Research Assistants
Dr. İlkay Koçer Kuloğlu
Burcu Ökmen Altaş

BASIC CONTROL SYSTEM EQUIPMENTS: TRANSDUCERS

1. INTRODUCTION

Many measurements cannot be used for control until they are converted to physical quantities (such as electric voltage or current, or a pneumatic signal, i.e., compressed air or liquid) which can be transmitted easily. Transducers are used for that purpose. Briefly, the term transducer is applied to any device which converts a mechanical or other measurable phenomenon into an electrical one or vice versa. For example, strain gauges are metallic conductors whose electric resistance changes when they are subjected to mechanical strain. Thus, they can be used to convert a pressure signal to an electric one. In this experiment some useful transducers will be practiced.

2. THEORY

2.1. Wheatstone Bridge Circuit

Figure 1 shows the basic Wheatstone bridge circuit, consisting of four resistors and a sensitive center zero meter connected to a D.C. source.

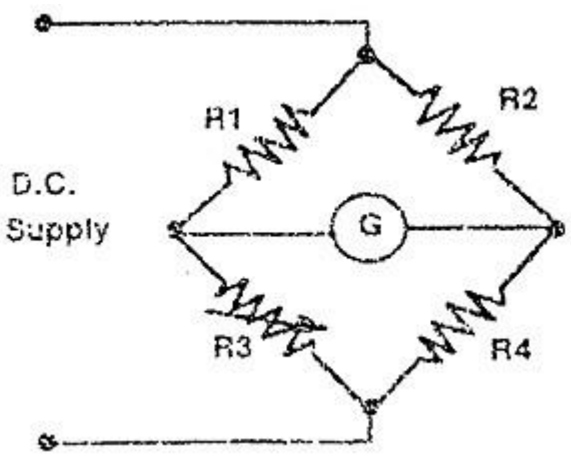

Figure 1. The basic Wheatstone bridge circuit

R1, R2, R3 are accurate resistors, R3 being variable and calibrated over its full range, and R4 is the unknown resistor whose value is being measured.

During measurement, R3 is adjusted until there is no current flowing in the galvanometer circuit. i.e., the galvanometer current is zero or null. Under these conditions, the bridge is said to be balanced. Hence the term nullbalance.

From the known values of R1, R2 and R3 at balance, the value of R4 can be calculated from;

$$R4 = \frac{R2}{R1} * R3 \qquad \text{(Eq.1)}$$

The expression is derived as follows:

With no current in the galvanometer circuit, the voltage at two connections to it must be at same value. This means that the voltage across R1 and R2 must be the same value and similarly those across R3 and R4 must be the same value. Also with no current in the galvanometer, the current in R1 must equal that in R3 and the current R2 must equal that in R4.

If current I1 flows in R1 and R3 and current I2 flows in R2 and R4;

$$I1.R1 = I2.R2 \qquad \text{(Eq.2)}$$

$$I1.R3 = I2.R4 \qquad \text{(Eq.3)}$$

Dividing Eq. (2) by Eq. (3)

$$\frac{I1.R1}{I1.R3} \quad \frac{I2.R2}{I2.R4} \qquad \text{(Eq.4)}$$

Hence, Eq.(1) can obtained from Eq.(4).

The unknown resistance, R4 depends on the values of the ratio R2:R1 and the value of R3 at balance. The resistors R1 and R2 are normally referred to as the "ratio arms" of the bridge.

The value of the supply voltage or the magnitude of the currents flowing in the resistors does not affect the result. This means that the supply voltage need not be stabilized and that the circuit currents can be kept to low values for a component where the self-heating effect of the current flowing could affect the result. Also, the galvanometer current accuracy is unimportant since, under balance conditions, the current in it is zero. The main characteristics required for the galvanometer are a low resistance and a high sensitivity so that a small deviation of voltage from zero produces a large-scale reading.

2.2. Temperature Transducers

Figure 2 shows the layout of the temperature transducers of the experimental setup.

