MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION
(Autonomous)
(ISO/IEC - 27001 - 2005 Certified)

WINTER-17 EXAMINATION

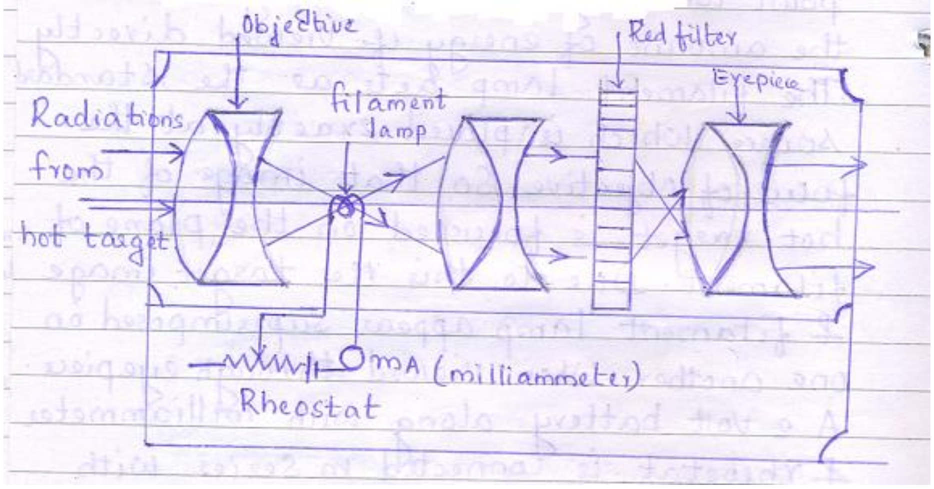
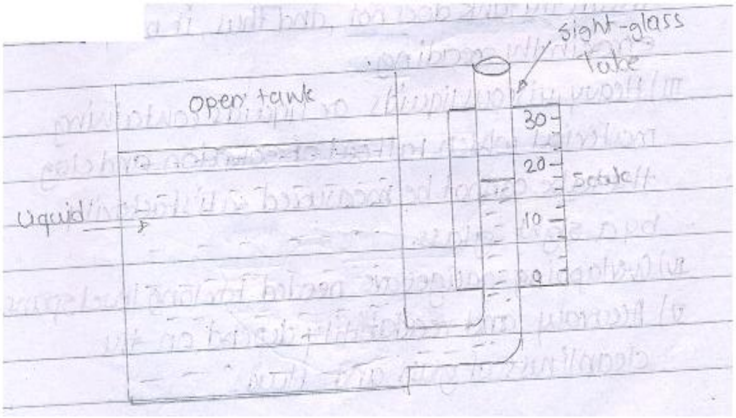
Model Answer

Subject Title: Chemical Process Instrumentation & Control Subject code: 17561

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q No.	Answer	Marks
1a	**Attempt any THREE**	12
1a-i	**Definition:** **Static characteristics**: Static characteristics are those that must be considered when the instrument is used to measure a condition not varying with time. **Dynamic characteristics**: Dynamic characteristics are those that must be considered when the instrument is used to measure a condition varying with time. **List of static characteristics (any four)** Calibration, accuracy, precision, repeatability, drift, sensitivity, resolution, dead zone, static error.	1 1 ½ mark each
1a-ii	**Principle of radiation pyrometer:** According to Stefan Boltzmann's law, the intensity of radiant energy emitted by a hot target varies as the fourth power of its absolute temperature. $\Phi_b = \sigma A T^4$ σ –Stefan Boltzmann constant. T – Absolute temperature. A - Area **Diagram of optical pyrometer:**	2

		2
1a-iii	**Sight glass method for level measurement:**  Sight glass instrument consists of graduated tube of toughened glass which is connected to the exterior of the tank at the bottom. The liquid level in the sight glass matches the level of liquid in the tank. As the liquid level in the tank rises and falls, the liquid level in the sight glass also rises and falls accordingly. Thus by measuring the level in the sight glass, the level of the liquid in the tank is measured.	2

	Methods of level measurement of liquids (any four): 1.Float type level indicator method 2. Hydro static methods 3. Differential methods 4. Electrical methods 5. Radiation methods 6. ultrasonic methods	½ mark each
1a-iv	**Principle of ultrasonic flow meter** : Measurement of flow rate is determined by the variation in parameters of ultrasonic oscillations. These devices measure flow by measuring the time taken for ultrasonic wave to transverse a pipe section , both with and against the flow of liquid within the pipe.	2
	Explanation: It consists of two transducers, A and B, inserted into a pipe line, and working both as transmitter and receiver. The ultrasonic waves are transmitted from transducer A to transducer B and vice versa. An electronic oscillator is connected to supply ultrasonic waves alternately to A or B which is working as transmitter through a change over switch, when the detector is connected simultaneously to B or A which is working as receiver. The detector measure the transit time from upstream to downstream transducer and vice versa.	2
1b	**Attempt any ONE**	6
1b-i	**McLeod gauge:** **Working:** To operate the gauge, the piston is first withdrawn, causing the level of mercury in the lower part of the gauge to fall below the level of the junction between the	

	two tubes. The unknown pressure source is connected to the gauge from where it also flows and fills the bulb and capillary. Next, the piston is pushed in, moving the mercury level up to block the junction. At this stage,, the fluid in the capillary and the bulb is at pressure P. Further movement of the piston compresses the fluid in the tube and the mercury level is raised till it reaches the zero reference point in R. Measurement of the height above the mercury column in the capillary allows the calculation of the compressed volume of the fluid. The expression for calculating the unknown pressure is $P = A\rho g y^2 / V$ Where A is capillary area ρ is density of fluid y is height above the mercury column in capillary	3
	Diagram:	3

