The UNIVERSITY of JORDAN
FACULTY OF ENGINEERING & TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING
ENGINEERING MEASUREMENTS (0904422)
Second Exam, Third Semester 2013-2014

Dr. Jehad A. A. Yamin **Date: 14-08-2014** **Time:** 90 minutes.

Name : .....لؤي عصام الحسين... **Univ No. :** ...0110524.....

Important Notes:

- **The exam consists of 9 (NINE) questions.**
- **Answer all questions.**
- لا تستخدم اختصارات في الحل بل اكتب معنى الرمز الذي تحسبه ثم اكتب المعادلة المطلوبة ثم عوض بها ثم اكتب الجواب مع الوحدة.
- لن يقبل أي جواب بدون الوحدة (Units)

Q. No.	Marks
1	2
2	2
3	2
4	2
5	2
6	2
7	6
8	6
9	6
Total	19 / 30

Q1): A bimetallic-strip element has length of 50 mm. The thickness of each metal is 1mm, and the element is initially straight at 25°C.
Calculate the radius of curvature and linear movement of the free end in a perpendicular direction downward from the initial line when the temperature is 200°C. One of the metals is Invar, whose co-efficient of thermal expansion (α_B) is negligible and the other is nickel-chrome-iron alloy (α_A) with, a linear expansion co-efficient of 12.5×10^{-6} °C. **(2 Marks)**

r: radius of curvature, t: thickness of the two element (t_1+t_2), m: the ratio between the thickness of the two metals
n: the ratio between the coeff. of expansion of two metals $\left(\frac{\alpha_{High}}{\alpha_{low}}\right)$

$m = \frac{t_{High}}{t_{low}} = 1$, $t = t_1 + t_2 = 2mm$,

$$r = \frac{t}{2}\left(\frac{1 + \alpha_B(T_2 - T_1)}{(\alpha_A - \alpha_B)(T_2 - T_1)}\right) = \frac{2}{2}\left(\frac{1 + \alpha_B(T_2 - T_1)}{12.5 * 10^{-6}(200-50)}\right)$$

$= 533.33$ mm

Q2) A diaphragm gauge is made of mild steel to measure the pressure differential of certain device. The diameter of the diaphragm is 15mm and its thickness is 0.205mm. The deflection indicated by the diaphragm was 0.0475mm. <u>what was the pressure measured by this diaphragm and how much was the maximum stresses induced</u>? Take the Young's modulus of elasticity (E) for steel as 200 GN/m^2, Poisson's ratio (ν) as 0.28 and density (ρ) as 7.8×10^3 kg/m^3. **(2 Marks)**

diameter of the diaphram, D = 15mm, t: thickness of diaphram, t = 0.205 mm
deflection $\delta_m = 0.0475$mm, P: pressure, σ_m: maximum stress, E: modulus of elasticity

$$P = \frac{256 E t^3 \delta_m}{3(1-\nu^2)D^4} = \frac{(256)(200*10^9)(0.205*10^{-3})^3(0.0475*10^{-3})}{3(1-(0.28)^2)(0.015)^4}$$

$= 149.691$ kpa

$$\sigma_m = \frac{3D^2P}{16t^2} = \frac{3(0.015)^2(149.691*10^3)}{16(0.205*10^{-3})^2}$$

$= 150$ Mpa

Q3) In the previous question (Q2). If the known error in thickness is +0.1%, known error in diameter is -1%, known error in density is +0.5% and that for modulus of elasticity is -0.05%. What will be the known error in the pressure? Also calculate the fraction known error in pressure based on the true value. **(2 Marks)**

δt, δD, $\delta \rho$, δE

$$P = \frac{256 E t^3 \delta_m}{3(1-\nu^2)} D^{-4}$$

$E_2 = E_1 * -0.05 + E_1$
$= 190$ Gpa

$t_2 = 0.2255$ mm

$D_2 = D_1 * -1\% + D_1$
$= \frac{-15}{100} + 15 = 14.85$mm

$$P_2 = \frac{256(190)*10^9(2.255*10^{-3})^3(0.0475*10^{-3})}{3(1-0.28^2)(14.85*10^{-3})^4}$$

