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(*University of Choice*)
**MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY (MMUST)**

**MAIN CAMPUS**

**UNIVERSITY EXAMINATIONS 2023/2024 ACADEMIC YEAR**

**FOURTH YEAR FIRST SEMESTER MAIN EXAMINATIONS**

**FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL AND INDUSTRIAL ENGINEERING**

**COURSE CODE: MIE 451**

**COURSE TITLE: MEASUREMENTS AND INSTRUMENTATION**

**DATE: FRIDAY 15/12/2023** **TIME: 8: 00 AM – 10:00 AM**

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**INSTRUCTIONS TO CANDIDATES**

Question ONE (1) is compulsory
Answer Any Other TWO (2) questions

TIME: 2 Hours

MMUST observes ZERO tolerance to examination cheating

This Paper Consists of 5 Printed Pages. Please Turn Over.

**QN 1 [30mks]**

(a) *i)* Distinguish between the following with regards to measurements:

*i)* Active and passive transducers [1mk]

*ii)* Intelligent and dumb instruments [1mk]

*iii)* Analogue and digital instruments [1mk]

*iv)* Sensor and transducer [1mk]

*ii)* A resistance temperature detector (RTD) is used in a furnace for automatic temperature measurement. The RTD is connected into a bridge circuit that gives a voltage output, which is fed into an instrumentation amplifier, to filter out common mode signals and then converted to a digital signal by a Flash A/D converter. The digitized signal is then transmitted to computers in a remote station via a cable, for further processing and monitoring. Represent this information in a well labelled block diagram, indicating the elements of the measurement system. [5mks]

*iii)* List FIVE criteria for choosing the most suitable measuring instrument for a given application. [5mks]

(b) *i)* State two conditions for which emf is generated in thermocouples. [2mks]

*ii)* A copper-constantan (type T) thermocouple with sensitivity of $0.5\text{mV}/°\text{C}$ and a resolution of $0.5°\text{C}$ is used to measure temperature in the range of $0°\text{C}$ to $200°\text{C}$ giving the following sampled results; [4mks]

| Temp (°C) | 0 | 105 | 200 |
|---|---|---|---|
| $E.m.f.$ (mV) | 0 | 5.275 | 10.125 |

Assuming a linear relationship between the $e.m.f$ and temperature over the full range, determine the non-linearity error at $105°\text{C}$ as a percentage of the full range output.

(c) *i)* Highlight FIVE features of intelligent instruments [5mks]

*ii)* Briefly explain the elements of data acquisition system giving relevant examples in each category. [5mks]

**QN 2 [20mks]**

(a) *i)* State the principle of operation of piezoelectric sensors. [1mk]

*ii)* Show that the output voltage ($V$) of a piezoelectric crystal is proportional to applied pressure $P$. [2mks]

*iii)* With aid of a well labelled diagram, explain the working principle of piezo-electric accelerometers. [4mks]

*iv)* Four piezoelectric crystals, each of charge sensitivity $S = 2pC/N$, surface area $= 1cm^2$, thickness $t = 0.1\ cm$, Young's modulus $E = 9 \times 10^{10} Pa$ and relative permittivity $\varepsilon_r = 5$, are arranged in parallel under a platform. A weight of 24N is placed

on the platform. Two electrodes pick the voltage changes in each crystal. Calculate;

*i)* Voltage across the electrodes [2mks]

*ii)* The change in crystal thickness [3mks]

*Take:* $\varepsilon_0 = 8.85 \times 10^{-12} F/m$

(b) If the output voltage from each piezoelectric crystal is fed through a charge amplifier, into a ramp A/D converter with a 16-bit precision and a maximum quantization error of $\pm 0.05125V$. Assuming uniform quantization error, calculate:

*i)* The quantization interval [1mk]

*ii)* Range of possible input signals if the minimum input is $1.5V$ [1mk]

(c) A parallel plate capacitance transducer uses plates of area $500mm^2$, separated by an airgap of 0.2mm. Take $\varepsilon_0 = 8.85 \times 10^{-12} F/m$ and $\varepsilon_r = 1$ for air. Calculate:

*i)* The change in capacitance if a linear displacement reduces the air gap **to** 0.18mm. [2mks]

*ii)* Transducer sensitivity. [2mks]

*iii)* Suppose a mica sheet of $\varepsilon_r = 8$ and thickness $0.01mm$ is inserted in the gap, determine the change in capacitance for the same displacement in (i). [2mks]

**QN 3 [20mks]**

(a) *i)* Explain the working principle of a strain gauge load cell. [2mks]

*ii)* State TWO applications of strain gauge transducers. [2mks]

*iii)* List TWO sources of errors in strain gauges. [2mks]

(b) A pressure gauge consisting of a *stainless steel diaphragm* of modulus of elasticity $E = 2 \times 10^8 kN/m^2$ and a *strain gauge* tranducer is used to measure gauge pressure in a steam pipe. The strain gauge ($\boldsymbol{R_x}$) of sensitivity $G = 2$ and resistance $R = 120\Omega$ is bonded on the diaphragm and connected into a bridge circuit as shown in **Fig.1**.