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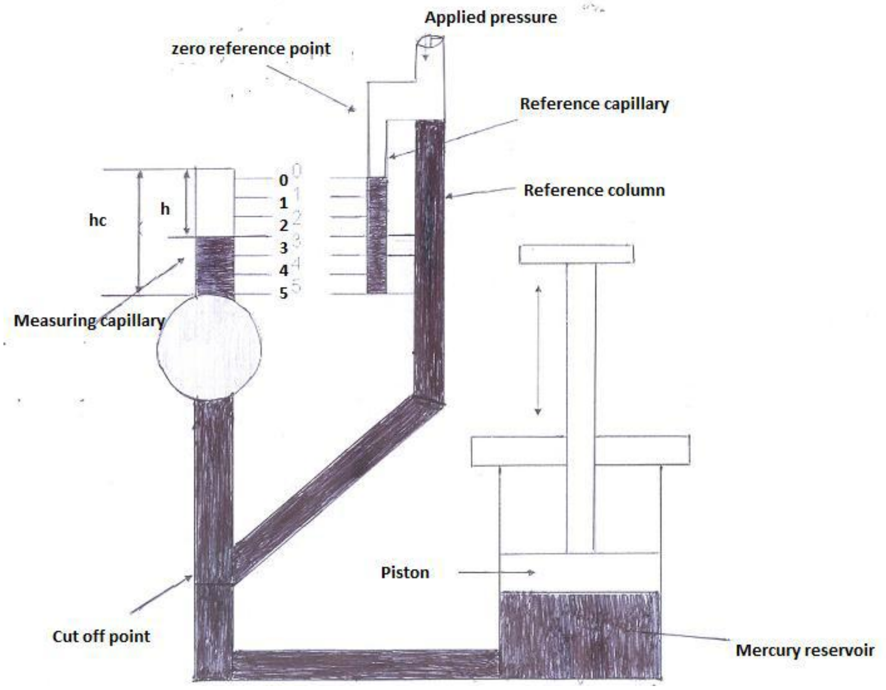

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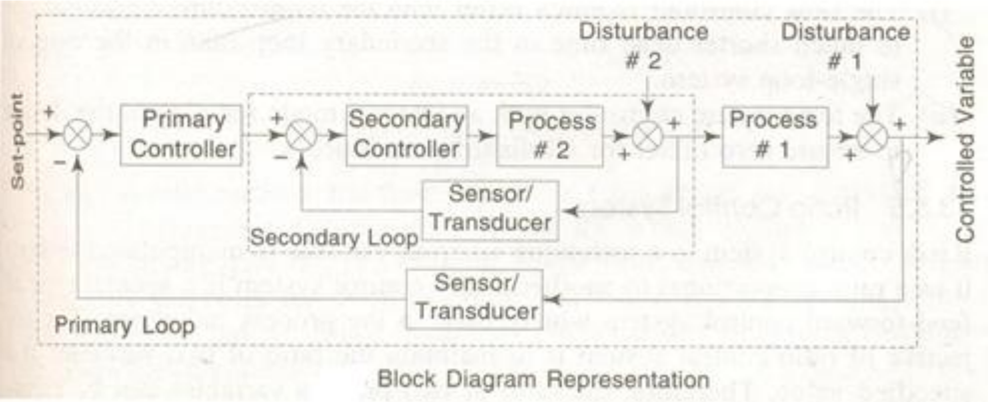
<td>1b-ii</td>
<td>
Cascade control:

Block diagram



Block Diagram Representation

Description:

In a cascade control system, there is one manipulated variable and more than
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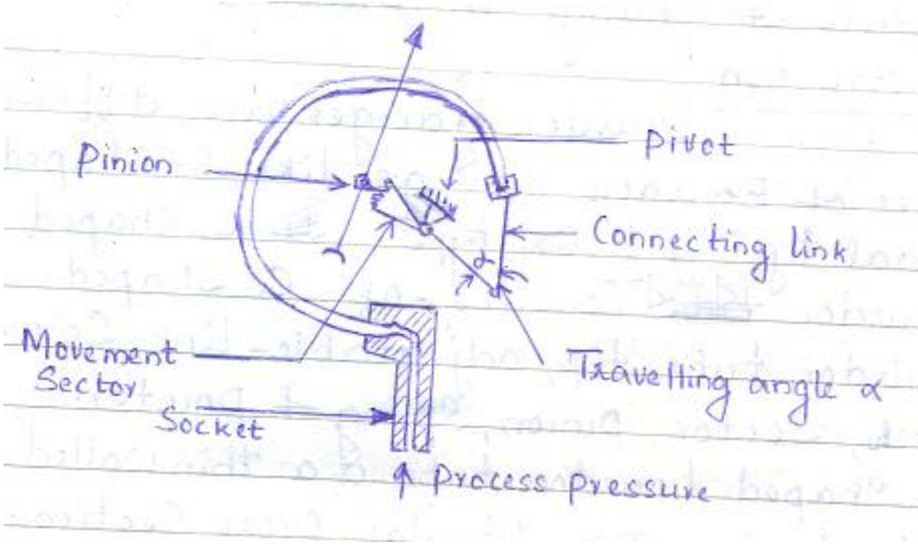
	one measurement. It employs 2 feedback controllers, with the output of the master (primary) controller changing the set point of the slave (or secondary) controller. It eliminates the effect of disturbances and improves the dynamic response of control loop. The feedback controller attempts to maintain the process variable at its set point in response to all the disturbances and ensures zero steady state offset for step like disturbances. Cascade control system considers the likely disturbances and tune the control system to the disturbances that strongly degrades the performance. It uses an additional secondary measured process input variable that has the important characteristics of indicating occurrence of the key disturbances.	3
2	**Attempt any FOUR**	16
2-a	**Comparison between open loop and closed loop control system.**	1 mark each for any four points

Sr No.	**Open loop control system**	**Closed loop control system**
1	Feedback doesn’t exists	Feedback exists
2	Output measurement is not necessary	Output measurement is necessary
3	Any change in output has no effect on input	Changes in output affects the input
4	Error detector is absent	Error detector is present
5	Inaccurate and unreliable	Highly accurate and reliable
6	Highly sensitive to disturbance	Less sensitive to disturbance
7	Highly sensitive to environmental changes	Less sensitive to environmental changes

