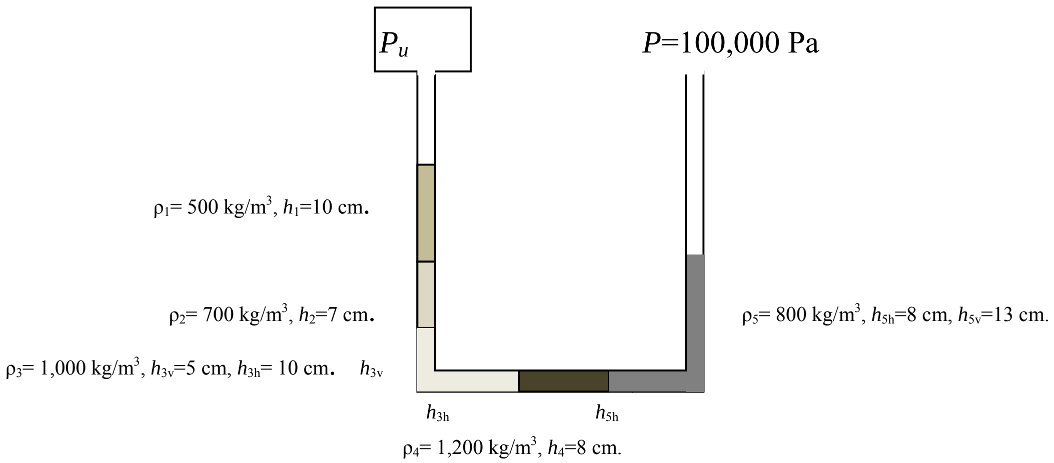
Final Examination   Sensing and Actuation AT74.03   November 20, 2014

Time: 10:00-11:30 h.   Open Book
Marks: 100

Attempt all questions.

Q.1 Determine the unknown absolute pressure, P_u, when fluid in the U-tube manometer is as shown the below figure. Use gravitational acceleration of 10 m/s^2. (20)

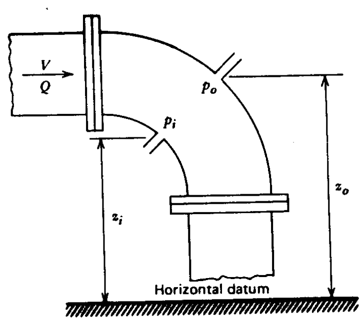


<u>Solution</u>

$$P_u = 100{,}000 + 800 \times 10 \times 0.13 - 1{,}000 \times 10 \times 0.05 - 700 \times 10 \times 0.07 - 500 \times 10 \times 0.1 \quad (1)$$

$$P_u = 99{,}550 \quad \text{Pa} \quad \underline{(2)}$$

Q.2 An elbow meter is equipped on ethanol pipe to determine the ethanol volume flow rate. When the volume flow rate is 2 m^3/s, the pressure sensor installed at the inside surface at 5 m height indicates 500 Pa higher pressure than the pressure from other pressure sensor installed at the outside surface at 5.3 m height. Determine the ethanol volume flow rate when the pressure difference changes from 500 Pa to 800 Pa. Mass density of ethanol is 790 kg/m^3 and gravitational acceleration is 10 m/s^2. Determine also the pressure difference at no flow. (20)



Solution

The relation between volume flow rate and pressure difference follows,

$$Q = CA\sqrt{2\left(\frac{p_o}{\rho} + gz_o - \frac{p_i}{\rho} - gz_i\right)} \tag{1}$$

$$2 = k\sqrt{2\left(\frac{-500}{790} + 0.3\times 10\right)} \tag{2}$$

$$k = 0.92 \tag{3}$$

At 800 Pa pressure difference,

$$Q = 0.92\sqrt{2\left(\frac{-800}{790} + 0.3\times 10\right)} = 1.83\ \text{m}^3/\text{s} \tag{4}$$

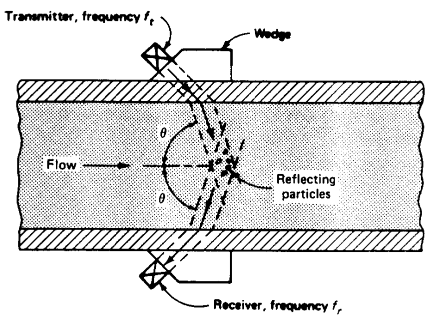
At no flow,

$$0 = 0.92\sqrt{2\left(\frac{P}{790} + 0.3\times 10\right)} \tag{5}$$

$$P = -2370\ \text{Pa} \tag{6}$$

Q.3 Doppler ultrasonic flowmeter is used to determine water flow speed. When water flows at 10 m/s, the frequency at the receiver is 39.8 kHz. When water flows at 20 m/s, the frequency at the receiver is 38.6 kHz. Determine the water flow speed when the frequency at the receiver becomes 38 kHz. The ultrasonic transmitter emits ultrasonic wave at a constant frequency.

