AUSTRALIAN MARITIME COLLEGE

SEMESTER 2 - FINAL EXAM EXAMINATION 2004

SOLUTIONS TO EXAMINATION PAPER

SUBJECT INSTR & PROCESS CONTROL TIME ALLOWED 3 HOURS

NO OF QUESTIONS TO BE ATTEMPED SIX (6)

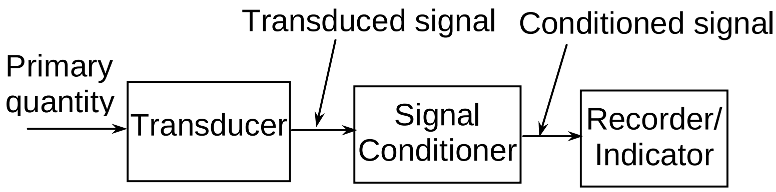
<table>
<tr><th>QUESTION NO</th><th>SOLUTION</th><th>MARK ANALYSIS</th></tr>
<tr><td>Q1</td><td>(a) The general block diagram of a measuring system can be represented as follows (Figure 1).


Figure 1 General block diagram of a measurement system

<u>Transducer Block:</u> has a function as an energy converter that receives the physical quantity being measured and converts it into some other physical variable; eg flow to pressure, speed to voltage, stain to resistance. The transducer is undoubtedly the weakest link in the measuring chain, for measured quantity is always modified by the presence of the transducer, making a perfect measurement theoretically impossible.

<u>Signal Conditioner Block:</u> has a function to rearrange the transduced signal into a form which can be readily recorded or monitored. This block may be an amplifier, or an impedance matching device, or a transmitter.

<u>Recorder Block:</u> may be a recorder, display, or indicating device. The recorder block has a function to record or indicate the measure quantity.</td><td>2</td></tr>
<tr><td></td><td><u>(b) A transducer used in the maritime industries is pressure bellows</u>:
Transducers or sensors are the devices that convert the quantity being measured into an optical, mechanical, or more commonly – electrical signal. The energy-conversion process that takes place is</td><td></td></tr>
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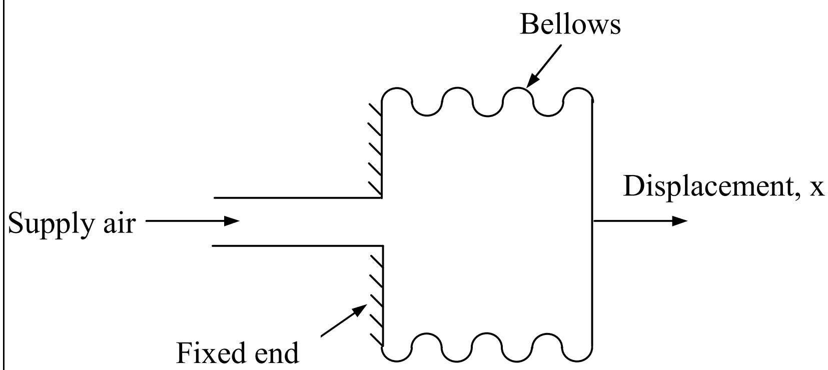
referred to as transduction. Examples of transducers may be resistance displacement transducer, pressure bellows, force diaphragm, etc. The following is a brief description of pressure bellows.

The bellows is used in some pneumatic devices to provide feedback and also as a transducer to convert an input pressure signal into a displacement. A simple bellows arrangement is shown in following figure. The bellows will elongate when the supply pressure increases and some displacement, x, will occur. The displacement will be proportional to the force acting on the base, i.e. supply pressure × area. The actual amount of displacement will be determined by the spring-stiffness of the bellows. Thus

$$\begin{pmatrix}\text{Supply}\\ \text{pressure}\end{pmatrix}\times\begin{pmatrix}\text{Area of}\\ \text{bellows}\end{pmatrix}=\begin{pmatrix}\text{Spring}-\text{stiffness}\\ \text{of bellows}\end{pmatrix}\times(\text{Displacement})$$

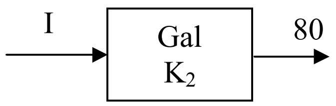
The spring-stiffness and the bellows area are both constants and therefore the bellows is a proportional transducer.



Bellows mechanism

In some feedback arrangements a restrictor is fitted to the air supply to the bellows. The effect of this will be to introduce a time delay into the operation of the bellows. This time delay will be related to the size of the restriction and the capacitance of the bellows.

In practice it is usual for bellows to be made of brass with a low spring-stiffness and to insert a spring. The displacement may therefore be increased, and also the effects of any pressure variations.

	(c) (i) The percentage error of the galvanometer at the reading of spot defection of 80 mm is e_2 (%) @ 80mm = $\frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\,(\%)$ $= +\frac{1.25}{80-1.25} \times 100(\%) = +1.5873\%$ (ii) The percentage error of the piezo-electric transducer at reading of output voltage corresponding to the spot deflection of 80mm is calculated as follows:  From the above, we have true value of spot deflection: 78.75 mm The current needed is $I = \frac{t.s.d}{K_2} = \frac{78.75}{10} = 7.875\mu A = 7.875 \times 10^{-6}\,A$ The total impedance is: $R = R_1 + R_2 = 250+50 = 300$ Ohms The output voltage is $V = IR = 7.875 \times 10^{-6} \times 300 = 2.3625mV$, this is the true value of the output voltage of the transducer. The percentage error of the transducer is: e_1 (%) @ 2.3625mV = $\frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\,(\%)$ $= +\frac{0.025}{2.3625} \times 100(\%) = +1.0582\%$ *The reading of the transducer is 2.3625+0.025 = 2.3875mV* (iii) The maximum possible error is: Maximum possible error = $e_1 + e_2$ $= +1.5873\% + 1.0582\% = 2.6455\%$ The probable error is: Probable error = $+\sqrt{e_1^2 + e_2^2} = +\sqrt{1.5873^2 + 1.0582^2}$ $= +1.9077\%$ (iv) The input pressure is $K_1 = \frac{V}{P_{in}} \Rightarrow P_{in} = \frac{V}{K_1} = \frac{2.3625}{4.5} = 0.525bar$	1+2+1+2
02	(a)	2

