

ELEC 341 – f1

Study - Final Exam 100 Marks

Required Files

Available on Canvas

- **e341-f1.pdf**
- **f1DSPlot.p**
- **f1Submit.p**
- **e341-APE.pdf**

Exam description (this document)

Data-Sheet curve generator

*Grading script (**LATEST** version)*

Instructions for submitting graded work (for reference)

Regulations

Open Book

- **ANY** reference material **OK**

Lockdown Browser

- **ANY** Matlab scripts stored online **OK**
- **NO** communication
- **NO** file sharing

Fig 1a: Plant

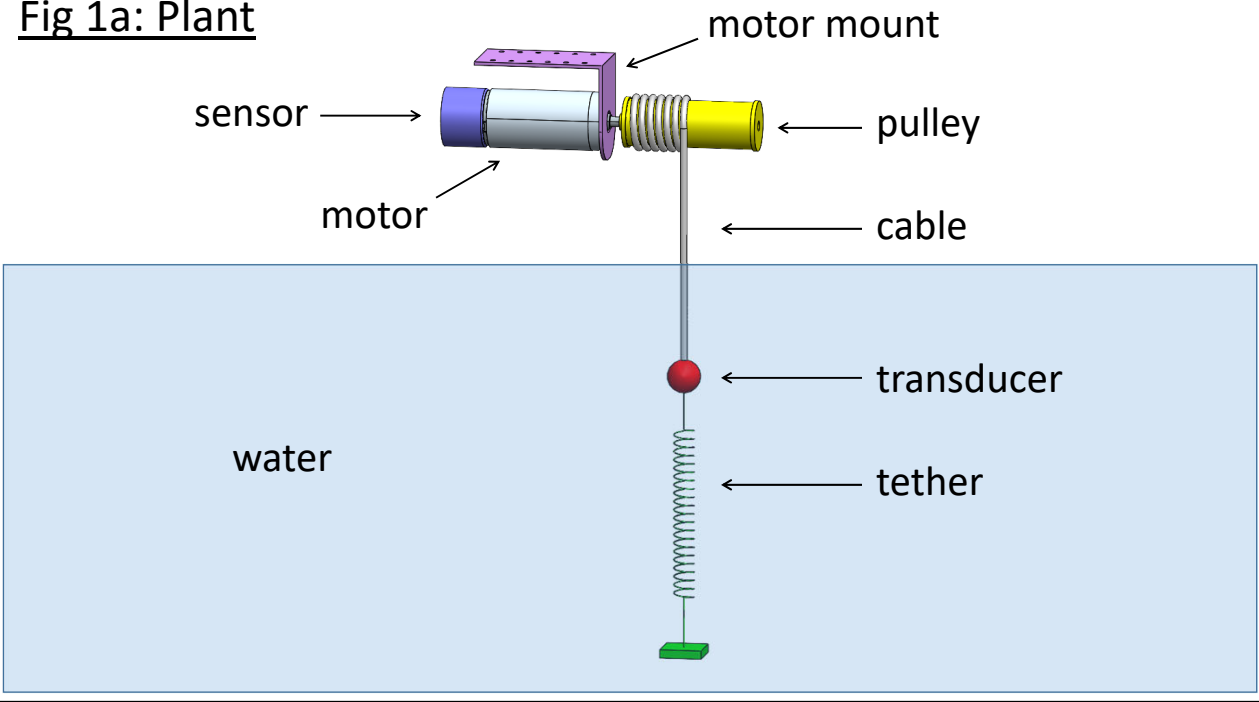


Fig 1b: Plant Parameters

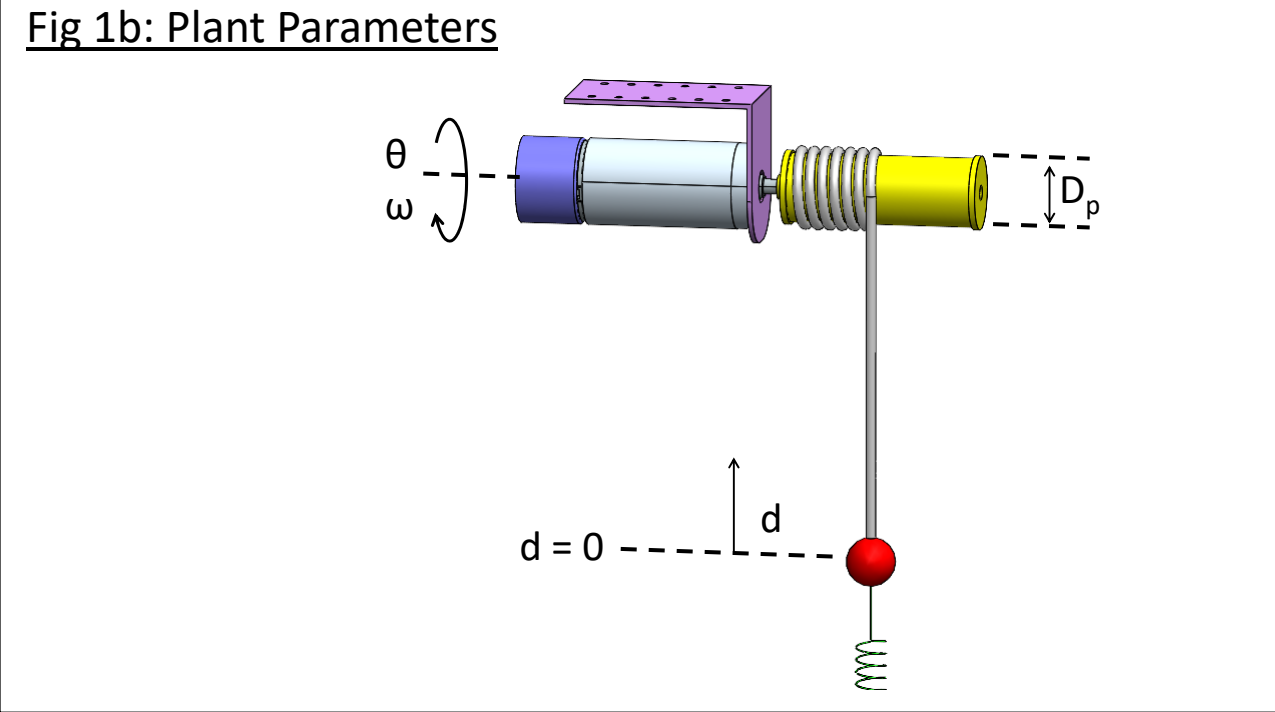


Fig 2: Sensor

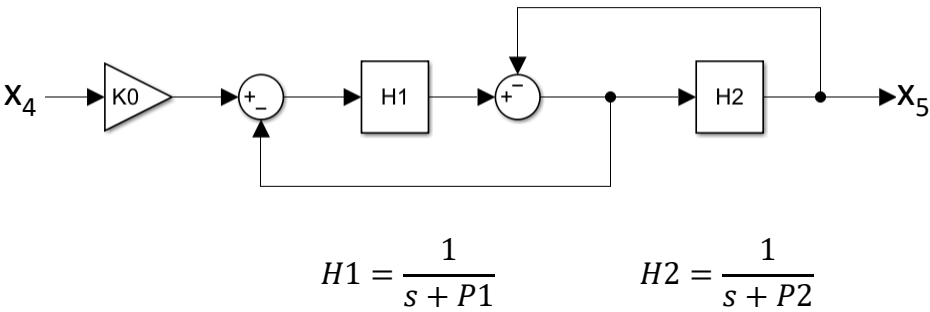


Fig 3: Plant (Pos-Control)

