

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

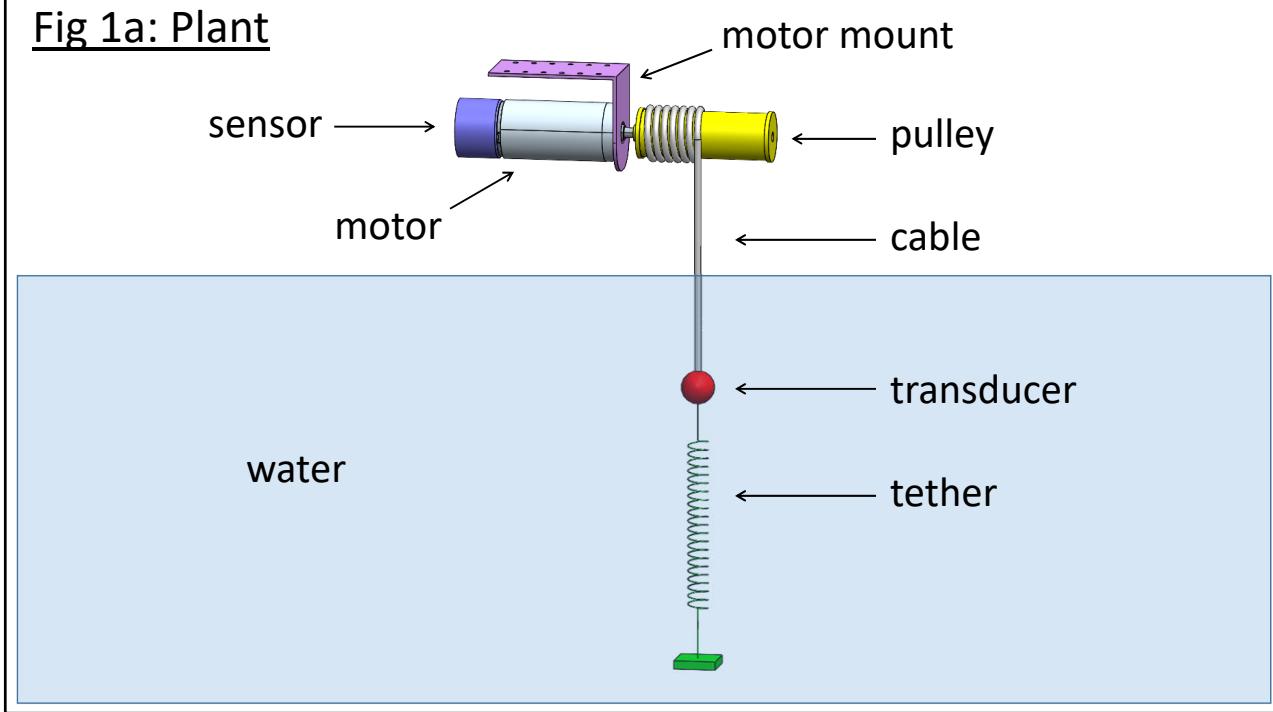


Fig 1b: Plant Parameters

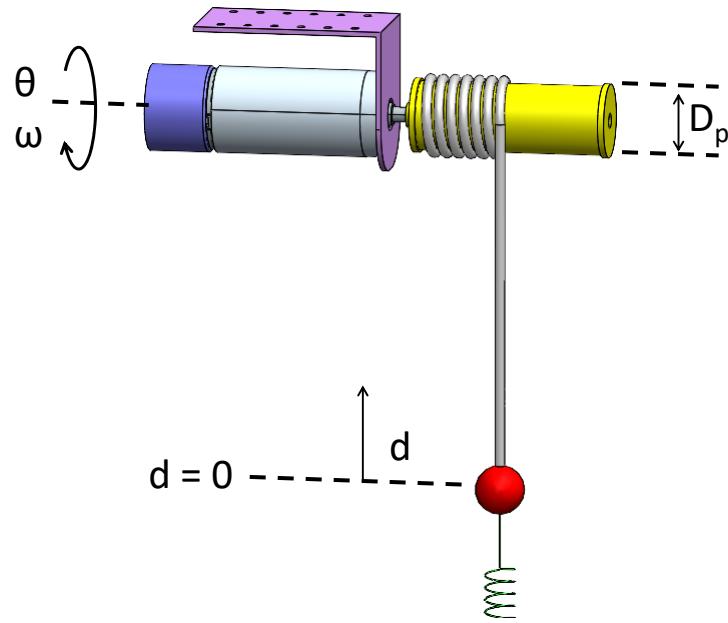
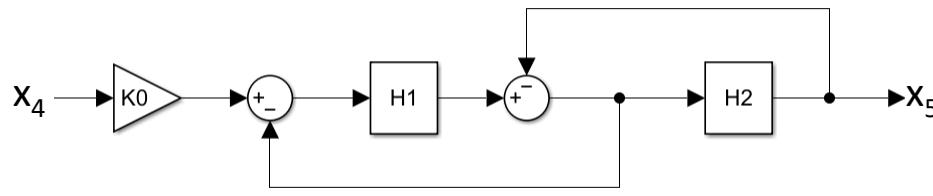


