ELEC 341 – p1

Project Part 1 – System ID
50 Marks (but graded 2x)

Required Files

Available on Canvas

- **e341-p1.pdf** *Project description (this document)*
- **p1DSPlot.p** Data-Sheet curve generator
- **p1Submit.p** *Grading script (**LATEST** version)*
- **e341-APE.pdf** *Instructions for submitting graded work (for reference)*

Topics

Black Box System ID
- 2nd order approximation

White Box System ID
- circuit analysis & state-space

System Verification
- DC gains

Fig 1a: Gripper

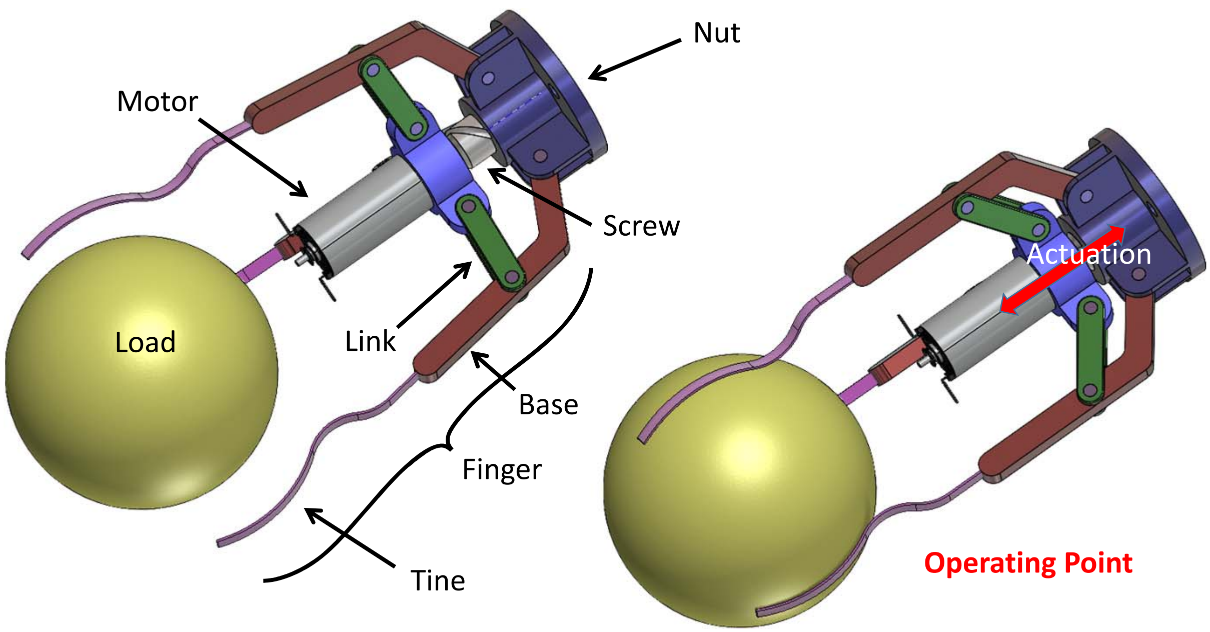


Fig 1b: Operating Point

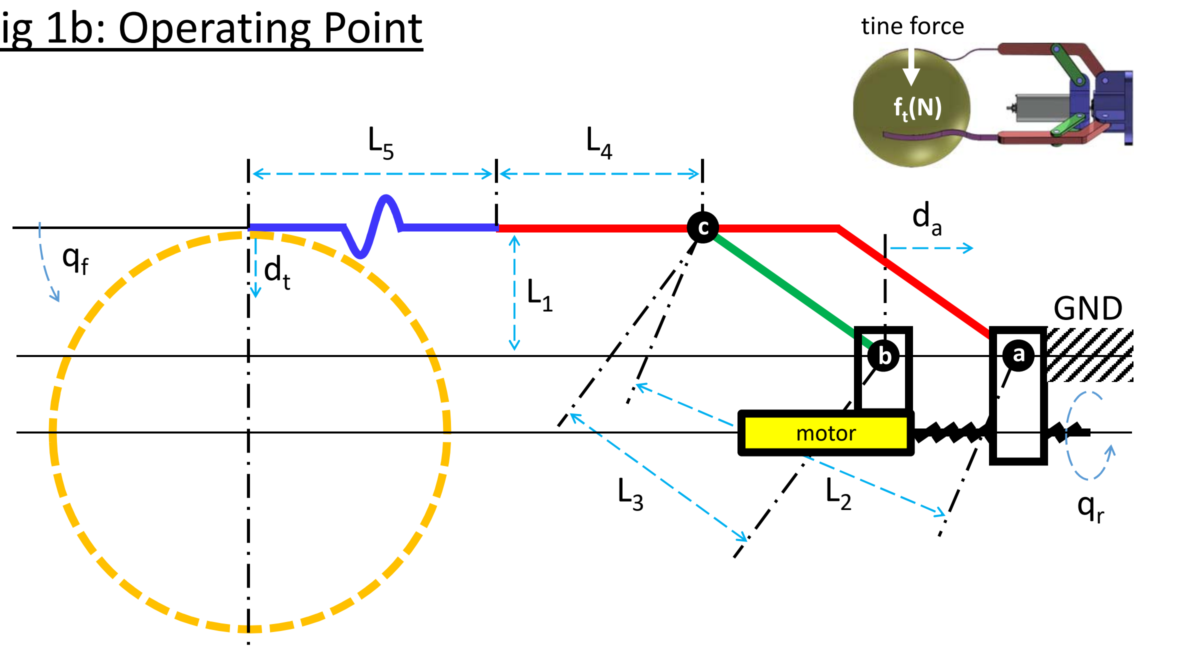


Fig 1c: Effective Geometry

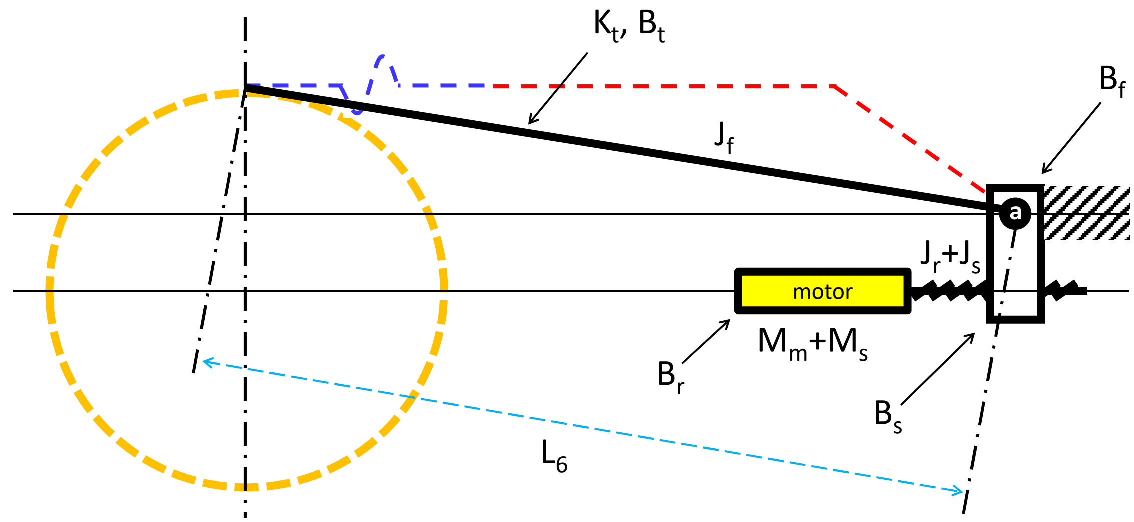


Fig 2: Sensor

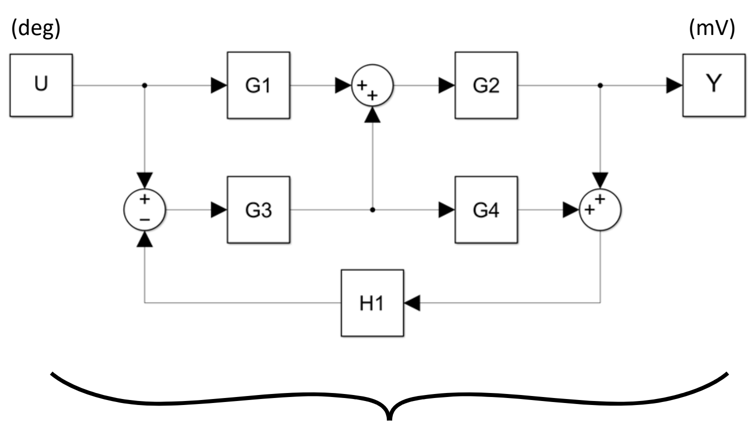
$$G_1 = \frac{P_1}{s + P_2}$$

$$G_2 = \frac{P_3}{s + P_4}$$

$$G_3 = \frac{10^5}{s + P_5}$$

$$G_4 = \frac{P_6}{s + P_7}$$

$$H_1 = \frac{4}{s + P_8}$$



$$H_s = \frac{Y}{U}$$

Fig 3: Plant (Pos-Control)