8	Simple in construction and cheap	Complicated in construction and hence costly
9	Highly affected by non-linearities	Reduced effect of non-linearity

2-b	C type Bourdon tube pressure gauge Diagram  	2
	Working: When the fluid under pressure enters the bourdon tube, its cross section tends to become more and more circular that causes straightening of the tube. Since one end of the tube is fixed, straightening of the tube causes the free end to deflect, which is called as tip travel. The amount of tip travel for given rise in pressure is a function of tube length, wall thickness, cross section and elastic modulus of the tube material. Sector and pinion converts the amplified tip travel into proportional rotary motion of the pointer connected to the pinion. The pointer deflection can be read on the scale calibrated in terms of pressure.	2

2-c	**Factors to be considered for the selection of control valve :** 1. The first step in control valve selection involves collecting all relevant data and completing the ISA Form S20.50. The piping size must be set prior to valve sizing, and determining the supply pressure may require specifying a pump 2. The size of the valve is required; select the smallest valve C_v that satisfies the maximum C_v requirement at 90% opening. While performing these calculations, checks should be made regarding flashing, cavitation, sonic flow and Reynolds number to ensure that the proper equation and correction factors are used. As many difficulties occur due to oversized valves as to undersized valves. Adding lots of “safety factors” will result in a valve that is nearly closed during normal operation and has poor rangeability. 3. The trim characteristic is selected to provide good performance; goals are usually linear control loop behavior along with acceptable rangeability. 4. The valve body can be selected. The valve size is either equal to the pipe size or slightly less, for example, a 3-inch pipe with a 2-inch globe valve body. When the valve size is smaller than the process piping, an inlet reducer and outlet expander are required to make connections to the process piping. 5. The actuator is now selected to provide sufficient force to position the stem and plug. 6. Finally, auxiliaries can be added to enhance performance. A booster	1 mark each for any 4 points

	can be increase the volume of the pneumatic signal for long pneumatic lines and large actuators. A positioner can be applied for slow feedback loops with large valves or valves with high actuator force or friction. A hand wheel is needed if manual operation of the valve is expected.	
2-d	**Elements of Computer Aided Process Control hardware:** Computer aided process control hardware consists of four basic parts or subsystems. 1. Central Processing Unit(CPU) 2. Storage device 3. Input/ Output device 4. Bus interface **The Central Processing Unit (CPU)** consists of control unit, arithmetic logic unit (ALU), main memory(Primary storage) and general purpose registers. Computer fetches data from primary memory under the command of control unit. ALU performs arithmetic & logical operations on the data and transfers it to primary storage. The processed data is further transferred to input/output devices (I/O) as per the requirements of application program. **Storage:** They are of three types- 1.Main storage or immediate access storage 2.Auxiliary or secondary memory 3.Cache memory **Input/output devices:** It is the sub system through which the CPU communicates with the outside world. The input-output (I/O) devices of process control computers are divided into three types. (1) Operator I/O devices: These are used to communicate with the operators	1 3

	(people). Process operators uses devices such as keyboards, push button, switches etc to input data or command to the computer and receive information from computer via devices such as VDU(Visual Display Unit),LED (Light Emitting Diode), numerical display etc. (2) Process I/O devices : These devices communicate between CPU and plant devices such as sensors, limit switches etc for input and control valves, motor starters etc for output, through ADC and DAC subsystems. (3) Computer I/O devices. These devices directly communicate with the CPU for data and information exchange with the peripheral devices. **Bus interface:** A bus is an electronic pathway in the computer that provides a communication path for data flow between the CPU and its memory and amongst the CPU and the various peripheral devices connected to the computer.	
2-e	**Application of PLC:** 1) PLC can be a vital part of industrial automation as it produces on/off voltage outputs to actuate elements such as electric motors, solenoids etc. 2) It can also be used in sequential controllers used for periodical on/off of fans, heaters and light switches. **Application Of DCS:** 1) DCS are designed for continuous process where the control signal is analog rather than discrete. 2) It is a powerful integrated control system having capabilities such as, data acquisition, advanced process control and batch control capabilities for various industrial environments such as cement factory, oil refinery,	2 2

<table>
<tr><td></td><td>power plant etc.</td><td></td></tr>
<tr><td>2-f</td><td>Difference between single seated and double seated valve
<table>
<tr><th>Single seated valve</th><th>Double seated valve</th></tr>
<tr><td>1. Only one plug is present</td><td>1. Two plugs</td></tr>
<tr><td>2. Valve can be completely closed. Therefore flow can be completely stopped.</td><td>2. It cannot be fully closed. Therefore flow cannot be completely stopped.</td></tr>
<tr><td>3. Force required to operate the valve against the upward thrust is large.</td><td>3. Force required to move the valve is comparatively less.</td></tr>
<tr><td>4. Suitable for small flow rates.</td><td>4. Suitable for large flow rates</td></tr>
</table></td><td>1 mark each</td></tr>
<tr><td>3</td><td>Attempt any FOUR</td><td>16</td></tr>
<tr><td>3-a</td><td>Resistance temperature detector:
Description:
The resistance of certain metals changes with temperature change. Resistance thermometer utilizes this characteristic. With the increase of temperature, the electrical resistances of certain metals increases in direct proportion to the rise of temperature. Therefore, if the electrical resistance of a wire of a known and calibrated material is measured, the temperature of the wire can be determined. Platinum, copper and nickel are generally used in resistance thermometers.
Construction of practical resistance thermometer is shown in fig. The resistance element is surrounded by a porcelain insulator which prevents short circuits between wire & the metal sheath. Two leads are attached to each side of the platinum wire. When this instrument is placed in a liquid or a gas medium whose temperature is to be measured, the change in temperature causes the platinum wire inside the sheath to heat or cool, resulting in a proportional</td><td>2</td></tr>
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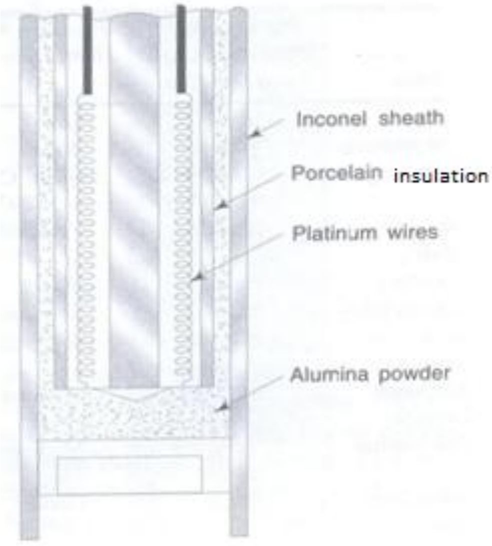
	change in the wire's resistance. This change in resistance can be directly calibrated to indicate the temperature. 	2
3-b	**Principle of air purge system:** When liquid is held in a tank, then it exerts equal pressure on the walls of the tank. Such a pressure is due to the weight of liquid present above a certain reference point or base and is called hydrostatic head or pressure. Air purge system works on measuring the pressure required to force a gas into a liquid at a point beneath the surface. This method uses a source of clean gas or air and is connected through a restriction to a bubble tube immersed at a fixed depth in to the vessel.	4
3-c	**Construction and working of bellows**	

