UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: December 2015

Module Number: ME 6302 **Module Name: Automatic Control Engineering**

[Three Hours]

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

Important:
Some necessary equations and a partial table of Laplace transformation pairs have been provided on the question paper. You may make additional assumptions, if necessary, by clearly stating them in your answers. Some standard notations may have been used without defining them.

Q1. a) A plant is described by the following differential equation.

$$\frac{d^2y(t)}{dt^2}+4\frac{dy(t)}{dt}+3y(t)=\frac{du(t)}{dt}+5u(t)$$

Determine the transfer function $G_{OL}(s) = Y(s)/U(s)$ of the plant.

[2.0 Marks]

b) Draw the closed loop control system for the plant using single feedback gain K and derive the closed loop transfer function.

[2.0 Marks]

c) Determine the value(s) of K for critical damping of the response.

[3.0 Marks]

d) Calculate DC gain(s) of the critically damped closed loop plant.

[1.0 Mark]

e) Show that an additional gain of 1+(5/3)K is needed to maintain zero steady state error.

[2.0 Marks]

f) Can you use critically damped controllers in practical mechatronic applications? Justify your answer with examples.

[2.0 Marks]

Q2. a) *'Root Locus Design method can be used to locate poles at some desired locations. However, it is not possible to locate poles* ***arbitrarily****'*. Explain above statements giving reasons.

[2.0 Marks]

b) A feedback control system through a single feedback gain is shown in the Figure Q2. Derive the gain and phase conditions of the Root Locus design.

[1.0 Mark]

c) The open loop plant is modeled by, $G(s)= 1/(s+3)(s^2+6s+20)$. Determine,

i) Parts of the Root Locus on the real axis.
ii) Number of asymptotes and asymptote angle(s).
iii) Asymptote intersection point(s).
iv) Angle(s) of departure/arrival.
v) Break away/in point(s).

[4.0 Marks]

Q2. is continued to Page 2.

d) Sketch the Root Locus.

[2.0 Marks]

e) Determine the maximum stable feedback gain using Routh Array method.

[2.0 Marks]

f) Describe how you could figure out the pole locations causing the highest oscillatory response from the Root Locus (Part (d)).

[1.0 Mark]

Q3. a) Describe why second order systems are the most popular in control systems literature and also in industrial control system implementations.

[1.0 Mark]

b) *'Single feedback gain tuning method is not always applicable in industrial plant control'.* Briefly explain the above statement and suggest a suitable modification.

[1.0 Mark]

c) Motion control systems are widely used in industrial applications. Assurance of performance specifications such as peak overshoot, rise time and settling time are very important for industrial applications. A feedback loop of such a motion control system is shown in the Figure Q3.

i) Obtain the Root Locus for the closed loop system.

ii) Motion control system demands 3% overshoot and 1s settling time. Show that the desired poles are located outside the system Root Locus.

iii) Introduce a lead compensator to move the Root Locus to the desired location. **Calculate** the value of the feedback gain K in the desired system?

iv) Sketch the modified Root Locus and calculate new DC gain of the compensated closed loop system.

v) Introduce a front gain to adjust the response to unity DC gain and show the entire system in a block diagram.

[5.0 Marks]

Hint: For under-damped generic second order systems

The transfer function, $G(s) = \dfrac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$

Peak Overshoot $PO = e^{\frac{-\zeta\pi}{\sqrt{1-\varsigma^2}}}$, Settling time $t_s = \dfrac{4.6}{\varsigma\omega_n}$.

d) Briefly explain this statement: *'In control system design, Lag compensators are less frequently used compared to Lead compensators'.*

[2.0 Marks]

e) Briefly explain the use of Notch Filters in control system design.

[1.0 Mark]

f) Modern vehicles are fitted with cruise control that, at the press of a button, automatically maintains a set speed. In this way, the driver can cruise at a speed limit or economic speed without continually checking the speedometer. Design a feedback control in block diagram for a cruise control system. (Provide suitable front controller and relevant blocks/parameters in your diagram.)

[2.0 Marks]

Q4. Figure Q4 shows the frequency response of the plant model (forward transfer function) given by $G(s) = \dfrac{2(s^2 + 2s + 3)}{s^4 + 8s^3 + 11s^2 + 9s + 4}$. You are required to design a compensator to improve the plant's closed loop response.

a) What is the bandwidth of the system?