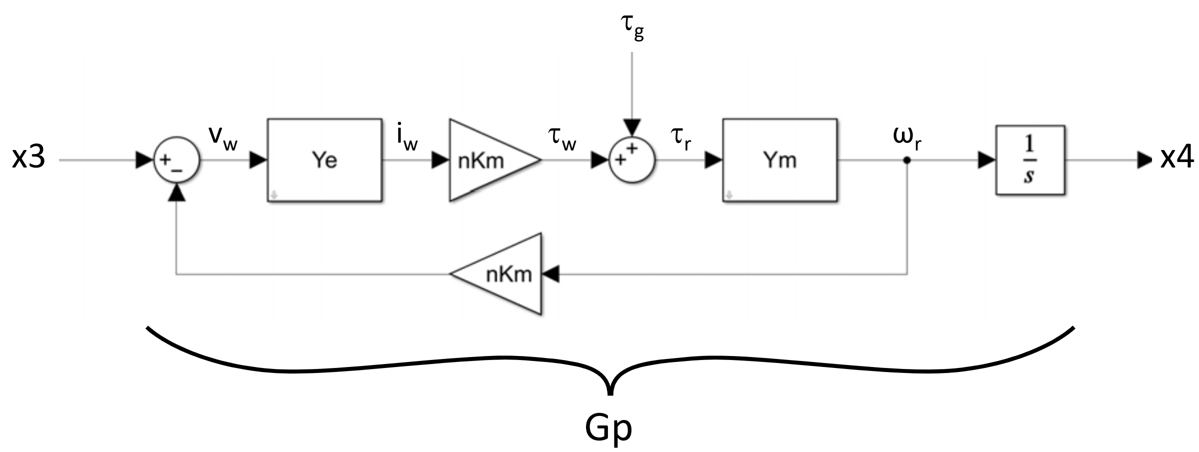


Fig 4: System (Pos-Control)

