Kuwait University
College of Engineering and Petroleum

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ME417 CONTROL OF MECHANICAL SYSTEMS

Part II: Controller Design Using Root-Locus

Lecture 3: Transient Response Design via Gain Adjustment

Spring 2021

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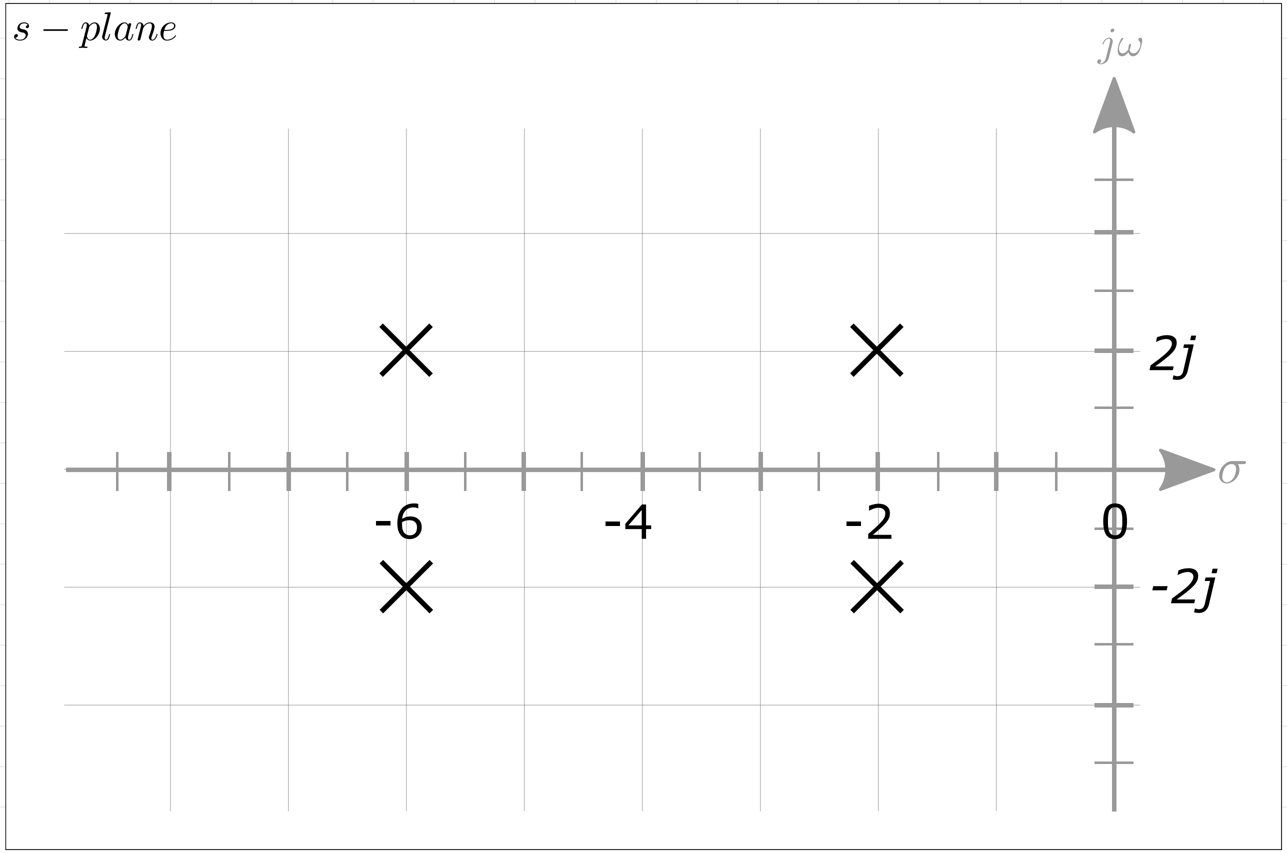
Lecture Plan

- Objectives:
  - Introduce Controller Design through Gain Adjustment
- Reading:
  - *Nise: 8.6-8.7*
- Practice problems included

Complete the root-locus sketch by quick inspection (use first 5 rules).

- What information can you derive about the system, from the figure?
- Is a second-order approximation valid for the closed-loop system?
- What range of damping ratios is possible to obtain with a proportional controller?