[1.0 Mark]

b) Determine the required forward path gain (K) to increase the bandwidth to 10 rad/s.

[2.0 Marks]

c) How will the rise time and the overshoot of the closed loop step response change (Increase or decrease) after increasing the bandwidth?

[2.0 Marks]

d) Design a lead compensator to increase the overall phase margin to 45° while maintaining the bandwidth of 10 rad/s.

Hint: The solution to the equation $\phi_{max} = \tan^{-1}\left(\dfrac{\omega_{\phi_{max}}}{z_{le}}\right) - \tan^{-1}\left(\dfrac{z_{le}}{\omega_{\phi_{max}}}\right)$ is given by

$$z_{le} = \frac{\omega_{\phi_{max}}}{\tan\left(\dfrac{\phi_{max} + 90^\circ}{z}\right)} \text{ with } \omega_{\phi_{max}} = \sqrt{(z_{le}\, p_{le})}.$$

[4.0 Marks]

e) Calculate the unit step steady state error of the designed closed loop system.

[3.0 Marks]

Q5. An engineer plans to use a PID controller to control a certain chemical flow rate to a tank as shown in Figure Q5. He uses a flow meter system with unit gain to measure the chemical flow rate. The flow control valve can be approximately modeled by the transfer function $\dfrac{Q(s)}{V(s)} = \dfrac{1}{10s+1}$. The engineer first sets the proportional control gain K_P to 0.3 and keeps both K_I and K_D values to zero. When operating the system with this setting he finds that the system response is too slow and there is a large steady state error.

a) Calculate the steady state error for a unit step input at the given setting.

[2.0 Marks]

b) Calculate the time constant for the closed loop system. (Remember that the time constant of the first order system $\dfrac{\alpha}{\tau s + 1}$ is τ.)

[2.0 Marks]

c) How should he change (increase/decrease) the gain K_P to increase speed of the response?

[1.0 Mark]

d) Calculate the new time constant after changing K_P by factor of 10 as you suggested in part (c).

[2.0 Marks]

Q5. is continued to Page 4.

e) What should he do in order to eliminate the steady state error for a step input?

[1.0 Mark]

f) Mathematically show that your suggestion in part (e) eliminates the step response steady state error of this system.

[2.0 Marks]

g) The engineer determines that signals from the flow meter are somewhat noisy and there is no signal filtering method in use. What could happen to the system response if he tunes K_D to large value?

[2.0 Marks]