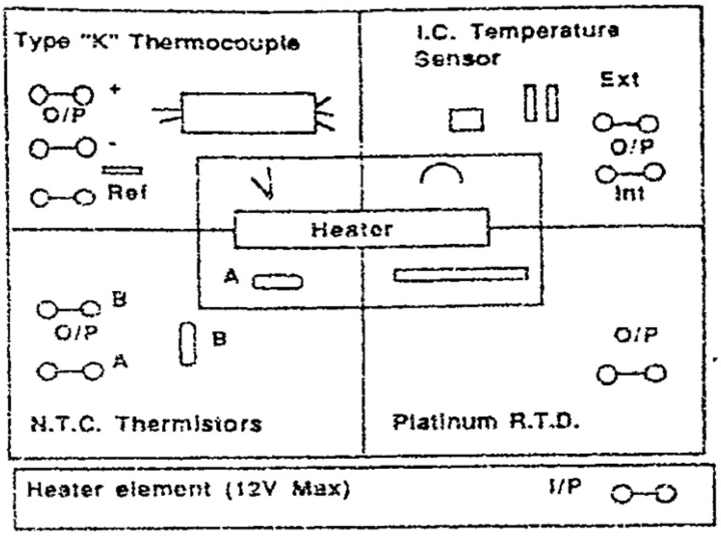

Figure 2. The layout of the temperature transducers of the experimental setup.

The I.C. Temperature Transducer

This is an integrated circuit containing 16 transistors, 9 resistors and 2 capacitors contained in a transistor type package. The device provides an output of 10mV/K. A measurement of the output voltage therefore indicates the temperature directly in K. (e.g. At the temperature of 20 ° C (293 K) the output voltage will be 2.93 V).

The Platinum R.T.D. (Resistance Temperature Dependent) Transducer

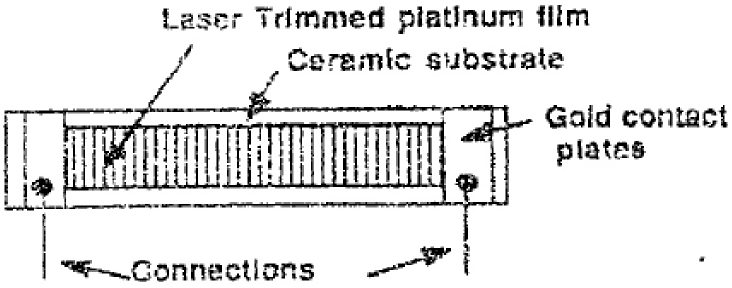

Figure 3. The platinum R.T.D. transducer

The construction of the platinum R.T.D. transducer is shown in Figure 3., consisting basically of a thin film of platinum deposited on a ceramic substrate and having gold contact plates at each end that contact with the film. The platinum film is trimmed with a laser beam so that the resistance is 100 Ω at 0 °C.

The resistance of the film increases as the temperature increases, i.e. it has a positive temperature coefficient. The increase in resistance is linear, the relationship between resistance change and temperature rise being 0.385Ω/°C for the unit.

$$R_t = R_o + 0.385T \quad \text{(Eq.5)}$$

where Rt is the resistance at temperature T and Ro is the resistance at 0°C = 100Ω.

Normally, the unit would be connected to a D.C. supply via a series resistor and the voltage drop across the transducer is measured. The current flow through the transducer will then cause some self-heating, the temperature rise due to this being of the order of 0.2°C/mW dissipated in the transducer.

The N.T.C.(Negative Temperature Coefficient) Thermistor

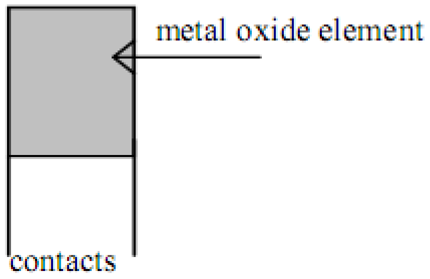

Figure 4. The N.T.C. thermistor

The construction of the N.T.C. thermistor is shown in Figure 4, consisting basically of an element made from sintered oxides of metals such as nickel, manganese and cobalt and with contacts made to each side of the element.