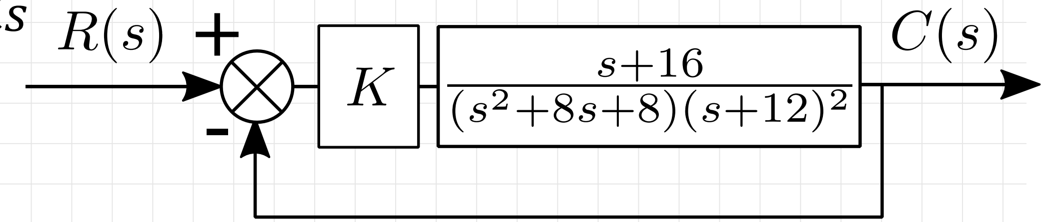
Sketch a rough root-locus for the system shown and find the following using MATLAB:

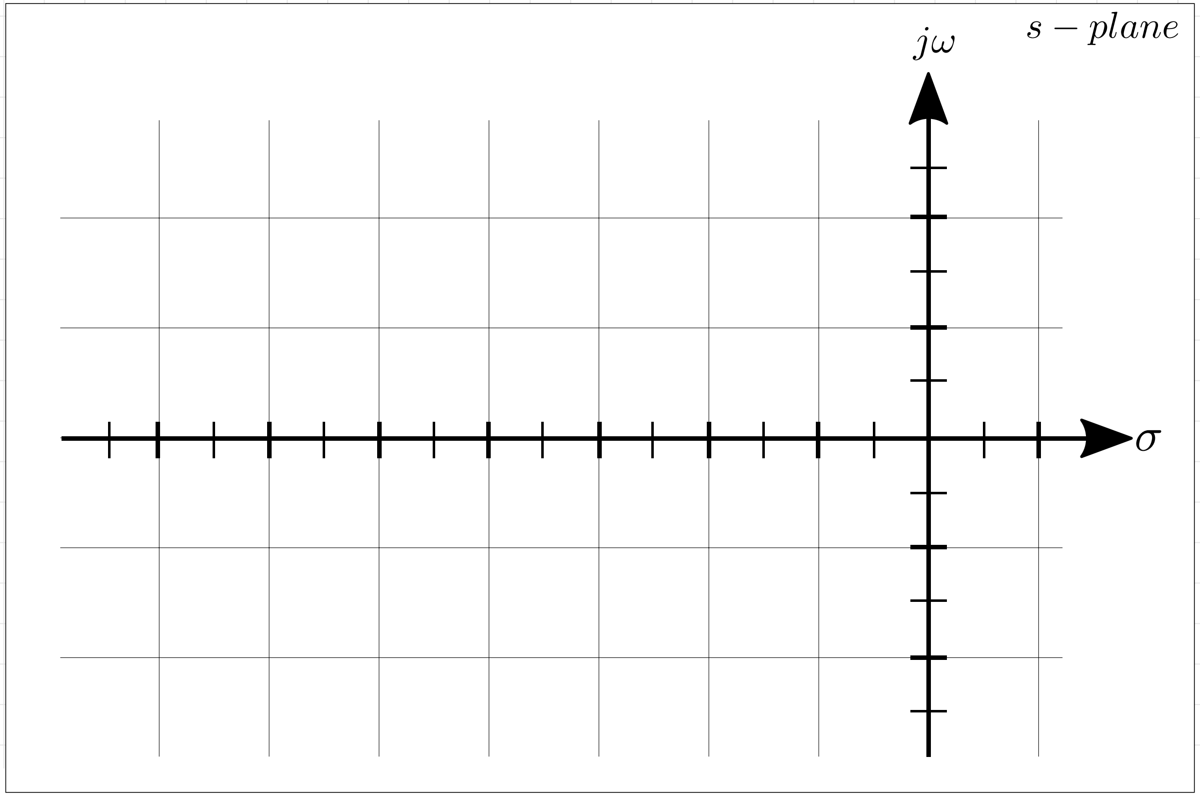
a. The exact point and gain where the locus crosses the $j\omega - axis$

b. The break-away point on the real axis

c. The range of K within which the system is stable.

d. Find the exact point and gain where the locus crosses the $\frac{4}{5}$ damping ratio line





Transient Response Design of Higher-Order Systems via Root-Locus

- Remember that the performance specification points: $T_s, T_r, T_p, \%OS$ were defined for a **general** second-order systems: For feedback systems, that is systems with two complex closed-loop poles and no closed-loop zeros.
- Under some conditions, we can justify a second-order approximation when dealing with higher order systems, or systems with closed-loop zeros:
    1. *If higher order poles (the 3rd pole and higher) are further into the LHP than the dominant second-order pair of poles. (The "five times" rule of thumb)*
    2. *If closed-loop zeros, if present, are close enough to higher order closed-loop poles that results in their effect being diminished (cancelled).*
    3. *If closed-loop zeros, if present, and not cancelled by higher-order closed loop poles, are instead further into the LHP than the dominant second-order pair of poles.*