An automatic control system, including it recording (indicating) elements, can be represented by the following general block diagram.

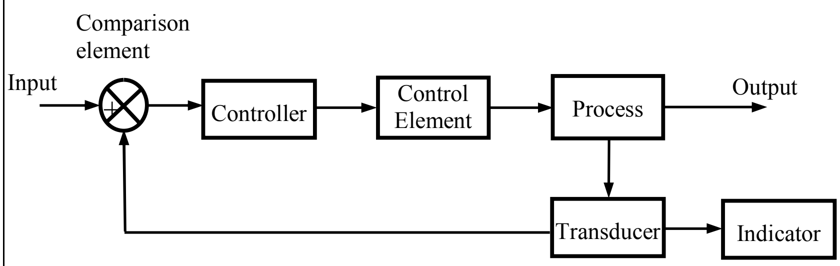


Figure 4 General block diagram of a control system

Comparison Element Block: compares the output or control variable with the desired input (reference signal) and generate an error or deviation signal to the controller. The comparison element performs the mathematical operation of subtraction.

Controller Block: calculates control signals from the error signal, and generates the control signals to the Control Element. The controller block can be a PID controller where the control signal.

Control Element Block: Control element block is the element in which the amplified and conditioned control signal is used to regulate some energy source to the process. The control element block is often referred as an actuator. Control element block may be a valve or a motor.

Process Block: is the dynamic system where the process is implemented.

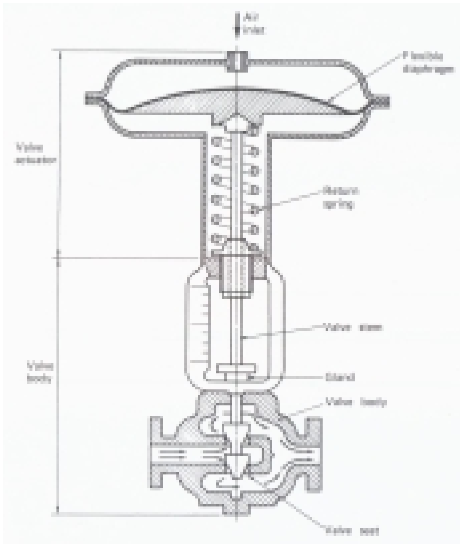
Transducer Block: is a sensing device that receives the physical quantity being measured from the process, converts it into some other physical variable and generates this signal to an indicating device or feeds back to the comparison element.

Indicator Block: indicates or records the measured quantity.

(b) 4

Sample Answer - Brief Description of Diaphragm Control Valve:

Simple Structure: A pneumatically operated spring-and-diaphragm control valve has a schematic structure as shown in the following figure.



Schematic diagram of a pneumatic actuating valve

The control valve is essentially a pressure-reducing valve and consists of two major parts: the valve actuator and the valve-body assembly.

Valve Actuator: The most common type of valve actuator is the pneumatically operated spring-and-diaphragm actuator illustrated in the above figure, which uses air pressure in the range 0.2bar to 1.0bar unless a positioner is used which employs higher pressure to give larger thrusts and quicker action. The air can be applied to the top (air-to-close) or the bottom (air-to-open) of the diaphragm, depending on the safety requirements in the event of an air-supply failure.

Valve Body: The above figure shows a double-seated valve that has two valve plugs and seats. Due to the fluid entering the centre and dividing in both upward and downward directions, the hydrodynamic effects of fluid pressure tent to cancel out and the valves are said to be "balanced". Due to the two valve opening, flow capacities up to 30% greater than for the same nominal size single-seat valve can be achieved. They are, however, more difficult to design to achieve tight shut-off.

Operating Principle: The valve uses a flexible diaphragm and return spring. In order to operate the valve, an inlet pneumatic signal is needed. Normally, the pneumatic signal is supplied by a current-to-pneumatic converter. When the inlet pressure increases, a force acts on the diaphragm, and closes the valve. When the inlet pressure decreases, the spring force will open the valve.

Features/Valve Flow Chracteristics: One characteristic of pneumatic controls is that they almost exclusively employ pneumatic actuating valve. A pneumatic actuating valve can provide a large power output. Sin a pneumatic actuator requires a large power input to produce a large power output, it is necessary that a sufficient quantity of pressurized air be available. In practical pneumatic actuating valves, the valve characteristics may not be linear; that is, the flow may not be directly proportional to the valve system position, and also they may be other nonlinear effects, such as hysteresis.

From the above figure, assuming that the area of the diaphragm is A. Assume also that when the actuating error is zero the inlet pressure (control pressure) is equal to $\overline{P}_C$ and the valve displacement is equal to $\overline{X}$.