As the temperature of the element increases, its resistance falls, the resistance/temperature characteristic being nonlinear. The resistance of the thermistors provided with the DIGIAC 1750 unit is of the order of 5KΩ at an ambient temperature of 20°C (293°K). The relationship between resistance and temperature is given by the formula:

$$R2 = R1 \exp\left(\frac{B}{T2} - \frac{B}{T1}\right) \qquad \text{(Eq.6)}$$

where

R1=Resistance at temperature T1(K)

R2=Resistance at temperature T2 (K)

B=Characteristic temperature (4350 K)

Two similar unit are provided, one being mounted inside the heated enclosure, this being connected to the +5V supply and designated A. The other is mounted outside the heated enclosure, is connected to the 0V connection and is designated B.

- **The Type "K" Thermocouple Temperature Transducer**

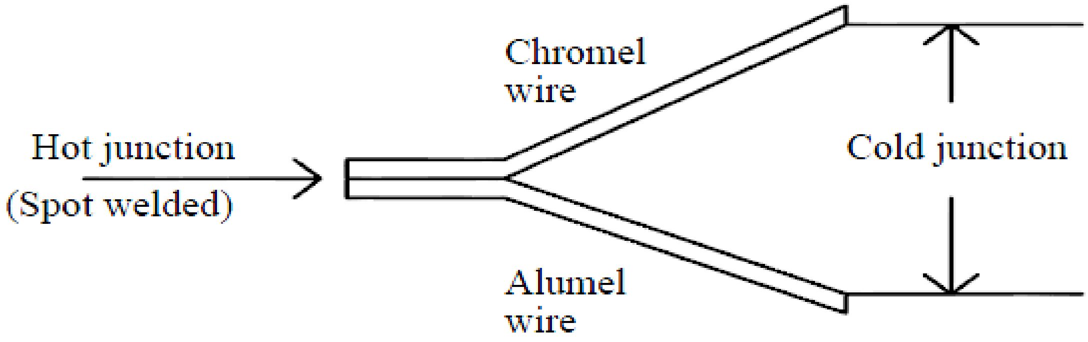

Figure 5. The type "K" thermocouple transducer

Figure 5 shows the basic construction of a thermocouple, consisting of two wires of different materials joined together at one end. For the type "K" thermocouple the two materials are alumel and chromel. With this arrangement, when the ends that are joined together are heated, an output voltage is obtained between the other two ends. The ends that are joined together are referred to as the "hot" junction and the other ends are referred to as the "cold" junction.

The magnitude of the output voltage depends on the temperature difference between the "hot" and "cold" junctions and on the materials used. For the type "K" thermocouple the output voltage is fairly linear over the temperature range 0-100°C and of magnitude 40.28μV/°C difference between the "hot" and "cold" junctions.

2.3. Transducers for Environmental Measurement

- **The Strain Gauge Transducer**

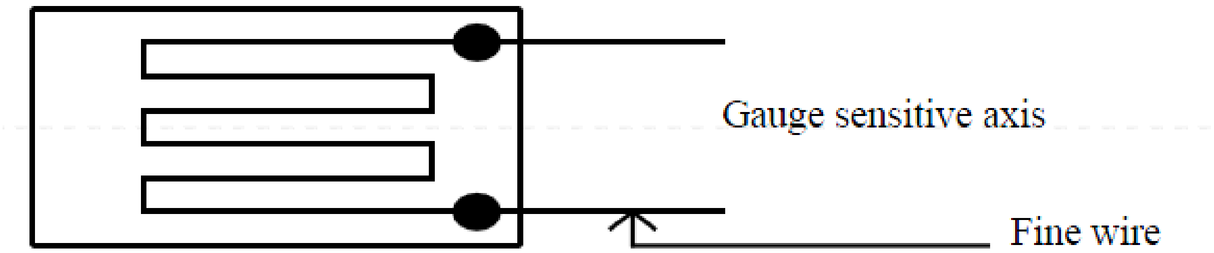

Figure 6. The Strain Gauge Transducer

Figure 6 shows the construction of a strain gauge, consisting basically of a grid of fine wire or semiconductor material bonded to a backing material. When in use, the unit is glued to the member under test and is arranged so that the variation in length under loaded conditions is along the gauge sensitive axis. Increase in loading then increases the length of the gauge wire and hence increases its resistance.

