King Saud University
College of Engineering
Mechanical Engineering Department
Mid-Term Exam. 1st sem. (1428/1429)

Subject: **Mechanical Measurements** **ME 302**

Question # 1

The water mass flow rate ($\rho = 998$ kg/m^3 ± 0.2 %) flowing in a pipe (diameter = 5cm ± 2%) is measured by an orifice with flow coefficient
C = 0.6 ± 0.02 (95% confidence level) and is given by:

$$\mathbf{m} = \mathbf{C\,A}\sqrt{2\cdot\rho\cdot\Delta P} \quad \text{kg/sec}$$

Where A is pipe area, and **Δp** is the pressure drop across the orifice in Pascal.
The experimental results recorded for the pressure drop **(Δp)** are:

10.5, 10, 10.6, 10.2, 10.1, 9.8, 9.9, 10, 9.4, 9.5 kPa

- Calculate Δp and its uncertainty using 95% confidence level.
- Calculate the percentage uncertainty in mass flow rate.
- Which parameter contributes more to the uncertainty in mass flow rate

Question # 2

If the flow velocity (U) is an input signal to a measuring system (Hot wire) and the output is E volt which can be represented by the relation:

$$E^2 = 1.5U^{0.5}$$

- Find the static sensitivity of this measuring system at U= 25 m/s
- Transfer the above relation to a straight line relation.

Question # 3

Given the voltage signal $E = 2\sin(1000\pi t)$ which is sampled with Δt= 1.5 milisec.

- Find the measured apparent frequency.
- Draw the frequency spectrum before and after sampling.
- Suggest how to avoid this aliasing.

Question # (4)

A thermocouple having a time constant of 2 seconds is used to minter the temperature of a fluid flowing in a conduit. The temperature of the fluid varies as under,

$$T(t) = 50 + 5\sin(\frac{2\pi t}{10}).$$

Find

(a) Amplification ratio for the thermocouple
(b) Phase difference
(c) Time delay
(d) Output function of the thermocouple.

Question # (5)

(a) What are the basic functional elements of a measuring system and what is their main function/
(b) What is the principle of a piezo-electric transducer?
(c) What is the principle of a strain gage transducer? How does the temperature change affect the output of the strain gage?

Question # (6)

A load cell having a sensitivity of 1.5Ω/N is used as the sensing resistance of a four arm Wheat Stone bridge. At no load all the resistance arms of the bridge have a resistance of 600Ωs. The excitation voltage of the bridge is 12 Volts. Find the output of the bridge when a load of 1 kN is applied to the load cell.

(1) Mech. Measurement Midterm 1428-29 - 1st:

$\rho = 998\ kg/m^3 \pm 0.2\%$ $u_\rho/\rho = 0.2\% = 0.002$

$d = 5cm \pm 2\%$ $\frac{u_d}{d} = 2\% = 0.02$

$C = 0.6 \pm 0.02$ $\frac{u_c}{C} = 0.033$

$\Delta P_i = 10.5,\ 10,\ 10.6,\ 10.2,\ 10.1,\ 9.8,\ 9.9,\ 10,\ 9.4,\ 9.5$

$n = 10 \quad \Delta\bar{P} = 10\ kPa$

$\Sigma d^2 = 1.12 \qquad S_{\Delta P} = \sqrt{\frac{\Sigma d^2}{n-1}} = 0.353$

$\nu = n-1 = 9 \quad \alpha = 0.05 \quad \frac{\alpha}{2} = 0.025$

$t_{\frac{\alpha}{2},\nu} = 2.262$

$\therefore u_p = \pm t_{\alpha/2,\nu} \frac{S_x}{\sqrt{n}} = \pm \frac{2.262 \times 0.353}{\sqrt{10}}$

$u_p = \pm 0.252\ kPa$

$\therefore \Delta P = 10 \pm 0.252\ kPa \qquad \frac{u_p}{\Delta P} = 0.025$

$m = C A \sqrt{2 \rho \Delta P}$

$m = C \frac{\pi}{4} d^2\ 2\ \rho^{\frac{1}{2}}\ \Delta P^{\frac{1}{2}}$

$\frac{u_m}{m} = \pm\sqrt{\left(\frac{u_c}{c}\right)^2 + \left(2\frac{u_d}{d}\right)^2 + \left(\frac{1}{2}\frac{u_\rho}{\rho}\right)^2 + \left(\frac{1}{2}\frac{u_{\Delta P}}{\Delta P}\right)^2}$

$= \pm\sqrt{(0.033)^2 + (2 \times 0.002)^2 + \left(\frac{0.002}{2}\right)^2 + \left(\frac{0.025}{2}\right)^2}$

$= 0.0533$

$\boxed{\frac{u_m}{m} = \pm 5.33\%}$

(2) $E^2 = 1.5\,U^{0.5}$

$K = \frac{dE}{dU}$ $\qquad 2E\,dE = 0.5 \times 1.5\,U^{-0.5}\,dU$

$$\frac{dE}{dU} = \frac{0.5 \times 1.5\,U^{-0.5}}{2E}$$

$$\frac{dE}{dU} = \frac{0.5 \times 1.5\,U^{-0.5}}{1.5\,U^{0.5}} = \frac{0.5}{U}$$