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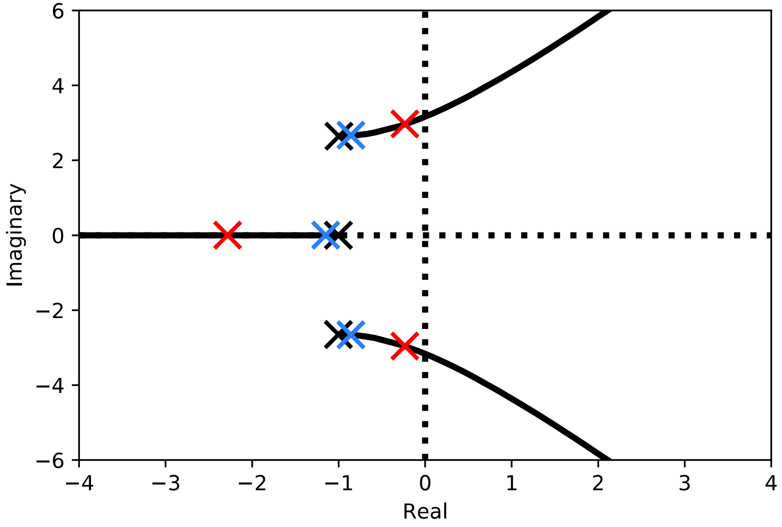
Second-Order Approximations

1. If higher order poles (the 3rd pole and higher) are further into the LHP than the dominant second-order pair of poles. (The "five times" rule of thumb)

- *For the system shown, note how increasing the gain moves the higher-order pole further into the LHP and brings the dominant complex pole pairs closer to the* $j\omega - axis$

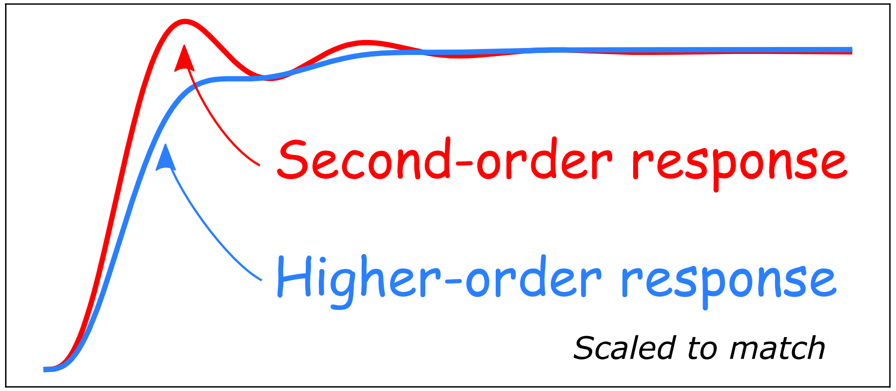


× Open-Loop poles

× Closed-Loop poles w/ K=0.05

× Closed-Loop poles w/ K=4

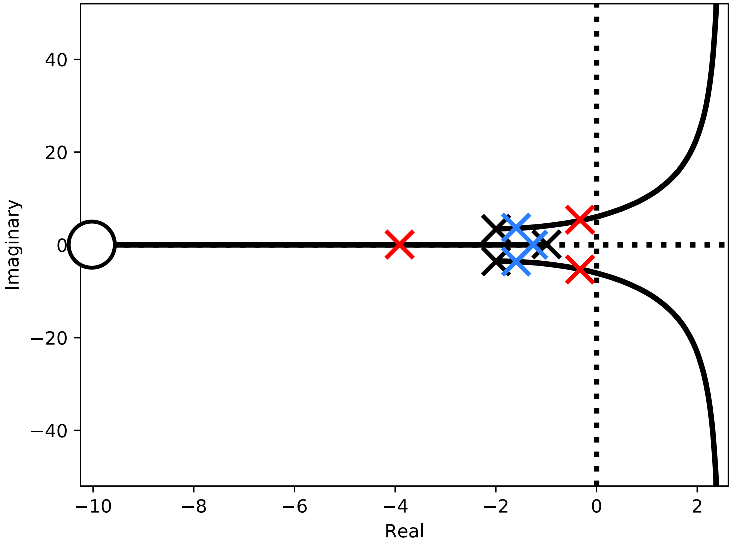
$$1 + KG(s) = 1 + K\frac{1}{(s^2+2s+8)(s+1)} = 0$$