The gauge is normally connected in a Wheatstone bridge arrangement with the bridge balanced under no load conditions. Any change of resistance due to loading unbalances the bridge and this is indicated by the detector (Galvanometer).

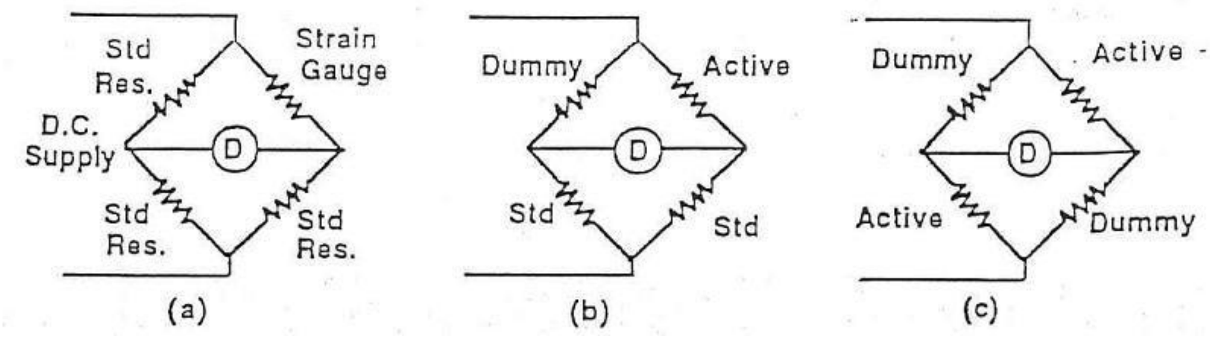

Figure 7. The basic Wheatstone bridge arrangement.

Figure 7.a shows the basic Wheatstone bridge arrangement with one strain gauge transducer. This circuit is liable to give inaccurate results due to temperature changes. A temperature change will also produce a change of resistance of the gauge and this will be interpreted as a change of loading.

To correct for this an identical gauge is used and connected in circuit as shown in Figure 7.b. This gauge is placed near the other gauge but is arranged so that it is not subjected to any loading.

Any variation of temperature now affects both gauges similarly and there will be no effect on the bridge balance conditions. The gauge subjected to the loading is referred to as the active gauge and the other is referred to as the dummy gauge.

The output from the circuit is small and to increase this, four gauges are normally used with two active gauges and two dummy ones as shown in Figure 7.c.

