EE C128 / ME C134 – Feedback Control Systems

Lecture – Chapter 1 – Introduction

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Lecture abstract

Topics covered in this presentation

- Feedback control systems
- Open- vs. closed-loop control
- Analysis & design objectives
- Transient response
- Stability & instability
- System response (natural & forced)
- Steady state error
- Robustness

Chapter outline

- 1 – Introduction
  - 1.1 Introduction
  - 1.2 A history of control systems
  - 1.3 System configurations
  - 1.4 Analysis and design objectives
  - 1.5 The design process
  - 1.6 Computer-aided design
  - 1.7 The control systems engineer

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OL systems, [1, p. 8]

Open-loop (OL) system

- Has poor *sensitivity to disturbances*, i.e., it cannot compensate for disturbances that add at the input nor output of the plant

Examples

- Toaster (input: time, output: color)
- Irrigation sprinkler (input: time, output: soil moisture)
- Stepper motors in inkjet printers (input: steps, output: position)
- Motor voltage speed control (input: voltage, output: speed)

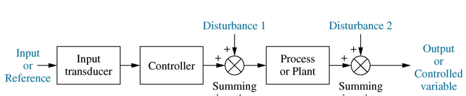

Figure: Block diagram of an OL control system

CL (FB control) systems, [1, p. 9]

Closed-loop (CL) system

- Corrects for disturbances by gathering measurements, feeding measurements back through a feedback (FB) path, and comparing measurements to previous and future inputs

Examples

- Cruise control (input: throttle, measurement: speed, output: speed)

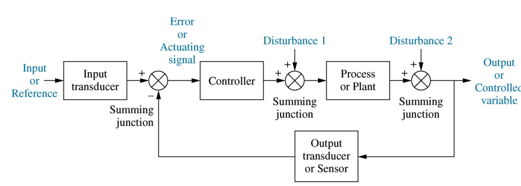

Figure: Block diagram of a CL system

Comparison of OL & CL systems, [1, p. 8-9]

OL system

- Advantages
  - Simple
  - Inexpensive
- Disadvantages
  - Lower accuracy
  - Higher sensitivity to noise, disturbances, and changes in the environment
  - Other considerations

CL system

- Advantages
  - Higher accuracy
  - Less sensitivity to noise, disturbances, and changes in the environment
- Disadvantages
  - Complex
  - Expensive
  - Stability

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Analysis & design objectives, [1, p. 11]

Transient response

- Due to the system and the way the system acquires or dissipates energy
- Response prior to the steady-state response in stable systems

Steady-state (forced) response

- Due to input for linear systems
- Response that remains after the transient response has decayed to 0

Analysis & design objectives, [1, p. 11]

Stability

- Total response = natural response + forced response
- Natural response
  - Defines the stability of the system (3 types)
    - Decays to 0, leaving the forced response, i.e., dissipates system energy
    - Oscillates, i.e., holds system energy constant
    - Grows without bound, i.e., acquires system energy
- Forced response
  - Particular solution is dependent on the input
- Unstable
  - Natural response is so much greater than the forced response that the system is no longer controllable nor observable
- Stable
  - Transient and steady-state response can be designed

Analysis & design objectives, [1, p. 11]

Robustness

- Sensitivity to parameter changes

Other considerations

- Hardware selection, e.g., power requirements and sensor accuracy
- Finances

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The control system design procedure, [1, p. 15]

1. Transform requirements into a physical system
   - System concept
   - Qualitative description
   - Determine inputs and outputs
   - Description of the physical system
2. Draw a functional block diagram
   - Detailed layout
   - Describes the component parts of the system (function and hardware) and shows their interconnections
3. Create a schematic
   - Transform the physical system into a schematic diagram
   - Make approximations and neglect certain phenomena
   - Start simple, check assumptions later through analysis and simulation, if too simple, i.e., does not adequately account for observed behavior, add phenomena
   - Use knowledge of the physical system, physical laws, and practical experience

The control system design procedure, [1, p. 15]

