AUSTRALIAN MARITIME COLLEGE

SEMESTER 2 - SUPP EXAM EXAMINATION 2004

SOLUTIONS TO SUPPLEMENTARY EXAMINATION PAPER

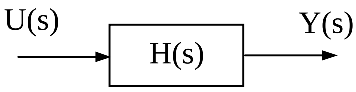
SUBJECT INSTR & PROCESS CONTROL TIME ALLOWED 3 HOURS

NO OF QUESTIONS TO BE ATTEMPED SIX (6)

QUESTION NO		MARK ANALYSIS
01	(a) A continuous-time dynamic system can be represented by an ordinary differential equation. Transfer function of the dynamic system is defined as a ratio of the Laplace transform of the output to the Laplace transform of the corresponding input, usually with zero initial conditions and expressed by the following formula: $H(s) = \frac{Y(s)}{U(s)}$ where H(s), Y(s), and U(s) are transfer function, output and input, respectively. A transfer function can be expressed in the fraction form as follows: $H(s) = \frac{N(s)}{D(s)}$ Poles of the transfer function are defined as solutions (or roots) of the equation D(s) = 0, and zeroes of the transfer function are defined as solutions (or roots) of the equation N(s) = 0. Example: The transfer function H(s) = $\frac{s+1}{s^2+3s+5}$ has poles at $s_{1,2}$ = $\frac{-3 \pm \sqrt{11} \times j}{2}$ and zero at s = -1.	4 Marks
	(b) (i) Taking Laplace transforms of two sides of the differential equation with all zero initial conditions, the transfer function is $H(s) = \frac{Y(s)}{U(s)} = \frac{2+1.5s}{5s^2+7s+3}$ (ii) This transfer function has 2two poles at $s_{1,2}$ = $\frac{-7 \pm \sqrt{11} \times j}{10}$ and one zero at s = $-\frac{2}{1.5}$.	4 Marks

02

(a) Block diagram: A block (rectangle) containing a transfer function can be used to represent the relationship between an output and an input of a dynamic system as shown in the following figure.

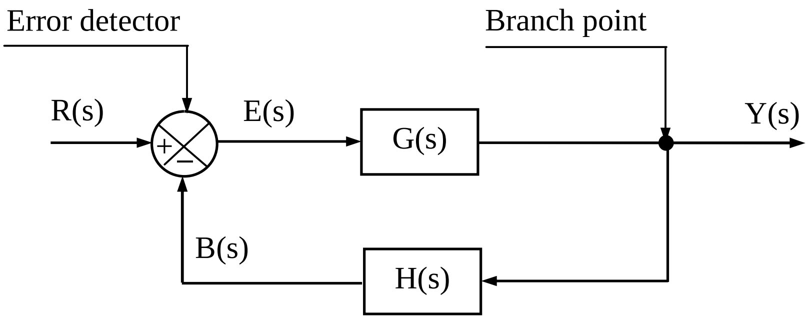


The relationship between the output and input can be expressed by the following formulas:

$$H(s)=\frac{Y(s)}{U(s)} \text{ or } Y(s)=H(s)U(s)$$

A number of blocks interconnected by lines become a block diagram. This is effectively a shorthand representation of a control system or a part of the system.

The following figure illustrates a block diagram for a feedback (closed-loop) control system.



The comparison detector or component can be represented by a circle with plus sign and minus sign as shown in the above figure. From the figure, it can be seen that E(s) = R(s) – B(s). Some terms related to the block diagram are given below.