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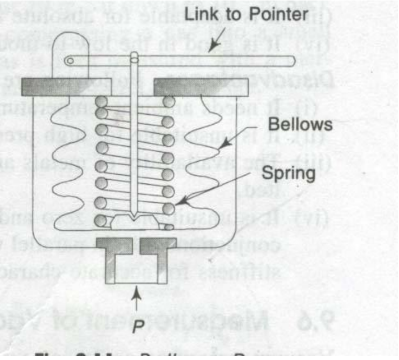

Bellows are made of an alloy (phosphor bronze) which is ductile, has high strength and retains its properties over long use, i.e has very little hysteresis effect. In the above figure pressure is applied to one side of the bellow and the resulting deflection is counter balance by a spring. This arrangement indicates the gauge pressure. Spring opposed bellow elements are very sensitive and are quite useful in working signaling and tripping devices because of the considerable amount of movement for a given change in pressure. It is made of metallic bellows enclosed in a shell which is connected to pressure source. Pressure acting on the outside of the bellow compresses the bellows and moves its free end against the opposing force of the spring. A rod resting on the bellow transmits the motion to a pointer.
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<td>3-d</td>
<td>Construction and working of thermal flow meter:</td>
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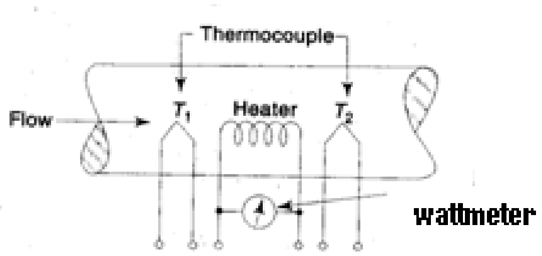


It consists of an electric immersion heater for the heating of flowing fluid. Two thermocouples (or resistance thermometers) T1 and T2 are placed at each side of the heater. The thermocouple T1 measures the temperature of fluid before it is heated, while the thermocouple T2 measures the temperature so after. The power supply to the heater equals the heat transferred to the fluid, i.e. Q, and is measured by a wattmeter. Thus by measuring the values of Q, T1 and T2 the flow rate W of liquid is determined from the equation

$W=Q/Cp(T_2-T_1)$

Where

Q=heat transfer

W= mass flow rate of fluid

Cp= specific heat of fluid

T_1=initial temperature of the fluid after heat has been transferred

T_2=final temperature after heating the fluid.

4

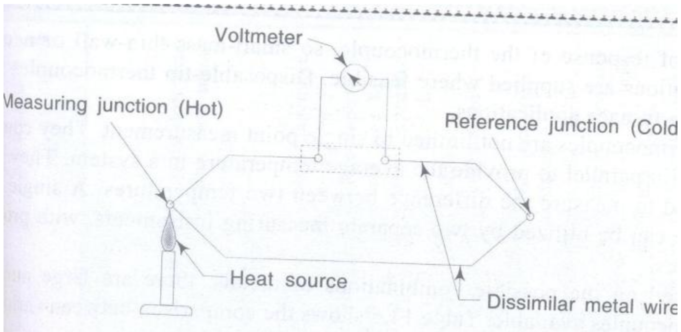
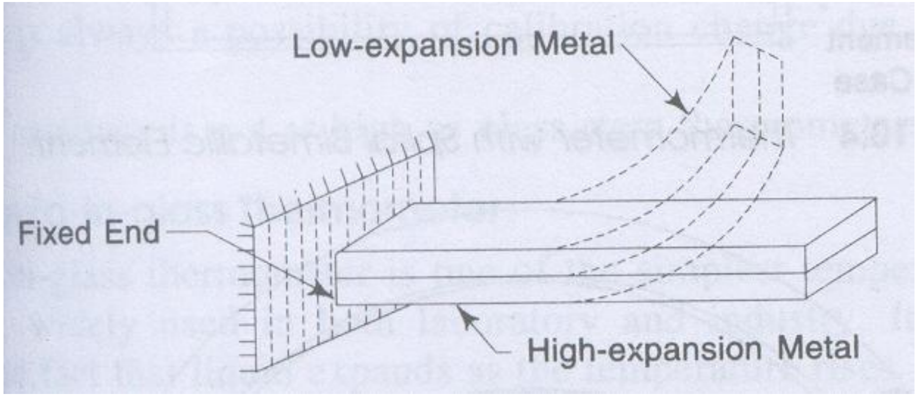
3-e **Comparison between P,PI,PD and PID controller (4points):**

