ENG10

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

B.ENG (HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER 2 EXAMINATIONS 2023/2024

INSTRUMENTATION AND CONTROL

MODULE NO: EEE5011

Date: Monday 13th May 2024 **Time: 10:00 – 12:30**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE:

Formula Sheet (attached).

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Question 1

(a) A first order system has the following transfer function:

$$\frac{40}{s+10}$$

State the steady state value and the time constant.

[2 marks]

Find the response of the system to a unit ramp input.

[8 marks]

(b) A second order system has the following transfer function:

$$\frac{200}{s^2+20s+900}$$

(i) Find the natural frequency ω_n, the damping ratio ζ and the damped frequency ω_d. **[6 marks]**

(ii) Calculate the peak time and the rise time for the system **[6 marks]**

(iii) Calculate the percentage overshoot for the system. **[3 marks]**

Total 25 marks

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Question 2

(a) Consider the system block diagram shown in Figure 2a.

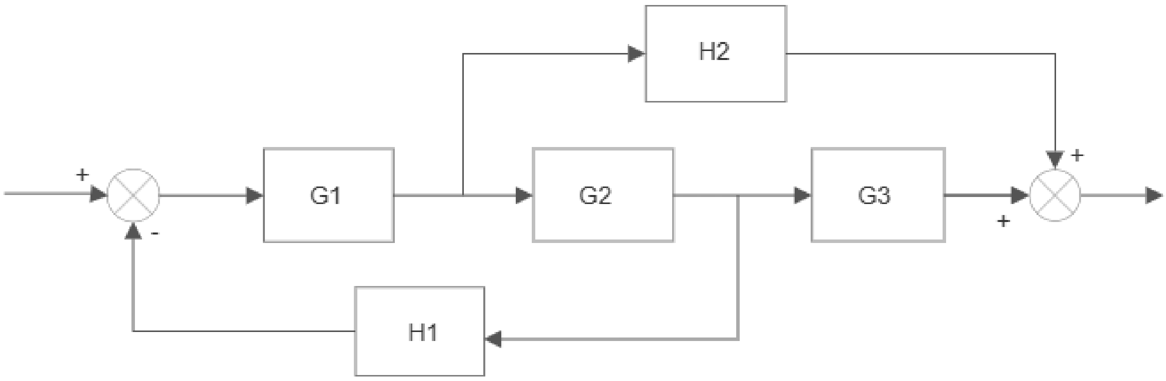

Figure 2a

By applying the rules for block reduction, find the transfer function to represent this system as a single block.

[15 marks]

(b) Consider the system block diagram shown in Figure 2b.

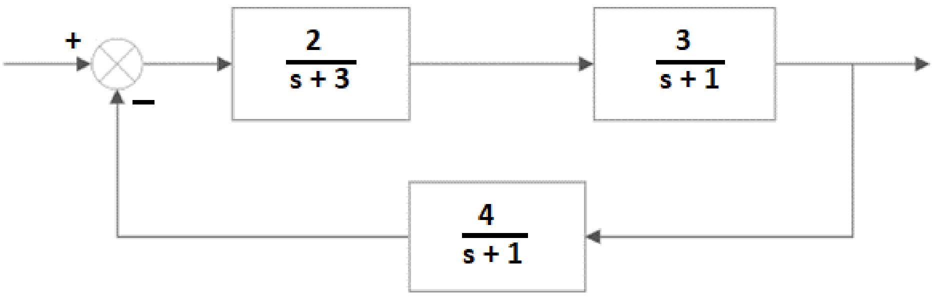

Figure 2b

Calculate and simplify the closed loop transfer function for the system.

State, with reasons, whether or not the system is stable.