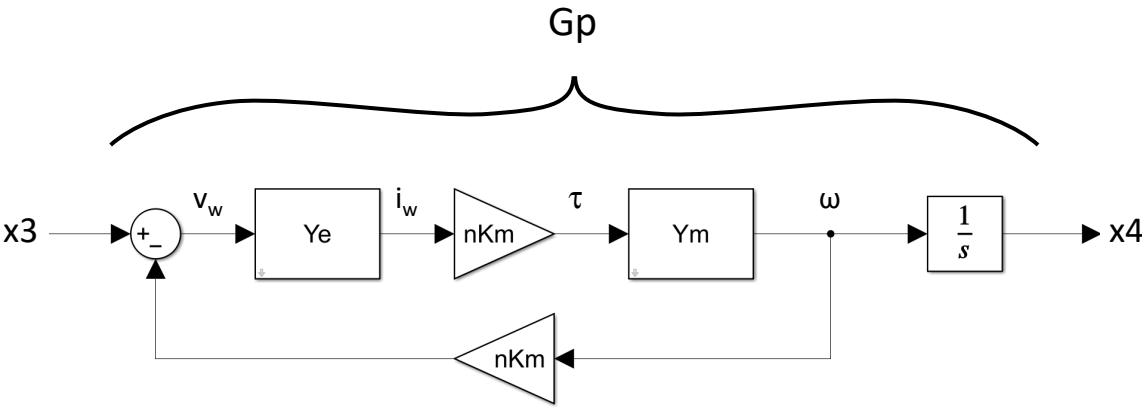


Fig 4: Control System (Pos-Control)

