EE160: Introduction of Control (Sample)

2022-2023 Final Exam

Teacher: Dr. Yang Wang

Time and Location

2022-xx-xx, Thursday, 13:30-15:30 , 120 mins,

Regulation

This is an "closed-book" exam, but you can bring one A4 cheat sheet with you. Note that, you are NOT allowed to use mobile phones or other electronic devices except calculator.

Scores

Question 1:10 points
Question 2:10 points
Question 3:10 points
Question 4:10 points
Question 5:10 points

Max 50 points in total.

Question 1: True of False (10 points)

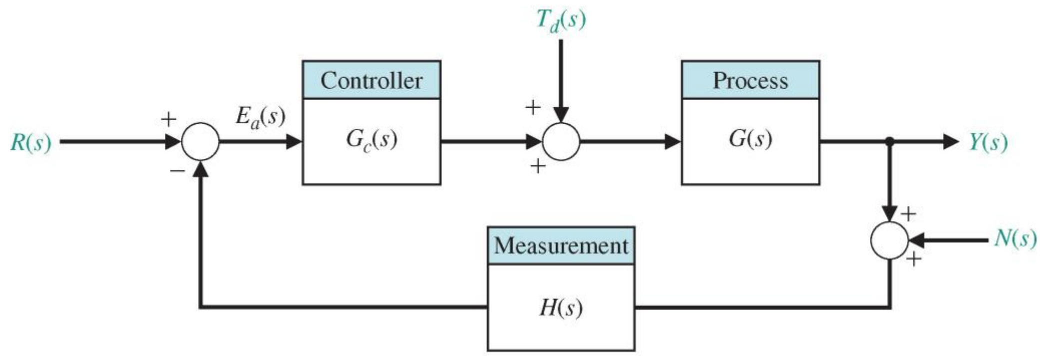
1. A system with only one input and one output is the so-called SISO system.
2. The roots of the characteristic equation are the zeros of the closed-loop system.
3. The rise time is defined as the time required for the system to settle within a certain percentage of the input amplitude.
4. Generally, a phase-lag compensator speeds up the transient response.
5. A deadbeat response of a system is a rapid response with minimal percent overshoot and zero steady-state error to a step input.
6. On the root locus plot, the number of separate loci is equal to the number of poles of the open-loop transfer function
7. Ackerman's formula is used to check observability of a system.
8. The poles of a system can be arbitrarily assigned through full-state feedback if and only if the system is completely controllable and observable.
9. Given a LTI system described by differential equations, we can develop a unique state space model for it.
10. A plot of the real part of G(jw) versus the imaginary part of G(jw) is called a Bode plot.

Answer

1. T
2. F
3. F
4. F
5. T
6. T
7. F
8. T
9. F

Question 2 System Modelling (10 points)

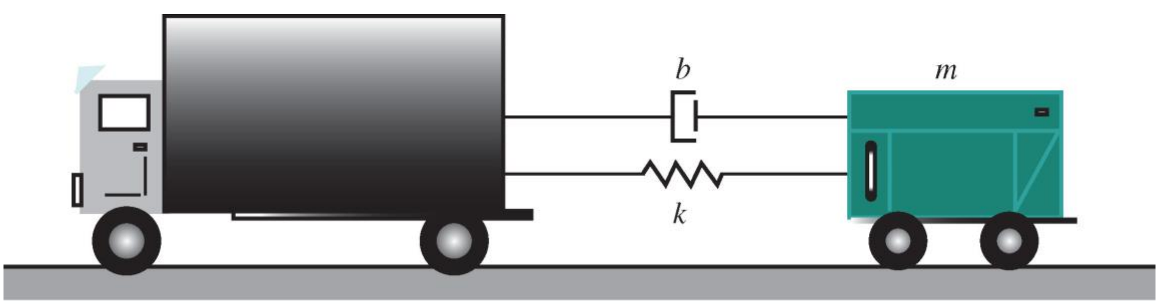
Consider the block diagram below as specified in the following various problem statements.



Given

$$G_c(s) = 10$$
$$H(s) = 1$$

and the process G(s) describes a proper relation between the speed of the truck and the speed of the cart in the figure below



where a cart of mass m = 1000 kg is attached to a truck using a spring of stiffness k =20,000 N/m and a damper of constant b = 200 Ns/m. The truck moves at a constant acceleration of a = 0.7 m/s2.

1) **If Td(s) = 0, and N(s) = 0, write down the state-space realization of the open-loop system in a controllable canonical form. (2 points)**
2) **Draw the signal flow graph for the state model you developed in question 1) (3 points)**
3) **Find out the transfer function between R(s) and Y(s) of the closed-loop system. (2 points)**
4) **If the input R(s) is a unit step input, Td(s) =0.5sin(2t), and N(s) = -1, find out the final value of the output $E_a(s)$. (3 points)**

