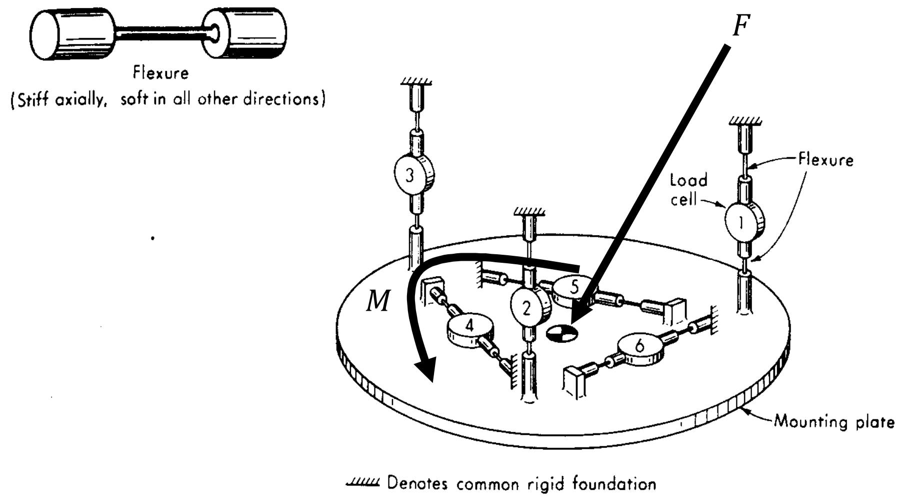
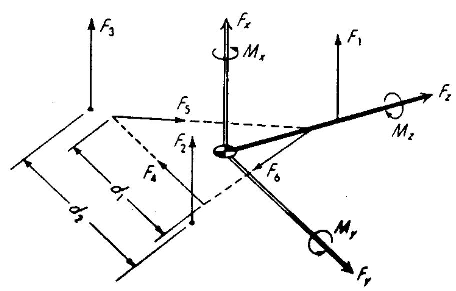
Final Examination Sensing and Actuation AT74.03 November 24, 2017

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

Attempt all questions.

Q.1 6 flexures are used to determine magnitude and direction of the force, F, and the moment, M , applied to the mounting plate as shown in the below figure.





Determine the magnitude and direction angles respect to x, y, and z axis of the applied force and moment when the measured forces from flexures 1-6 are 50 N, 80 N, 90 N, 30 N, 45 N, 20 N. Use $d_1 = 15\ cm, d_2 = 20\ cm.$ (20)

<u>Solution</u>

$$F_x = F_1 + F_2 + F_3 = 50 + 80 + 90 = 220\ N \tag{1}$$

$$F_y = \frac{F_5 - 2F_4 + F_6}{2} = \frac{45 - 2(30) + 20}{2} = 2.5\ N \tag{2}$$

$$F_z = \frac{\sqrt{3}(F_5 - F_6)}{2} = \frac{\sqrt{3}(45 - 20)}{2} = \sqrt{3} \times 12.5 = 21.65\ N \tag{3}$$

$$M_x = -d_1 \frac{F_4 + F_5 + F_6}{2\sqrt{3}} = -0.15 \frac{30 + 45 + 20}{2\sqrt{3}} = -4.11\ Nm \tag{4}$$

$$M_y = d_2 \frac{2F_1 - F_2 - F_3}{2\sqrt{3}} = 0.20 \frac{2(50) - 80}{2\sqrt{3}} = -4.04\ Nm \tag{5}$$

$$M_z = d_2 \frac{F_3 - F_2}{2} = 0.20 \frac{90 - 80}{2} = 1\ Nm \tag{6}$$

$$F = \sqrt{F_x^2 + F_y^2 + F_z^2} = \sqrt{220^2 + 2.5^2 + 21.65^2} = 221.08\ N \tag{7}$$

$$\theta_{Fx} = -\frac{180}{\pi} acos\left(\frac{220}{221.08}\right) = -5.67° \tag{8}$$

$$\theta_{Fy} = -\frac{180}{\pi} acos\left(\frac{2.5}{221.08}\right) = -89.35° \tag{9}$$

$$\theta_{Fz} = -\frac{180}{\pi} acos\left(\frac{21.65}{221.08}\right) = -84.38° \tag{10}$$

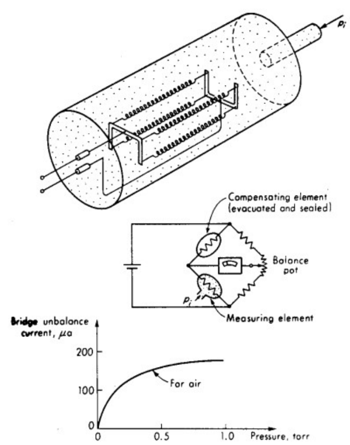
$$M = \sqrt{M_x^2 + M_y^2 + M_z^2} = \sqrt{(-4.11)^2 + (-4.04)^2 + 1^2} = 5.85\ Nm \tag{11}$$

$$\theta_{Mx} = -\left(\frac{180}{\pi} acos\left(\frac{-4.11}{5.85}\right) - 180°\right) = 45.37° \tag{12}$$

$$\theta_{My} = -\left(\frac{180}{\pi} acos\left(\frac{-4.04}{5.85}\right) - 180°\right) = 46.32° \tag{13}$$

$$\theta_{Mz} = -\frac{180}{\pi} acos\left(\frac{1}{5.85}\right) = -80.16° \tag{14}$$

Q.2 Pirani gage is used to determine unknown pressure, p, by measuring the current, i, from the unbalanced bridge circuit as shown in the below figure.