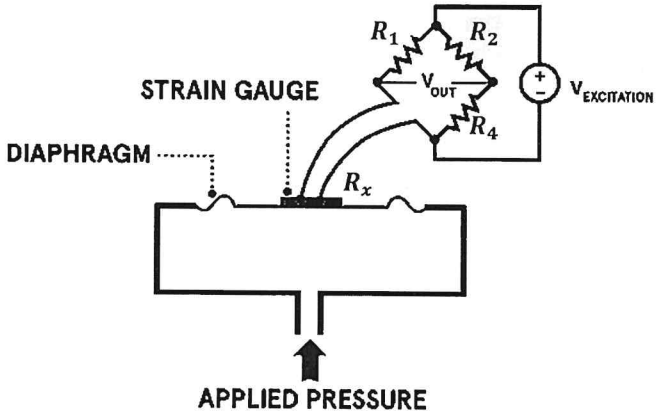


**Fig. 1**

If gauge pressure of $100Mpa$ is applied on the diaphragm, determine:

*i)* Percentage change in resistance. [3mks]

*ii)* The offset voltage if the strain gauge is connected into a bridge circuit with 3 other precision resistors $R_1 = R_2 = R_4 = 120\Omega$ and excitation voltage of $10V$. [2mks]

*iii)* The differential output voltage from the bridge circuit contains noise signals and therefore it's fed into an instrumentation amplifier circuit as shown in **Fig.2**. If $R_5 = R_6 = R_7 = 100\ k\Omega$, and determine gain resistance $R_3$ that gives an output $V_o = 6V$. [3mks]

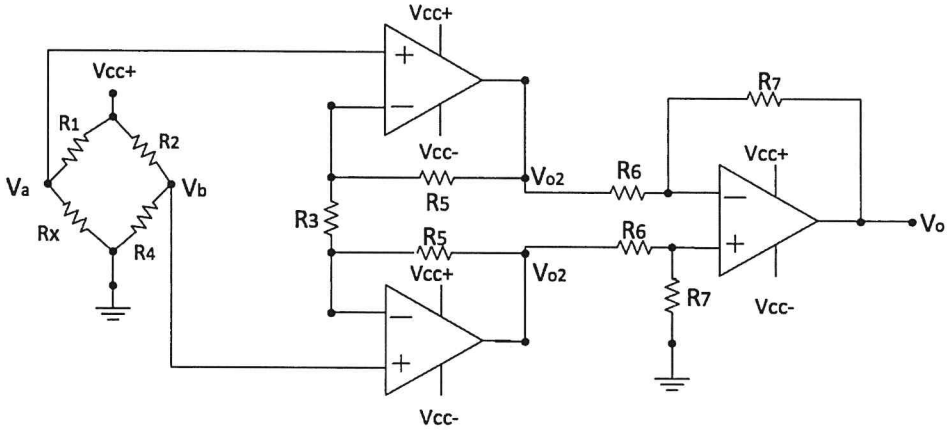


**Fig. 2**

*iv)* If the analogue output from the instrumentation amplifer in (*iii*) is to be fed into a 4-bit successive approximation ADC, describe how a digital equivalent signal is generated. [6mks]

**QN 4 [20mks]**

(a) List THREE transducers that can measure the shaft speed of a motor. [3mks]

(b) *i)* Explain the principle of operation of Hall effect sensors using a well labelled sketch. [4mks]

*ii)* Distinguish between *Hall sensors* and *magneto-resistive sensors.* [3mks]

*iii)* A silicon plate of thickness $1mm$, width $10mm$, length $100mm$ and Hall coefficient $3.66 \times 10^{-4} m^3/C$ is placed in magnetic field of $0.5\ Wb/m^2$ acting perpendicularly. If a current of $10^{-2}A$ flows through the plate, calculate the Hall voltage developed. [3mks]

(c) Describe using a well labelled diagram how the electromagnetic tachogenerator is used to measure angular displacement of a shaft. [4mks]

(d) With the aid of a block diagram, describe the architecture of an intelligent instrument. [3mks]

**QN 5 [20mks]**

(a) Considering a force sensitive resistor (FSR):

*i)* Explain the working principle. [1mk]

*ii)* With aid of a well labelled diagram, describe its structure. [2mks]

*iii)* Give TWO applications of FSRs. [2mks]

(b) A linear resistance potentiometer is 50mm long and is uniformly wound with a wire having a resistance of $10k\Omega$. Under normal conditions, the slider is at the center of the potentiometer. When the potentiometer is used to measure changes in fuel level, the resistance of the potentiometer for two cases are 3850Ω and 7560Ω.

*i)* Find the linear displacement for each case and comment whether they are in the same direction. [3mks]

*ii)* Calculate the resolution and state if it is possible to measure 100Ω resistance with the potentiometer. [2mks]

(c) Explain the working of the following opto-electronic devices:

*i)* Photodiodes [3mks]

*ii)* Phototransistors [3mks]

(d) Explain importance the following signal conditioning techniques:

*i)* Amplification [2mks]

*ii)* Isolation [2mks]