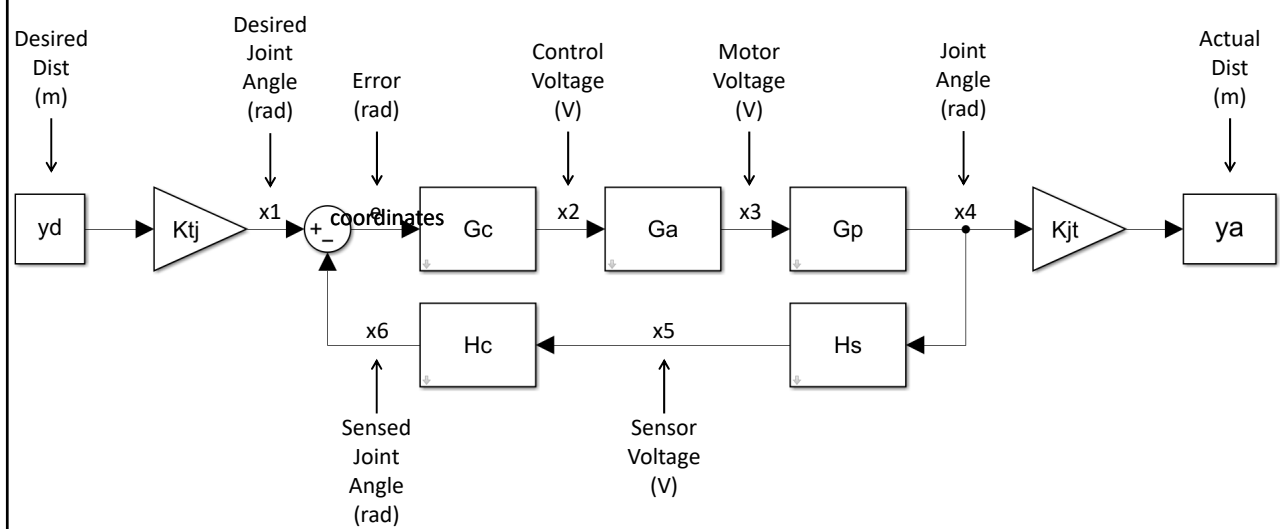


Fig 5: Worksheet

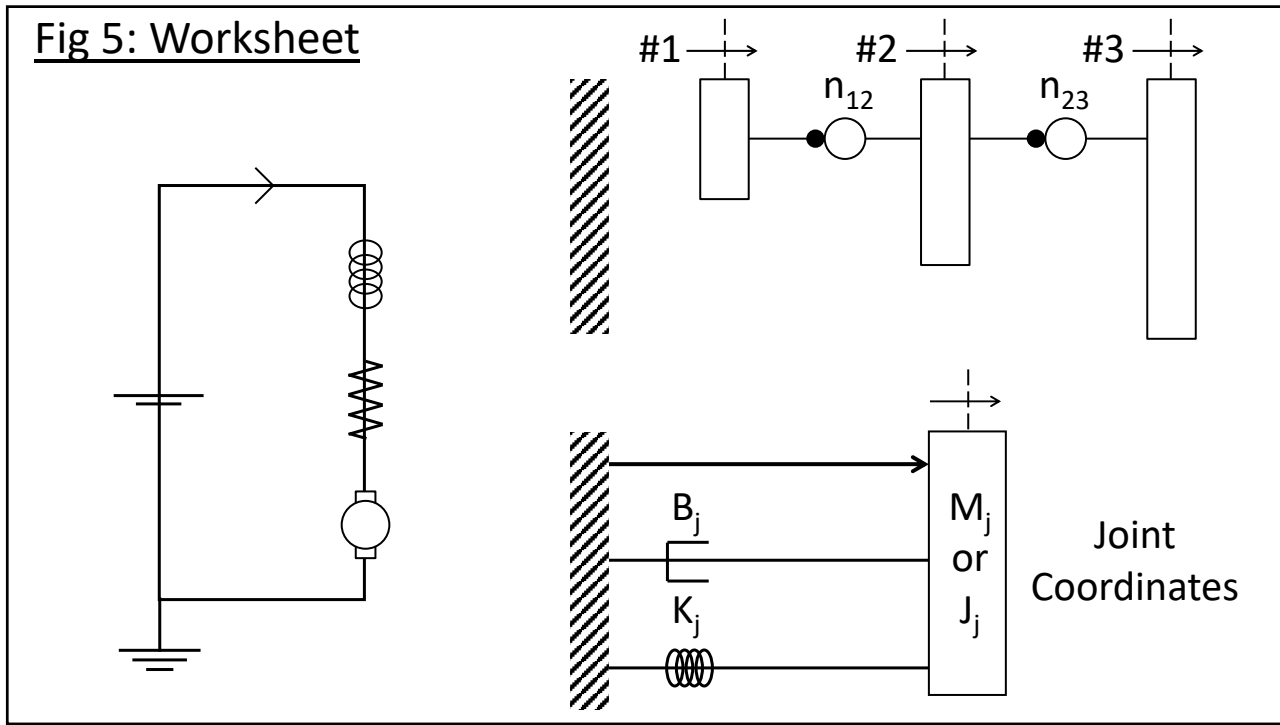


Table 1: Plant

Parameter	Value	Physical Units
D_p	#A	cm
J_p	#B x 2×10^{-4}	Nms ² /rad
M_t	#C / 2	Kg
B_p	#D x 10^{-5}	Nms/rad
B_w	#E + #F	Ns/m
K_t	#G / 2	N/m

Table 2: Sensor

Parameter	Value	Physical Units
K_0	3×10^6	V/rad
P_1	#B x 25	rad/s
P_2	#C x 25	rad/s

Table 3: Motor

Parameter	Value	Physical Units
R_w	#A / 3	Ω
L_w	#B / 5	H
K_m	#C x 2×10^{-2}	Nm/A
J_m	#D x 4×10^{-4}	Nms ² /rad
B_m	#E x 2×10^{-6}	Nms/rad

Table 5: RCGs

Parameter	Value	Physical Units
WnRes	0.1	rad/s
ZetaRes	10^{-2}	pure
TargPM	60	deg
OS_u	≤ 70 (WRT ref OS_u)	%
T_s	≤ 50 (WRT ref T_s)	%
T_r	$< T_s$	sec
E_{ss}	0	%

Table 4: Control System

Parameter	Value	Physical Units
CF	#D x 20	Hz
DC	#E + #F	%

SYSTEM IDENTIFICATION

- The Plant is shown in **Fig 1** has parameters shown in **Table 1**.
- The system adjusts the depth of an aquatic transducer used to monitor whales.
 - A motor is attached to a pulley and rotates at angle q_1 and speed ω_1 .
 - Rotating the motor in a positive direction ($q_1 > 0$), increases height ($d_2 > 0$).
 - The pulley advances a cable which is attached to a transducer.
 - The transducer is attached to a flexible tether which is fixed to the ocean floor.
 - The transducer moves to distance d_2 (y_a in **Fig 4**).
 - The transducer is neutrally buoyant so gravity can be ignored.
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- The pulley has diameter D_p and inertia J_p .
 - The friction between the cable and pulley is B_p .
 - The cable is infinitely stiff and its mass is included in J_p .
 - The transducer has mass M_t .
 - The water slows transducer motion with damping B_w .
 - The tether pulls the transducer downward with spring constant K_t .