[10 marks]

Total 25 marks

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Question 3

Consider the control system shown in figure 3:

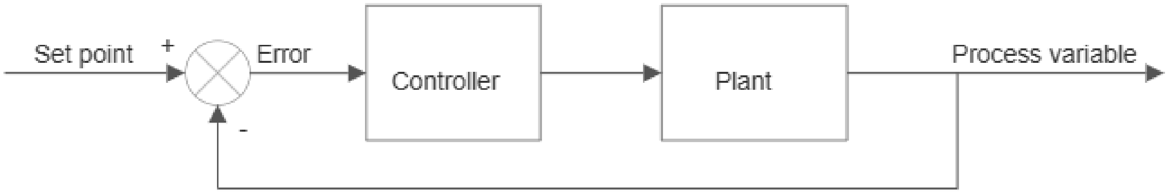

Figure 3

The controller is an integral controller, and the plant is

$$G(s) = \frac{4}{s+6}$$

and the system uses unity negative feedback. We wish to design the controller so that the overshoot does not exceed 5% and the steady state error for a unit ramp input does not exceed 0.5.

(i) Write down the *open loop* transfer function of the system. [2 marks]

(ii) Find an expression for the steady state error for unit ramp input in terms of *K*. [4 marks]

(iii) Find the range of values for *K* for which the steady state error does not exceed 0.5. [3 marks]

(iv) Find the *closed* loop transfer function of the system. [4 marks]

(v) Find expressions for the natural frequency and the damping ratio in terms of *K*. [5 marks]

(vi) Find the value of the damping ratio that gives an overshoot of 5%. [3 marks]

(vii) Find the range of values for *K* for which the overshoot does not exceed 5%. [4 marks]

Total 25 marks

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Question 4

(a) Consider the control system with disturbance shown in figure 4a

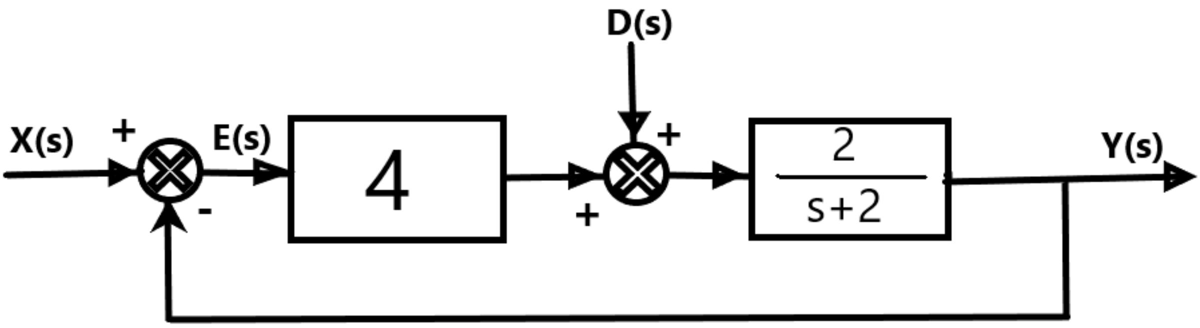

Figure 4a

Find an expression for the error $E(s)$ in terms of the input $X(s)$ and the disturbance signal $D(s)$. [9 marks]

If the input is a unit step, and the disturbance is a step of size 0.4, find the value of the steady state error. [6 marks]

(b) Consider the control system shown in figure 4b.

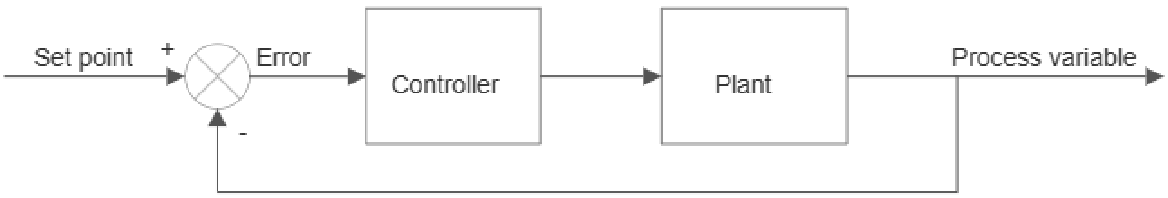

Figure 4b

The controller is an integral controller K/s, and the plant is

$$G(s) = \frac{2}{s^2 + 10s + 4}$$

(i) Find the closed loop transfer function for the system. [6 marks]

(ii) Find the range of values for *K* for which the system is stable. [4 marks]

Total 25 marks

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Question 5

a) Explain the term accuracy in instrumentation device systems and how the accuracy value of a device can be achieved. [6 marks]

b) In a temperature measuring system, the transfer function is 5 mV/k ± 2.1%, and the accuracy of the transmitter is ±1.7%. What is the system accuracy?