The Air Flow Transducer

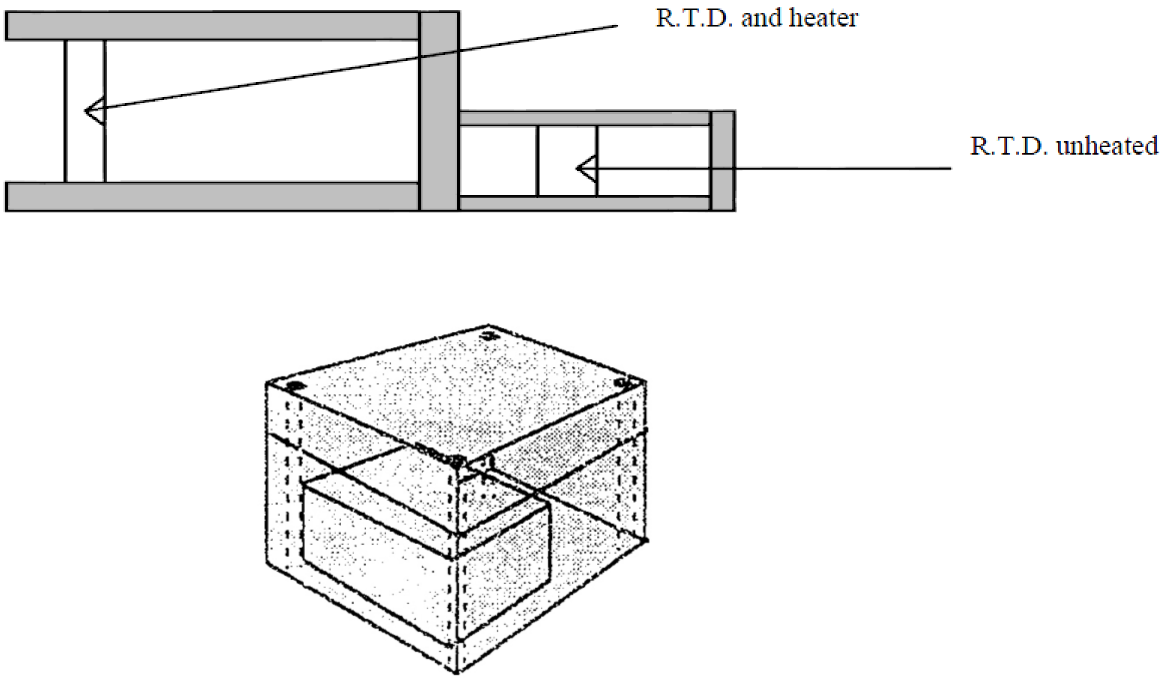

Figure 8. The basic construction of an air flow transducer

Figure 8 shows the basic construction of an air flow transducer, consisting of two R.T.D.'s mounted in a plastic case. One of the devices has an integral heating element incorporated with it and the other is unheated.

The operation of the device uses the principle that when air flows over the R.T.D.'s, the temperature of the heated unit will fall more than that of the unheated one. The temperature difference will be related to the air flow rate and this in turn will affect the resistance of the R.T.D.'s. With the digiac 1750 unit, the transducer is enclosed in a clear plastic container and provision is made for air to be pumped over the device.

The Air Pressure Transducer

Figure 9 shows the basic construction of an air pressure transducer, consisting of an outer plastic case which is open to the atmosphere via two ports. Within this case is an inner container from which the air has been evacuated and on the surface of this, a strain gauge Wheatstone Bridge circuit is fitted.

The air pressure in the outer container will produce an output from the bridge and variation of the pressure will produce a variation of this output.

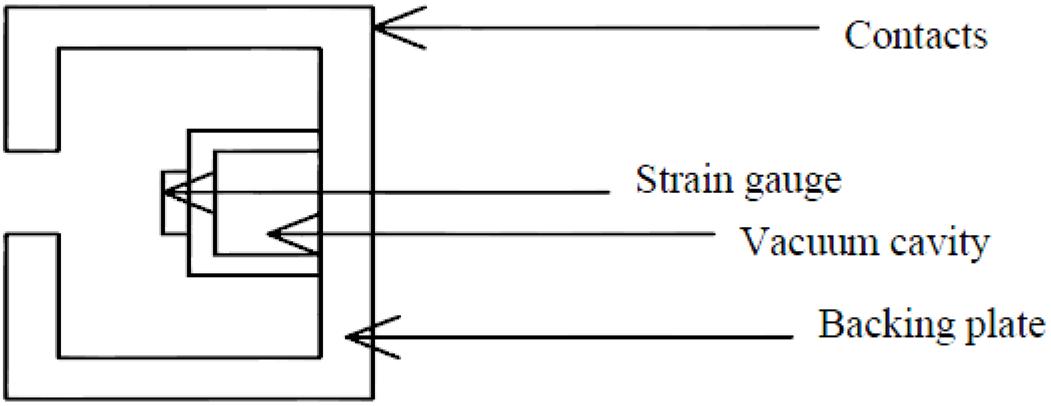

Figure 9. The basic construction of an air pressure transducer

The transducer output can be calibrated to indicate the absolute pressure and is termed an absolute pressure transducer.