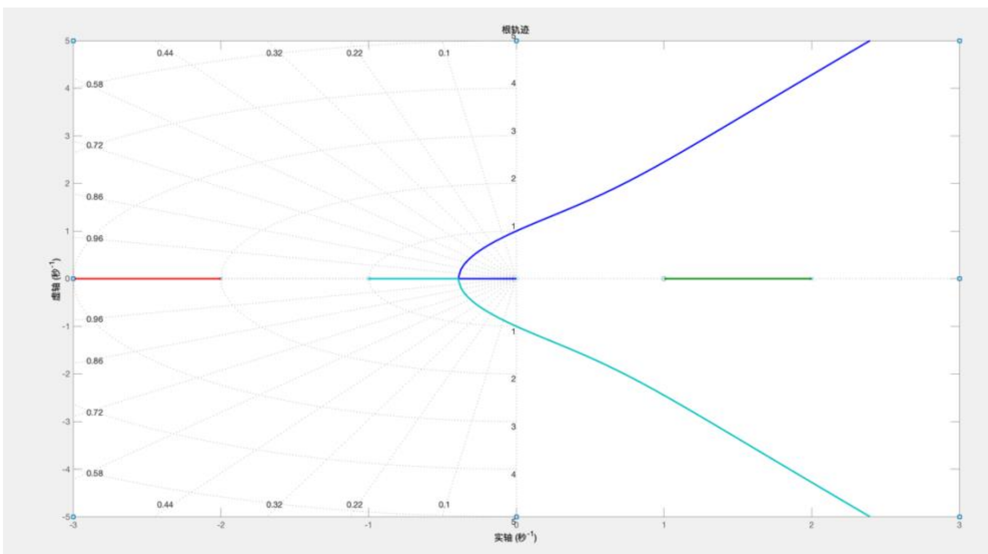
Question 3 Root locus and the Performance of the feedback control system(10 points)

Consider a unity feedback control system with the process described by

$$G(s) = \frac{s-1}{s(s-2)}$$

and a controller $G_c(s)$

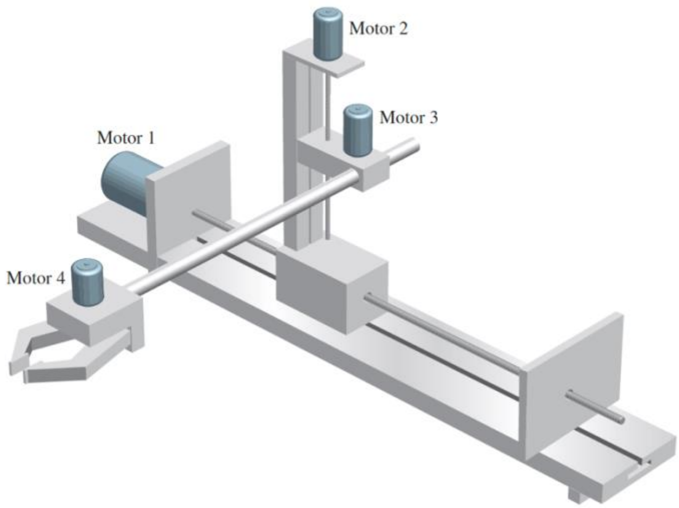
1) **Given the root locus as shown in figure below, derive the transfer function of the controller and draw the block diagram of the closed-loop system. (2 points)**



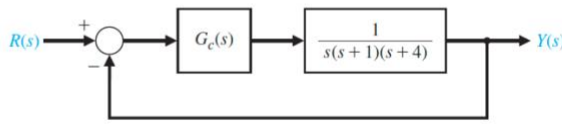
2) **Determine the value of K that leads to a marginally stable system. (3points)**
3) **Find a proper value of K such that the percentage overshoot of the closed-loop system might be smaller 30%. (3 points)**
   Hint: utilizing the root locus above and note that the answer is not unique.
4) **Predict the settling time of your design in question 3) and draw the estimates of the time response of the system with respect to a unit step input. (2 points)**

Question 4 Frequency Response method(10 points)

A three-axis pick-and-place application requires the precise movement of a robotic arm in three dimensional space, as shown in Figure below for joint 2.



(a)



(b)

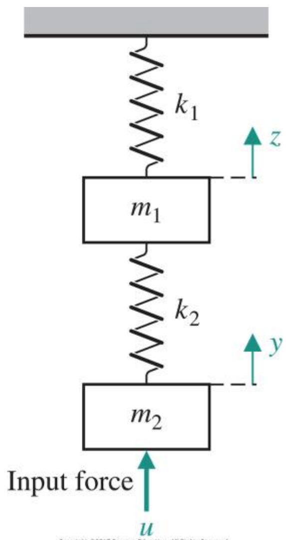
The arm has specific linear paths it must follow to avoid other pieces of machinery.

1) Let $G_c(s) = K$, and determine the gain K via Bode plot method such that the overshoot for a step input should be less than 13%.(5 points)

2) Based on the bode plot you developed in question 1), desgin a phase-lead compensator and reduce the settling time to Ts<3 s.(5 points)

Question 5: Controller Design based on the state space model (10 points)

The motion control of a lightweight hospital transport vehicle can be represented by a system of two masses, as shown in Figure below, where m1 = m2 = 1 and k1 = k2 = 1.



(1) Determine the state vector differential equation.(2 points)

(2) Establish the state space model of the system.(2points)

(3) We wish to stabilize the system by letting $u(t) = -kx_i(t)$, where u(t) is the force on the lower mass, and $x_i(t)$ is one of the state variables. Select an appropriate state variable $x_i(t)$. (2points)

(4) Consider the subsystem for the mass 2, and treated the force brought by the spring as a measurable external force. Verify that the system is observable. If so, design an observer by placing the roots of the observer poles at $s_{1,2} = -1 \pm j$.(4 points)