Feed-forward transfer function (FFTF): $G(s)=\frac{Y(s)}{E(s)}$

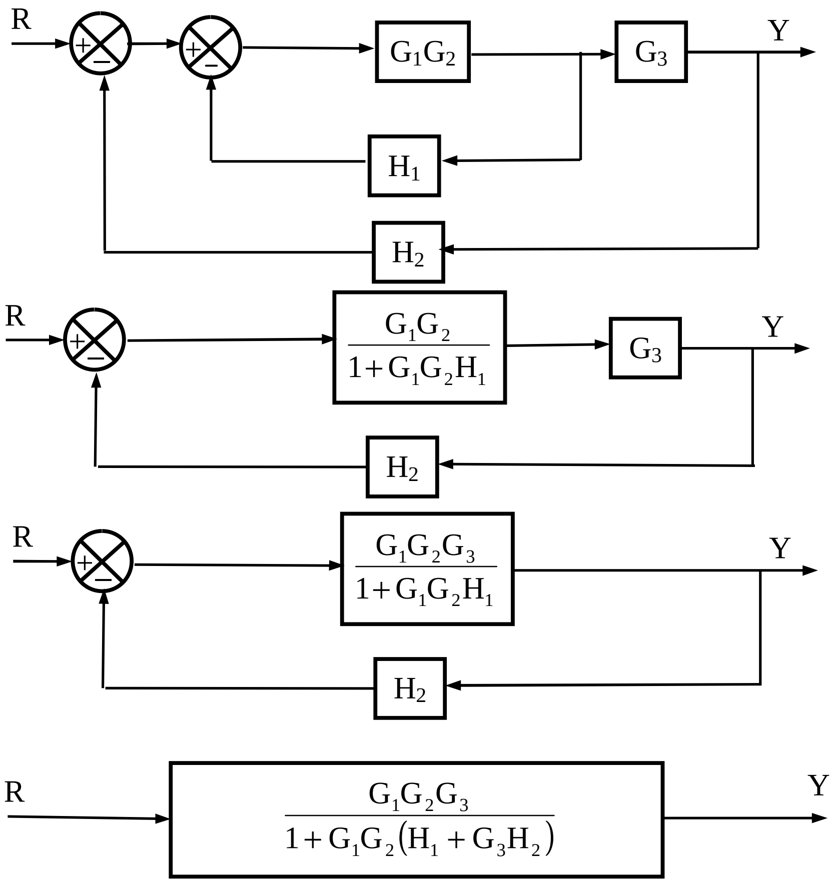
The block H(s) is in the feedback path. The ratio of the feedback signal B(s) to the actuating error signal E(s) is call the open-loop transfer function, i.e.

Open-loop transfer function (OLTF): $\frac{B(s)}{E(s)}=G(s)H(s)$

The ratio of the process signal Y(s) to the set-point signal R(s) is called the closed-loop or feedback transfer function, i.e:

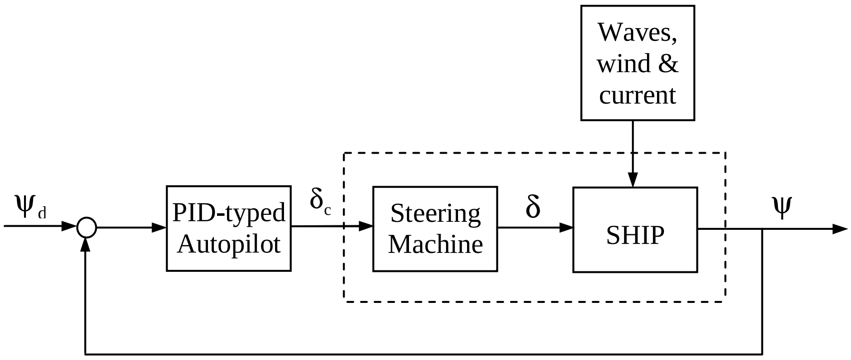
Closed-loop transfer function (CLTF): $\frac{Y(s)}{R(s)}=\frac{G(s)}{1+G(s)H(s)}$

4 Marks

	(b) The block diagram can be reduced as follows:  	4 Marks

(a) (a) A sample answer is as follows: PID-typed ship autopilot:

Structure (using block diagram): Autopilot for ship's course-keeping (also course-changing) is normally based on feedback from a gyrocompass measuring heading. Heading rate measurements can be obtained by a rate sensor, gyro, numerical differentiation of the heading measurement or a state estimator. This is common practice in most control laws utilizing proportional, derivative and integral action. The control objective for a course-keeping autopilot can be expressed as ψ_d = constant. The following figure – block diagram – shows a simple structure of a PID-typed ship autopilot. On the contrary, course-changing manoeuvres suggest that the dynamics of the desired heading should be considered in addition.



Block diagram of autopilot for automatic heading

The variables in an autopilot consist of desired heading (set-point) ψ_d, control signal (rudder angle) δ, and heading ψ.

