UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: November 2017

Module Number: EE6302 **Module Name: Control System Design**

[Three Hours]

[Answer **all questions**, each question carries 15 marks]

Note : All the abbreviations have their usual meanings.

Q1 a) i) Briefly explain the method of manual tuning the PID parameters for a bounded response with a steady state error.

ii) By using a suitable block diagram, explain the possibility of using a PD type controller for reducing the overshoot of a system response.

iii) Explain the effect of disturbance rejection on reference tracking.

[6.0 Marks]

b) You are required to design a simple speed control system of a dc motor as shown in Figure Q1 (b). The motor is running at no-load with negligible load torque.

i) By considering the expression for system poles, show that the motor speed control system undergoes critically damped stage at $k_p = \frac{(0.5b+J)^2}{20J} - \frac{b}{10}$

ii) Determine the factor by which k_p should be multiplied to reduce the overshoot from 85% to 35% by assuming the motor viscous friction constant (b) is negligible as compared with the initial gain k_p.

[4.5 Marks]

c) When the dc motor shown in Figure Q1(b) is running a load with 2 Nm load torque.

i) If $J = 0.1\ kgm^2$ and $b = 1\ Nms$, find the range of k_p, in order the steady state error due to the load torque to be less than $0.01\ rads^{-1}$.

ii) Find the k_p and k_D parameters for a PD type controller in place of P type controller which damp out the torque disturbance within 0.5 s in terms of 1% settling time. The peak overshoot of the motor speed due to the load torque is detected after *100 ms* since the motor starts.

[4.5 Marks]

Q2 a) i) Define the root locus considering a negative feedback system.

ii) Explain the magnitude and the phase conditions to be satisfied at a point on the root locus.

iii) In root locus design method, briefly explain the method of locating poles in the s-plane according to design requirements.

iv) Briefly explain the usage of a compensator for increasing the undamped natural frequency of a system.

[6.0 Marks]

b) Consider the root locus given in Figure Q2 (b).

i) Write the general characteristic equation for the closed loop plant G(s). You may use a real parameter k ($0 < k < \infty$) in your answer.

ii) With the help of root locus given or the answer in part (i), determine,

I. Number of asymptotes.

II. Asymptote(s) angle(s) and intersection point(s).

III. Break-away and Break-in points.

IV. Corresponding departure or arrival angle at each and every pole and zero of the open-loop plant.

iii) With the help of root locus given and the data point marked on the root locus, find only one set of system poles for each of the following.

I. The system response is marginally stable.

II. The system response is critically damped.

III. The system response is underdamped.

[5.5 Marks]

c) Consider the root locus given in Figure Q2 (b). It is desired to to use a lead compensator [i.e. $D(s) = k(s+z)/(s+p)$] to increase the system speed to $\omega_n = 3rads^{-1}$ while maintaining the damping ratio (ξ) at 0.5. The noise suppression requirements require that the lead pole to be at -1. Determine the transfer function of the lead compensator.

[3.5 Marks]

Q3 a) i) Write the general form of state-space model of a system. Name the matrices in your model.

ii) Derive the transfer function of the system using the state-space model you have written in part i).

iii) With the help of the state-space model written in part i), define controllability and observability of a system.

iv) State the Rooth's necessary and sufficient conditions to have a stable system.

[6.5 Marks]

b) Consider the circuit shown in Figure Q3 (b). The input voltage is v_i and the output voltage (v_o) is the voltage across the capacitor.

i) Find a suitable state vector to express the system in state-variable form.

ii) Obtain the state-space model of the system given in Figure Q3 (b).

iii) Hence show that the transfer function of the system is,

$$G(s) = \frac{4}{(s+1)(s+4)}$$

[5.5 Marks]

c) i) Examine the controllability and the observability of the system mentioned in part (b).

ii) Using Rooth's stability criterion, evaluate the stability of the system derived in part b (iii) and verify your answer with your knowledge on control system stability.

[3.0 Marks]

Q4 a) i) What is frequency response of a system?

ii) Define amplitude ratio M and phase ϕ related to the frequency response of a system whose transfer function is $G(s)$.

iii) Define the terms; phase margin and gain margin, associated with the Bode plots.

iv) How do we examine the system stability using the stability margins?

