NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING

MENG MANUFACTURING SYSTEMS/ENGINEERING & OPERATIONS MANAGEMENT

COMPUTER CONTROL OF MANUFACTURING SYSTEMS

TIE 6120

Stage II Examination paper

MARCH 2025

This examination paper consists of **6** printed pages

Time Allowed:	**3 hours**
Total Marks:	**100**
Examiner's Name:	**G. Kanyemba and I. Mapindu**

INSTRUCTIONS AND INFORMATION TO CANDIDATE

1. The question paper consists of Section A and Section B.
2. Answer a total of **four (4)** questions, any two questions from Section A, and from Section B answer question four (4) and any other question.
3. Each Question carries a total of 25 Marks.
4. Start the answer to each full question on a fresh page.
5. Use of calculator is permissible.
6. Ensure neatness and legibility of work.

SECTION A

QUESTION 1

A field controlled d.c. motor develops a torque $T_m(t)$ proportional to the field current $i_f(t)$. The rotating parts have a moment of inertia I of 1.5 kg m^2 and a viscous damping coefficient C of 0.5 Nm s/rad.

When a current of 1.0 A is passed through the field coil, the shaft finally settles down to a steady speed $\omega_o(t)$ of 5 rad/s.

(a) Determine the differential equations relating $i_f(t)$ and $\omega_o(t)$. [6]

(b) What is the value of

(i) the coil constant K_c, [3]

(ii) and hence what is the torque developed by the motor when a current of 0.5 A flows through the field coil? [2]

(c) Given the system in Figure Q1, where R(s) is the input signal, E(s) is the error signal and Y(s) is the output signal.

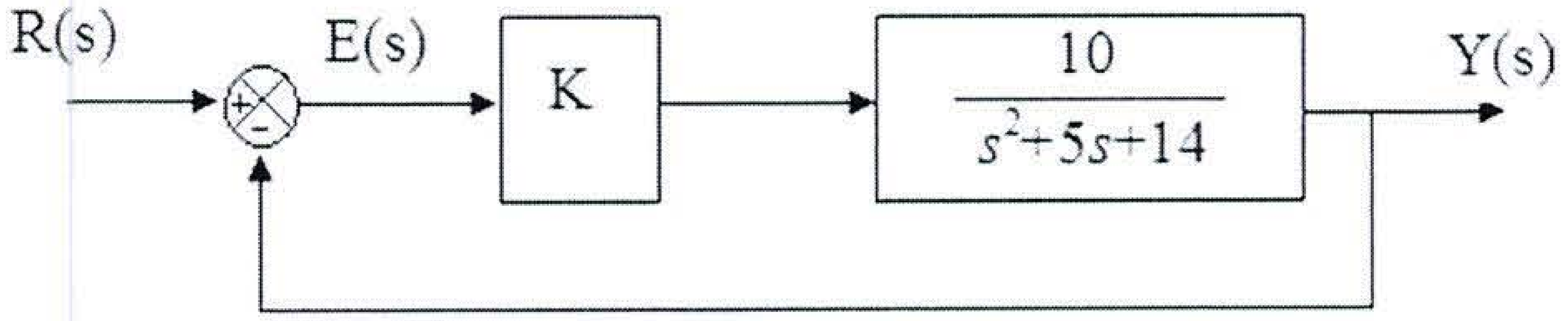

Figure Q1 Control System

(i) What is the closed-loop transfer function of the system? [4]

(ii) Calculate the value of the controller gain K required to achieve a steady error of $e_{ss} \leq 0.2$ to a unit step input? [10]

QUESTION 2

(a) Explain the experimental process of coming up with a system model in process control engineering. [10]

(b) Why is the (Proportional Integral Derivative) PID controller trusted for most industrial process control applications? [4]

(c) In practice, how do you establish the values of the constants of the PID controller? [6]

(d) Explain the practical challenges in implementing the PID controller and how they can be mitigated. [5]

QUESTION 3

(a) Figure Q3 shows the block diagram of a robtic painting arm control system.

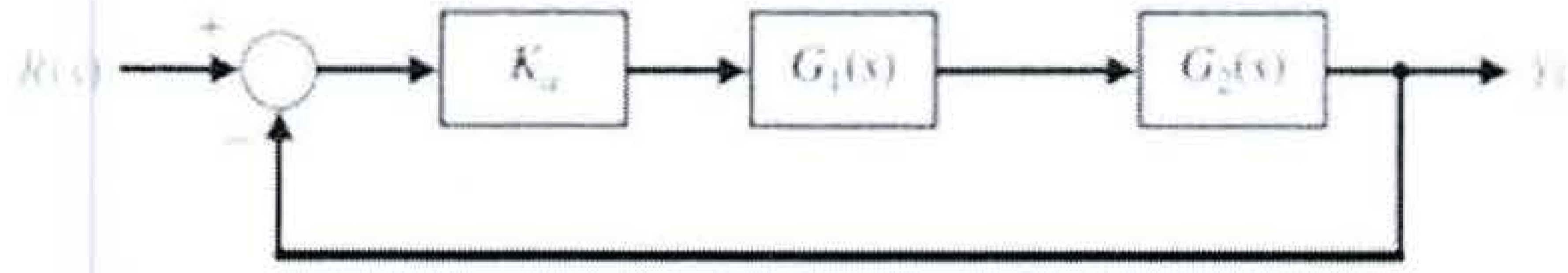

Figure Q3: Block diagram of a robotic painting arm control system.