If the relation between the pressure and the current is expressed by $p = mi^n$, when m, n are unknown coefficients. When the pressure is 0.5 Torr the current is measured at 160 μA. When the pressure is 1 Torr the current is measured at 200 μA. Determine the pressure in the Parani gage when the current is measured at 300 μA. (15)

Solution

$$p = mi^n \tag{1}$$

$$0.5 = m160^n \tag{2}$$

$$1 = m200^n \tag{3}$$

(3)/(2),

$$2 = 1.25^n \tag{4}$$

$$n = 3.1063 \tag{5}$$

$$m = 7.12 \times 10^{-8} \tag{6}$$

$$p = 7.12 \times 10^{-8} \times 300^{3.1063} = 3.52 \text{ Torr} \tag{7}$$

Q.3 Bernoulli equation, expressed by $\frac{P_1}{\rho} + \frac{V_1^2}{2} + gh_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gh_2$, is valid for incompressible frictionless flow of fluid. Pressure loss per length, $\frac{\Delta P}{L}$, from friction in a uniform diameter pipe, D, depends on the velocity squared, V^2, of the fluid as expressed by Darcy-Weisback equation, $\frac{\Delta P}{L} = f_D \frac{\rho V^2}{2D}$. If pressure of water with flow rate of 10 litre/second flowing through 100 m length with 100 mm uniform diameter drops 16.5 kPa, determine the amount of pressure drop if the water with flow rate of 20 litre/second flows through 50 m length of the same pipe. (15)

Solution

Pressure drop,

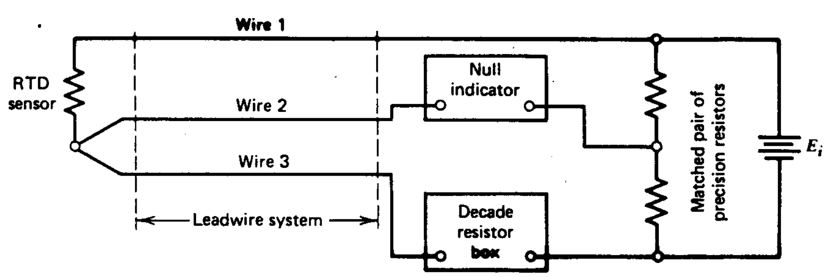
$$\Delta P = Q^2 L \frac{f_D \rho}{A^2 2D} = Q^2 L k \tag{1}$$

$$16.5 = 10^2 (100) k \tag{2}$$

$$k = 1.65 \times 10^{-3} \tag{3}$$

$$\Delta P = 20^2 (50) 1.65 \times 10^{-3} = 33 kPa \tag{4}$$

Q.4 RTD is made of platinum with temperature coefficient of resistivity of $3.93 \times 10^{-3} \Omega/ ℃$ has 3 lead-wires made of copper with temperature coefficient of resistivity of $3.86 \times 10^{-3} \Omega/ ℃$ as shown in the below figure.



1000 Ω maximum in 0.01-Ω steps

The Wheatstone bridge circuit is balanced at 20°C by adjusting the resistance at the resistor box to the same value as the RTD resistance of 100 Ω. The resistance of each copper lead-wire is 20 Ω at 20°C. Determine the temperature if the output voltage indicates 2 mV when the supply voltage, E_i, of the bridge circuit is 5 V. (15)

Solution

$$\Delta E = \frac{r}{(1+r)^2}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2}\right)E_i \quad (1)$$

$$2\times10^{-3} = \frac{1}{(1+1)^2}\left(\frac{\Delta T(3.93+\ .86)}{(100+\ \ )} - \frac{\Delta T(3.86)}{(100+2\ \ )}\right)5\times10^{-3} \quad (2)$$

$$\Delta T = 48.86°C \quad \underline{(3)}$$

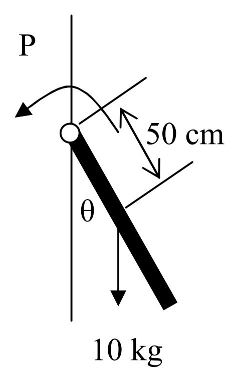
Q.5 If a permanent magnet DC motor has torque constant of $K_T = 55\times10^{-3}$ Nm/A, determine the back-emf constant, K_{emf} in V/rpm. (15)

Solution

Permanent magnet DC motor has the same value of torque constant and back-emf constant in SI unit. Thus,

$$K_{emf} = 55\times10^{-3}\frac{Vs}{rad} = 55\times10^{-3}\frac{Vs}{rad}\times\frac{1m}{60s}\times\frac{2\pi rad}{1revolutio} = 5.76\times10^{-3}V/rpm \quad \underline{(1)}$$

Q.6 Determine the power, P, in W from a motor as a function of arm angle, θ in degree from 0 degree to 360 degrees, used to rotate a single link arm of 10 kg at a constant speed of 30 degree/s in counter-clockwise direction if the coulomb friction is 1.5 Nm and viscosity friction coefficient of 0.2 Nms/degree as shown in the below figure. Use gravitational acceleration of 9.8 m/s^2. Determine the maximum power and the minimum power required from the motor. (20)



Solution

At constant speed, the motor power is used to conquer gravity torque, coulomb friction torque and viscosity friction torque.

$$P = T\omega = \left(mglsin\theta + f_{coulomb} + f_{viscosity}\right)\omega \quad (1)$$

$$P = (10\times9.8\times0.5sin\theta + 1.5 + 0.2\times30)\frac{30\pi}{180} \quad (2)$$

$$P = 25.66sin\theta + 3.93 \quad \underline{(3)}$$

$$P_{max} = 29.59\,W, P_{max} = -21.73\,W \quad \underline{(4)}$$