- The Sensor shown in **Fig 2** has parameters shown in **Table 2**.
- The sensor is attached to the motor so input (x_4) is motor angle q_1 , (see **Fig 1**)
 - The output (x_5) is sensor voltage.
 - The inertia and friction of the sensor are negligible.

- The Plant detail shown in **Fig 3** has motor parameters shown in **Table 3**.
- The windings have resistance R_w and Inductance L_w .
 - The motor constant is K_m .
 - The motor has total inertia J_m .
 - The motor bearings have friction B_m .
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- The Control System shown in **Fig 4** has parameters shown in **Table 4**.
- The input & output is the desired & actual **distance** of the **Transducer** (d in **Fig 1**).
 - G_p is the plant (motor and mechanism) shown in **Fig 1** & **Fig 3**.
 - The controller operates at a control frequency CF .
 - The duty-cycle is **DC**.
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- The Worksheet in **Fig 5** is generic. **Add or remove elements as needed**.
- The Worksheet may be used to model the plant.
 - It includes 3 reference frames (#1 - #3) joined by transmissions with ratios n_{12} & n_{23} .
 - In joint coordinates, it has equivalent mass M_j or inertia J_j .
 - In joint coordinates, it has equivalent damping B_j .
 - In joint coordinates, it has equivalent stiffness K_j .

The **unit** step response of voltage amplifier $G_a = x_3/x_2$ in Fig 4 is shown by **f1DSPlot.p**.
If G_a is **under-damped**, use **SETTLE TIME** to find a 2nd order approximation.
If G_a is **over-damped**, find a 1st or 2nd order approximation, whichever is preferred.

1. 10 mark(s) Amplifier

- Q1.Ga (V/V) LTI Object

Find sensor gain: $H_s = x_5/x_4$ (see Figs 2&4)
Separate H_s into Gain K_s and Dynamics D_s .

2. 10 mark(s) Sensor

- Q2.Ks (V/rad) Scalar
- Q2.Ds (pure) LTI Object

Identify Joint, Task, and all other coordinate systems in Fig 5.
Transform all impedances to **Joint** coordinates.
Find the total equivalent inertia J_j , damping B_j and stiffness K_j .

3. 5 mark(s) Equivalent Impedance

- Q3.Jj (Nms²/rad) Scalar
- Q3.Bj (Nms/rad) Scalar
- Q3.Kj (Nm/rad) Scalar

Find ELEC admittance: $Y_e = i_w/v_w$ (see Fig 3)
Find MECH admittance: $Y_m = \omega/\tau$ (see Fig 3)
Find plant gain: $G_p = x_4/x_3$ (see Fig 3)

4. 5 mark(s) Plant Model

- Q4.Ye (A/V) LTI Object
- Q4.Ym (rad/Nms) LTI Object
- Q4.Gp (rad/V) LTI Object

Find the state-space matrices (**A,B,C,D**) for the plant G_p .
Use the state \bar{x} , input \bar{u} , and output \bar{y} vectors shown (see Fig 5b).
The output f_w is the force (N) of the water on the transducer (Task coordinates).
The output f_k is the force (N) of the spring on the transducer (Task coordinates).

5. 10 mark(s) State Space

- Q5.A (mixed) 3x3 Matrix
- Q5.B (mixed) 3x1 Matrix
- Q5.C (mixed) 2x3 Matrix
- Q5.D (mixed) 2x1 Matrix

$$\bar{x} = \begin{bmatrix} i_w \\ \omega_j \\ \tau_{Kj} \end{bmatrix} \quad \bar{u} = [x_3] \quad \bar{y} = \begin{bmatrix} f_w \\ f_k \end{bmatrix}$$

Find system gain: $GH_s = x_5/x_2$ (see Fig 4)

Find the frequency of the most dominant pole w_d of GH_s .

Find the maximum filter delay N_f for non-dominant controller FB dynamics.

For the purpose of finding N_f , **ROUND-UP** w_d to the next highest **integer**.

Find the corresponding **IIR** filter time constant **tau** and weighting factor **beta**.

6. 10 mark(s) IIR Filter

• Q6.GHs	(V/V)	LTI Object
• Q6.wd	(rad/s)	Scalar
• Q6.Nf	(pure)	Scalar
• Q6.tau	(s)	Scalar
• Q6.beta	(pure)	Scalar

***COW:** If you round w_d down rather than up, the pole becomes dominant.*

Round **tau** to 2 significant digits.

