DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR

Control Systems Simulation Laboratory (EE-751)

7th Semester Electrical

Experiment No. 751/1

I. Title: SHAPING THE TIME RESPONSE

II. Objective: To plot the step and impulse response of a system and find range of K for stability using Routh's Criterion

III. Apparatus: PC with MATLAB©; Calculator

IV. Experiments: Work out and compute problems step by step and submit the results in report sheets.

1.1: First Order Type Zero Transfer Function (T. F.)–

$$G_1(s) = \frac{1}{(s+\sigma)} \tag{1.1}$$

1. Locate the pole in the s-plane for $\sigma > 0$. Comment on the stability.
2. Find the time constant T.
3. Compute the Impulse Response of the system $G_1(s)$.
4. Compute the step response for $\sigma = 1$.
5. Invoke MATLAB© and:
   - i) Enter the transfer $G_1(s)$ for $\sigma = 1$.
   - ii) Plot the Impulse Response and Step Response on same axes.
   - iii) Roughly sketch the plots.

1.2: Non min Phase T. F. between Elevator Input and Altitude of a Boeing 747 aircraft:

$$\frac{h(s)}{\partial_e(s)} = \frac{30(s-6)}{s(s^2+4s+13)} = G_2(s) \tag{1.2}$$

1. Locate the poles and zeroes of the system $G_2(s)$ on the s-plane.
2. In MATLAB© plot altitude response to a 1^0 impulse input in the elevator for t = 0 to 6 secs.
3. Roughly sketch the plot, comment on its nature and fill up **Table 1**.
4. Compare the denominator of $G_2(s)$ with that of standard 2nd order system and then find the Natural Frequency of Oscillation, $\boldsymbol{\omega_n}$ and the Damping Ratio, $\boldsymbol{\xi}$.
5. Using $\boldsymbol{\omega_n}$ and $\boldsymbol{\xi}$ found in step 4 calculate the time domain specifications and fill in **Table1.**
6. Comparing the values in Table 1, comment on the accuracy of MATLAB©

1.3: Closed Loop Proportional Control:

Consider the block diagram of a Feedback Control System with variable forward path gain K:

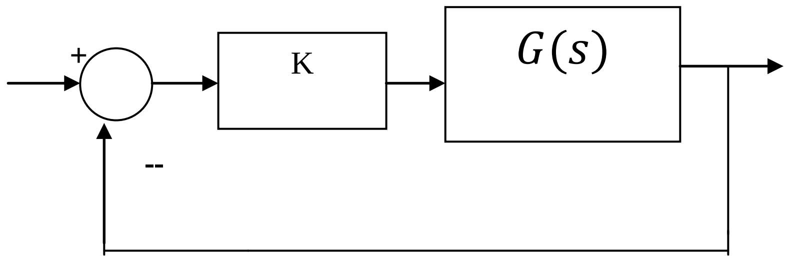

Fig 1

With, $G_3 = \frac{(s+1)}{s(s-1)(s+6)}$

1. Comment on the stability of the Open Loop System
2. Using Routh's array find range of K for (closed loop) stability. Let critical K be K_{cr}.
3. Invoke MATLAB©. Find open loop loop poles for K = K_{cr}, (K_{cr}+4.5), (K_{cr}+6.5).
4. For these values of K plot impulse responses (on same axes) for t = 0 to 12 secs. **('axis')**
5. Record rough sketch of the plot.

Experiment No. 751/2

I. Title: SATELLITE ATTITUDE CONTROL USING P-D CONTROLLER

II. Objective: A Proportional Derivative (P-D) controller is designed by shaping the Root Locus for Satellite Attitude Control.

III. Apparatus: PC with MATLAB/SIMULINK©; Calculator

IV. Experiments: Work out and compute problems step by step and submit the results in report sheets.

2.1: Root Locus of the Plant:– Control of attitude of a satellite described by a "double integrator" plant:

$$G_4(s) = \frac{1}{s^2} \tag{2.1}$$

1. Apply unity feedback around $G_4(s)$ along with a forward path gain K as in **Fig 1**.
2. Draw the Root Locus for variable K. Fill up **Table 2**.
3. Invoke MATLAB©. Use "rlocus" to draw Root Locus with axes: (use "axis" command) X- axis (-6,2) and Y-axis (-3, 3). Record rough sketch.
4. Comment on the i) Root Locus and from the Root Locus ii) Predict the transient response of the closed loop system.

2.2: Root Locus based P-D control of the Plant:–

1. The characteristic equation of (2.1) with P-D control is:

$$1 + (K_P + K_D s)\frac{1}{s^2} = 0 \tag{2.2}$$

2. To put (2.2) in Root Locus form, define K = K_D, and arbitrarily select $\frac{K_P}{K_D} = 1,$ which gives:

$$1 + K\frac{(s+1)}{s^2} = 0 \tag{2.3}$$

3. Draw the Root Locus of (2.3) for variable K. Fill up **Table 2**.
4. Invoke MATLAB©. Draw the Root Locus with axes: X- axis (-6,2) and Y-axis (-3, 3). Record rough sketch.
5. Comment on the change in i) Root Locus due to addition of controller zero and from root locus predict ii) Transient Response of the closed loop system with the P-D control.