In the following analysis, we shall consider small variations in the variables and linearize the pneumatic actuating valve. Let us define the small variation in the control pressure and the corresponding valve displacement to be p_c and x, respectively. Since a small change in the pneumatic pressure force applied to the diaphragm repositions the load, consisting of the spring, viscous friction, and mass, the force balance equation becomes:

$$Ap_c = m\ddot{x} + b\dot{x} + kx$$

where m = mass of the valve and the valve system, b = viscous-friction coefficient, and k = spring constant.

If the force due to the mass and viscous friction negligibly small, then the above equation can be simplified to:

$$Ap_c = kx$$

The transfer function between x and p_c thus becomes:

$$\frac{X(s)}{P_c(x)} = \frac{A}{k} = K_c$$

If q_i, the change in flow through the pneumatic valve, is proportional to x, the change in the valve-stem displacement, then

$$\frac{Q_i(s)}{X(s)} = K_q$$

where K_q is constant. The transfer function between the q_i and p_c becomes:

$$\frac{Q_i(s)}{P_c(s)} = K_c K_q = K_v$$

	where K_v is constant. The standard control pressure for this kind of pneumatic actuating valve is between 3 and 15 psig. The valve-stem displacement is limited by the allowable stroke of the diaphragm and is only a few inches. If a longer stroke is needed, a piston-spring combination may be employed. In pneumatic actuating valves, the static-friction force must be limited to a low value so the excessive hysteresis does not result. Because of the compressibility of air, the control action may not be positive, that is, an error may exist in the valve-stem position. The use of a valve positioner results in improvements in the performance of a pneumatic actuating valve. **Scope of Applications**: This type of actuating valve is applied for general-purpose control and safety applications such as remote start/stop of flow, pressure relief, flow control, pressure control, level control, and excess-flow shutdown. **Advantages and Disadvantages (if known)**: Advantages: Off-the-shelf standard variety of pneumatic valves, fittings and pneumatic components to enable any control or safety applications. Cost effective and reliable actuating and control system. Low pressure actuating and control system. Disadvantages: Compressed air can be contaminated or subjected to condensation. Low actuating forces due to limited compressed air pressure. *Note that the above answer is full. You will get full mark if you give outline answer.*	
	(c) Based on the mass balance: the change in mass in the tank is equal to the difference between the inlet mass and the outlet mass, we have: $\frac{dm}{dt} = w_i - w_o$ or $\rho A \frac{dy}{dt} = \rho q_i - \rho q_o \quad (1)$ From the assumption that head-flow relationship is linear, we have $q_o = \frac{y}{R}$ Therefore, we have the differential equation characterizing the relationship between the level and the inlet flow rate as follows: $A \frac{dy}{dt} + \frac{y}{R} = q_i \quad (2)$ With zero initial conditions, the transfer function of (2) is	6

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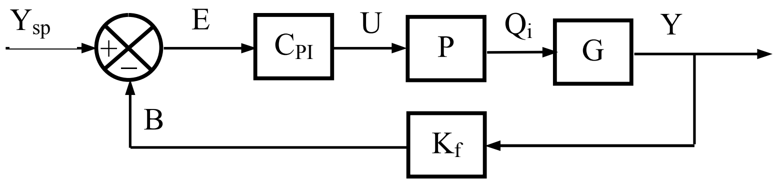
$$G(s) = \frac{Y(s)}{Q_i(s)} = \frac{k}{Ts+1} \qquad (3)$$

where k = R, and T = AR.

Block diagram of the whole system:



where $C_{PI} = K_P + K_I \frac{1}{s} = \frac{K_P s + K_I}{s}$,

$P = \frac{4}{s+2}$, $G = \frac{k}{Ts+1}$, and $K_f = 5$

Total feedback transfer function: based on the above block diagram, the total feedback transfer function is as follows.

$$F.B.T.F = \frac{Y}{Y_{sp}} = \frac{C_{PI}PG}{1 + C_{PI}PGK_f}$$

$$= \frac{\frac{K_P s + K_I}{s}\frac{4}{s+2}\frac{k}{Ts+1}}{1 + \frac{K_P s + K_I}{s}\frac{4}{s+2}\frac{k}{Ts+1}K_f}$$

$$= \frac{(K_P s + K_I)4k}{s(s+2)(Ts+1) + (K_P s + K_I)4kK_f}$$

$$= \frac{(K_P s + K_I)4k}{Ts^3 + (2T+1)s^2 + (20K_P k + 1)s + 20K_I k}$$

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03

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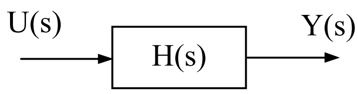
(a) Transfer function of a dynamic system is defined as the ratio of the Laplace transform of the output to the corresponding Laplace transform of the input. Given the following system with input U(s) and output Y(s), the transfer function is defined as follows:

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



A transfer function is often a fraction of two polynomial (numerator and denominator polynomials and represented by the following expression:

$$H(s) = \frac{N}{D} = \frac{b_n s^n + b_{n-1}s^{n-1} + ... + b_1 s + b_0}{a_m s^m + a_{m-1}s^{m-1} + ... + as + a_0} \quad (m \geq n)$$

Poles of a transfer function are the roots of the equation D = 0.