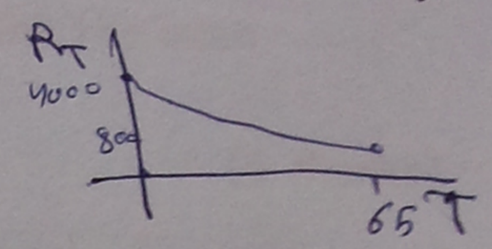
$= 197.041$ kPa

$E = P_2 - P_1$
$= +47.35$
Ex. =

T_o : reference temperature
R_{T_o} : Resistance at reference temperature,

Q4) A sensor has resistance of 4000 Ohm at 0 C and 800 Ohm at 65 C. Find the most accurate relationship for this device? Comment on your choice. **(2 Marks)**

$T_o = 0°C$, $R_{T_o} = 4000\,\Omega$, $T_1 = 65°C$, $R_{T_1} = 800\,\Omega$



the device is thermistor becaus Resistance decreases with temperature, the range of temperature large than 50°c so linear approximate is not valid, so we use logarithmic equation

$R_{T_f} = R_{T_o}\, e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_o}\right)}$, β : coeff. of variation between temperature and Resistance

$800 = 4000\, e^{\beta\left(\frac{1}{338} - \frac{1}{273}\right)} \Rightarrow \beta = \ln(0.2) * \left(\frac{1}{338} - \frac{1}{273}\right)^{-1} = 2248.758\,K$

find A : constant

$R_{T_o} = A\, R_{T_o}\, e^{\beta/T_o} \Rightarrow A = \frac{1}{e^{2248.758/273}} = 2.646 * 10^{-4}$

$R_T = R_{T_o} A\, e^{\beta/T} = 1.0585\, e^{\frac{2248.758}{T}}$

Q5) A compressive force is applied to a structural member. The strain is 5 micron. Two separate strain gauges are attached to the structural member. One strain gauge is made of Nickle (unstrained resistance = 120Ω, gauge factor = -12.1), the other one is made of Nichrome (unstrained Resistance = 120Ω, gauge factor = 2).Calculate the resistance of each one after they are strained. **(2 Marks)**

$\epsilon = -5 * 10^{-6}$: strain, unstrained resistance R, Gauge factor G_f, R_f : Resistance after strained

Nickle
$G_f = -12.1$
$R = 120\,\Omega$

$G_f = \frac{\Delta R / R}{\epsilon} \Rightarrow -12.1 = \frac{R_f - R_f^{=120}}{\frac{R=120}{-5*10^{-6}}}$

$R_f = 7.26 * 10^{-3} + 120 = 120.00726\,\Omega$

Nichrome
$G_f = 2$, $R = 120\,\Omega$

$G_f = \frac{\Delta R / R}{\epsilon} \Rightarrow 2 = \frac{R_f - 120}{\frac{120}{-5*10^{-6}}}$

$R_f = 119.9988\,\Omega$

Q6) A pitot static tube is used to measure the airplane velocity. The pressure difference shown by a U-tube manometer at that height is equivalent to 0.1m of water. Take the specific weight of air at that height is 11.87 N/m³, water density is 1000 kg/m³ and the pitot tube coefficient is 0.99. Neglect air compressibility. Calculate the airplane velocity (km/hr). **(2 Marks)**

γ_m : specific weight for manometer (H_2O)

h_m : height of manometer = 0.1m H_2O, specific weigh of air $\gamma_f = 11.87\,N/m^3$

velocity of air water density $\rho = 1000\,kg/m^3$, pitot tube coefficient $C = 0.99$, compressibility $Y = 1$