Fig 2: Sensor

$$H1 = \frac{1}{s + P1} \quad H2 = \frac{1}{s + P2}$$

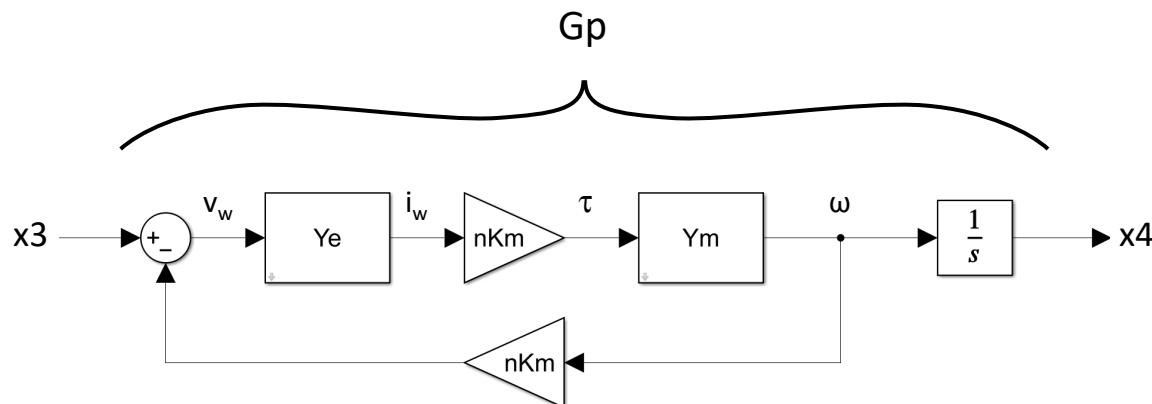
Fig 3: Plant (Pos-Control)