1 mark each

P	**PI**	**PD**	**PID**
1.High maximum deviation	High maximum deviation	smallest maximum deviation	A compromise between PI and PD
2.Moderate	long period of	Smallest	A compromise

period of oscillation	oscillation	oscillation	between PI and PD
3.Maximum offset	No offset	Offset smaller than P type.	A compromise between PI and PD
4. Considerable time required for oscillation to stop.	Large time required for oscillation to stop compared to P type..	Shortest time required.	
5.Mathematical expression m= K_pe	Mathematical expression $m = K_p\left(e + \frac{1}{T_i}\int_0^t edt\right)$	Mathematical expression $m = K_p\left(e + T_d\ \frac{de}{dt}\right)$	Mathematical expression $m = K_p\left(e + \frac{1}{T_i}\int_0^t edt + T_d\ \frac{de}{dt}\right)$

4a	**Attempt any THREE**	12
4a-i	**Thermocouple** **Principle:** **Seebeck effect**: Seebeck discovered that when there is temperature difference between two junctions of thermocouple ,an emf is developed between the junctions. This emf causes electric current to flow through thermocouple	2

	circuit. This is called thermo electric effect by which thermal energy is converted to electrical energy. **Peltier effect**: It is defined as the change in heat content when 1 coulomb of charge crosses the junction. **Diagram**  	2
4a-ii	**Bimetallic thermometer** **Principle:** When heated different solids expand differently depending on their coefficient of thermal expansion. **Diagram**  	1 2

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<td>Working:
Bimetallic strip consists of twobstrips of metal such as invar and brass welded together, each strip made from a metal having a different coefficient of thermal expansion. Whenever the welded strip is heated, the two metals change length in accordance with their individual rates of thermal expansion. The two metals expand to different lengths as the temperature rises. This forces the bimetallic strip to bend towards the side with low coefficient of thermal expansion as shown in Fig above. If one end of the bimetallic strip is fixed so that it cannot move, the distance the other end bends is directly proportional to the square of the length of the metal strip, as well as to the total change in temperature, and is inversely proportional to the thickness of the metal. The movement of the bimetallic strip is utilized to deflect a pointer over a calibrated scale.</td>
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<td>4a-iii</td>
<td>Difference between variable head meter and variable area meter:
(any four)
<table>
<tr><th>Variable head meter</th><th>Variable area meter</th></tr>
<tr><td>1. Area of flow is constant and pressure drop varies with flow rate</td><td>Pressure drop is constant and area of flow varies with flow rate</td></tr>
<tr><td>2. Cannot give volumetric flow rate directly</td><td>Can give volumetric flow rate directly</td></tr>
<tr><td>3. Relatively cheap</td><td>costly</td></tr>
<tr><td>4. Simple in construction</td><td>complex</td></tr>
<tr><td>5. Need straight pipe before and after the meter</td><td>Does not need</td></tr>
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<td>1 mark each</td>
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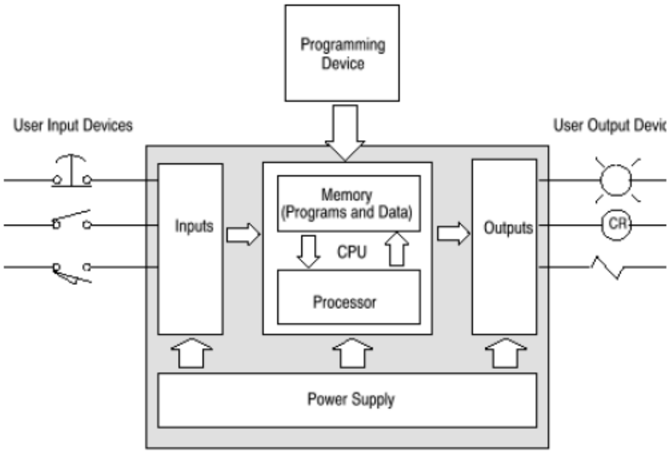
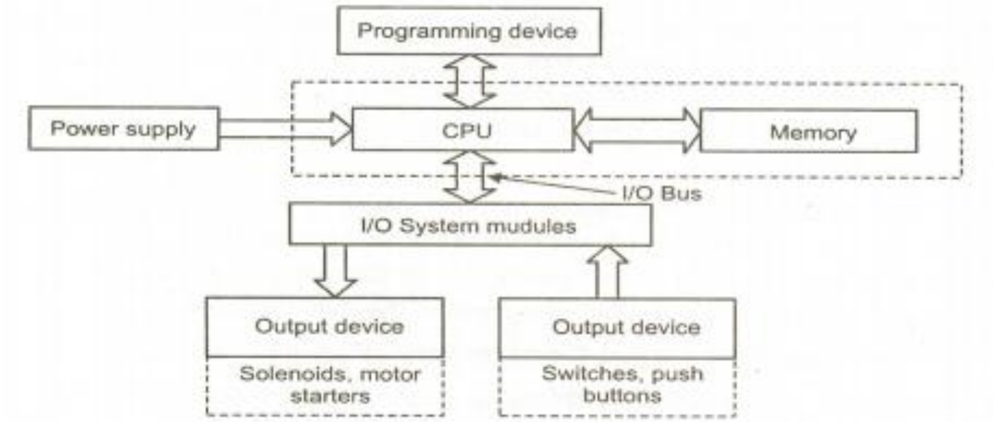
4a-iv	**Principle of positive displacement meter** As the liquid flows through the meter, it separates the flow of liquid into separate known volumetric increments which are counted and totaled. The sum of the increments gives the measurement of the total volume of liquid passed through the meter. **OR** These meters have two chambers of known volumetric capacity and they are arranged so that when one chamber is being filled, the other is being emptied. For measuring the total flow over a certain period, the fluid is continuously filled and emptied from the chamber and then the number of times the chamber is being filled and emptied in that period is counted which when multiplied by the volumetric capacity of the chamber gives the total flow.	1
	Advantages of rotating vane meter (any two) 1. It allows low pressure loss 2. It has relatively high temperature and pressure rating 3. It has a good accuracy 4. It is available in numerous construction material	2
	Application (any one): 1. It is most widely used in the petroleum industry and is used for such services as gasoline and crude oil metering. 2. Cooling water monitoring 3. General mechanical engineering 4. Waste water treatment 5. All heavy goods industry 6. Chemical industry	1