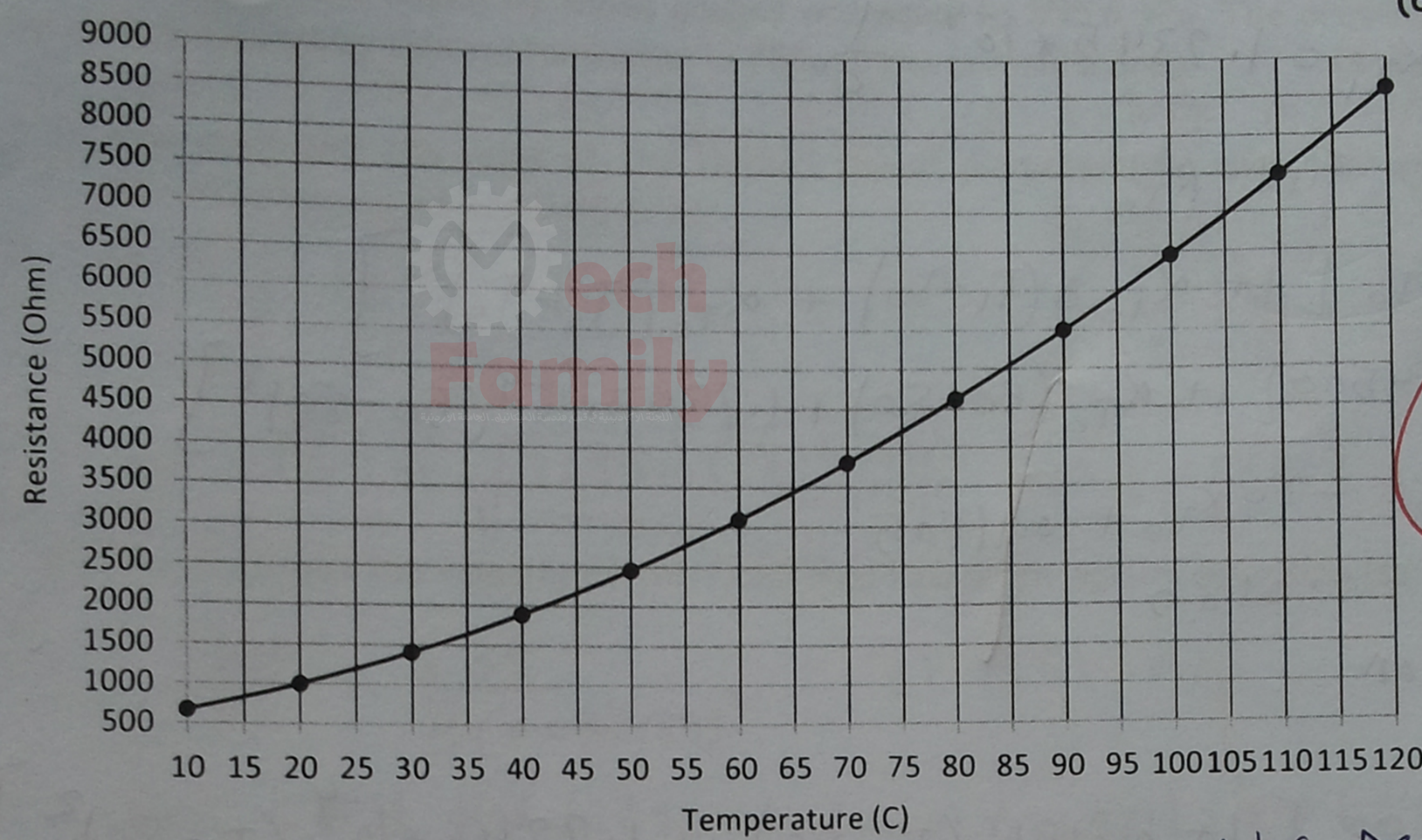
$U = C\sqrt{2g\,h_m\left(\frac{\gamma_m}{\gamma_f} - 1\right)} = 0.99\sqrt{2(9.81)(0.1)\left(\frac{9810}{11.87} - 1\right)}$

$= 39.841\,m/s$

$= 143.427\,km/hr$

Q7) Find the linear and quadratic equations for the sensor given by the graph below for the whole temperature range (50 to 110 °C).
What is the name of this device? What is it used for? What do you think the main properties of the material used in this sensor?