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	Zeros of a transfer function are the roots of the equation N = 0. Example (a continuous-time transfer function): a dynamic system is characterized by the following differential equation: $\ddot{y} + 5\dot{y} + 12y = K(\dot{u} + u)$ where y is output, and u is input, and K is constant. The transfer function of this system is as follows: $H(s) = \frac{Y(s)}{U(s)} = \frac{(s+1)K}{s^2 + 5s + 12}$ This transfer function has zeros at s = -1, and poles at $s = \frac{-5 \pm \sqrt{23}j}{2}$	
	(b) Transfer function is $H(s) = \frac{Y(s)}{U(s)} = \frac{c}{\frac{1}{b}s^2 + as + b}$ For a = 1, b = 5 and c = 7, we have the system: $H(s) = \frac{Y(s)}{U(s)} = \frac{7}{\frac{1}{5}s^2 + s + 5} = \frac{35}{s^2 + 5s + 25}$ The system has no zeros, and has poles at $p_{1,2} = \frac{-5 \pm \sqrt{25 - 4 \times 25}}{2} = -2.5 \pm 2.5\frac{\sqrt{3}}{2}j$ From the above equation, we have poles of the system $p_{1,2} = \frac{-a \pm \sqrt{a^2 - 4 \times b \times \frac{1}{b}}}{\frac{1}{b}} = b\left(-a \pm \sqrt{a^2 - 4}\right)$ The system response is not oscillatory when poles are real numbers, i.e. $a^2 - 4 \geq 0$, a $\geq$ 2 or a $\leq$ -2.	4
	(c) The open-loop transfer function is $O.L.T.F = \frac{B}{E} = \frac{K_D s^2 + K_P s + K_I}{s} \frac{K}{s(Ts+1)} G_T$ $C.L.T.T = \frac{Y}{R} = \frac{\frac{K_D s^2 + K_P s + K_I}{s} \frac{K}{s(Ts+1)}}{1 + \frac{K^D s^2 + K_P s + K_I}{s} \frac{K}{s(Ts+1)} G_T}$	6

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$$= \frac{\left(K_D s^2 + K_P s + K_I\right)K}{s^2(Ts+1) + \left(K_D s^2 + K_P s + K_I\right)KG_T}$$

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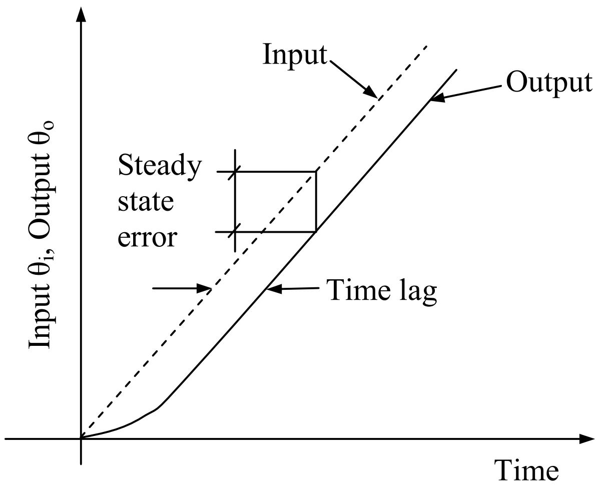
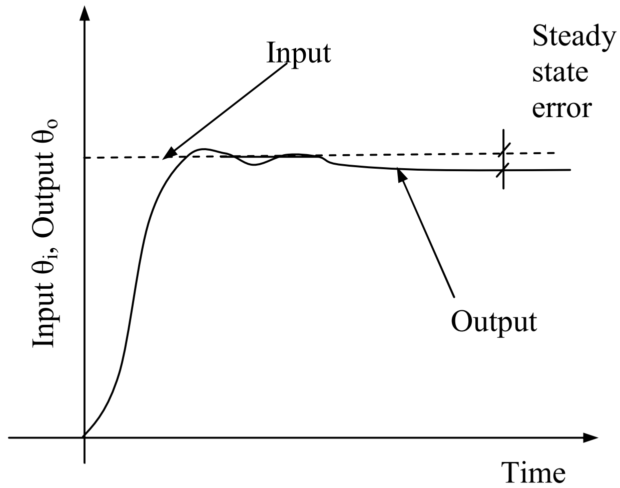
(a) Steady State Error:
One of the objectives of most control systems is that the system output response follows a specific reference signal accurately in the steady state. *The difference between the output and the reference in the steady state* is defined as the steady-state error as shown in the following figures.





The reference signal may be step, ramp, or sine-wave input. The SSE is finite, zero or infinite. The final value theorem states that if the limit of the error e(t) exists when t tends to infinity, then there exists the limit of sE(s) when s tends to zero. The value of the limit of sE(s) when s tends to zero is the steady state error. Therefore, the steady sate error can be calculated as follows:
Step 1: Find C.L.T.F
Step 2: Calculate error E(s) = R(s) – Y(s) =