Operating Principle: The autopilot based on the PID control law is illustrated by the following algorithm. Ship steering dynamics is characterised by the following Nomoto's 1st-order model:

$$T\ddot{\psi} + \dot{\psi} = K\delta \text{ or in form of transfer function}$$

$$\frac{\psi(s)}{\delta(s)} = \frac{K}{s(Ts+1)}$$

The error is difference between the desired heading and the measured heading:

$$e = \psi_d - \psi \text{ or } E(s) = \psi_d(s) - \psi(s)$$

During autopilot control of a ship it is observed that a rudder off-set is required to maintain the ship on constant course. The reason for this is a yaw moment caused by the rotating propeller and the slowly-varying environmental disturbances. These are wave drift forces (2nd-order wave disturbances) and LF components of wind

(b) Based on the unsteady-state mass balance for the tank contents, we obtain:

$$\rho A \frac{dh}{dt} = \rho q_i - \rho q_o$$

Substituting the flow-head relation, $q_o = y / R$, we have

$$A\frac{dy}{dt} = q_i - \frac{y}{R}, \quad A\frac{dy}{dt} + \frac{y}{R} = q_i \quad \text{or} \quad AR\frac{dy}{dt} + y = Rq_i$$

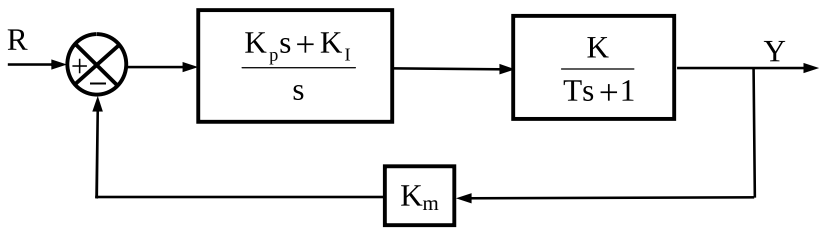
where K = R, T = RA.

The transfer function is

$$G(s) = \frac{Y(s)}{Q_i(s)} = \frac{K}{Ts+1}$$

This transfer function has pole as s = -1/T, and no zero.

(ii) The block diagram of the system is:



Based on this block diagram, we have the total feedback transfer function:

$$\text{C.L.T.F} = \frac{Y}{R} = \frac{\frac{K_p s + K_I}{s}\frac{K}{Ts+1}}{1 + \frac{K_p s + K_I}{s}\frac{K}{Ts+1}K_m}$$

$$= \frac{(K_p s + K_I)K}{Ts^2 + (K_p K_m + 1)s + K_I K_m K}$$

4 Marks

04

(a) <u>1. Static sensitivity</u> of a measuring system is defined as the ratio of change in output to the corresponding change in input, and expressed by the following equation:

$$K = \frac{\Delta y}{\Delta u}$$

where Δy is change in output, and Δu is change in input. The unit of sensitivity depends on units of output and input. Static sensitivity is also called gain or magnification.

<u>Example:</u> a pressure measuring system consisting of pressure sensor, amplifier and pen recorder has three individual sensitivities of K_1 (pC/bar), K_2 (V/pC) and K_3 (mm/V), the overall sensitivity is $K = K_1 \times K_2 \times K_3$ (mm/bar).

<u>2. Accuracy and precision:</u> Accuracy is an indication of the nearness with which the true value is measured. Accuracy is normally stated in terms of the errors that are the difference between the indicated value and the true value:

$$\text{Error}(\%) = \frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\%$$

In practice, it is common to express the error as percentage of the measuring range (maximum scale) of the equipment below:

$$\text{Error}(\%) = \frac{\text{indicated value} - \text{true value}}{\text{max scale value}} \times 100\%$$

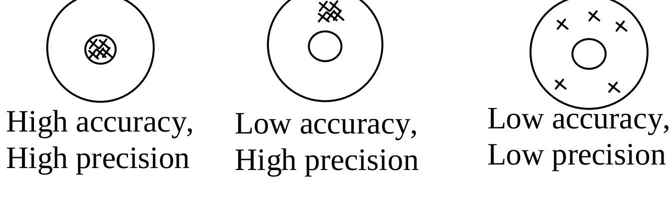
<u>Example:</u> A 0-10 bar pressure gauge was found to have an error of ± 0.15bar when calibrated by the manufacturer, the percentage error of the gauge is:

$$\text{Error}(\%) = \frac{\pm 0.15}{10} \times 100(\%) = \pm 1.5\%$$

Precision of a measuring system is the ability to provide reading which are very close in value for the same input applied on a number of occasions. The term precision is related to the term reproducibility that is used to specify the closeness of results giving for a constant input. Precision does not mean accuracy. The following example illustrates the difference between accuracy and precision:

× = result

○ = Centre circle represents true value



4 Marks

3. Possible and probable errors:

Possible error: If a measurement involves the use of three devices with individual maximum possible errors of $\pm a(\%), \pm b(\%)$ and $\pm c(\%)$, respectively, the possible error is the sum of individual possible errors, and expressed by the following formulas:

$$\text{Max possible error} = \pm a(\%) \pm b(\%) \pm c(\%)$$

Probable error, or root-sum-square error, of overall system is defined as follows:

$$\text{Probable error} = \pm\sqrt{a^2 + b^2 + c^2}\ (\%)$$

Example: A measuring system has 3 devices with individual errors of $\pm 1.5\%$, $\pm 0.75\%$ and $\pm 1.75\%$, the system has maximum possible error and probable error below:

Maximum possible error = $\pm 1.5(\%) \pm 0.75(\%) \pm 1.75(\%) = \pm 4.0(\%)$

Possible error = $\pm\sqrt{1.5^2 + 0.75^2 + 1.75^2}\ (\%) = \pm 2.4238(\%)$

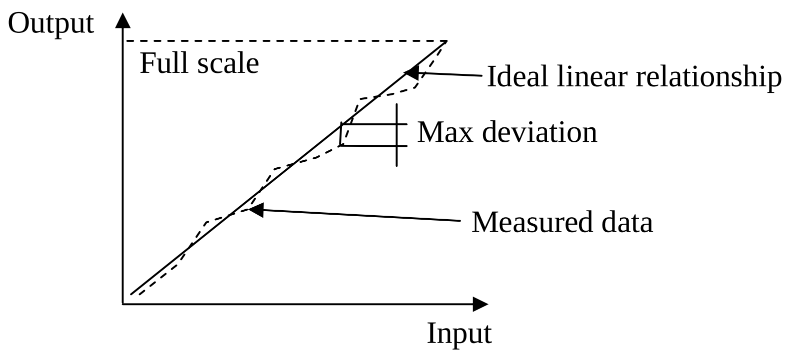
4. Linearity: Linearity is a term related to a linear input-output relationship. Linearity is defined as the ratio of the maximum deviation from a linear relationship between the input and output, to the full scale, i.e. as percentage of maximum deviation per full scale.

Example: An ohmmeter used to measure resistance in range of 0-200Ohms gave the maximum deviation of 2.0Ohms. The linearity is

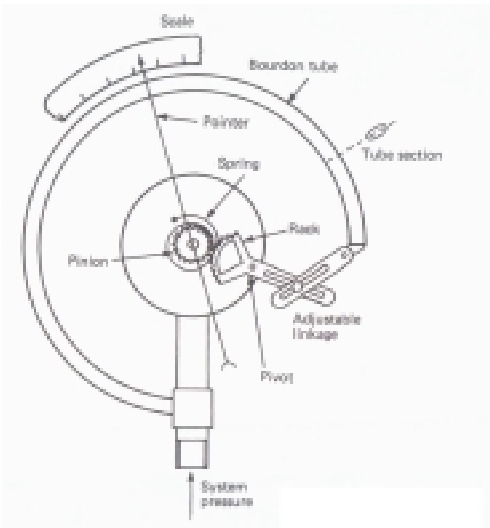
$$\text{Linearity} = \frac{\text{max deviation}}{\text{full scale}} \times 100\,(\%) = \frac{2.0}{200} \times 100 = 1.0(\%)$$

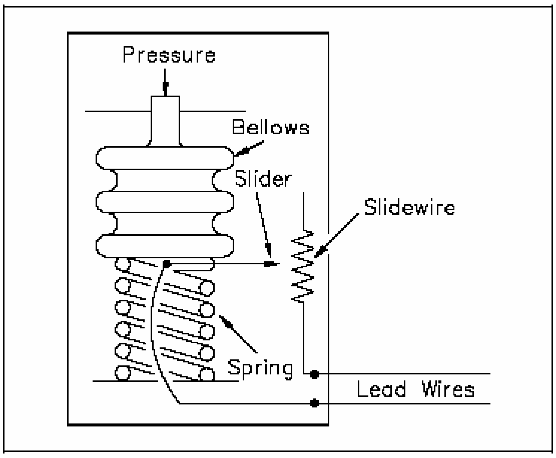
4 Marks

(This example may be illustrated by a simple graph as follows):



