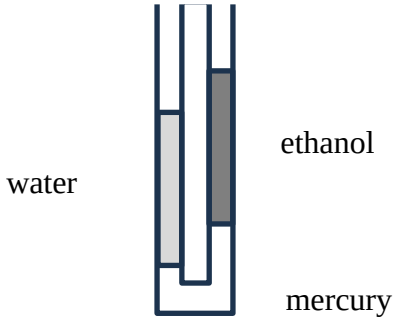
Final Examination Sensing and Actuation AT74.03 April 25, 2024

Time: 9:00-10:30 h. Open Book
Marks: 100

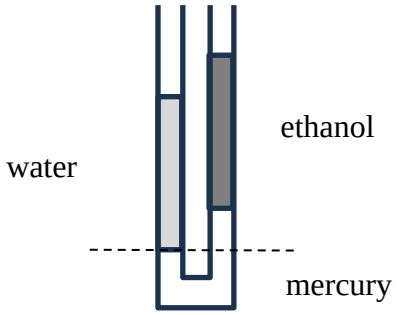
Attempt all questions.

Q.1 A U-tube manometer with 1 cm^2 cross section area is filled with 20 cm^3 each of mercury, water and alcohol as shown in the figure below.



If both ends of the monometer are exposed to atmospheric pressure, determine the height difference between both ends of the manometer. Water, ethanol and mercury have the mass density of 1,000, 790 and 13,550 kg/m^3 respectively. (20)

Solution



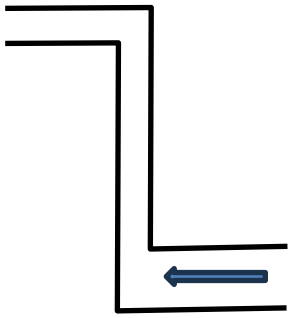
Equate the pressure at the dotted line,

$$\rho_{wat} g h_{wat} = \rho_{eth} g h_{eth} + \rho_{mer} g h_{diff} \quad (1)$$

$$(1{,}000) g (20) = (790) g (20) + (13{,}550) g h_{diff} \quad (2)$$

$$h_{diff} = 0.31 \text{ cm} \quad (3)$$

Q.2 Water flows in a pipe from the first floor to the second floor as shown in the figure below.



If the diameter of the pipe in the first floor is 2.5 cm and the diameter of the pipe in the second floor is 2 cm and the second floor is 3 m higher than the first floor. The flow is assumed frictionless and incompressible. Determine the flow rate if the pressure on the first floor is higher than the pressure on the second floor 30,000 Pa. Water has mass density of 1,000 kg/m^3 and gravitational acceleration is 9.8 m/s^2. (20)

Solution

From Bernoulli equation,

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + gz_2 \quad (1)$$

Substitute $V = Q/A$,

$$\frac{p_1}{\rho} + \frac{Q^2}{2A_1^2} + gz_1 = \frac{p_2}{\rho} + \frac{Q^2}{2A_2^2} + gz_2 \quad (2)$$

$$Q = \frac{A_2}{\sqrt{1-(A_2/A_1)^2}} \sqrt{2\left(\frac{p_1-p_2}{\rho} + g(z_1 - z_2)\right)} \quad (3)$$

$$Q = \frac{\pi(0.02)^2/4}{\sqrt{1-(0.02/0.025)^4}} \sqrt{2\left(\frac{30{,}000}{1{,}000} + 9.8(-3)\right)} = 0.000448 \text{ m}^3/\text{s} \quad (4)$$

Q.3 The bridge circuit of a thermistor is balanced at the reference temperature of 0 ℃ with all the resistance of 100 Ω. When the temperature is 100 ℃, the voltage output from the bridge circuit indicates -2 V. Determine the temperature in ℃ if the voltage output from the bridge circuit indicates 1 V. The bridge circuit is supplied by 5 V power supply. (20)

Solution

The relation between the thermistor resistance and voltage output at 100 ℃,

$$R = R_T\left(\frac{1+2\Delta E_0/E_i}{1-2\Delta E_0/E_i}\right) \quad (1)$$

$$R = 100\left(\frac{1-2(2)/5}{1+2(2)/5}\right) = 11.11 \quad (2)$$

Thermistor relation,

$$R = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)} \quad (3)$$

$$\beta = \frac{TT_0}{T_0-T}\ln\left(\frac{R}{R_0}\right) \quad (4)$$

$$\beta = \frac{373\times273}{(273-373)}\ln\left(\frac{11.11}{100}\right) = 2{,}237.5 \quad (5)$$

When the voltage output is 1 V,

$$R = 100\left(\frac{1+2(1)/5}{1-2(1)/5}\right) = 233.33 \quad (6)$$

$$T = \frac{1}{\left[\frac{1}{\beta}\ln\left(\frac{R}{R_0}\right)+\frac{1}{T_0}\right]} = \frac{1}{\left[\frac{1}{2{,}237.5}\ln\left(\frac{233.33}{100}\right)+\frac{1}{273}\right]} = 247.72\,K = -25.58\,℃ \quad (7)$$

Q.4 An actuator is used to drive an object with mass of 2 kg from speed of zero under coulomb friction of 5 N and viscosity friction coefficient of 3 Ns/m to have a constant acceleration of 10 m/s^2 for 10 seconds. Determine the required power from the motor as a function of time and the maximum power. (20)

Solution

The required force

$$F = cv + (ma + f) \quad (1)$$

$$P = cv^2 + (ma + f)v \quad (2)$$

$$v = at \quad (3)$$

Substitute (3) into (2),

$$P = ca^2t^2 + (ma^2 + fa)t \quad (4)$$

$$P = 3(10)^2t^2 + (2(10)^2 + 5(10))t \quad (5)$$

$$P = 300t^2 + 250t \quad (6)$$

$$P(10) = 30{,}000 + 2{,}500 = 32{,}500\,W \quad (7)$$

Q.5 Design a robot which can interact with a human trainer who moves the robot end effector to any locations. Show tentative drawing of the robot mechanism. List all the required sensors and actuators. Show how to interface all the sensors and actuators with the processor unit. (20)