- **The Humidity Transducer**

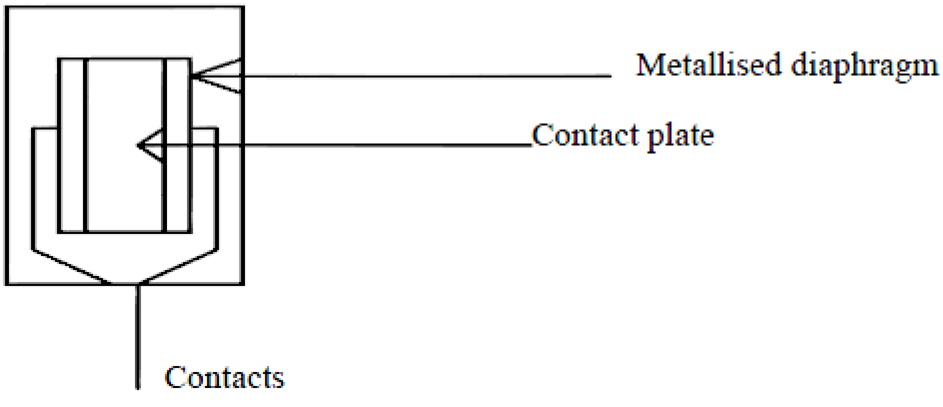

Figure 10. The basic construction of a humidity transducer

Figure 10 shows the construction of a humidity transducer, consisting basically of a thin diaphragm disc of a material whose properties vary with humidity. Each side of the disc metallised and the unit forms a capacitor, the capacitance varying with the humidity.

The unit is housed in a perforated in a plastic case. The unit is connected in series with a resistor with the output taken from the resistor. With an alternating voltage applied to the input, the output voltage will vary humidity due to the variation of capacitance of the transducer.

3. EXPERIMENTAL SET UP

3.1. The characteristics of an I.C. temperature transducer

- I.C. temperature transducer
- 20 V Digital voltmeter
- Connecting leads

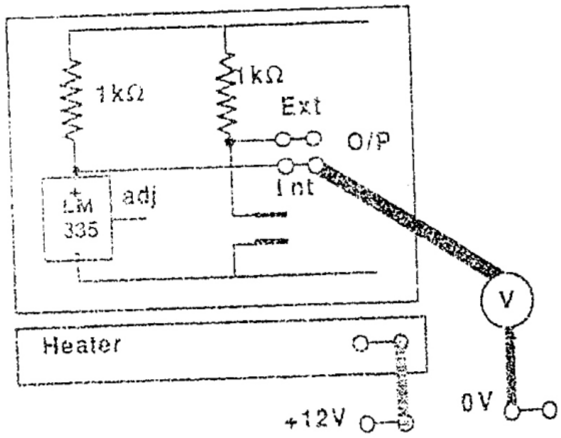

Figure 11. The experimental setup of section 3.1.

3.2. The characteristics of a platinum R.T.D. transducer

- Platinum R.T.D. transducer
- 10 kΩ wirewound resistor
- 20 V range digital voltmeter
- Connecting leads

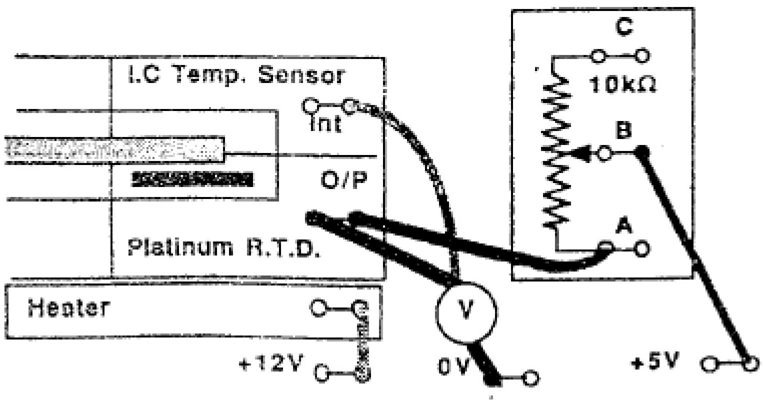

Figure 12. The experimental setup of section 3.2.

3.3. The characteristics of an N.T.C. thermistor

- N.T.C. thermistor
- 10 kΩ turn resistor
- 20 V digital voltmeter
- Connecting leads

