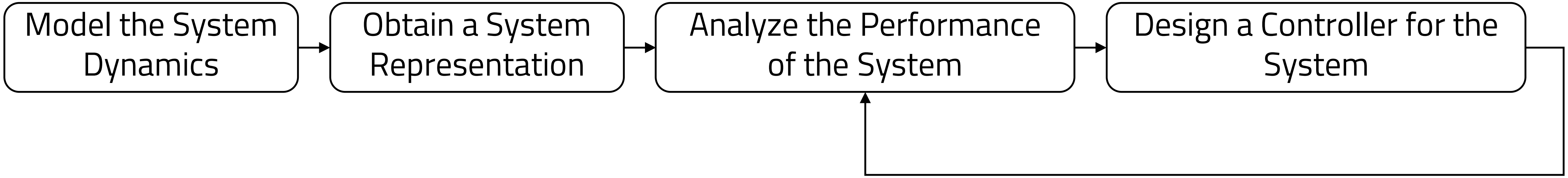
Analysis - Stability

- For a linear system
  - Total Response = Forced Response + Natural Response

- For a control system to be useful, the natural response must
  1. Eventually approach zero, or
  2. Oscillate

Design

- There is not a single unique design approach
- Design is a creative process
- However, presenting a structured process helps in understanding principles
- In summary, the process:

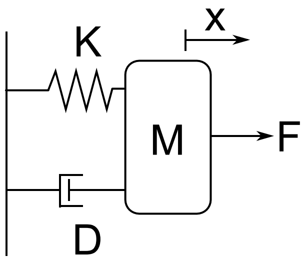


Model the System Dynamics

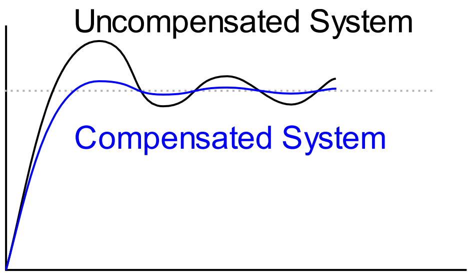
Obtain a System Representation

Analyze the Performance of the System

Design a Controller for the System



$$\frac{X(s)}{F(s)} = \frac{1}{s^2+2\zeta\omega_n+\omega^2}$$



Case Study – Rocket Launch Control

- Consider a space rocket launch, discuss
  - How you would model the rocket and the environment?
  - What Performance Criteria would you consider?
  - How would you design a controller? What is your input and output?
  - How would you test your controller?

Case Study – Rocket Launch Control