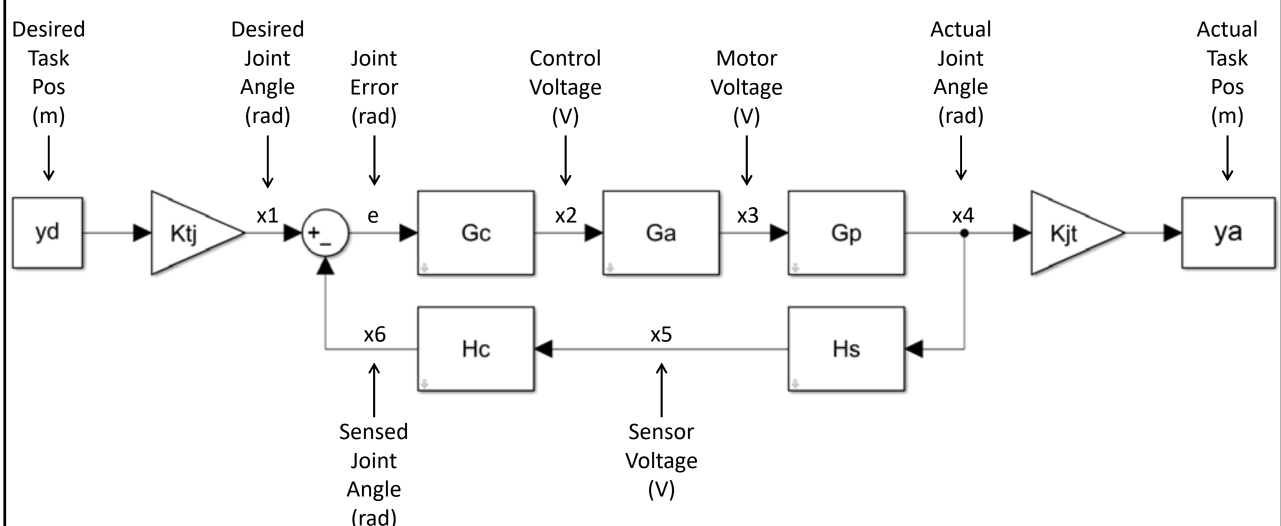


Fig 5: System Model

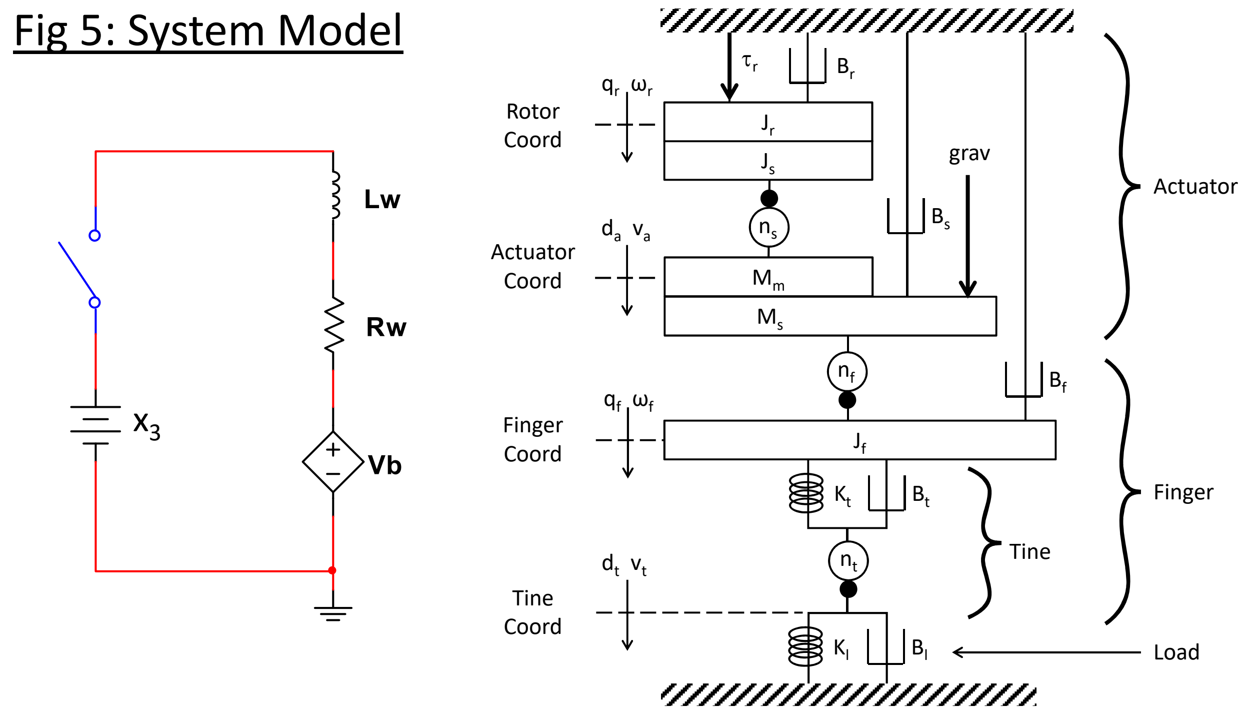


Table 1: Plant

Parameter	Value	Physical Units
J_s	#A / 5	g-cm^2
M_s	#B / 4	g
B_s	#C / 3	Ns/m
n_s	#D / (2 x #E)	turn/cm
J_f	#F / 3	g-cm^2
B_f	#G	mNms
n_f	#H	deg/cm
B_t	#A	mNms
K_t	#B x #C	mNm
n_t	*from geometry*	*n/a*
B_l	#D / 5	Ns/m
K_l	#E x #F	N/m
L_6	(#G + #H) x 4	mm

Table 2: Sensor

Parameter	Value	Physical Units
P_1	#A x 7	n/a
P_2	#B x 800	rad/s
P_3	#C x 8	n/a
P_4	#D x 700	rad/s
P_5	#E x 600	rad/s
P_6	#F x 50	n/a
P_7	#G x 500	rad/s
P_8	#H x 5	rad/s

Table 3: Motor

Parameter	Value	Physical Units
R_w	#A / 2	Ω
L_w	#B x 30	μH
K_m	#C	mNm/A
J_r	#D / 15	g-cm^2
B_r	#E / 30	μNms
M_m	#F + #G	Kg

Table 4: Control System

Parameter	Value	Physical Units
CF	#A x #B x 5	Hz
DC	#C + #D + #E + #F	%

Table 5: RCGs

Parameter	Value	Physical Units
WnRes	0.1	rad/s
ZetaRes	10^{-2}	pure
TargPM	40	deg
OS_u	≤ 60 (WRT ref OS_u)	%
T_s	≤ 75 (WRT ref T_s)	%
T_r	< final T_s	sec
E_{ss}	0	%

DESCRIPTION

A gripper is shown in **Fig 1**.