[3 marks]

c) Explain what the time constant factor of a sensor is in terms of first-order and second-order responses. [6 marks]

d) A linear pressure sensor has a time constant of 3.1 seconds, and a transfer function of 29 mV/kPa. What is the output after 1.3 seconds, if the pressure changes from 17 to 39 kPa? What is the pressure error at this time? [7 marks]

e) The pressure in a system has a range from 0 to 75 kPa. What is the current equivalent of 27 kPa, if the transducer output range is from 4 to 20 mA? [3 marks]

Total 25 marks

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Question 6

a) Explain what a Galvanometer is and describe its key working principles.
[8 marks]

b) Given the drawing of a Kelvin bridge shown below, draw its equivalent using the Star-Delta transformation. [8 marks]

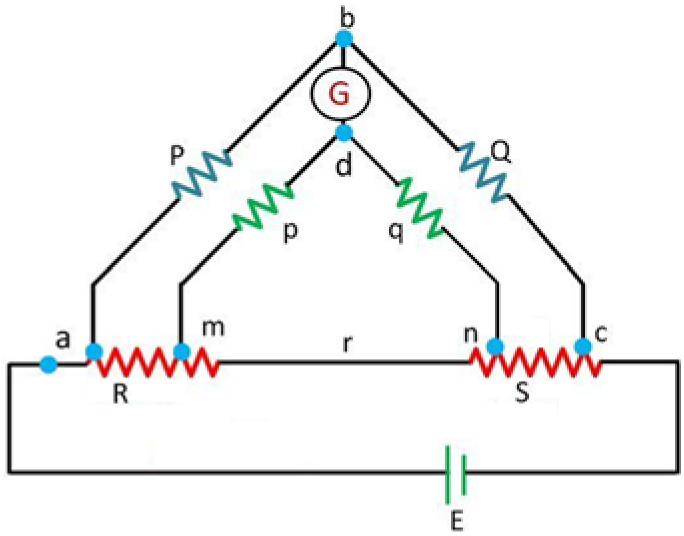

Figure 6b

c) Derive the expression to find the unknown resistance R of a Kelvin Double bridge under the balanced condition, in which the current in galvanometer = 0A. [9 marks]

Total 25 marks

END OF QUESTIONS

A FORMULA SHEET APPEARS OVER THE PAGE

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FORMULA SHEET

Parameters of second order systems

Relation between ω_n, ω_d and ζ:

$$\omega_d = \sqrt{1-\zeta^2}\,\omega_n \qquad \omega_n = \frac{1}{\sqrt{1-\zeta^2}}\omega_d \qquad \zeta = \sqrt{1-\left(\frac{\omega_d}{\omega_n}\right)^2}$$

Relation between damping ratio and percentage overshoot:

$$overshoot = 100exp\left(-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right) \qquad \zeta = \sqrt{\frac{(\ln A)^2}{\pi^2+(\ln A)^2}}$$

Rise time, peak time, and 5% and 2% settling times:

$$t_{rise} = \frac{\pi-\phi}{\omega_d} \text{ where } \phi = \cos^{-1}(\zeta) \qquad t_{peak} = \frac{\pi}{\omega_d}$$

$$t_{settle,5\%} \approx \frac{3}{\zeta\omega_n} \qquad t_{settle,2\%} \approx \frac{4}{\zeta\omega_n}$$