4b	**Attempt any ONE**	6
4b-i	**Types of control valve:** **1. Based on number of plugs:** Control valves can be classified as single seated valve and double seated valve **2. Based on action:** Control valves operated through pneumatic actuators can be either air to open or air to close **3. Based on flow characteristics** Control valves can be classified as quick opening valve, linear opening valve , equal percentage valve **4. Based on construction** 1. Angle Valve 2. Globe valve 3. Diaphragm Valve 4. Butterfly valve 5. Rotary valve 6. Ball valve 7. Sliding cylinder valve **Function of valve actuator:** it is that portion of the valve that responds to the applied signal and results in the movement of the stem due to which the flow rate of fluid changes. It consists of diaphragm, stem and diaphragm returning spring	4 2
4b-ii	**PLC architecture:**	

Diagram



OR

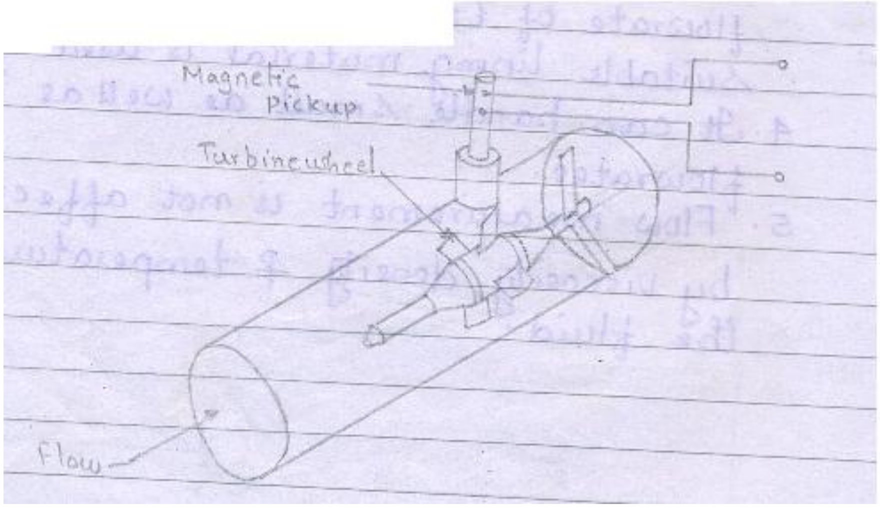


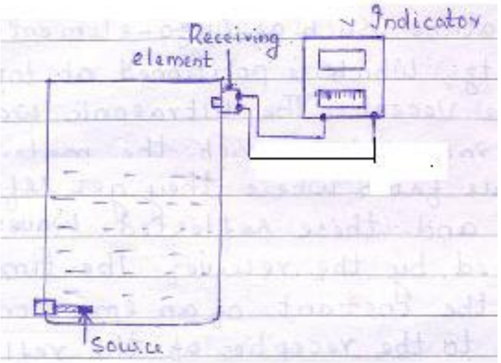
3

Explanation:

PLCs are industrially hardened microcomputers that perform discrete or continuous control functions in a variety of processing plant and factory environments.

A PLC architecture consists of the following main units.

	1. **Power supply**: Power supply unit converts power line voltages to those required by the solid state components. 2. **Input / Output system**: Inputs are real world signals of sensors. These signals can be Analog or Digital, low or high frequency, continuous or momentary. Outputs can be of discrete, register or analog. 3. **Central Processing Unit (CPU):** It performs the tasks necessary to fulfill the PLC functions such as scanning, I/O bus traffic control, program execution, peripheral and external device communications, and data handling and self-diagnostics. 4. **Memory Unit**: This is the library where the application program, input data, as well as output data are being stored. 5. **Programmer Unit**: Programmer unit provides an interface between the PLC and user during program development, start-up and trouble shooting.	3
5	**Attempt any FOUR**	16
5-a	**Working of turbine flow meter:** 	4

	The flow of liquid past the wheel causes the wheel to rotate at a rate which is proportional to the velocity of the fluid. This is achieved by fabricating the turbine blades from a ferromagnetic material and placing a permanent magnet and coil inside the meter housing. A voltage pulse is induced in the coil as each blade on the turbine wheel moves past it and these pulses are measured by a pulse counter.	
5-b	Nuclear radiation method (or) radiation method **Explanation:**  It consists of a radioactive source such as minute quantity of capsulated radioactive isotope like cobalt60 fixed either inside or outside the vessel, radiation receiving element fixed to the side of the vessel directly across the source along with the indicator. As the liquid level inside the vessel changes, the amount and intensity of radioactive radiations received by the receiver changes. Larger the level of liquid inside the vessel, smaller is the intensity of radiation and vice versa.	1 3
5-c	**Working of capacitance level indicator**	4

