Universiti Malaysia PAHANG

Engineering • Technology • Creativity

FACULTY OF MECHANICAL ENGINEERING

FINAL EXAMINATION

COURSE	**:**	**AUTOMATIC CONTROL**
COURSE CODE	**:**	**BHA3323**
LECTURER	**:**	**MOHD AZRI HIZAMI RASID**
DATE	**:**	**07 JUNE 2017**
DURATION	**:**	**3 HOURS**
SESSION/SEMESTER	**:**	**SESSION 2016/2017 SEMESTER II**
PROGRAM CODE	**:**	**BHA**

INSTRUCTIONS TO CANDIDATE:

1. This examination paper consists of **FIVE (5)** questions. Answer **ALL** questions
2. All answers to a new question should start on a new page.
3. All calculations and assumptions must be clearly stated.
4. Candidates are not allowed to bring any material other than those allowed by the invigilator into the examination room.
5. The question should be answered in English.

EXAMINATION REQUIREMENTS:

1. Bode plot graph paper

APPENDIX:

1. Key equations
2. Bode plot graph

DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD TO DO SO

This examination paper consists of **NINE (9)** printed pages including the front page.

QUESTION 1 [10 Marks]

Figure 1 shows the different components of a speed control system of an electric motor.

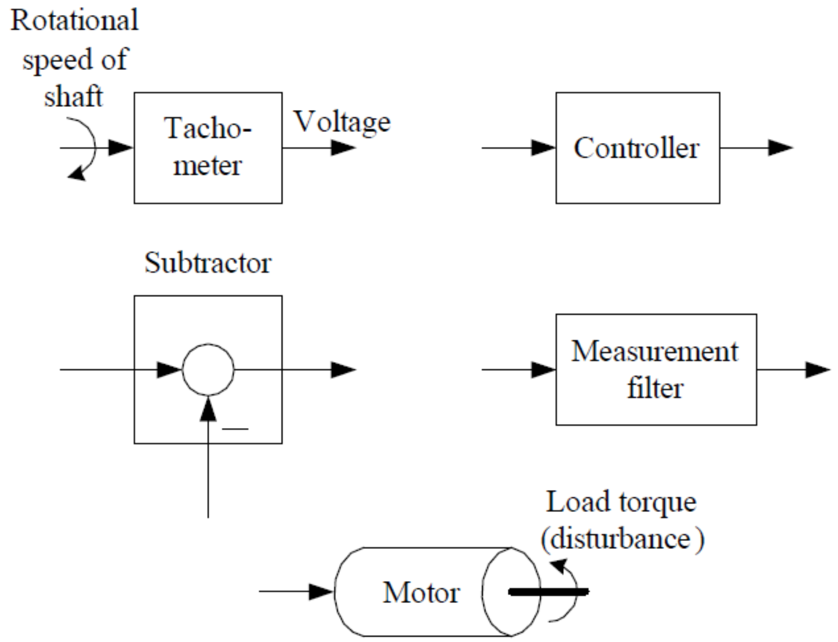

Figure 1: Components of motor speed control system

1. Construct a speed control system by connecting the components (draw a block diagram of the control system) and clearly label the control error signal in your block diagram.

(5 Marks)

2. Explain the control system works? (Assume that the speed initially is equal to the speed reference (setpoint), and that the load torque is increased so that the motor speed is reduced).

(5 Marks)

QUESTION 2 [25 Marks]

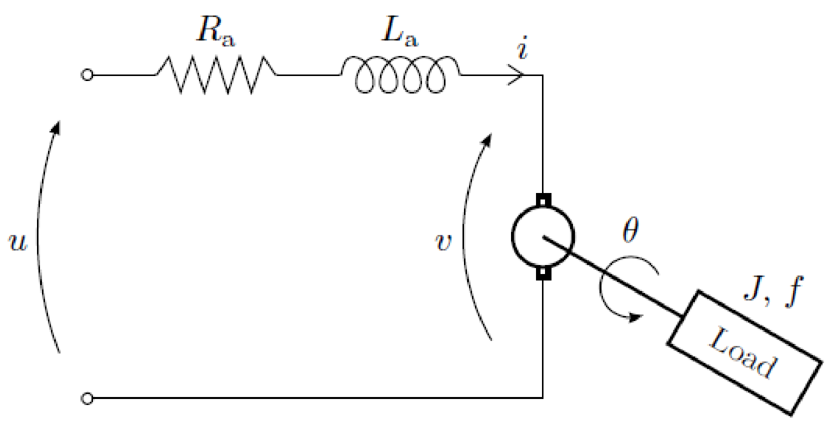

Figure 2: DC motor control system

DC-motor is a common component in a control system. A schematic picture of the motor is shown in **Figure 2**. The motor is characterized by a number of physical relationships as will now be explained. The rotating axis is described by

$$J\ddot{\theta} = -f\dot{\theta} + M$$

where θ is the angle of rotation, M is the torque, J is the moment of inertia of the load and f is the frictional coefficient. The interplay between rotor and stator is given by

$$M = k_a . i \text{ and } u = k_v\dot{\theta}$$

where i is the current, k_a a proportional constant characteristic for the motor, v is voltage induced by the rotating axis and k_v is a proportional constant. The input voltage u is the control signal and θ is the output.