- The gripper has a motor connected to the screw of a lead-screw.
- The nut of the lead-screw is fixed.
- Rotating the screw causes the motor & screw to move back and forth.

- The gripper has 3 symmetrical fingers, designed to grasp a spherical load.
- Each finger consists of a link, a base and a flexible tine.
- The tines bend as the load is grasped to minimize damage to a fragile load.

The gripper is not LTI.

- The load impedance disappears when the load is released.
- The geometry causes a time-varying relationship between motor and finger angle speed.

Instead, an LTI model is approximated, as shown in **Fig 1b**.

- Geometric non-linearities are avoided by considering a meaningful, fixed operating point.
- The operating point is when the tines first contact the load.
- Each tine is assumed to remain in contact with the load at all times (even when the gripper opens).
- Link inertia is small and is neglected.
- Load mass is small and is neglected. This is not the total load mass, but only the small element of mass that moves as the load is grasped and is slightly compressed.

The System Model shown in **Fig 5** has 3 transmissions and 4 coordinate frames.

- Rotor coordinates (angular motion)
- Actuator coordinates (linear motion)
- Finger coordinates (angular motion)
- Tine coordinates (linear motion)

Gripper parameters are shown in **Table 1**. and Motor parameters are shown in **Table 3**.

- The motor applies torque $\boldsymbol{\tau_r}$ to the screw of the lead-screw.
- The rotor and screw rotate to an angle $\mathbf{q_r}$.
- Friction between the motor rotor and stator is represented by rotor damping $\mathbf{B_r}$.
- The motor rotor has inertia $\mathbf{J_r}$ and the screw has inertia $\mathbf{J_s}$.
- For each unit of screw rotation, the screw translates a distance of $\mathbf{n_s}$.
- The actuator (motor & screw) move to a distance $\mathbf{d_a}$.
- The motor has mass $\mathbf{M_m}$ and the screw has mass $\mathbf{M_s}$.
- Friction between the screw and nut is represented by **linear** damping $\mathbf{B_s}$.
- For each unit of screw translation, the linkage rotates the fingers by $\mathbf{n_f}$.
- Each finger rotates to an angle $\mathbf{q_f}$.
- Each finger has inertia $\mathbf{J_f}$, which includes the inertia of the tine.
- The combined friction at joints "**a**", "**b**", and "**c**" is represented by $\mathbf{B_f}$.
- Each tine has angular stiffness of $\mathbf{K_t}$ and material damping $\mathbf{B_t}$.
- As each finger rotates, the tip of the unloaded tine translates a circumferential distance $\mathbf{n_t}$.
- Each tine tip translates at an effective circumferential distance $\mathbf{d_t}$.
- The load at each contact point has **linear** stiffness $\mathbf{K_l}$ and damping $\mathbf{B_l}$.

The motor voltage is supplied by an off-the-shelf (OTS) voltage amplifier.
Its **unit** step response $\mathbf{G_a = x_3/x_2}$ (see **Fig 4**) is shown by **p1DSPlot.p**.
The experimental data was recorded using a DAQ with a fixed resolution.
Estimate the continuous curve that was the input to the DAQ.
Estimate rise-time $\mathbf{T_r}$, peak time $\mathbf{T_p}$, settle time $\mathbf{T_s}$, and percent overshoot $\mathbf{OS_y}$.

1. 5 mark(s) Amplifier Metrics

- Q1.Tr (s) Scalar
- Q1.Tp (s) Scalar
- Q1.Ts (s) Scalar
- Q1.OSy (%) Scalar

Find an approximation of the **estimated** continuous curve.
If $\mathbf{G_a}$ is **under-damped**, use **PEAK TIME** to find a 2nd order approximation.
If $\mathbf{G_a}$ is **over-damped**, find a **1st** or **2nd** order approximation, whichever is preferred

2. 5 mark(s) 2nd Order Approx

- Q2.Ga (V/V) LTI Object

Motor angle is measured by a position sensor with an internal electronics.
The data-sheet provides the equivalent Block Diagram shown in **Fig 2**.