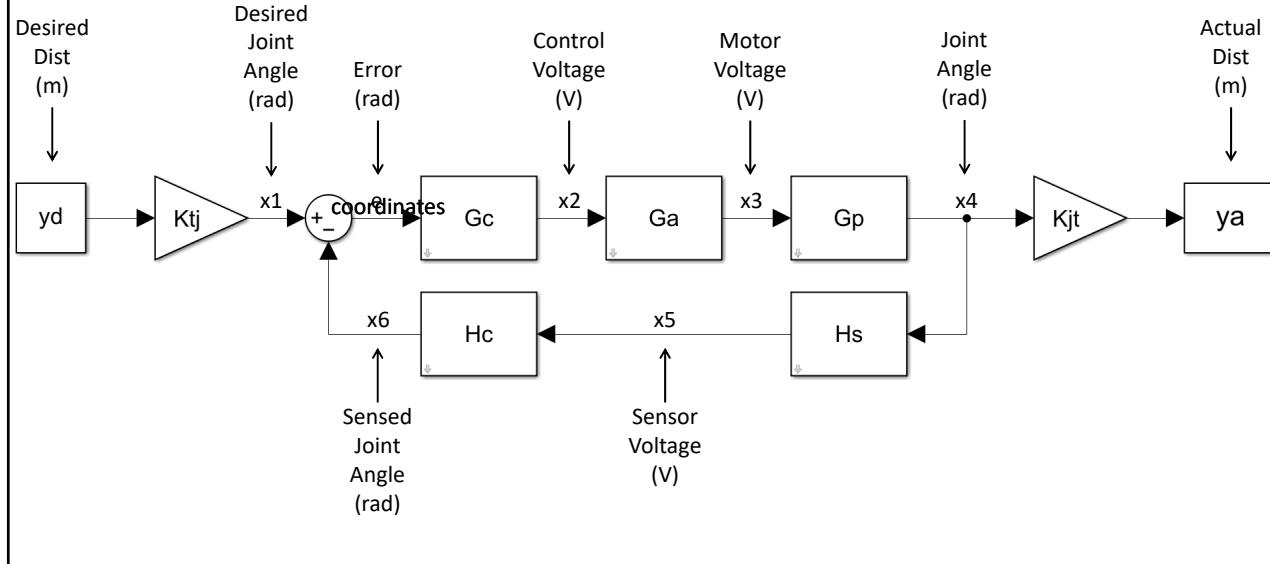
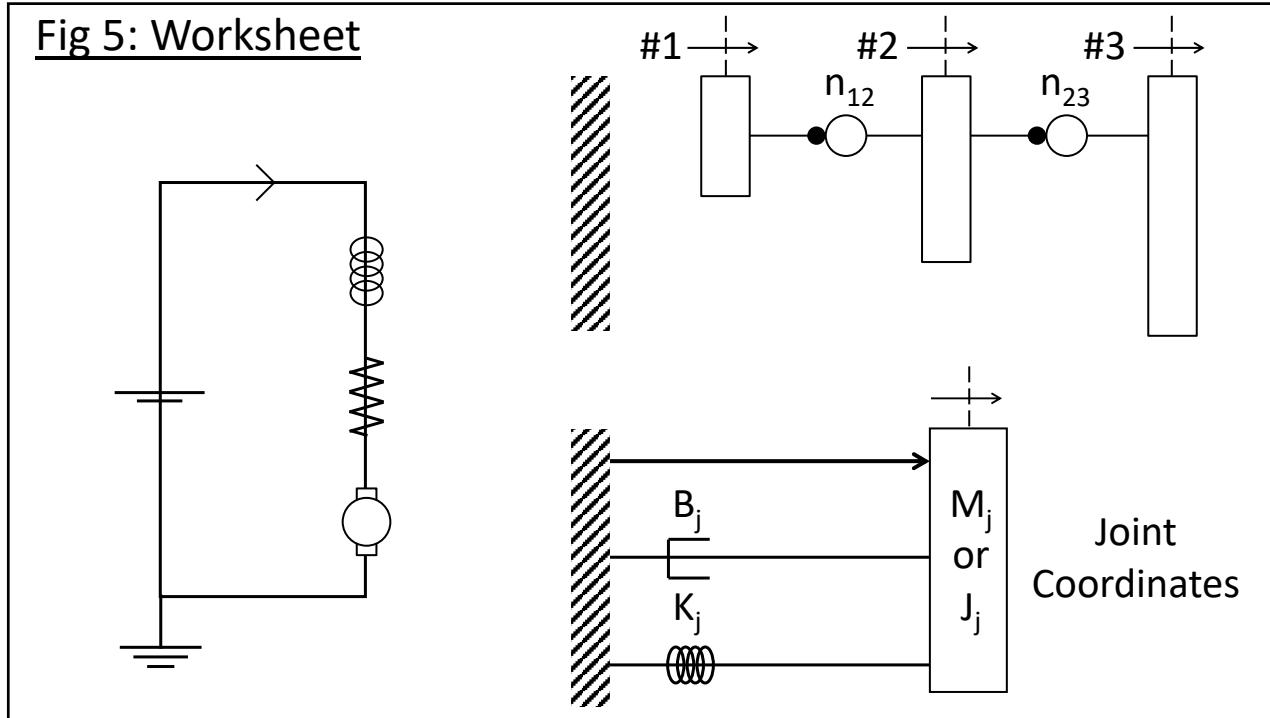
Fig 4: Control System (Pos-Control)Fig 5: Worksheet

Table 1: Plant

Parameter	Value	Physical Units
D_p	#A	cm
J_p	#B $\times 2 \times 10^{-4}$	Nms ² /rad
M_t	#C / 2	Kg
B_p	#D $\times 10^{-5}$	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 $\times 25$	rad/s
P_2	#C $\times 25$	rad/s

Table 3: Motor

Parameter	Value	Physical Units
R_w	#A / 3	Ω
L_w	#B / 5	H
K_m	#C $\times 2 \times 10^{-2}$	Nm/A
J_m	#D $\times 4 \times 10^{-4}$	Nms ² /rad
B_m	#E $\times 2 \times 10^{-6}$	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 $\times 20$	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.
- 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 .

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**.

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: $\mathbf{GH}_s = \mathbf{x}_5/\mathbf{x}_2$ (see Fig 4)

Find the frequency of the most dominant pole w_d of \mathbf{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

Find the controller feedback delay multiple **N**, assuming an IIR filter.

Find controller feedback gain: $\mathbf{H}_c = \mathbf{x}_6/\mathbf{x}_5$ (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, $\mathbf{G}_c=1$.

Find forward gain: $\mathbf{G} = \mathbf{x}_4/\mathbf{x}_2$ (see Fig 4)

Find feedback gain: $\mathbf{H} = \mathbf{x}_6/\mathbf{x}_4$ (see Fig 4)

Find loop gain: $\mathbf{GH} = \mathbf{x}_6/\mathbf{x}_2$ (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 \mathbf{D}_p .

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

Find the initial gain for marginal stability K_0 using the partial dynamics \mathbf{D}_p .

Find the cross-over frequency ω_{xo} .

10. 5 mark(s) Partial Dynamics

- Q10.Dp (pure) LTI Object
- Q10.K0 (V/rad) Scalar
- Q10.wxo (rad/s) Scalar

Find optimal ω_n & ζ 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 ω_n & ζ values, and the full dynamics \mathbf{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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