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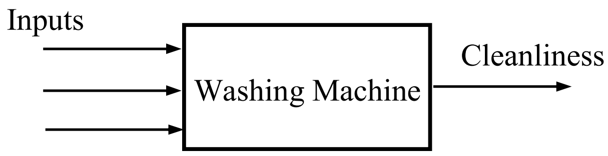
	$= R\left(1-\frac{Y}{R}\right) = R(1-C.L.T.F)$ Step 3: Calculate the steady state error: $SSE = \lim_{s\to 0} sE(s) = \lim_{s\to 0} s\,R(1-C.L.T.F)$	
	(b) The transfer function $H = \frac{k}{s^2+2\xi\omega_n s+\omega_n^2}$ The system has no zeros, and has poles at $p_{1,2} = -\xi\omega_n \pm \omega_n\sqrt{\xi^2-1}$ Close-loop transfer function: $C.L.T.T = \frac{H}{1+H}\ H = \frac{\frac{k}{s^2+2\xi\omega_n s+\omega_n^2}}{1+\frac{k}{s^2+2\omega_n\xi s+\omega_n^2}} = \frac{k}{s^2+2\omega_n\xi s+\omega_n^2+k}$ Error: $E = R(1-C.L.T.F) = R\frac{s^2+2\omega_n\xi s+\omega_n^2}{s^2+2\omega_n\xi s+\omega_n^2+k}$ (i) Unit step input signal (R = $\frac{1}{s}$, we have $SSE = \lim_{s\to 0} sE = \lim_{s\to 0} s\frac{1}{s}\frac{s^2+2\omega_n\xi s+\omega_n^2}{s^2+2\omega_n\xi s+\omega_n^2+k} = \frac{\omega_n^2}{\omega_n^2+k}$ (Substituting $\omega_n = 1.2\ \xi = 0.7\ \rightarrow$ SSE) (ii) Unit ramp input signal (R = $\frac{1}{s^2}$), we have $SSE = \lim_{s\to 0} sE = \lim_{s\to 0} s\frac{1}{s^2}\frac{s^2+2\omega_n\xi s+\omega_n^2}{s^2+2\omega_n\xi s+\omega_n^2+k} = \infty$	3
	(c) Open-loop Control Systems: Those systems in which the output has no effect on the control action are called open-loop control systems. In other words, in an open-loop control system the output is neither measured nor fed back for comparison with the input. **Features:** In any open-loop control system the output is not compared with the reference input. Thus, to each reference input there corresponds a fixed operating condition; as a result, the accuracy of the system depends on calibration. In the presence of disturbances, an open-loop control system will not perform the desired task. Open-loop control can be used, in practice, only if the relationship between the input and output is known and if there are neither internal nor external disturbances. Clearly, such systems	3

are not feedback control systems. Note that any control system that operates on a time basis is open loop.

Advantages: Relatively simple, resulting in cost, reliability and maintainability advantages, Inherently stable

Disadvantages: Relatively slow in response to demanded changes Inaccurate, due to lack of corrective action for error (that is, departure of actual value from desired value).

Example: One practical example is a washing machine. Soaking, washing, and rinsing in the washer operate on a time basis. The machine does not measure the output signal, that is, the cleanliness of the clothes.



Closed-loop (Feedback) Control Systems: A system that maintains a prescribed relationship between the output and the reference input by comparing them and using the difference as a means of control is called a feedback control system.

Features: In a closed-loop control system the actuating error signal, which is the difference between the input signal and the feedback signal (which may be the output signal itself or a function of the output signal and its derivatives and/or integrals), is fed to the controller so as to reduce the error and bring the output of the system to a desired value. The term closed-loop control always implies the use of feedback control action in order to reduce system error.

Advantages: Relatively fast in response to demanded changes Relatively accurate in matching actual to desired value

Disadvantages: Relatively complex, Potentially unstable, under fault conditions

Example: An example of a feedback control system is an autopilot system for control of ship course as illustrated by the following block diagram. In this autopilot, the course signal is feedback and compared to the set course (desired course), and the error is used to determine the control signal that is input of the steering machine. The steering machine drives the rudder to adjust the course of the ship at a desired course (regardless of outside

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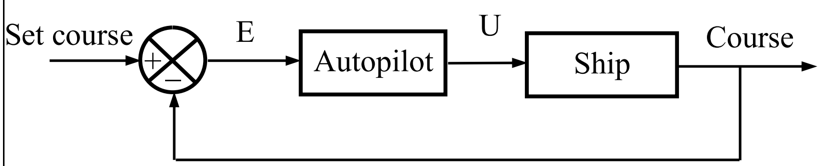
<td>conditions.)


<u>The main differences between the OLCS and the CLCS:</u> The comparison of the set point (reference) signal and the output signal in the CLCS.</td>
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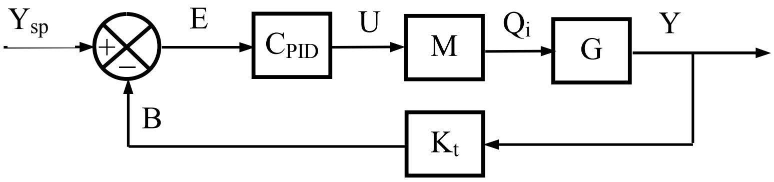
<td>(d) Block diagram of the system:


where C_{PID} = PID controller
$C_{PID} = K_P + K_I \frac{1}{s} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s}$,
M = motor $M = \frac{1}{s+2}$,
G = marine engine $G = \frac{1}{s(6s+1)}$, and
K_t = tachometer, $K_t = 5$

Total feedback transfer function:
$\text{T.F.T.F} = \frac{C_{PID} MG}{1 + C_{PID} MGK_t}$
(substituting individual transfer functions and re-organizing, a total feedback transfer function can be obtained)