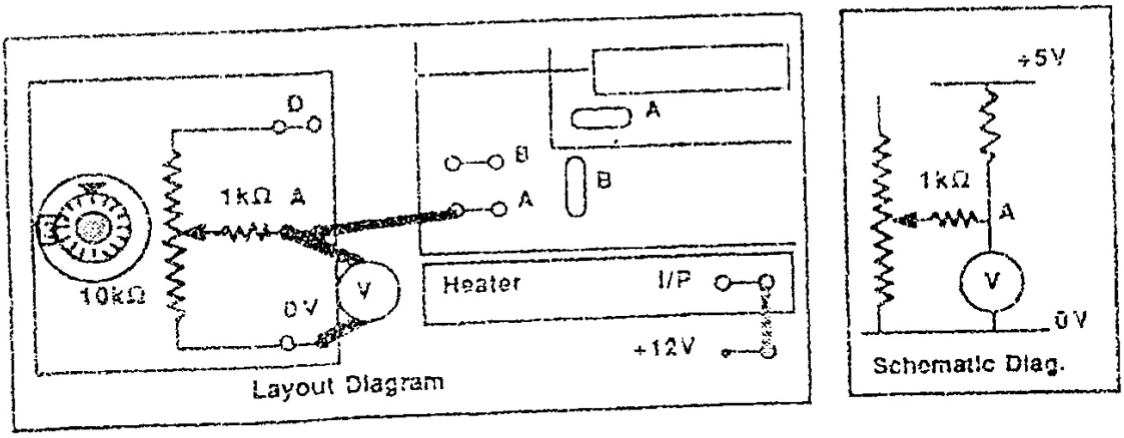

Figure 13. The experimental setup of section 3.3.

3.4. The characteristics of a K type thermocouple

- Type K thermocouple
- Instrument amplifier
- X100 amplifier
- Amplifier #1 with gain set 100 approximately
- 20 V digital voltmeter
- Connecting leads

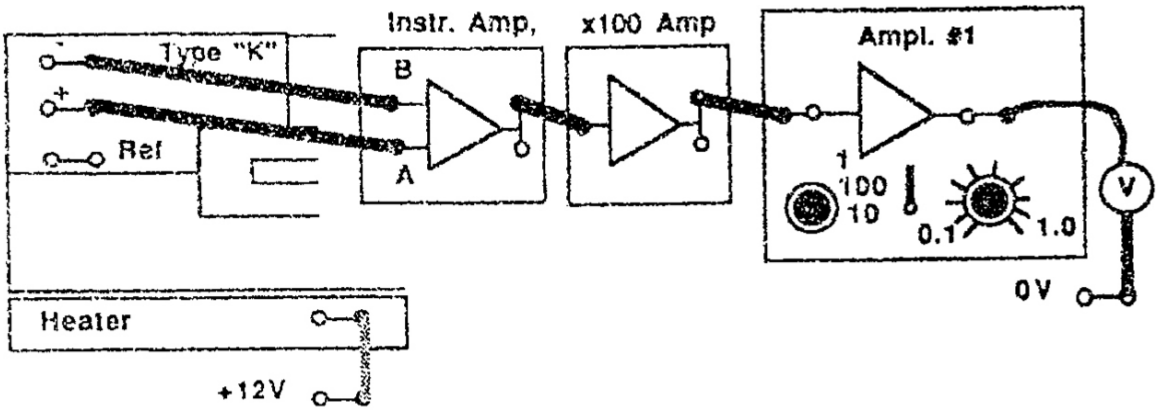

Figure 14. The experimental setup of section 3.4.

3.5. The characteristics of a strain gauge transducer

- Strain gauge transducer
- Instrument amplifier
- X100 amplifier
- Amplifier #1
- M.C. meter
- Coins for loading the beam
- Connecting leads

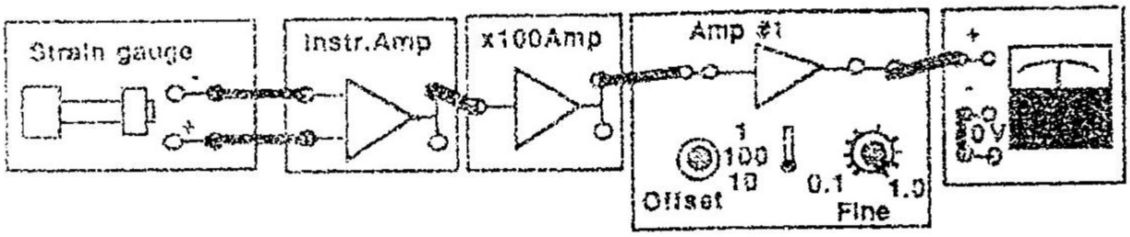

Figure 15. The experimental setup of section 3.5.