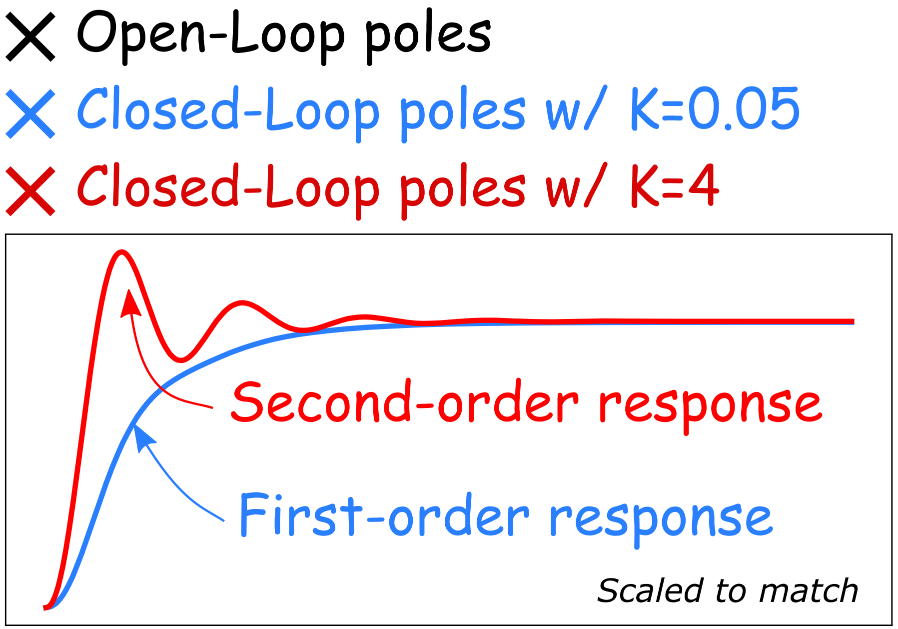
Step responses of CL system

2. Closed-loop zeros, if present, are close enough to higher order closed-loop poles that results in their effect being diminished (cancelled).

- Case A: A finite zero is to the left of CL higher-order pole
- *Increasing the gain not only pushes the higher-order pole further into the LHP, but rapidly cancels its effect due to pole-zero cancellation.*



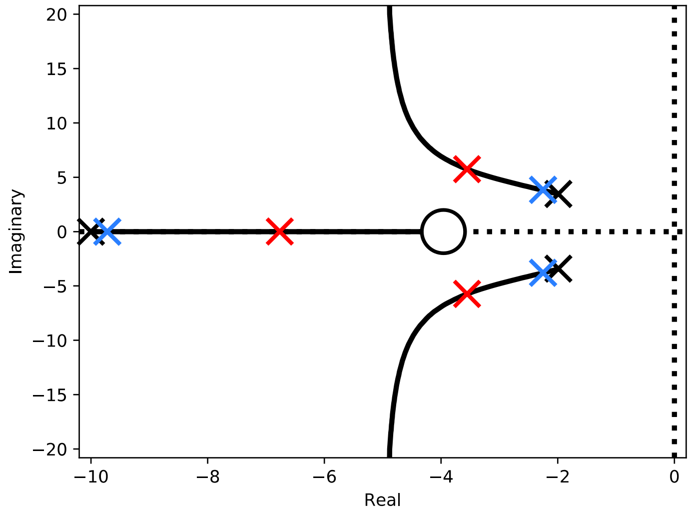
$$1 + KG(s) = 1 + K\frac{s+10}{(s^2+4s+16)(s+1)} = 0$$