[6.0 Marks]

b) It is required to control the angular displacement of a field controlled DC motor (FCDCM) as a unity feedback system.

i) The transfer function of the FCDCM is,

$$G(s) = \frac{\theta_L(s)}{V_T(s)} = \frac{K_M}{s(T_f s+1)(T_M s+1)}$$

Where, motor gain constant (K_M), Time constant (T_f) and the mechanical time constant (T_M) are 1, 1 and 0.1, respectively. Obtain the steady-state output of the FCDCM, when it is subjected to the input $V_T = 2\sin\left(2t - 60^0\right)$.

ii) Drawing approximate Bode plots for the system and giving reasons, analyze the stability of the system.

[5.5 Marks]

c) It is required to design a lead compensator $k_p(T_1+1)/(T_2+1)$ for a water level control system of a tank. The Bode plot for the open-loop plant is shown in Figure Q4 (c1). By giving reasons, find the first approximation for T_1 and T_2. Variation of the maximum phase lead vs (1/lead parameter (α)) is shown in Figure Q4(c2).

[3.5 Marks]

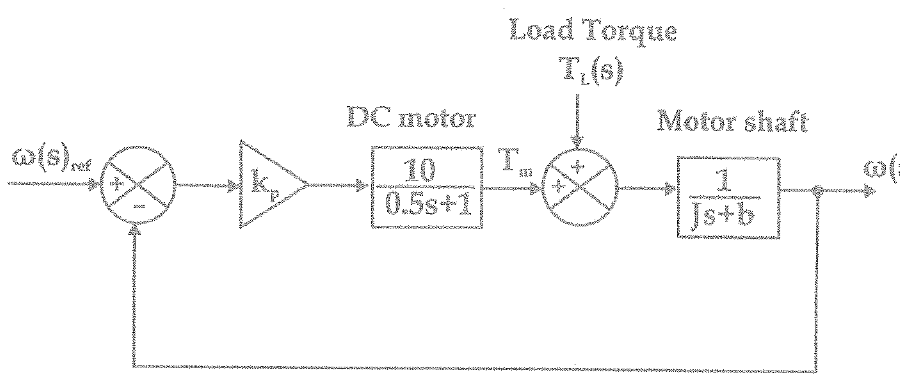


Figure Q1(b)

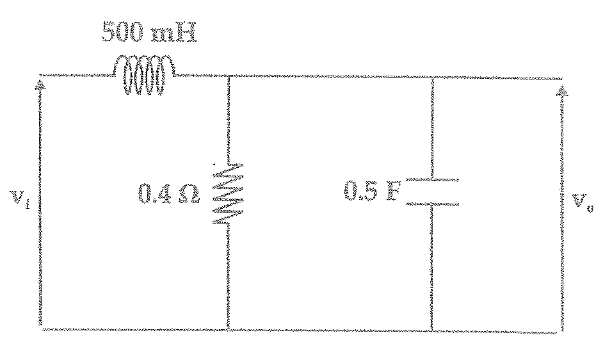
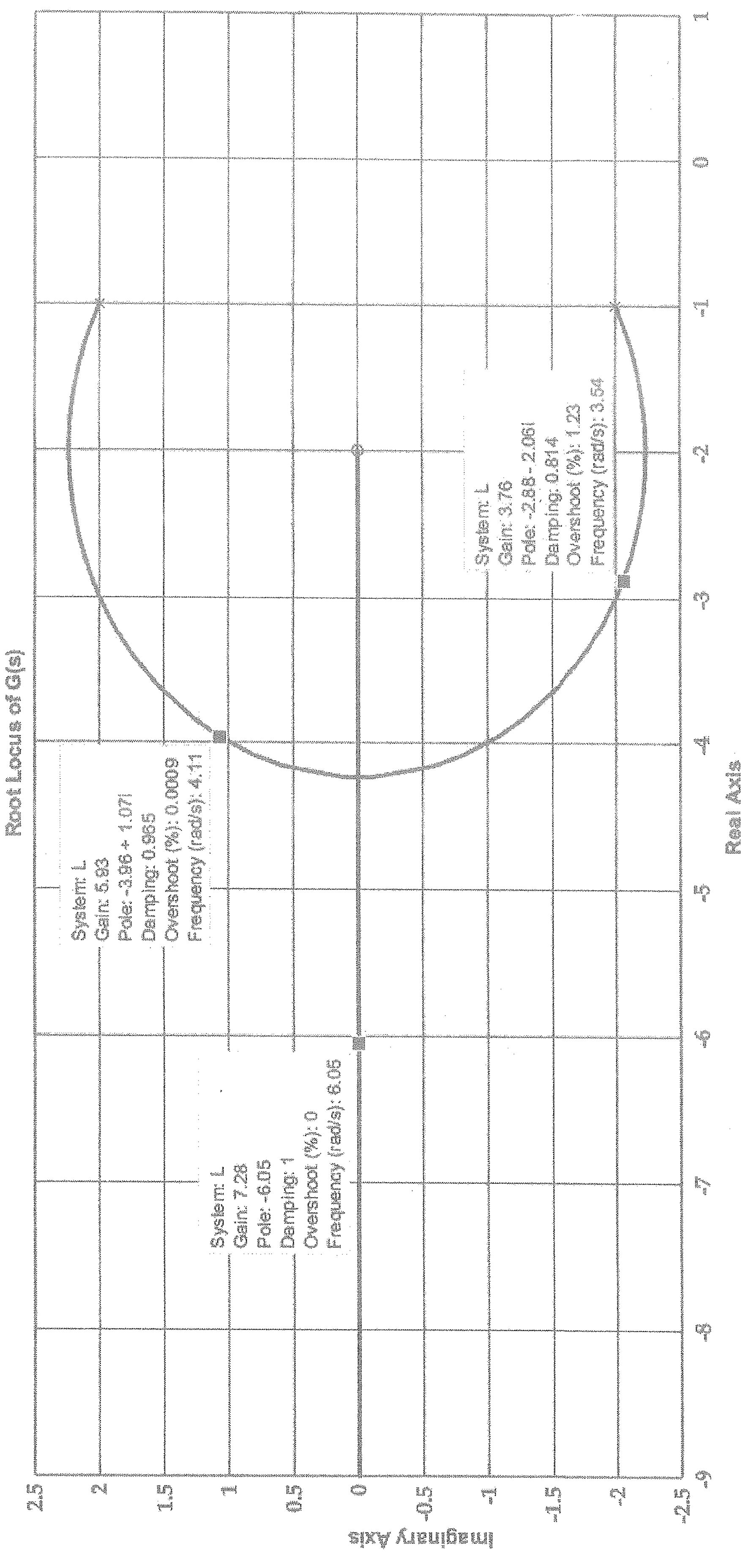