Table of Laplace Transforms

$\boldsymbol{f(t)}$	$\boldsymbol{F(s) = \int_0^\infty f(t)e^{-st}dt}$
1	$\frac{1}{s}$
t	$\frac{1}{s^2}$
e^{-at}	$\frac{1}{s+a}$
$\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$
$\cos\omega t$	$\frac{s}{s^2+\omega^2}$
$e^{-at}f(t)$	$F(s+a)$
$f'(t)$	$sF(s)-f(0)$

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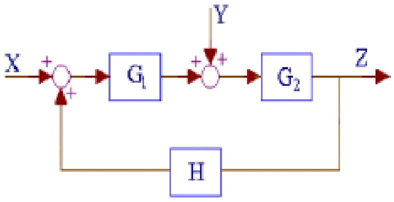
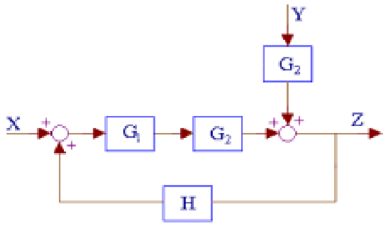
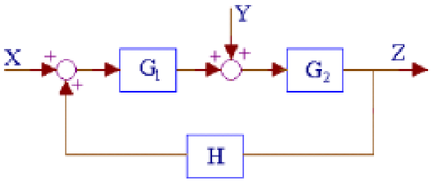
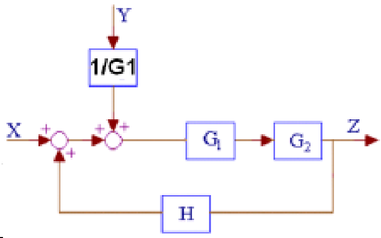
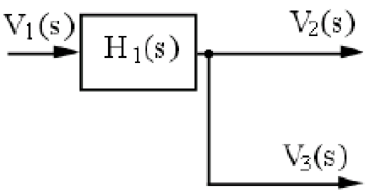
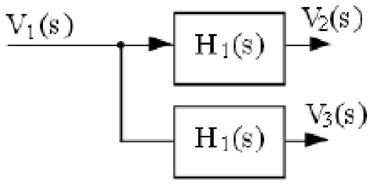
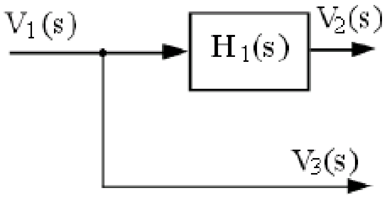
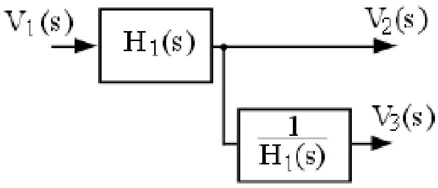
Block diagrams

Rule	Original Diagram	Equivalent Diagram
1. Moving a summing point beyond a block		
2. Moving a summing point in front a block		
3. Moving a takeoff point to front of a block		
4. Moving a takeoff point to beyond a block		

Blocks with feedback

$G(s)$ is forward path, $H(s)$ is feedback path.

Negative feedback: $\frac{G(s)}{1+G(s)H(s)}$

Positive feedback: $\frac{G(s)}{1-G(s)H(s)}$

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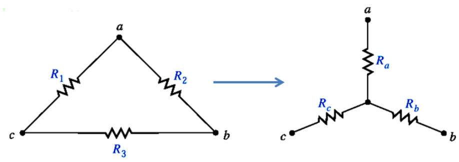
Three-phase systems:

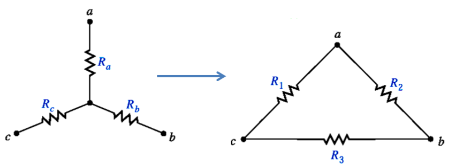


Delta to Star conversion:

$$R_a = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_b = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

$$R_c = \frac{R_3 R_1}{R_1 + R_2 + R_3}$$



Star to Delta conversion:

$$R_1 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

$$R_2 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}$$

$$R_3 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}$$

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