Similarly, the total feedback transfer function is
$\text{T.F.T.F} = \frac{C_{PID} MG}{1 + C_{PID} MGK_t}$
where $G = \frac{1}{s(s+3)}$ (substituting individual transfer functions and re-organizing, the total feedback transfer function can be obtained)</td>
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<td>05</td>
<td>(a) A sample answer is as follows:</td>
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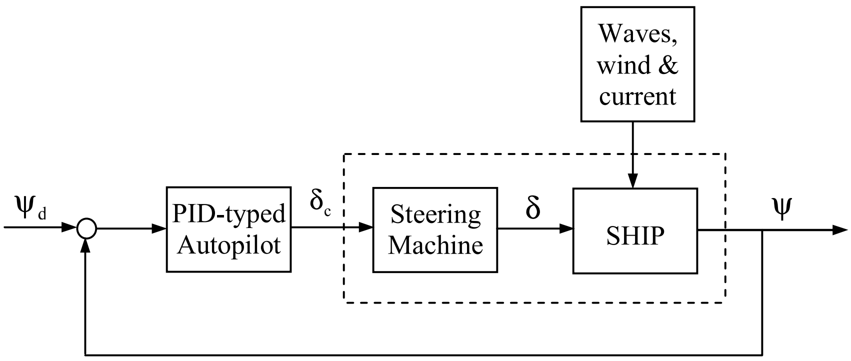
	PID-typed ship autopilot: Structure (using block diagram): Autopilot for ship's course-keeping (also course-changing) is normally based on feedback from a gyrocompass measuring heading. Heading rate measurements can be obtained by a rate sensor, gyro, numerical differentiation of the heading measurement 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: $T\ddot{\psi} + \dot{\psi} = K\delta$ 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: $e = \psi_d - \psi$ 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 and sea currents. However, steady-state errors due to wind, current and wave drift can all be compensated for by adding integral action to the control law. Consider the PID-control law:

$$\delta = K_P(\psi_d - \psi) + K_D(\dot{\psi}_d - \dot{\psi}) + K_I \int_o^t (\psi_d - \psi(t))dt \quad \text{or}$$

$$\delta(s) = \left(K_P + K_I \frac{1}{s} + K_D s\right) E(s) =$$

$$\left(K_P + K_I \frac{1}{s} + K_D s\right)(\psi_d(s) - \psi(s))$$

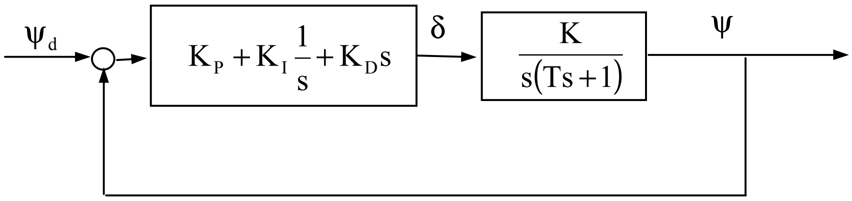
where $K_P > 0$, $K_D > 0$ and $K_I > 0$ are the regulator design parameters. Applying this control law to Nomoto's 1st-order model, we have

$$T\ddot{\psi} + \dot{\psi} = K\left[K_P(\psi_d - \psi) + K_D(\dot{\psi}_d - \dot{\psi}) + K_I \int_o^t (\psi_d - \psi(t))dt\right]$$

or

$$T\ddot{\psi} + (1 + KK_D)\dot{\psi} + KK_P\psi + KK_I \int_o^t \psi(t)dt = K\left[K_P\psi_d + K_D\dot{\psi}_d\right.$$

From this equation, we can obtain the total feedback transfer function. Alternatively, the total feedback transfer function for the PID autopilot can be obtained from the block diagram:

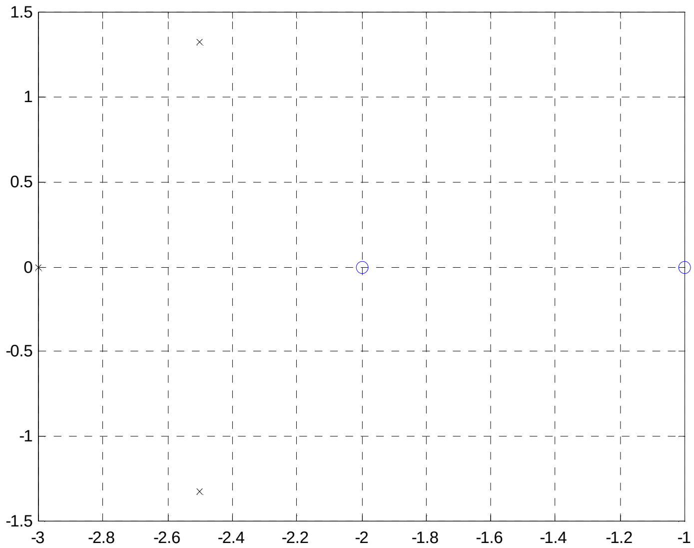


Block diagram for illustration of PID autopilot

$$\text{FBTF} = \frac{\psi(s)}{\psi_d(s)} =$$

$$\frac{\left(K_P + K_I \frac{1}{s} + K_D s\right)\frac{K}{s(Ts+1)}}{1 + \left(K_P + K_I \frac{1}{s} + K_D s\right)\frac{K}{s(Ts+1)}} = \frac{(K_D s^2 + K_P s + K_I)K}{s^2(Ts+1) + (K_D s^2 + K_P s + K_I)K}$$