(20)



Solution

The frequency difference of Doppler ultrasonic flowmeter,

$$\Delta f = \frac{2f_t cos(\theta)}{c}V = kV \tag{1}$$

$$f_t - 39.8 = k10 \tag{2}$$

$$f_t - 38.6 = k20 \tag{3}$$

(3)-(2),

$$1.2 = k10 \tag{4}$$

$$k = 0.12 \text{ kHz·s/m} \tag{5}$$

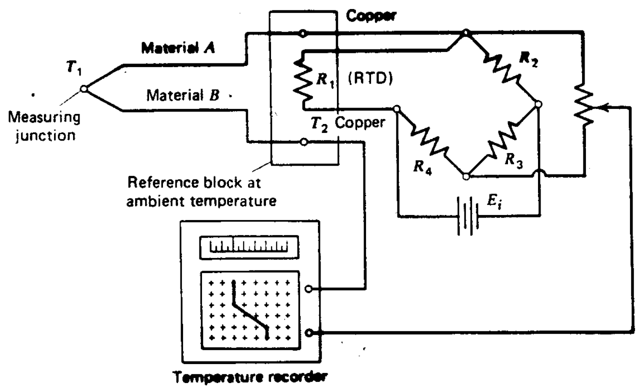
$$f_t = 41 \text{ kHz} \tag{6}$$

When ultrasonic receiver receives 38 kHz,

$$41 - 38 = 0.12V \tag{7}$$

$$V = 25 \text{ m/s} \tag{8}$$

Q.4 Prove that compensation of change of reference temperature is possible using the bridge circuit shown below. Assume that temperature coefficient of RTD and thermoelectric constant of thermocouple are constant and the relations are linear. (20)



Solution

Consider the bridge circuit,

$$\Delta E_o = \frac{r}{(1+r)^2}\left(\frac{\Delta R_1}{R_1}\right) E_i \tag{1}$$

$$\Delta E_o = \frac{r}{(1+r)^2}(\gamma \Delta T_2) E_i \tag{2}$$

Consider the thermocouple,

$$E_{recorder} = S_{copper-B}T_2 + S_{B-A}T_1 + S_{A-copper}T_2 - k\Delta E_o \tag{3}$$

$$E_{recorder} = S_{B-A}(T_1 - T_2) - c\Delta T_2 \tag{4}$$

When

$$c = k\frac{r}{(1+r)^2}\gamma E_i \tag{5}$$

At the reference temperature,

$$E_{recorder} = S_{B-A}(T_1 - T_2) \tag{6}$$

When T_2 varies,

$$E_{recorder} = S_{B-A}(T_1 - T_2 + \Delta T_2) - c\Delta T_2 = S_{B-A}(T_1 - T_2) + (S_{B-A} - c)\Delta T_2 \tag{7}$$

If we adjust so that

$$c = S_{B-A} \tag{8}$$

Thus,

$$E_{recorder} = S_{B-A}(T_1 - T_2) \quad \underline{(9)}$$

for any values of ΔT_2.

Q.5 Friction coefficient of rubber on dry asphalt is 0.85.

(a) Determine the maximum possible acceleration of an electrical car with 1,500 kg. Use gravitational acceleration of 10 m/s^2. (5)

(b) If the motor power is 100 hp and there is no energy loss to the environment, determine the maximum speed if the car accelerates from still position at the constant maximum acceleration calculated in (a). Determine the time required to achieve the maximum speed. (10)

(c) In order to achieve higher speed, the car acceleration must be smaller. Determine the maximum speed as the function of time required to achieve the maximum speed if the car accelerates from still position at a constant acceleration. (5)

<u>Solution</u>

Maximum friction,

$$f = N\mu = 1{,}500 \times 10 \times 0.85 = 12{,}750 \text{ N} \quad (1)$$

Maximum acceleration,

$$f = ma \quad (2)$$

$$a = \frac{12{,}750}{1{,}500} = 8.5 \text{ m/s}^2 \quad \underline{(3)}$$

Maximum velocity at maximum acceleration,

$$P = Fv \quad (4)$$

$$v = \frac{100 \times 746}{12{,}750} = 5.85 \text{ m/s} \quad \underline{(5)}$$

The time required to achieve the maximum speed,

$$v = u + at \quad (6)$$

$$5.85 = 0 + 8.5t \quad (7)$$

$$t = 0.69 \text{ s} \quad (8)$$

Maximum velocity as the function of constant acceleration which is less than 8.5 m/s^2,

$$P = Fv = mav = \frac{mv^2}{t} \quad (9)$$

$$100 \times 746 = \frac{1500v^2}{t} \quad (10)$$

$$v = 7.05\sqrt{t} \quad \underline{(11)}$$