4. Develop a mathematical model (block diagram)
   - Use physical laws
   - Relationship between the inputs and outputs of the dynamic system
   - Linear, time-invariant (LTI) differential equations (DEs)
   - High order, nonlinear, time-varying, or partial DEs
   - Transfer functions (alternate representations of LTI DEs transformed using the Laplace transform)
   - State-space representation (alternate representation of nth-order DEs as n simultaneous first-order DEs
   - Knowledge of parameter values

The control system design procedure, [1, p. 15]

5. Reduce the block diagram
   - Interconnect subsystem models to form block diagrams of larger systems
   - Each block represents a mathematical description with dynamics, relations, inputs, outputs, and parameters
6. Analyze & design
   - Compare time response specifications and performance requirements
     - Test input waveform signals
     - Sensitivity analysis
   - Improve time response and performance
     - Adjusting system parameters
     - Design additional hardware
     - Minimize sensitivity over an expected range of environmental changes

Test waveforms used in control systems, [1, p. 19]

Impulse

- Usage
  - Transient response (TR)
  - Modeling

$$\begin{aligned} \delta(t) &= \infty && \text{for } 0- < t < 0+ \\ &= 0 && \text{elsewhere} \end{aligned}$$

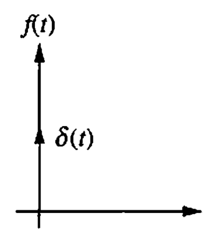

Figure: Impulse test waveform used in control systems

Test waveforms used in control systems, [1, p. 19]

Step

- Usage
  - TR
  - Steady state error

$$\begin{aligned} u(t) &= 1 && \text{for } t > 0 \\ &= 0 && \text{elsewhere} \end{aligned}$$

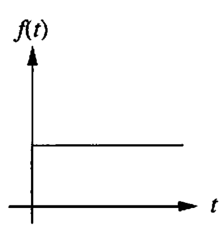

Figure: Step test waveform used in control systems

Test waveforms used in control systems, [1, p. 19]

Ramp

- Usage
  - Steady state error

$$\begin{aligned} tu(t) &= t && \text{for } t \geq 0 \\ &= 0 && \text{elsewhere} \end{aligned}$$

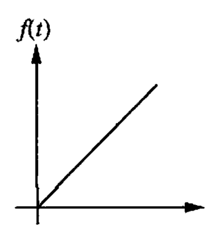

Figure: Ramp test waveform used in control systems

Test waveforms used in control systems, [1, p. 19]

Parabola

- Usage
  - Steady state error

$$\begin{aligned} \frac{1}{2}t^2u(t) &= \frac{1}{2}t^2 && \text{for } t \geq 0 \\ &= 0 && \text{elsewhere} \end{aligned}$$

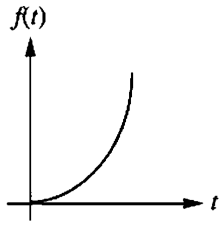

Figure: Parabola test waveform used in control systems

Test waveforms used in control systems, [1, p. 19]

Sinusoid

- Usage
  - Transient response
  - Modeling
  - Steady state error

$$\begin{aligned} \sin(\omega t)u(t) &= \sin(\omega t) && \text{for } t \geq 0 \\ &= 0 && \text{elsewhere} \end{aligned}$$

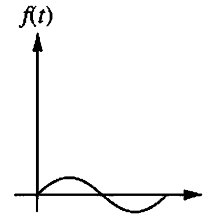

Figure: Sinusoid test waveform used in control systems

Test waveforms used in control systems, [1, p. 19]

Chirp

- Usage
  - Modeling

$$\begin{aligned} \sin(\omega(t)t)u(t) &= \sin(\omega(t)t) && \text{for } t \geq 0 \\ &= 0 && \text{elsewhere} \end{aligned}$$

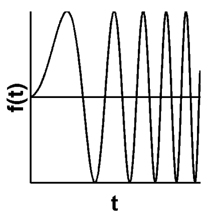

Figure: Chirp test waveform used in control systems

Bibliography

Norman S. Nise. *Control Systems Engineering*, 2011.