	$= \dfrac{(K_D s^2 + K_P s + K_I)K}{Ts^3 + (K_D K + 1)s^2 + K_P K s + K_I K}$ The closed-loop characteristic equation is obtained below: $Ts^3 + (KK_D + 1)s^2 + K_P K s + K_I K = 0$ Hence the triple (K_P, K_D, K_I) must be chosen such that all the roots of this 3rd-order polynomial become negative, i.e. the system is stable. These values of control gains can be found by applying an appropriate stability criterion or an empirical method. **Features/Characteristics:** In the autopilot system for ship, the heading error can be detected by a comparison element such as potentiometer in which inputs are desired heading and gyrocompass heading from a repeater. The final control element is perhaps a hydraulic steering machine that drives rudder. The autopilot has some steering modes such as Gyro/Auto (Automatic), Man (manual) and Manoeuvre or Emergency. The whole autopilot system is often a combination of hydraulic components, electric/electronic components and mechanic components. In addition to proportional control, derivative control and integral control, autopilots normally have the yaw, trim, draft, rudder limit, and weather controls. **Scope of Applications:** This type of PID autopilot is mainly applied in ship course-keeping and course-changing. It is also part of the Integrated Bridge System onboard modern ships. **Advantages and Disadvantages:** The control algorithm is simple. However, in severe weather conditions, it is necessary to change control gains. This is often done by the weather control function.	
	(b) (i) $H(s) = \dfrac{s^2 + 3s + 1}{(s+3)(s^2 + 5s + 8)}$ Zeros: $s^2+3s+1 = 0$, $z_{1,2} = \dfrac{-3 \pm \sqrt{3^2 - 4\times 1}}{2}$ = -1, -2 Poles: $(s+3)(s^2+5s+8) = 0$, $p_1 = -3$, $p_{2,3} = \dfrac{-5 \pm \sqrt{25 - 4\times 8}}{2} = -2.5 \pm \dfrac{\sqrt{7}}{2} j$	3

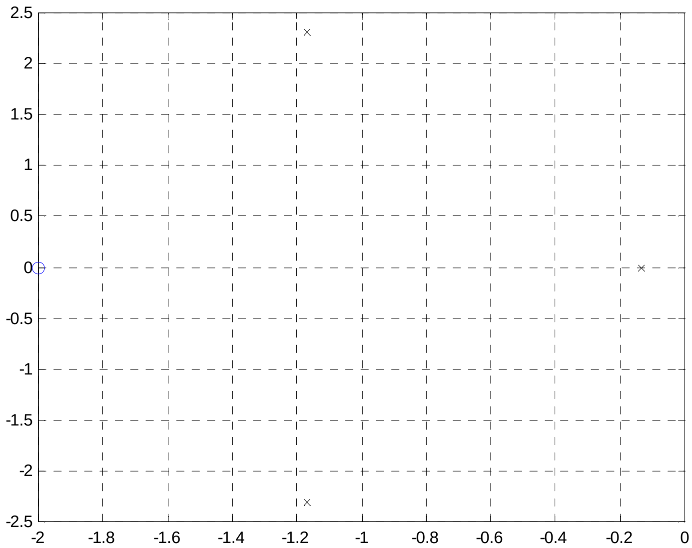


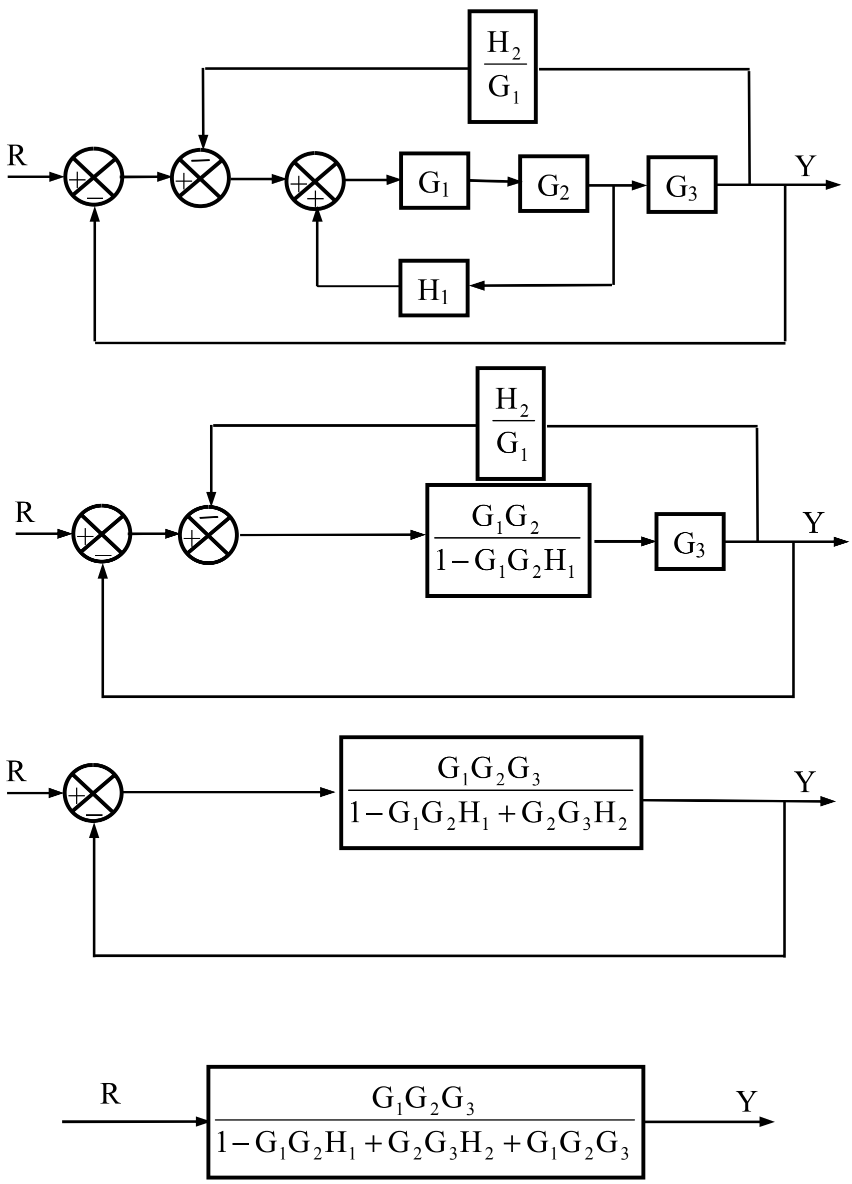
(ii) $H(s) = \frac{(s+2)K}{(7.5s+1)(3s^2+7s+20)}$ (K is constant)