K at $U = 25$ cm/s $= \frac{0.5}{0.25} = 2$

$E^2 = 1.5\,U^{0.5}$

$2 \log E = \log 1.5 + 0.5 \log U$

$\log E = \frac{1}{2} \log 1.5 + \frac{0.5}{2} \log U$

$\log E = \log 1.5^{\frac{1}{2}} + 0.25 \log U$

$\log E = \log 1.225 + 0.25 \log U$

$$\boxed{\log E = 0.088 + 0.25 \log U}$$

(3)

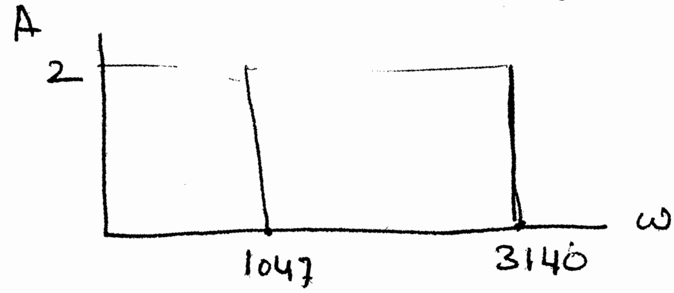
$E = 2\sin(1000\pi t) = 2\sin(3140t)$

$f = 500\ Hz$ $\qquad \Delta T_s = 1.5\times10^{-3}$ sec

$\therefore f_a = f_s - f$ $\qquad f_s = 666.67\ Hz$

$= 666.67 - 500 = 166.67\ Hz$

$E_a = 2\sin(1046.7t)$



The f_a is different than f $\therefore$ Aliasing occurs

To avoid aliasing $f_s > 2f = 2\times500 =$

$f_s > 1000\ Hz$ $\qquad f_s = 1050\ Hz$

(4)

$$T_{(t)} = 50 + 5\sin\left(\frac{2\pi t}{10}\right)$$

$$\omega = \frac{2\pi}{10} = 0.628 \text{ r/s}$$

$$\tau = 2 \text{ sec.}$$

$$T_s = 5^{\circ}C \quad \boxed{\frac{T_d}{T_s} = \frac{1}{\sqrt{1+(\omega\tau)^2}} = 0.623}$$

$$T_d = 5 \times 0.623 = 3.114^{\circ}C$$

$$\therefore \boxed{\phi = \tan^{-1}(\omega\tau) = 0.9}$$

$$\boxed{T_o = 50 \pm 3.114 \sin\left[\frac{2\pi t}{10} - 0.9\right]}$$

$$t_d = \frac{\phi}{\omega} = \frac{0.9}{0.628} = 1.43 \text{ sec}$$

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(5) (a) Basic functional Elements of a measuring System are

i Primary Sensing Element → To sense the input

ii Signal modyfying Element → To modify i/p for o/p compatability

iii Data Presentation Element → To present o/p

(b) – When a piezo electrical crystal is compressed it generates voltage.

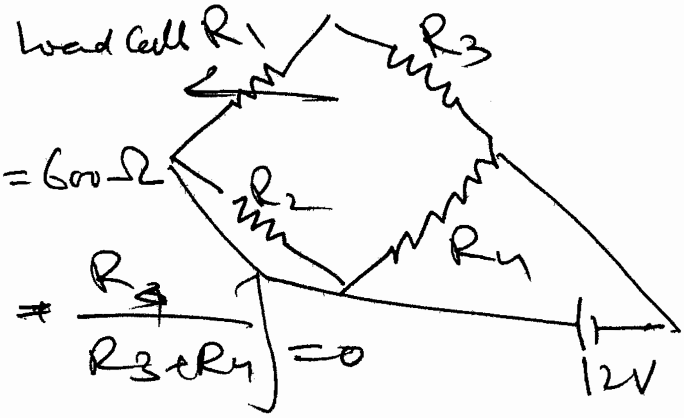
– When voltage is applied to its faces it expands.

(c) Strainguage is made of a resistance, when it is fixed to a loaded member, The load transfers to it. It elongates on tension in the same amount as the structural member on which it is fixed and compresses on compression. This change of length causes change in the resistance of strain gage. This change unbalances the 4 arm bridge to which it is at connected to. Therefore a change in output of the bridge is caused which is proportional to the load applied to the structural member.

(b)

No load

$R_1 = R_2 = R_3 = R_4 = 600\,\Omega$



$$\therefore \frac{e_o}{e_i} = \left[\frac{R_2}{R_1+R_2} \neq \frac{R_3}{R_3+R_4}\right] = 0$$

Load = 1 kN $K = 1.5\,\Omega/N$

$$\Delta R = 1.5 \times 1000 = 1500\,\Omega$$

load

$$\frac{e_o}{e_i} = \left[\frac{R_2}{R_1+\Delta R_1+R_2} - \frac{R_4}{R_3+R_4}\right]$$

$$= \left[\frac{600}{600+1500+600} - \frac{600}{600+600}\right] = \left[\frac{600}{2700} - \frac{600}{1200}\right] = 0.278$$

$e_o = e_i = -3.33$ volt