1. Use the equations above and Kirchhoff's voltage law to write a differential equation that relates u and θ. The inductance L_a can be neglected.

(7 Marks)

2. Determine the transfer function of the system from u to θ.

(3 Marks)

3. Deduce the response of the system in time domain by calculating θ and trace the time domain response graph when the input u is a step.

(15 Marks)

QUESTION 3 [20 Marks]

Develop the equivalent transfer function, $\boldsymbol{G(s) = C(s)/R(s)}$ for the multi-block system below.

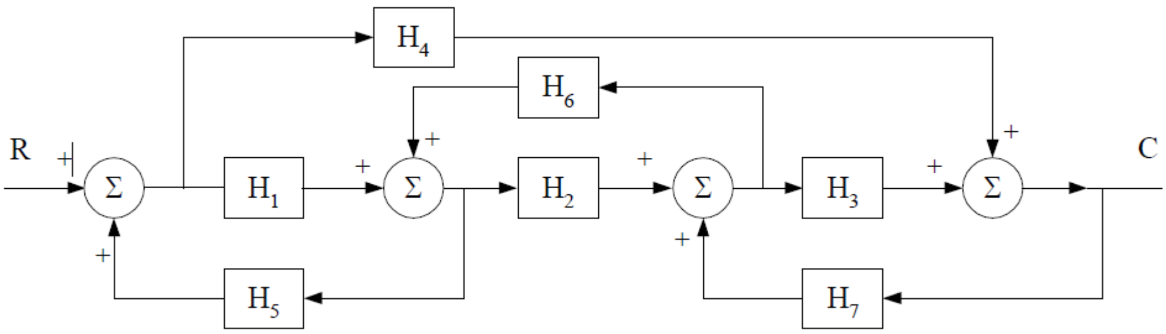

Figure 3: Multi-block system.

QUESTION 4 [25 Marks]

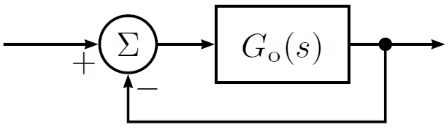

Figure 4: System $G_0(s)$ with feedback.

Draw a root locus with respect to K for the system in **Figure 4**, with $G_0(s)$ representing different system as mentioned below in a) b) and c).

For each of them, for which values of K are the systems stable? What conclusions on the principal shape of the step response can be drawn from the root locus?

a) A Ferris wheel:

$$G_0(s) = \frac{K(s+2)}{s(s+3)(s+1)}$$

(7 Marks)

b) A Mars rover:

$$G_0(s) = \frac{K}{s(s^2+2s+2)}$$

(9 Marks)

c) A magnetic floater:

$$G_0(s) = \frac{K(s+1)}{s(s-1)(s+6)}$$

(9 Marks)

QUESTION 5 [20 Marks]

A system is described by $Y(s) = G(s).U(s)$. **Figure 5** shows $\boldsymbol{u}(t) = sin(\omega t)$ and the corresponding output $y(t)$ (after all transients have faded away) for the frequencies ω = 1, 5, 10, and 20 rad/s (from top to bottom).