Find sensor gain: $\mathbf{H_s = x_5/x_4}$ (see **Figs 2**&**3**)

Find DC gain of $\mathbf{H_s}$: $\mathbf{K_s}$

Find dynamics of $\mathbf{H_s}$: $\mathbf{D_s}$

3. 5 mark(s) Analog Position Sensor

- Q3.Ks (V/deg) Scalar
- Q3.Ds (pure) LTI Object

COW: *Check your results.*

*A pole-zero plot **pzmap()** can be used to check if your transfer function is reasonable.*
You could also check the time constant of the step response.
You could also draw it using Simulink and compare the response.

Use circuit analysis to find electrical admittance $\mathbf{Y_e}$ in **Fig 3**.

Find electrical admittance: $\mathbf{Y_e = i_w/v_w}$

4. 5 mark(s) Elec Admittance

- Q4.Ye (A/V) LTI Object

Use circuit analysis to find mechanical admittance $\mathbf{Y_m}$ in **Fig 3**.

You can transform the mechanical circuit to an electrical circuit, or solve the mechanical circuit directly. It's your choice.

Find mechanical admittance: $\mathbf{Y_m = \omega_r/\tau_r}$

5. 5 mark(s) Mech Admittance

- Q5.Ym (rad/Nms) LTI Object

To account for gravity, add a constant gravitational torque τ_g to winding torque τ_w, as shown in **Fig 3**. The sign depends on orientation (fingers pointing up or down).

Find the **magnitude** of gravitational torque τ_g.

6. 5 mark(s) Gravitational Torque

- Q6.taug (Nm) Scalar

COW: *Only parts that move parallel to gravity, are affected by gravity.*

In Fig 4, **Joint Angle** is an angle that exists in something called **Joint Coordinates**.
From **Figs 3 & 4**, determine which coordinate system in **Fig 5** is **Joint Coordinates**.
Transform all impedances (in **Fig 5**) to **Joint Coordinates**.
Find the state-space matrices (**A** & **B**) for the plant $\mathbf{G_p}$.
For each desired output, add a row to the output matrices (**C** & **D**) and solve for **y/u**.
Neglect **gravity**. To account for gravity, a second set of transfer functions is needed and super-position is applied. That can be done later.

Find torque gain: $\mathbf{G_{tau} = \tau_r/x_3}$ (see **Figs 3-5**)

7. 5 mark(s) Torque Gain

- Q7.Gtau (Nm/V) LTI Object

Find motor angle gain: $\mathbf{G_q = q_r/x_3}$ (see **Figs 4-5**)

8. 5 mark(s) Motor Angle Gain

- Q8.Gq (deg/V) LTI Object

Find tine force gain (per tine): $\mathbf{G_f = f_t/x_3}$ (see **Figs 1b** & **4-5**)

9. 5 mark(s) Tine Force Gain

- Q9.Gf (N/V) LTI Object

Check your DC gains with a series of simple calculations, **done in the following order**.
If you apply 1 volt to the motor and wait a long time:

Find the winding current $\mathbf{i_w}$.
Find the motor torque $\mathbf{tau_r}$.
Find the lead-screw force $\mathbf{f_s}$.
Find the finger torque (per finger) $\mathbf{tau_f}$.
Find the tine force (per finger) $\mathbf{f_t}$.
Find the effective stiffness of the tine & load combined (per finger, in finger coordinates) $\mathbf{K_{tl}}$.
Find the associated finger angle $\mathbf{q_f}$.
Find the associated lead-screw distance $\mathbf{d_s}$.
Find the associated rotor angle $\mathbf{q_r}$.
Find the associated sensor voltage $\mathbf{v_s}$.

10. 5 mark(s) DC Gains

- Q10.iw (A) Scalar
- Q10.taur (Nm) Scalar
- Q10.fs (N) Scalar
- Q10.tauf (Nm) Scalar
- Q10.ft (N) Scalar
- Q10.Ktl (Nm) Scalar
- Q10.qf (deg) Scalar
- Q10.ds (m) Scalar
- Q10.qr (deg) Scalar
- Q10.vs (V) Scalar