(6 Marks)



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the devise is RTD (Resistance Temperature Detector)
it used for temperature measurement for (high temerature)

properties :-
1- non-toxid
2- corrosion Resistance
3- melting temperature > working temperature
4- the Relation between temperature and Resistance linear in the desire Range
5- Homogenous chemical combosition and nomogeneous geometry

linear :-
R_{T_0} : Resistance at Reference temperature
R_T : Resistance at temperature(T), α_{T_0} : Resistance-Temperature coefficient at Reference temp

$$R_T = R_{T_0}\left[1 + \alpha_{T_0}\Delta T\right] \quad , T_1 = 50 \quad , T_2 = 110°c$$

$$T_0 = \frac{T_1 + T_2}{2} = \frac{50+110}{2} = 80°c$$

$$R_{T_0} = 4500\ \Omega \quad , R_{T_1} = 2500\ \Omega \quad , R_{T_2} = 7500\ \Omega$$

$$\alpha_{T_0} = \frac{1}{R_{T_0}}\left[\frac{R_{T_2} - R_{T_1}}{T_2 - T_1}\right] = \frac{1}{4500}\left[\frac{7500 - 2500}{110 - 50}\right] = 0.01851\ \frac{1}{°c}$$

$$R_T = 4500\left[1 + 0.01851\,(T - 80°)\right]$$

quadratic

(I) $T_1 \rightarrow T_0$

Resistance temperature coeff at (T_1)

$$R_{T_1} = R_{T_0}\left[1 + \alpha_{T_0}\Delta T + \alpha_{T_1}\Delta T^2\right]$$

$$2500 = 4500\left[1 + \alpha_{T_0}(T_1 - T_0) + \alpha_{T_1}(T_1 - T_0)^2\right] \quad \text{— (1)}$$

(II) $T_0 \rightarrow T_2$

$$R_{T_2} = R_{T_0}\left[1 + \alpha_{T_0}(T_2 - T_0) + \alpha_{T_1}(T_2 - T_0)^2\right] \quad \text{— (2)}$$

$$7500 = 4500\left[1 + \alpha_{T_0}(110 - 80) + \alpha_{T_1}(110 - 80)^2\right] \quad \text{— (2)}$$

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~~Sum~~ sum the equation (1) and (2)

$$\frac{2500+7500}{4500} = 2 + 2\,\alpha_{T_1}(30)^2$$

$$\alpha_{T_1} = 1.2345 * 10^{-4}\ \frac{1}{C^\circ}$$

now to find R_{T_0}

$$R_{T_1} = R_{T_0}\left[1 + \alpha_{T_0}(T_1 - T_0) + \alpha_{T_1}(T_1 - T_0)^2\right]$$

$$2500 = 4500\left[1 + \alpha_{T_0}(50-80) + 1.2345 * 10^{-4}(50-80)^2\right]$$

$$-0.444 = -30\,\alpha_{T_0} + 0.11105$$

$$\alpha_{T_0} = 0.0185$$

equation

$$R_T = 4500\left[1 + 0.0185\,(T-80) + 1.2345 * 10^{-4}(T-80)^2\right]$$

Q8) A venturimeter of unknown diameter is used to measure the flow rate of water (density of water = 1000 kg/m^3 and dynamic viscosity = 1.08×10^{-3} N-s/m^2) inside a horizontal pipe of 100mm. The venture has coefficient of discharge = 0.99. The pressure drop between the throat and inlet was measured using two pressure gauges. The differential pressure shown by those gauges was equal to 355.6 kPa. The pressure loss in the system caused by this venturimeter is 75% of the pressure drop. **(6 Marks)**

ρ_w: density of water, μ: dynamic viscosity, C_D: discharge coefficient, ΔP_{1-2}: pressure drop

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1) How much was the value of the venturi throat diameter (d_2) such that the actual flow rate measured was 0.08 m^3/s.

flow rate

$$Q'_{act} = C_D A_2 \sqrt{\frac{2g\left[\frac{P_1-P_2}{\gamma_f} + (z_1-z_2)\right]}{1-\left(\frac{A_2}{A_1}\right)^2}}$$

γ_f: specific weigh for fluid (water)

A_2: Area at throat

z_1: the hight of inlet from referance

z_2: the hight of the throat from referance

A_1: Area of the inlet

$$0.08 = (0.99)\left(\frac{\pi}{4}\right) d_2^2 \sqrt{\frac{2(9.81)\left(\frac{355.6\times10^3}{(1000)(9.81)}\right)}{1-(d_2/d_1)^2}} \Rightarrow d_2 = 56.435 \text{ mm}$$

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2) How much was the velocity of the flow? And how much was its Reynolds Number?