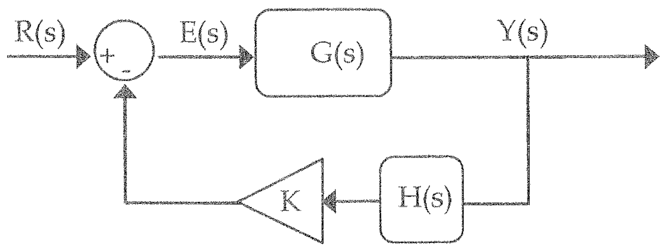

Figure Q2: The Feedback Control System

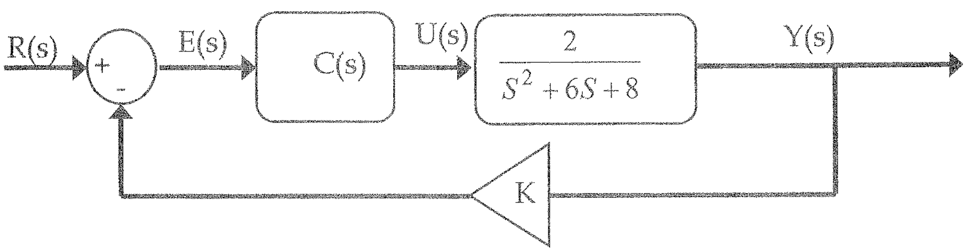

Figure Q3: The Motion Control System

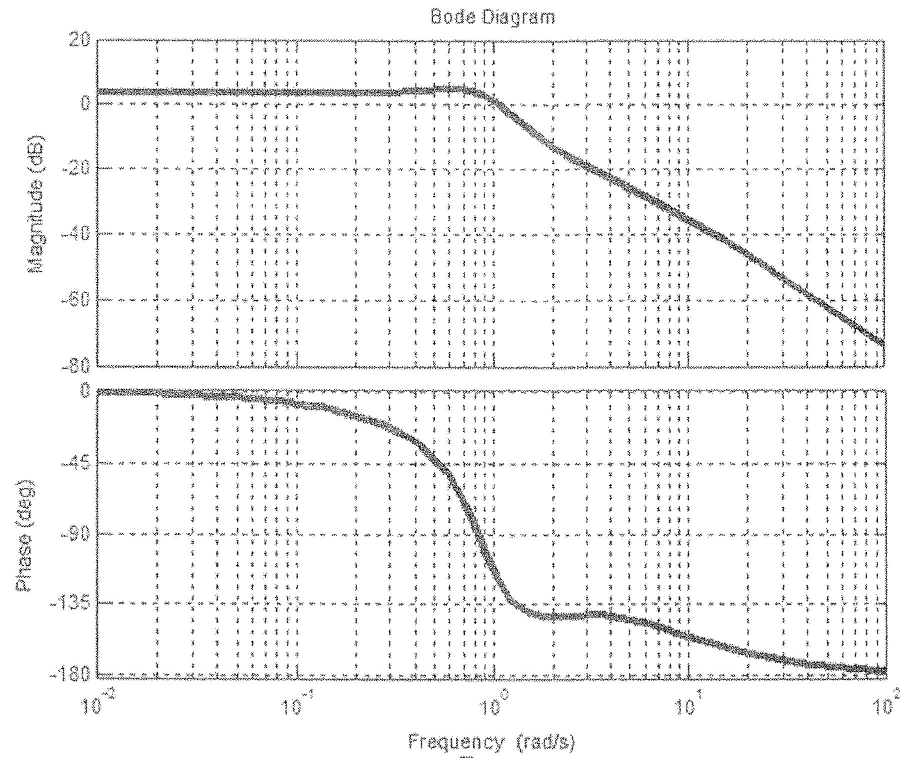

Figure Q4: The Bode Diagram

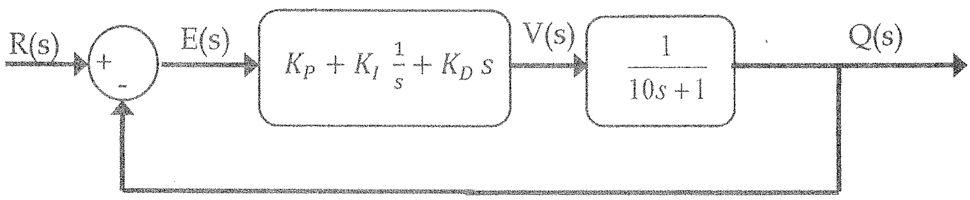

Figure Q5: PID Flow Control System

Table of Laplace Transform Pairs

step	$\frac{1}{s}$
ramp,t	$\frac{1}{s^2}$
impulse	1
$u(t-a)$	$\frac{e^{-as}}{s}$
$u(t-a)\ g(t-a)$	$e^{-as}\,G(s)$
t^n	$\frac{n!}{s^{n+1}}$
e^{-at}	$\frac{1}{(s+a)}$
$t^n e^{-at}$	$\frac{n!}{(s+a)^{n+1}}$
$\frac{1}{(n-1)!}\,t^{n-1}\,e^{-at}$	$\frac{1}{(s+a)^n}$
$\sin\omega t$	$\frac{\omega}{(s^2+\omega^2)}$
$\cos\omega t$	$\frac{s}{s^2+\omega^2}$
$e^{-at}\sin\omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$
$e^{-at}\cos\omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$
$\frac{\omega_0}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_0 t}\sin(\omega_0\sqrt{1-\zeta^2}t)$	$\frac{\omega_0^2}{s^2+2\zeta\omega_0 s+\omega_0^2}$
$1-\frac{\omega_0}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_0 t}\sin(\omega_0\sqrt{1-\zeta^2}t+\phi)$ *Where*, $\phi=\tan^{-1}\left(\frac{\sqrt{1-\zeta^2}}{\zeta}\right)$	$\frac{\omega_0^2}{s(s^2+2\zeta\omega_0 s+\omega_0^2)}$