Step responses of CL system

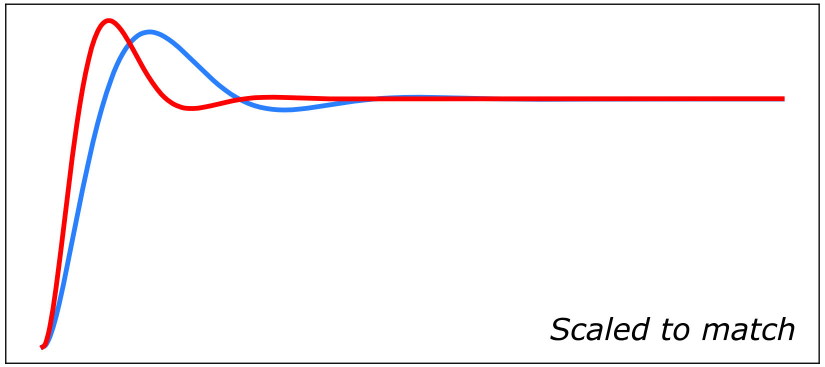
2. Closed-loop zeros, if present, are close enough to higher order closed-loop poles that results in their effect being diminished (cancelled).

- Case B: A finite zero is to the right of CL higher-order pole
- *Increasing the gain brings the higher-order pole closer to the dominant poles, which should increase the order of the system response; however, note that at the same time, the effect of this higher-order pole is cancelled due to pole-zero cancellation.*



$$1 + KG(s) = 1 + K\frac{s+4}{(s^2+4s+16)(s+10)} = 0$$

× Open-Loop poles
× Closed-Loop poles w/ K=0.05
× Closed-Loop poles w/ K=40



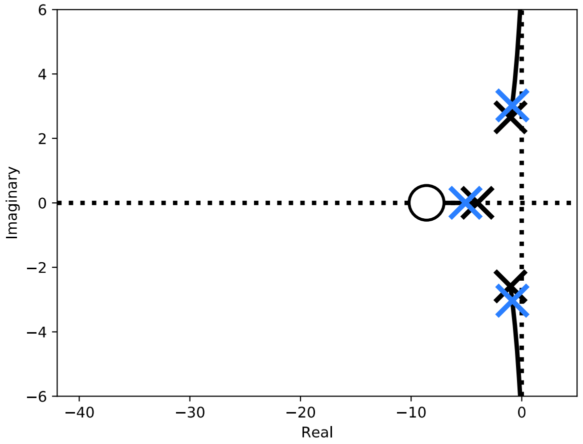
Step responses of CL system

3. Closed-Loop zeros, if present, and not cancelled by higher-order closed loop poles, are instead further into the LHP than the dominant second-order pair of poles.

- *This is the case where the zeros of the system are further into the LHP relative to the dominant closed-loop poles.*

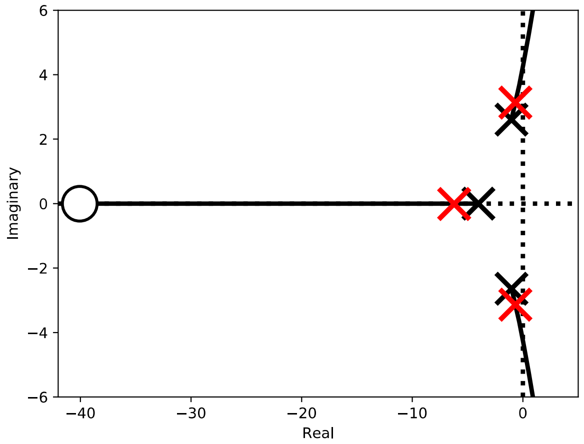
System 1

$$1 + K\frac{s+8}{(s^2+4s+16)(s+4)} = 0$$



System 2

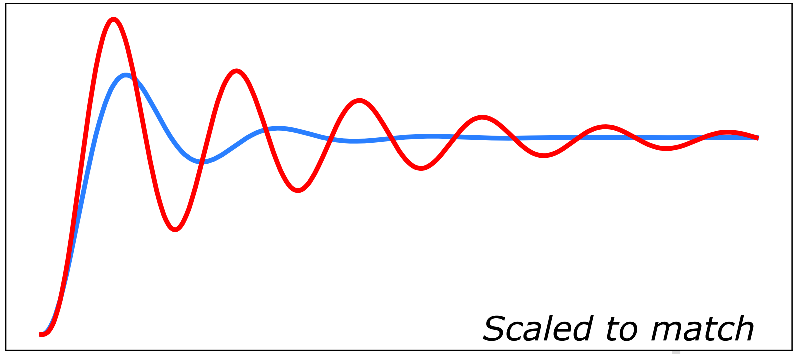
$$1 + K\frac{s+40}{(s^2+4s+16)(s+4)} = 0$$