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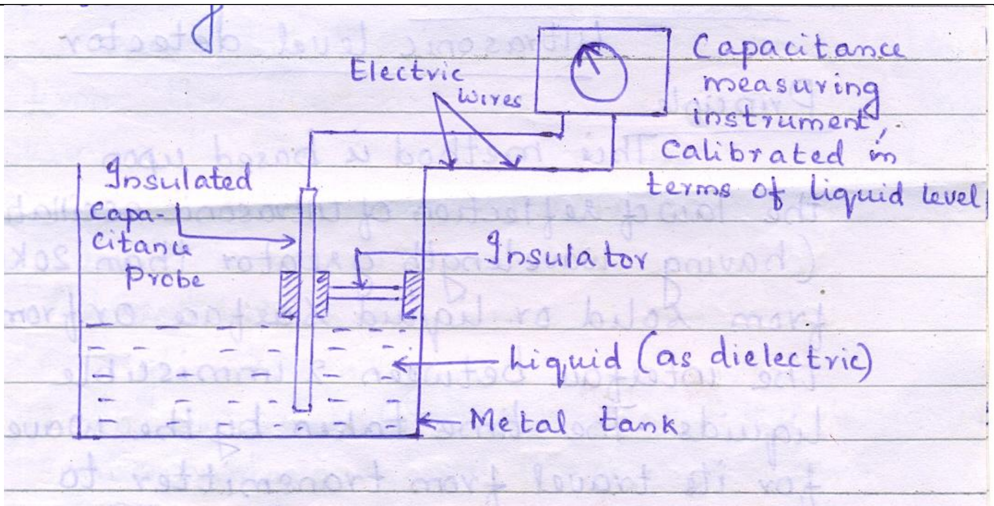

It consists of two conductors separated from each other by dielectric material between them. There is an insulated capacitance probe fixed near and parallel to tank wall such that the probe and metal tank wall acts as conductors with conducting liquid as the dielectric medium. These two conductors are connected to capacitance detecting element. As the liqid level changes, the dielectric constant changes due to which capacitance changes. Thus any change in liquid level can be measured in terms of change in capacitance.
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<td>5-d</td>
<td>**Working of LVDT**</td>
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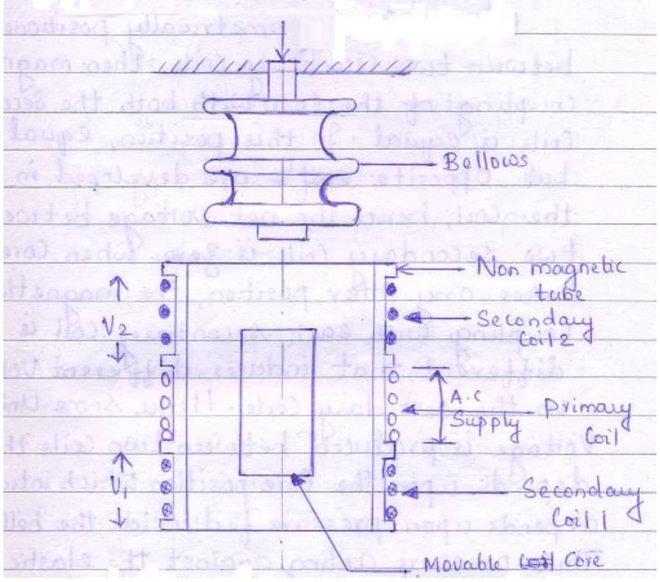

When the pressure inside the bellows changes, its free end gets deflected along with the movable core. When the core is symmetrically positioned between the two secondary coils, the magnetic coupling of the core with both the secondary coils is equal. In this position, equal but opposite emfs are developed in the coil, and hence the net voltage between two secondary coils is zero. When core takes any other position, the magnetic coupling with each secondary coil is different, that induces different voltages in the secondary coils. Hence some unbalance voltage is produced between the coils that depends upon the position of the core which in turn depends upon the pressure fed inside the bellows.
</td><td></td></tr>
<tr><td>5-e</td><td>1atm= 1 bar= 10^5 Pa= 760mm of Hg = 1 kg_f/ cm^2
i) 20atm= 2 x10^6pa
ii) 20atm =20bar
iii) 20atm =15200 mm of Hg
iv) 20atm = 20Kg_f/cm^2</td><td>
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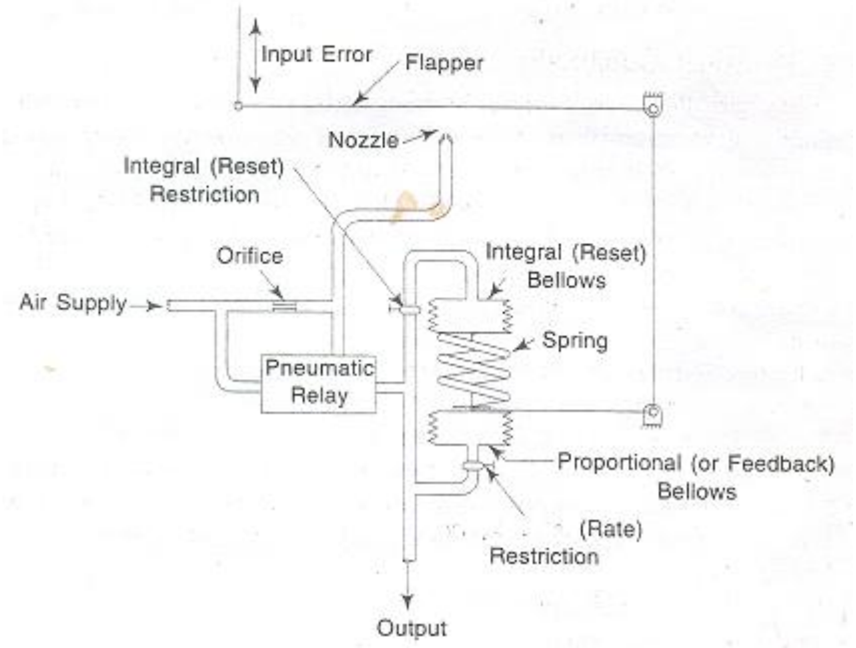
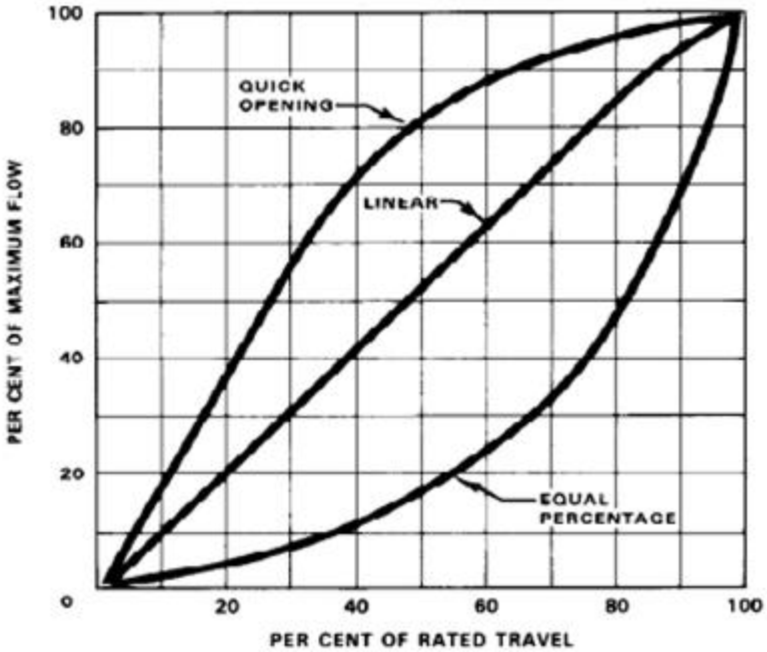
6	**Attempt any TWO**	16
6-a	**Working of pneumatic PID controller.** 	3
	It consists of a nozzle flapper assembly and a relay. As the input error increases baffle is moved towards the nozzle increasing the control output through the relay. This change in output pressure is applied to the bellows further closing the nozzle and increasing the output to the maximum. The nozzle back pressure iscontrolled by the nozzle flapper distance. A derivative restriction is introduced into the line leading to the feedback bellows. The addition of an integral (reset) bellows and the addition of an adjustable restriction (integral restriction) calibrated in time units, provide reset or integral control action. Reset or integral action increases the gain of the controller. Greater the restriction imposed upon the flow of air to the feedback bellows, greater will be the pressure drop across the restriction and greater will be the	5