Experiment No. 751/3

I. Title: FREQUENCY RESPONSE

II. Objective: To draw Bode and Nyquist plots

III. Apparatus: PC with MATLAB/SIMULINK©; Calculator; **Semilog Graph Paper**.

IV. Experiments: Work out and compute the problems step by step and submit results in report sheets.

3.1: Bode Plot of a standard second order system– Consider the standard second order system:

$$G_5(s) = \frac{\omega_n^2}{(s^2 + 2\xi\omega_n s + \omega_n^2)} \tag{3.1}$$

1. Draw the Bode Plots (Magnitude and Phase) for $\xi = 0.2$, 0.5 and 0.9 on Semilog papers. Add corrections to the straight line asymptotes using the resonant peak given by its absolute value

   $$M_r = \frac{1}{2\xi}, \text{ at } \omega = \omega_n$$

2. Invoke MATLAB©. Draw Bode Plots for $\xi = 0.2$, 0.5, 0.7 and 0.9. Record rough sketches.
3. Compare the plots obtained in steps 1 and 2 for similar values of ξ.

3.2: Nyquist Plot of an open loop unstable system– Consider the block diagram in **Fig. 1** with

$$G_6(s) = \frac{(s+1)}{s(0.1s-1)} \tag{3.2}$$

1. Draw the Nyquist Plot of $G_6(s)$. Comment on the (closed loop) stability.
2. Also find range of K for stability from the plot.
3. Invoke MATLAB©. Draw the Nyquist plot with axes: (use "nyquist" command) X- axis (-5,5) and Y-axis (-5, 5)
4. Compare the plots obtained in steps 1 and 3. Also note the Phase Cross Over Freq.

Experiment No. 751/4

I. Title: STATE SPACED MODELLING AND CONTROL

II. Objective: To find Time Response, Transfer Function and Eigen Values. Design an LSVF controller.

III. Apparatus: PC with MATLAB/SIMULINK©

IV. Experiments: Compute the problems step by step and submit the results in report sheets.

4.1: Cruise Control Step Response – The equation of forward motion of a car where the engine imparts the a force *"u(t)"* is given by:

$$\ddot{x}(t) + \frac{b}{m}\dot{x}(t) = \frac{u(t)}{m}, \quad (4.1)$$

where mass, m = 1000 kg, damper constant, b = 50 N-sec/m.

1. Derive the state space model of (4.1), taking the car position, *x(t)* and velocity, *v(t)* as the two states; the car position, *x(t)* as the output and the force, *u(t)* as the input. Find the A, B, C, D matrices.
2. Invoke MATLAB©. Enter the A, B, C, D matrices in the workspace and then find:
3. the Transfer Function *G(s)* from A, B, C, D. (**'ss2tf'**)
4. the poles of *G(s)* and eigenvalues of A matrix. (**'roots', 'eig'**)
5. Now obtain step response to an input *u(t)* = 500 N by multiplying B*500 in the model (since built in MATLAB© function **"step"** computes step response to a unit step signal). (Use: **'ss'** and **'sys'**)
6. Record a rough sketch of the plot.

4.2: Linear State Variable Feedback (LSVF) design for Satellite attitude Control – The single axis motion (angular position) of a satellite with input torque *"u(t)"* is given by:

$$I\ddot{\theta}(t) = d\,u(t), \quad (4.2)$$

where, d = 1 m, I = 5000 kg-m^2.

1. Derive the state space model of (4.2), taking angular position, *θ(t)* and angular velocity, $\dot{\theta}(t)$ as the two states; angular position, *θ(t)* as output and input torque, *u(t)* as the input. Find the A, B, C, D matrices.
2. Invoke MATLAB©. Enter the A, B, C, D matrices in the workspace and then find:
3. the Transfer Function *G(s)* from A, B, C, D. (**'ss2tf'**)
4. the poles of *G(s)* and eigenvalues of A matrix. (**'roots', 'eig'**) Comment on the open loop stability.
5. Find desired the closed loop poles, s_d with ω_n **= 1 rad/sec** and ξ **= 0.707**). Fill **Table 3.**
6. Find LSVF controller **K** (using MATLAB© function **"place"**) to place the CL poles at s_d.
7. Validate the design by checking eigen values of CL system matrix. Fill **Table 3.**

Table 1

	Natural Freq ω_n	Damping Ratio Ξ	Rise Time t_r	Settling Time t_s	Peak Overshoot M_p (p.u.)
Calculated Value					
Value from MATLAB	—	—			

Table 2

Transfer Function	Centroid	Angle of Asymptotes	Break Away Point	Angle of Departure
$\frac{1}{s^2}$				
$\frac{(s+1)}{s^2}$				

Table 3

	Desired CL poles s_d	LSVF controller K	CL Eigen Values (To Verify)
Value from MATLAB	—	—	

References:

1. Feedback Control of Dynamic Systems – G. F .Franklin, J. David Powell and A. Emami-Naeini.