ELEC 341 – 2021 Winter Term

Final Exam
50 Marks

Each **BULLET POINT** is a **DELIVARABLE**

Figure 1

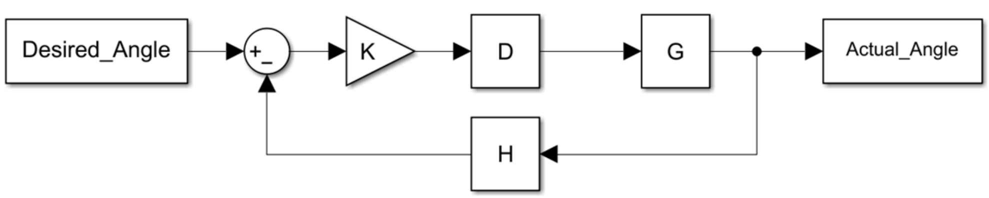

Figure 2

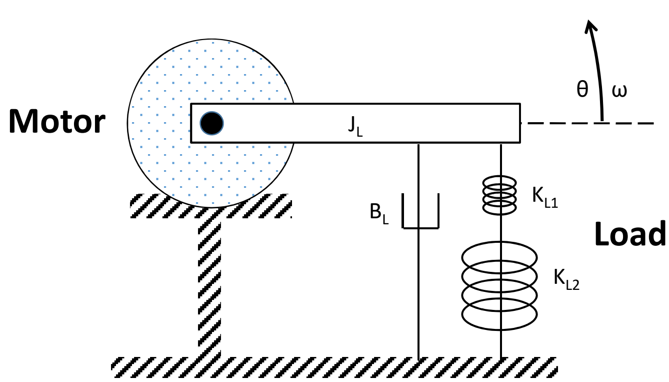

Table 1: Motor Specifications

Physical Parameter	Value	Physical Units
Nominal Voltage	12	V
No Load Current	250 + (10 x #A)	mA
Terminal Resistance	0.2	Ω
Terminal Inductance	0.5	mH
Rotor Inertia	100 + #B	gcm^2
Speed Constant	600 + (10 x #C)	RPM/V

Table 2: Micro-Controller Specifications

Physical Parameter	Value	Physical Units
Control Frequency	100 + (10 x #A)	Hz

Table 3: Load Specifications

Physical Parameter	Value	Physical Units
JL	#A + #B + #C	**μ**Nms^2/rad
BL	#D + #E + #F	**μ**Nms/rad
KL1	2	**m**Nm/rad
KL2	3 x #G	**m**Nm/rad

Table 4: Amplifier Specifications

Physical Parameter	Value	Physical Units
DC gain	#B	V/V
ωn	#A x #B x #C x #D	rad/s
zeta	#D / 10	pure

A servo-motor is a closed-loop control system that tracks a desired angle, as shown in Figure 1.
The system G consists of a voltage amplifier, motor and load.
A SCHEMATIC of the motor and load is shown in Figure 2.
The motor, load, controller, and amplifier specifications are listed in Tables 1-4.
All load impedances are ROTATIONAL. Note the physical units in Table 3.

Use any method you choose to compute the following transfer functions.

- Voltage Amplifier (V/V)
- Motor and Load (rad/V)
- Micro-Controller DAQ (rad/rad)

*Use **checkGH()** to verify GH before continuing.*

Hint: It is always wise to annotate the signals in your block diagram with physical units.

Caution: There are no part marks for this question.
It must be correct before completing the remainder of this exam.
Once verified, you know you have 20/50 marks and don't have to check it again.

1. 20 mark(s) Step 1: System Identification

Compute the **OPEN-LOOP** transfer function GH and plot the Root Locus.

- GH (rad/V)
- Root Locus (figure)

Design a **PID** Controller.

2. 3 mark(s) Steps 2-4: Phase X-Over Frequency (PXO)

Compute your starting double-zero using PXO for a controller with no dynamics (D=1) and then iterate the controller dynamics until a stable double-zero is found.
The double-zero is stable when it stops changing to **2 SIGNIFICANT DIGITS**.
Combine **ALL DOUBLE-ZERO VALUES** into a vector **zvec**.
For double-zeros in the **Left-Half-Plane**, zvec should contain **NEGATIVE** numbers.

- zvec = vector of double-zeros (rad/s)

3. 3 mark(s) Step 5: Initial Gain (K1)

Find the initial gain K1 that places the double-zero at the Gain X-Over Frequency (GXO).

- K1 = initial gain of controller (V/rad)
- GXO = Gain X-Over Freq (rad/s)
- PXO = Phase X-Over Freq (rad/s)

4. 2 mark(s) Step 6: Check Result

Plot the **Root Locus** and **identify K1** on the roots that are heading toward the Right-Half-Plane.
Generate the **Nyquist Contour after applying K1**.

- Root Locus (figure)
- Nyquist Contour (figure)

5. 3 mark(s) Step 7: Step Response

Find the Optimal Gain **Kopt** that minimizes **Rise Time** with minimal increase in **Overshoot**, and **Settle Time**.
There is no single right answer to this question so make sure all of the above Goals are satisfied.
Plot on the same graph, the Closed-Loop Step Responses of **K1** and **Kopt**.

- Step Response (K1 & Kopt) (figure)

6. 2 mark(s) Step 7: PID Gains

Compute the PID gains you would use in a micro-controller that correspond to **Kopt**.

- K = Primary Gain
- Kp = Proportional Gain
- Ki = Integral Gain
- Kd = Derivative Gain

7. 5 mark(s) Step 8: Heuristic Tune

Perform Heuristic Tuning to improve your **Closed-Loop Step Response**.
Minimize **Rise Time**, **Overshoot** and **Settle Time** as much as possible.
Your curve **MUST** overshoot at least **2%** . Recall that over-damped curves have an INFINITE Rise Time.
Provide your gains after Heuristic Tuning.

- K = Primary Gain
- Kp = Proportional Gain
- Ki = Integral Gain
- Kd = Derivative Gain

8. 5 mark(s) Step 8: Heuristic Tune

Plot on the same graph, the Closed-Loop Step Responses, before and after Heuristic Tuning.
Include a **Legend**.

- Step Response (BEFORE & AFTER) (figure)

9. 2 mark(s) Effective Zeros

Compute the two zeros resulting from Heuristic Tuning.
For zeros in the Left-Half-Plane, zvec should contain **NEGATIVE** numbers.
For a double-zero, zvec should contain two identical real numbers.
For complex zeros, zvec should contain complex conjugates.

- zvec = vector of two zeros (rad/s)

10. 5 mark(s) 2nd Order Approximation

Use **Overshoot** & **Rise Time T_R** (not T_{R1}) to compute a 2nd Order Approximation of your Heuristic Tuned response.
Plot both (Heuristic Tuned & 2nd Order Approximation) on the same graph.
Show 0.5 seconds of data.

- Step Response (TUNED & APPROX) (figure)