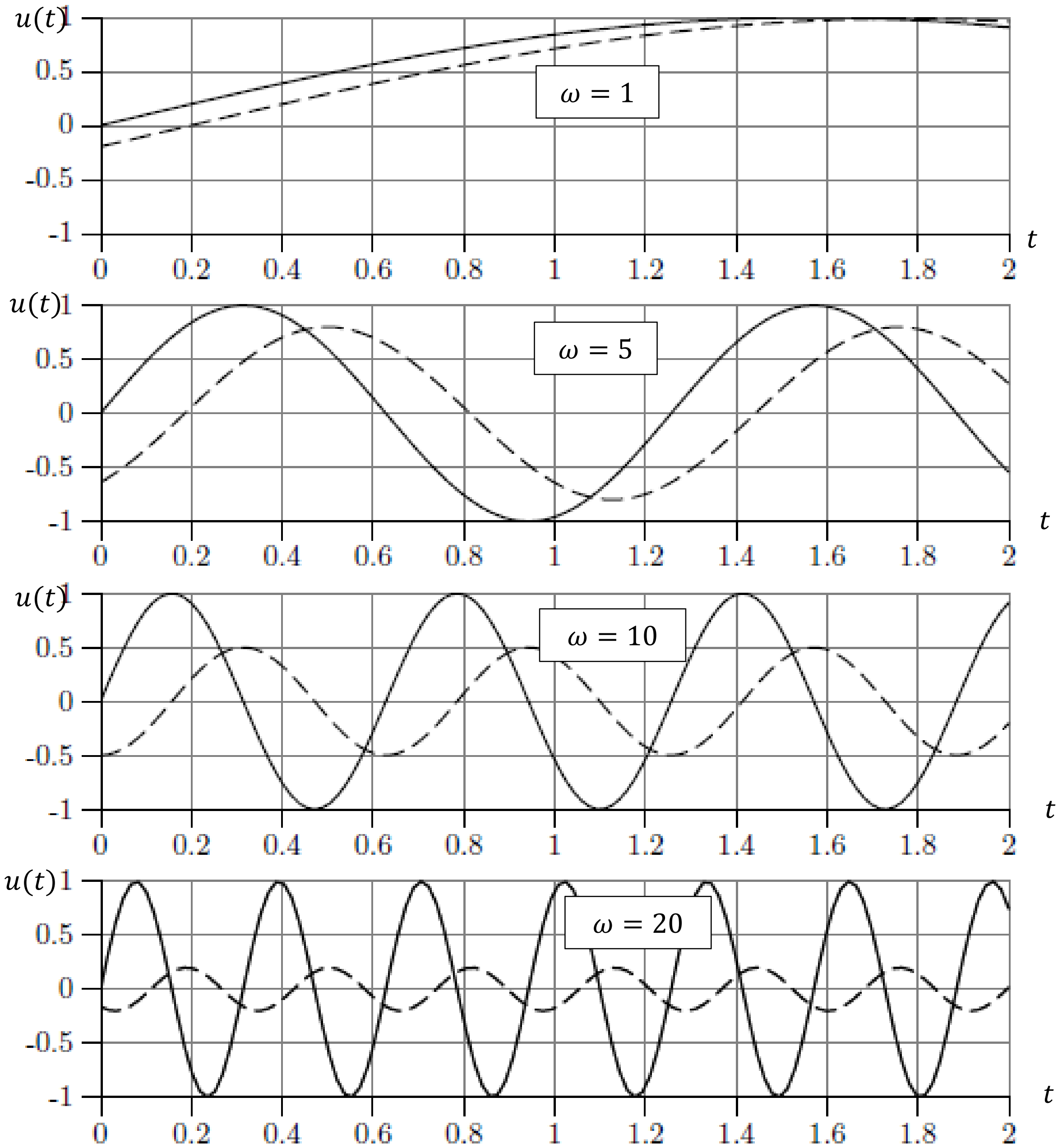

Figure 5 : $\boldsymbol{u(t) = sin(\omega t)}$ (solid) and $\boldsymbol{y(t)}$ (dashed).

1. Determine the gain ($|G(j\omega)|$) and phase ($argG(j\omega)$) for the system for each value of ω.

(10 Marks)

2. Determine the gain values in dB20 (20 log10($G(j\omega)|$)).

(5Marks)

3. Sketch the Bode plot using the values determined above (question 1. And 2.)
(Remark: Use the attached Bode plot and aatach with the answer script)

(5 Marks)

END OF EXAMINATION PAPER

APPENDIX – Key Equations

TIME RESPONSE

$$G(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad T_s = \frac{4}{\xi\omega_n} \qquad \sigma_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\%OS = 100e^{\left(\frac{-\xi\pi}{\sqrt{1-\xi^2}}\right)} \qquad T_p = \frac{\pi}{\omega_n\sqrt{1-\xi^2}} \qquad \xi = \frac{a}{2\omega_n}$$

ROOT LOCUS

$$\theta_a = \frac{(2k+1)\pi}{\#\text{finite poles} - \#\text{finite zeros}} \qquad \sigma_a = \frac{\sum \text{finite poles} - \sum \text{finite zeros}}{\#\text{finite poles} - \#\text{finite zeros}}$$

$$\sum_1^m \frac{1}{\sigma + z_i} = \sum_1^n \frac{1}{\sigma + p_i}$$

$$KG(s)H(s) = -1 = 1\angle 180^\circ$$
$$M = 1 \rightarrow \theta = (2k+1)180$$

For question 5. 3.