	(b) (i) The overall sensitivity is $K = K_1 \times K_2 \times K_3 = 80\frac{\text{pC}}{\text{bar}} \times 6.0\frac{\text{mV}}{\text{pC}} \times 1\frac{\text{cm}}{10^3\,\text{mV}} = 0.48\frac{\text{cm}}{\text{bar}}$ (ii) maximum possible system error: m.p.s.e = $0.14\% + 1.55\% + 1.75\% = +3.44\%$ probable (root-sum-square) error: p.e = $\sqrt{0.14^2 + 1.55^2 + 1.75^2} = +2.32\%$	4 Marks

05	(a) Pressure is force per unit area (fluid, gas): $P = \frac{F}{A}$ (N/m^2) Units for pressure: pascal (Pa) = N/m^2, atmosphere, 1 bar = 10^5Pa = 100kPa, Psi (pounds-force per square inch absolute). Pa is the pressure or stress that arises when a force of one Newton (N) is applied uniformly over an area of one square metre. Methods to measure pressure - pressure can be converted to force by letting it act on a known area. There are several methods to measure pressure such as barometer, U-tube manometer, diaphragm, Bourdon tube, bellows, flapper-nozzle, resistance transducer, inductive transducer, capacitive transducer, etc. **<u>Bourdon tube</u>**: This is probably the most commonly used gauge pressure measuring instrument and it utilizes the elastic deflection of a metal tube. The applied pressure creates a force which elastically deflects the metal tube until an equilibrium condition exists between them. The displacement of the tube is then converted into a reading on a scale. An elliptical section tube is formed into a C-shape and sealed at one end, see the following figure. The sealed end, which is free to move, has a linkage arrangement which will move a pointer over a scale. The applied pressure acts within the tube, entering through the open end which is fixed in place. The pressure acting within the tube causes it to change in cross-section and to attempt to straighten out. The resultant movement of the free end then registers as a needle movement over the scale. Other arrangements with the tube in a helical or spiral form are sometimes used with the operating principle being the same. While the datum or zero value is usually atmospheric to give gauge pressure readings, this gauge can be used to read vacuum pressure values, i.e. less then atmospheric. The needle moving linkage is adjustable to enable calibration adjustments to be made as required.  	4 Marks

	(b) The input current of the galvanometer corresponding to the spot deflection of 60mm is $K_2 = \frac{\Delta y}{I} \Rightarrow I = \frac{\Delta y}{K_2} = \frac{60mm}{10mm/\mu A} = 6\mu A = 6\times10^{-6}A$ The total resistance is $R = R_1 + R_2 = 350\Omega + 50\Omega = 400\Omega$ The voltage to be needed is $V = I\times R = 6\times10^{-6}A\times400\Omega$ $= 2.4\times10^{-3}V = 2.4mV$ The pressure to be measured: $K_1 = \frac{V}{\Delta P} \Rightarrow \Delta P = \frac{V}{K_1} = \frac{2.4mV}{2.5mV/bar} = 0.96bar$	4 Marks
06	(a) A D/P transmitter: Resistance-type D/P transmitter Operating principle: The resistance-type D/P transmitter is based on the combination of a bellows or a Bourdon tube with a variable resistor as shown in the following figure. As pressure changes, the bellows will either expand or contract. This expansion and contraction causes the attached slider (wiper) to move along the slide-wire, increasing or decreasing the resistance, and thereby indicating an increase or decrease in pressure. Structure of Resistance-type D/P transmitter is shown in the following figure.  The output signal is connected to a conditioning circuit such as a Bridge circuit, then an amplification circuit and an indicator. Range: 0 to hundreds of bar Advantages: simple, easy to use Disadvantages: wear in slider and slide-wire will affect accuracy, loading error.	4 Marks

	(b) Overall sensitivity: $K = K_1 \times K_2 = 0.8\dfrac{V}{mm} \times 5.0\ \dfrac{mm}{V} = 4.0\dfrac{mm}{mm}$ Pen movement: $K = \dfrac{\Delta y}{\Delta u}$, $\Delta y = K \times \Delta u = 4.0\dfrac{mm}{mm} \times 18mm = 72mm$	4 Marks
TOTAL		**48**

Notes: The above-mentioned answers are the complete solutions to the final examination paper. Students can get the maximum marks if they give the outlined correct answers to all questions.