$$U_{2act} = \frac{Q'_{act}}{A_2} = \frac{0.08}{\frac{\pi}{4}(0.056435)^2} = 31.981 \text{ m/s}$$

$$Re_{d_2} = \rho_f \frac{U_{2act}\, d_2}{\mu} = \frac{(1000)(31.981)(0.056435)}{1.08\times10^{-3}} = 1671155.3$$

3) If the pressure gauges were replaced with mercury manometer (SGm = 13.6) how much will be the deflection indicated by the manometer.

$$h_m\left(\frac{S.G_m}{S.G_f} - 1\right) = \frac{P_1-P_2}{\gamma_f} + (z_1 - z_2)$$

$$h_m\left(\frac{13.6}{1} - 1\right) = \frac{355.6\times10^3}{9810} \Rightarrow h_m = 2.8999 \text{ m}$$

$S.G_m$: specific Gravity for manometer fluid

$S.G_f$: specific Gravity for the water

h_m: the hieght of the manometer

4) If the compensating pump used is designed to run for 6500 hr/yr with electricity tariff rate of 0.0775 JD/kw-hr, how much should be the efficiency of the pump such that the cost of using this pump does not exceed 12000 JD/yr.

$$\text{cost} = \dot{W}_p * \text{Tariff Rate} * \text{time}$$

$$= Q' \frac{\Delta P_{loss}}{\eta_p} * \text{tariff rate} * \text{time}$$

$\dot{W}_p$: power of the pump

η_p: efficience for pump

ΔP_{loss}: pressure loss

$$12000 = \frac{(0.08)(0.75 * 355.6)}{\eta_p} * 0.0775 * 6500$$

$\eta_p = 0.896 * 100\% = 89.6\%$

5) If the per unit uncertainty in throat area is 2%, that of pressure is 2% and that for velocity approach factor = 0.0221. How much is the per unit uncertainty in the value of flow?

$$Q'_{act} = C_D A_2 \sqrt{\frac{2g\left(\frac{\Delta P_{1-2}}{\gamma_f} + (z_1 - z_2)\right)}{1-\left(\frac{A_2}{A_1}\right)^2}}$$

$\frac{\partial Q}{}$

W_{A_2}: uncertainty of the area throat

W_p: uncertainty of pressure

W_v: uncertainty for velocity

W_Q: uncertainty for flow rate

$$W_{A_2} = \underbrace{0.02}_{\text{relative uncert}} * \frac{\pi}{4}(0.056435)^2 = 0.01571$$

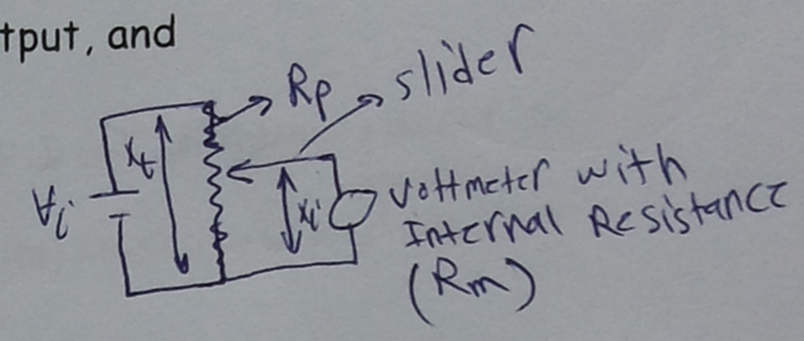
$$W_p = \frac{7.112}{(355.6 * 0.02)}, \quad W_v = \frac{2.211}{100} * 31.981 = 0.7068$$

Q9) Potentiometer is one example of a transducer element. Design your own system utilizing Potentiometer for temperature measurement and explain how will it work and give the mathematical relation on which it depends. **(6 Marks)**

The answer must contain:

1) Clear Figure of the device.
2) Clear explanation on its working principle.
3) Any mathematical model that relates the input with output, and

R_p: Resistance of potentiometer



the slider is made of Bimetallic material so when temperature rise or fall the slider will move and the reading of ~~output~~ output voltage will change

$$V_o = V_i \frac{K}{\left(K\left((1-K)\left(\frac{R_p}{R_m}+1\right)\right)\right)}$$

, V_i: Input voltage

V_o: output voltage

$K = \frac{X_i}{X_t}$

Wish You All the Best