Figure Q3(b)



Root Locus of G(s)
Real Axis
Imaginary Axis
System: L
Gain: 5.93
Pole: -3.96 + 1.07i
Damping: 0.965
Overshoot (%): 0.0009
Frequency (rad/s): 4.11
System: L
Gain: 3.76
Pole: -2.88 - 2.06i
Damping: 0.814
Overshoot (%): 1.23
Frequency (rad/s): 3.54
System: L
Gain: 7.28
Pole: -6.05
Damping: 1
Overshoot (%): 0
Frequency (rad/s): 6.05

Figure Q2(b)

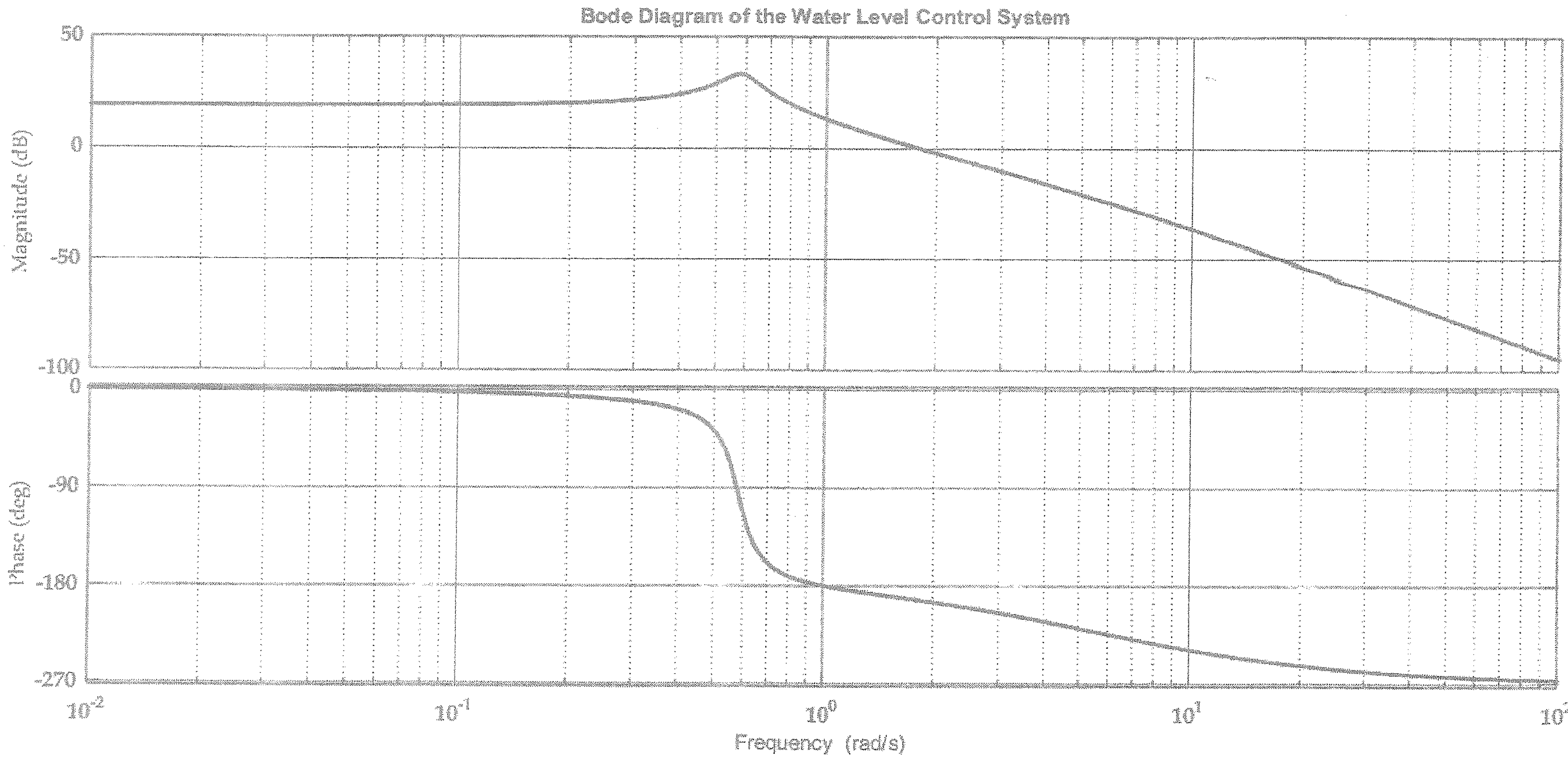

Bode Diagram of the Water Level Control System
Magnitude (dB)
50
0
-50
-100
Phase (deg)
0
-90
-180
-270
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Frequency (rad/s)

Figure Q4(c1)

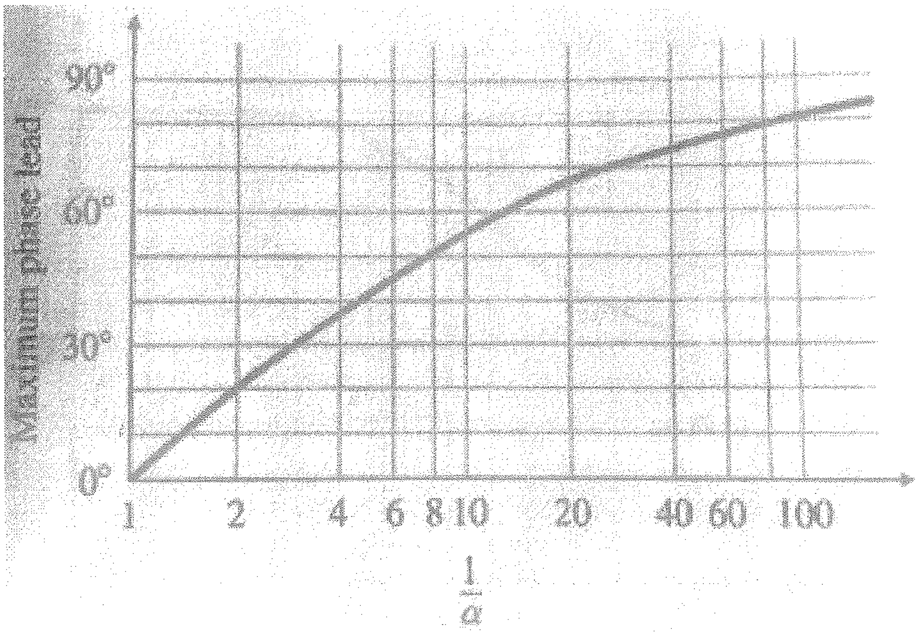


Figure Q4(c2)