Find the associated number of **FIR** filter coefficients **num**.

7. 3 mark(s) FIR Filter

• Q7.num	(pure)	Scalar
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Find the controller feedback delay multiple **N**, assuming an IIR filter.

Find controller feedback gain: $H_c = x_6/x_5$ (see Fig 4)

8. 2 mark(s) Feedback Path

• Q8.N	(pure)	Scalar
• Q8.Hc	(rad/V)	LTI Object

Begin with a unity gain, 0-order controller. In other words, $G_c=1$.

Find forward gain: $G = x_4/x_2$ (see Fig 4)

Find feedback gain: $H = x_6/x_4$ (see Fig 4)

Find loop gain: $GH = x_6/x_2$ (see Fig 4)

Find static gains: K_{tj} & K_{jt} (see Fig 4)

9. 5 mark(s) System Model

• Q9.G	(rad/V)	LTI Object
• Q9.H	(pure)	LTI Object
• Q9.GH	(rad/V)	LTI Object
• Q9.Ktj	(rad/m)	Scalar
• Q9.Kjt	(m/rad)	Scalar

CONTROL

Develop a **PID** controller. Refer to **Table 5** for RCGs.

Find the Partial Dynamics **D_p**.

Use the same filter in the derivative path that you designed for the feedback path.

Find the initial gain for marginal stability **K₀** using the partial dynamics **D_p**.

Find the cross-over frequency **w_{xo}**.

10. 5 mark(s)

Partial Dynamics

• Q10.Dp

(pure)

LTI Object

• Q10.K0

(V/rad)

Scalar

• Q10.wxo

(rad/s)

Scalar

Find optimal **w_n** & **z** values to maximize phase margin **PM** using search resolution **WnRes** & **ZetaRes** shown in **Table 5**. Only search values rounded to the search resolution.

Find the associated zero(s) **Z** from the optimal **w_n** & **z** values, and the full dynamics **D**.

11. 10 mark(s)

Controller Zero(s)

• Q11.Z

(rad/s)

1x2 Vector

• Q11.PM

(deg)

Scalar

• Q11.D

(pure)

LTI Object

Find the master gain **K** that delivers the **TargPM** shown in **Table 5**.

12. 2 mark(s)

Master Gain

• Q12.K

(V/rad)

Scalar

Find the **Reference** gains **K_p**, **K_i**, **K_d**, corresponding to unity master gain **K=1**.

13. 3 mark(s)

Reference Gains

• Q13.Kp

(pure)

Scalar

• Q13.Ki

(sec⁻¹)

Scalar

• Q13.Kd

(sec)

Scalar

Find the **Reference** performance metrics, rise time **T_r**, peak time **T_p**, settle time **T_s**, input overshoot **OS_u**, output overshoot **OS_y**, and steady-state error **E_{ss}**.

14. 3 mark(s)

Reference Performance Metrics

• Q14.Tr

(sec)

Scalar

• Q14.Tp

(sec)

Scalar

• Q14.Ts

(sec)

Scalar

• Q14.OSu

(%)

Scalar

• Q14.OSy

(%)

Scalar

• Q14.Ess

(%)

Scalar

Use heuristic tuning to satisfy the RCGs shown in **Table 5**.
All RCGs are relative to the **Reference** performance metrics.
Find the **Tuned** gains K_p , K_i , K_d , corresponding to unity master gain $K=1$.

15. 12 mark(s) Tuned Gains

- Q15.Kp (pure) Scalar
- Q15.Ki (sec^{-1}) Scalar
- Q15.Kd (sec) Scalar

Find the **Tuned** performance metrics, rise time T_r , peak time T_p , settle time T_s , input overshoot OS_u , output overshoot OS_y , and steady-state error E_{ss} .

16. 5 mark(s) Tuned Performance Metrics

- Q16.Tr (sec) Scalar
- Q16.Tp (sec) Scalar
- Q16.Ts (sec) Scalar
- Q16.OSu (%) Scalar
- Q16.OSy (%) Scalar
- Q16.Ess (%) Scalar

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