× Open-Loop poles

× Closed-Loop poles for System 1 w/ K=1

× Closed-Loop poles for System 2 w/ K=1

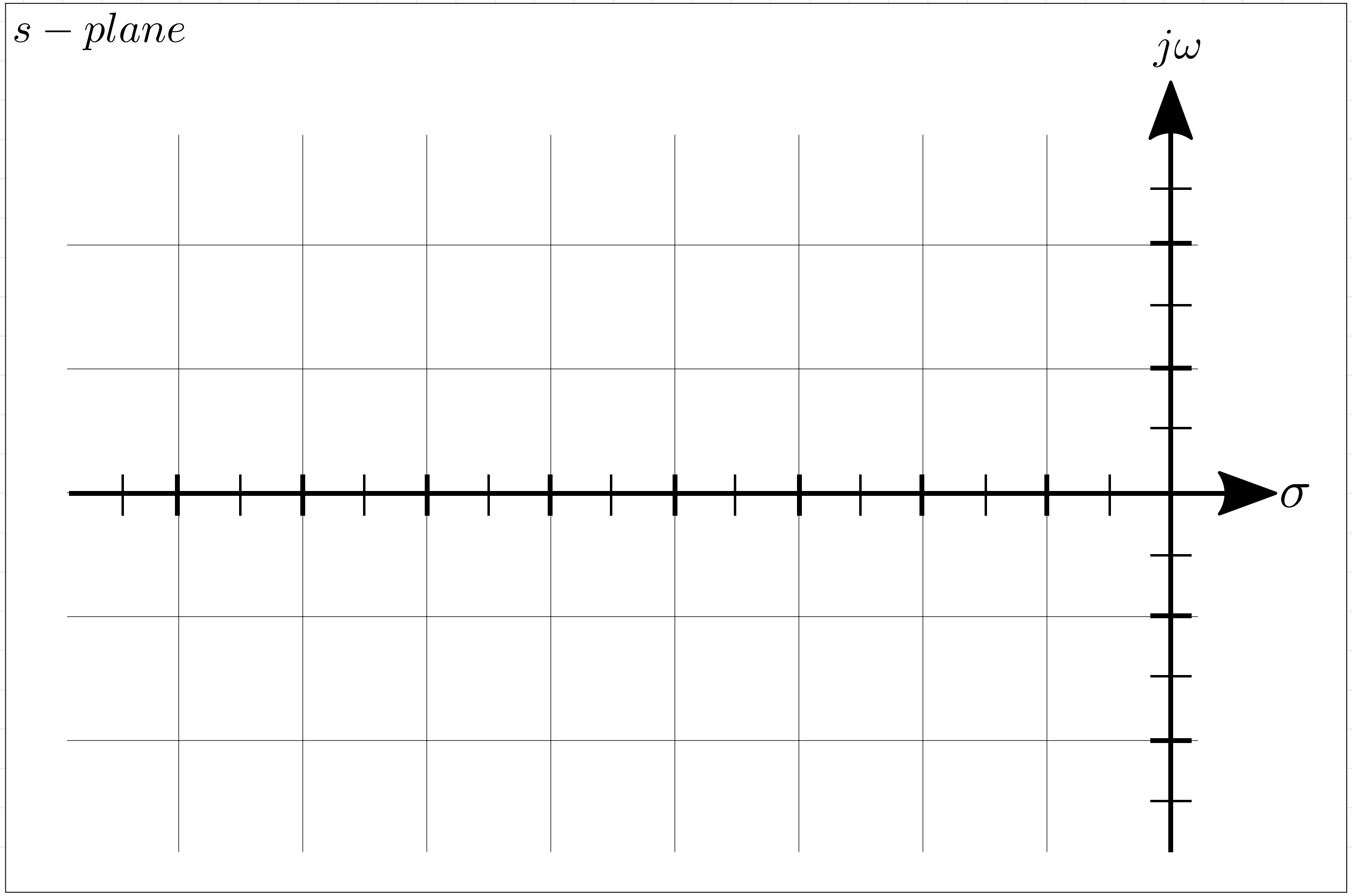


Step responses of CL system

Design a feedback system with a proportional controller, using the root-locus technique, for the dynamic system with the plant transfer function:

$$G_p(s) = \frac{(s+2)}{s(s+1)(s+8)}$$

To yield a damped frequency of $15 rad/s$. Also estimate T_s, T_p, e_{ss} to unit ramp input. Justify your second-order approximation. Verify with MATLAB



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Continue Example

Nise 6th Global Edition:

8-28, 8-30, 8-32, 8-38