	increase of pressure due to derivative action. The rate at which integral action is applied depends on the rate at which air flows through the integral restriction. By causing both positive and negative feedback to lag the output pressure, both rate and reset action may be obtained which is known as PID control action.	
6-b	**Valve Characteristics:** The relation between stem position, plug position and rate of flow is described in terms of flow characteristics of valve. Two types of valve characteristics are there –Inherent and Installed or effective.  **Inherent flow characteristics** are plotted when constant pressure drop is maintained across the valve. There are two different inherent flow characteristics- linear and equal percent. **Linear Opening characteristics:** Linear characteristics valve has linear relation between valve opening and flow rate at constant pressure drop	2

	$Q = by$ Q- Flow rate at constant pressure drop b - constant y - valve opening / valve stem travel Generally used • For slow process • When more than 40% of the system pressure drop occurs across the valve.	2
	Equal Percentage characteristics : In equal percentage valve equal increment of the stem travels give equal % change of the existing flow $Q = be^{ay}$ Q= Flow rate at constant pressure drop a& b = constant e = base of natural logarithms y = valve opening / valve stem travel Generally used • For fast processes • When high rangeability is required At heat exchangers where an increase in product rate requires much greater increase in heating and cooling medium.	2
	Installed flow characteristics are plotted when the differential pressure across the valve changes. **Quick opening** – In this there is maximum flow for minimum travel It is approximately linear when the flow rate is less but beyond 30% the flow increases rapidly with valve opening	2

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It gives approximately 90% flow at 30% travel

- For on – off control

When maximum valve capacity must be obtained quickly

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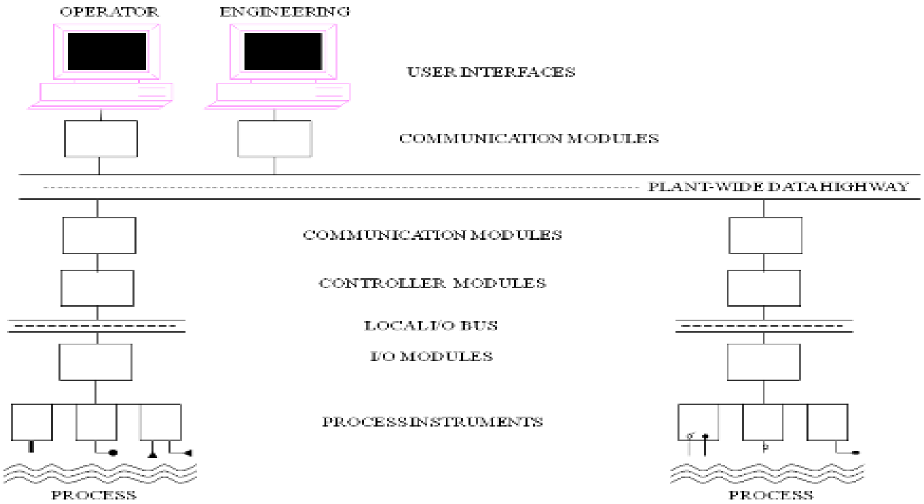
Distributed control system:

Block diagram:



Explanation:

In DCS equipment is separated in functional area and is installed in different work areas of a process plant. The plant operator monitors and manipulates the set-points of the process parameter from central control room.

Controlling portion of the DCS, distributed at various location performs following two function at each location.

1. Measurement of analog variable and discrete inputs
2. Generation of output signals to actuators that can change process condition

In Figure above the operator console in the conrol room is connected through a data highway to several distributed system components.

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	A DCS consist of the following modules: 1 Operator stations that use microprocessor based CRT display and keyboard communication with control device and displays 2 Remote multifunction microprocessor based controllers (PLCs) 3 A digital data link (data highway) that connects the multifunction controllers with the central operator stations. The first priority of DCS is to provide operator interfacing and real time process control. DCS has flexibility of implementation of sequential control and integration among the various types of control.	