Given that $G_1(s) = \frac{5000}{s+1000}$ and $G_2(s) = \frac{1}{s(s+20)}$.

Use the Routh-Hurwitz stability check criteria to find the value of K_a that would make the above system stable. [13]

(b) A simplified transfer function model of the motor and the tool head for an Electrical Discharge Machining (EDM) setup is found to be

$$G(s) = \frac{10}{s(1+s\tau)}, \text{ where } \tau = 0.001 \text{ s.}$$

A controller takes the difference between the actual and desired positions and generates an error signal. This error is multiplied by an amplifier gain K.

(i) Derive the error transfer function of the system. [6]

(ii) Determine the steady-state error of the system when it is subjected to a unit step input. [6]

Section B: Answer Question Four and any other question.

QUESTION 4 (Compulsory).

The surface finish of a part produced using the milling process is very crucial to its performance in the final application. The machining parameters that determine the quality of the surface finish are feed rate, spindle speed and depth of cut.

You are given the following data:

	Parameter	**Membership Functions**	**RANGE**	**Triangular Parameters**
INPUTS	Feed Rate (mm/min)	Low	50-100	[50 75 100]
		Medium	90-150	[90 120 150]
		High	140-200	[140 160 200]
	Spindle Speed (rpm)	Low	250-660	[250 500 660]
		Medium	500-1000	[500 750 1000]
		High	800-1500	[800 1200 1500]
	Depth of cut (mm)	Shallow	0.1-1	[0.1 0.5 1]
		Moderate	0.9-3	[0.9 1.5 3]
		Deep	2-5	[2 3.5 5]
OUTPUT	Surface Finish (μ m)	Micro-smooth (S2)	0.1-0.9	[0.1 0.5 0.9]
		Smooth (S1)	0.7-3	[0.7 1.9 3]
		Moderate (M)	2-5	[2 3.5 5]
		Rough (R1)	4-8	[4 6 8]
		Extra-rough (R2	7-10	[7 8.5 10]

(a) By standardizing the ranges of all variables so that they fit on a single scale on the graph, develop triangular membership functions for the inputs and the output. [7]

(b) Create reasonable fuzzy rules that relate the inputs to the output. Ensure that the rules cover all reasonable combinations.

[3]

(c) Using your graph, perform defuzzification to determine the surface finish in μm for a feed-rate of 65 mm/min, spindle speed of 930 rpm and depth of cut of 0.2 mm.

[15]

QUESTION 5

An adaptive control system is required to maintain constant cutting force during end milling for time-varying cutting conditions. As a control engineer, you are tasked with developing such a system.

(a) Develop and explain an adaptive control scheme to maintain constant cutting force during end milling for time-varying cutting conditions augmenting the performance index of the controller to reduce input signal oscillation. Provide a supporting detailed diagram for the architecture of the control system.

[20]

(b) Evaluate the use of adaptive control over the use of fixed controllers. [5]

QUESTION 6

Integrating optimized adaptive control systems with Computer Aided Process Planning (CAPP) enhances intelligent manufacturing systems. Using a machined part example of your choice, analyse this integration's industrial applicability and identify areas needing further research. Include a clear diagram illustrating the integration architecture. [25]

End of Examination question paper.

Appendix A: Laplace Tranforms table

	Time function $f(t)$	*Laplace transform* $\mathscr{L}[f(t)] = F(s)$
1	unit impulse $\delta(t)$	1
2	unit step 1	$1/s$
3	unit ramp t	$1/s^2$
4	t^n	$\frac{n!}{s^{n+1}}$
5	e^{-at}	$\frac{1}{(s+a)}$
6	$1 - e^{-at}$	$\frac{a}{s(s+a)}$
7	$\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$
8	$\cos \omega t$	$\frac{s}{s^2+\omega^2}$
9	$e^{-at} \sin \omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$
10	$e^{-at}(\cos \omega t - \frac{a}{\omega} \sin \omega t)$	$\frac{s}{(s+a)^2+\omega^2}$

(c) Constant multiplication

$$\mathscr{L}[af(t)] = aF(s)$$

(d) Real shift theorem

$$\mathscr{L}[f(t-T)] = e^{-Ts}F(s) \quad \text{for} \quad T \geq 0$$

(e) Convolution integral

$$\int_0^t f_1(\tau)f_2(t-\tau)\mathrm{d}\tau = F_1(s)F_2(s)$$

(f) Initial value theorem

$$f(0) = \lim_{t \to 0}[f(t)] = \lim_{s \to \infty}[sF(s)]$$

(g) Final value theorem

$$f(\infty) = \lim_{t \to \infty}[f(t)] = \lim_{s \to 0}[sF(s)]$$