Zeros: s +2 = 0, z = -2

Poles: (7.5s+1)($3s^2$ + 7s + 20) = 0; $p_{1,2} = -\frac{1}{7.5}$ $p_{3,4}$ =

$$\frac{-7 \pm \sqrt{49 - 4 \times 20 \times 3}}{2 \times 3} = \frac{-7 \pm \sqrt{191}j}{6}$$



	(c) The block diagram is reduced as follows 	3
06	(a) Linear velocity is a vector quantity and is the rate of change of linear displacement in a direction. Linear speed is a scalar quantity which gives the magnitude of the linear velocity + Angular velocity is a vector quantity and is the rate of change of angular displacement about an axis. Angular speed is a scalar quantity, which gives the magnitude of the angular velocity + Frequency is the number of cycles, oscillations, or vibrations of a wave motion or oscillation in one second. + Units of linear velocity: m/s, km/s, km/h + Units of angular velocity: deg/s, rad/s + Units of frequency: Hz, kHz, MHz + Methods to measure velocities: there are many methods to	2

	measure velocities, they are mechanical, pressure, electrical & electronic methods. Doppler method is the most used method to measure moving objects.	
	(b) Doppler effect: Point 1: Description of the Doppler phenomenon: Doppler phenomenon occurs with sound and relative movement. Example, the whistle from a moving train: as the train approaches a stationary listener, the pitch (frequency) of the whistle sounds higher than when the train passes by (recedes), at which time the pitch sound the same as if the train were stationary. As the train recedes from the listener, the pitch decreases. The Doppler phenomenon is explained by the Doppler shift, the difference between the frequency of transmit signal and reflection frequency of reflection signal (echo). Point 2. Relationship between transmit frequency and Doppler shift: A stationary source of sound transmits a signal at a frequency of f_t (Hz) and velocity of c (m/s^2). When the transmit signal meets a moving object (target) at a velocity of v (m/s^2), it is reflected at a reflection frequency of f_r (Hz). The Doppler shift for a moving towards target is $f_d = f_r - f_t$, for a moving away target, $f_d = f_t - f_r$. The Doppler shift is calculated by $f_d = \pm \frac{2vf_t}{c}$ (+ for moving towards targets, - for moving away targets) If both the source and target are moving, the Doppler shift is calculated by $f_d = \pm \frac{2v_r f_t}{c}$ where v_r is relative velocity between the sound source and the moving target. The relative velocity is determined by $v_r = v_s \pm v$ where v_s = velocity of moving sound source, v = velocity of moving target (+ for opposite direction, and – for the same direction) Based on the measurement of Doppler shift, the velocity of the moving target can be measured. Point 3. The Doppler effect can be applied in instrumentation and control engineering to measure velocity of moving objects. A sound source with high frequency (ultrasonic sound), or a transmit signal source is used to transmit sound waves in form of pulses, the sound waves are reflected when they meet an object. By measuring the Doppler shift, the velocity of the object can be detected. On board vessels, Doppler effect is applied in speed logs	4

	in which the transmitter is also the receiver. The sound waves transmitted from the transmitter meet the seabed bottom and are reflected to the receiver. By measuring the reflection signal and Doppler shift, the ship speed (against the bottom) can be detected.	
	(c) f = 1/T T = 2.5s, we have f = 1/2.5 = 0.4Hz T = 45ms, we have $f = 1/(45\times10^{-3})$=22.22Hz T = 20µs, we have $f = 1/(20\times10^{-6})$ = 50kHz T = 1/f f = 50Hz, we have T = 1/50 = 20ms f = 2.5kHz, we have $T = 1/(2.5\times10^{3})$ = 0.4ms f = 30MHz, we have $T = 1/(30\times10^{6}) = 33.3\times10^{-9}$s = 33.3ns	3
	(d) (i) The differential pressure is $\Delta P = (\rho - \rho_o)gh$ $= (13.56\text{-}0.8)\times10^3\,(kg/m^3)\times9.81(m/s^2)\times 60\times10^{-2}\,(m)$ $= 12.76\times0.981\times6\times10^3\,N/m^2 = 75.105\times10^3\,Pa = 75.1kPa$ (ii) Volumetric flow $Q = VA$ $V = k\sqrt{\frac{\Delta P}{\rho_o}} = 1.5\sqrt{\frac{75.105\times10^3}{800}} = 14.534m/s$ $A = \left(\frac{d}{2}\right)^2\pi = \frac{10\times10^{-2}}{4}\times3.14 = 0.0785m^2$ $Q = 14.534m/s\times0.0785m^2 = 1.1416m^2/s$ $W = Q\rho_o = 1.1416\times800 = 913.3kg/s$ $W_{(day)} = W\times3600\times24 = 913.3\times3600\times24\times10^3 = 78909.12$ tons	3
TOTAL MARKS		**72**

Notes: The above 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.