3.6. The characteristics of an air flow transducer

- Air flow transducer
- Instrument amplifier
- 20 V digital voltmeter
- Amplifier #1
- M.C. meter
- Connecting leads

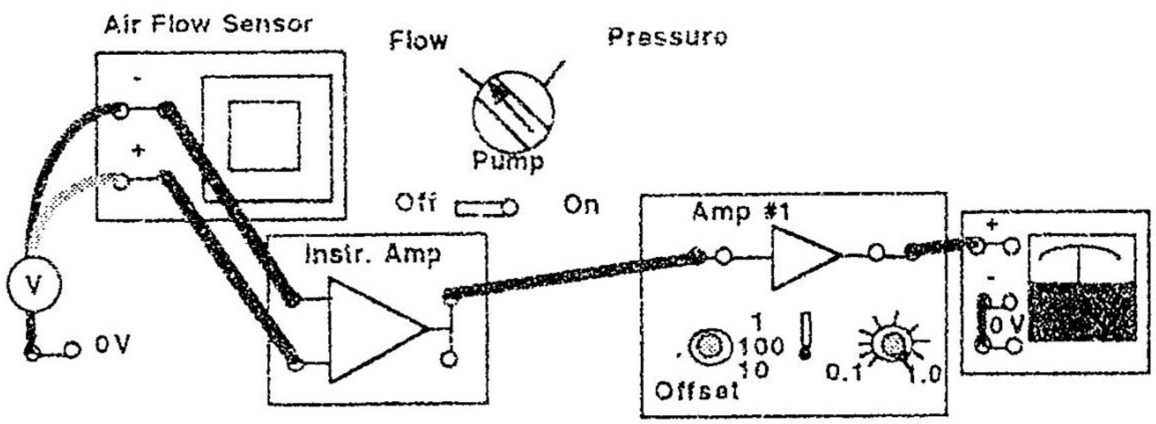

Figure 16. The experimental setup of section 3.6.

3.7. The characteristics of an air pressure transducer

- Air pressure transducer
- Instrument amplifier •

X100 amplifier

- 20 V digital voltmeter
- Amplifier #1
- M.C. meter
- Connecting leads

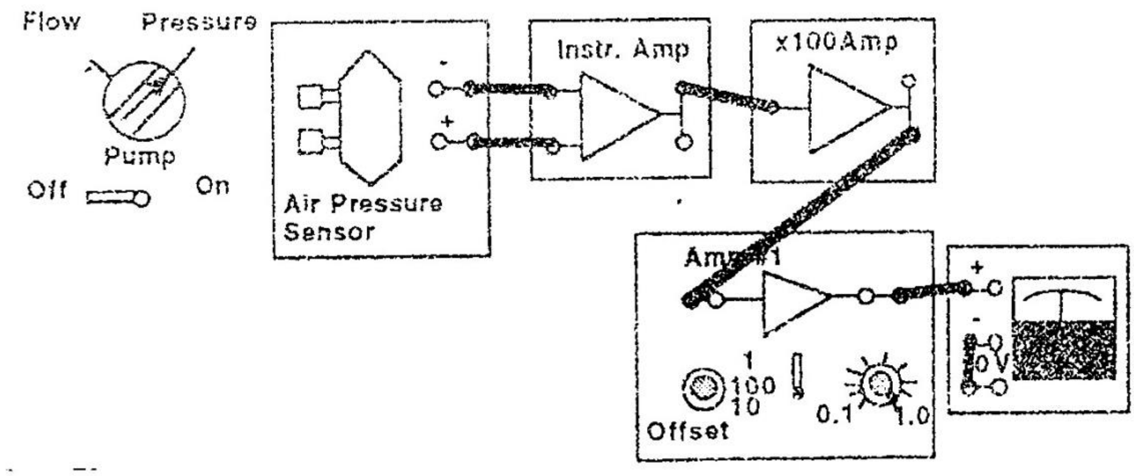

Figure 17. The experimental setup of section 3.7.

4. EXPERIMENTAL SET UP

4.1. The characteristics of an I.C. temperature transducer

The device provides an output of 10mV/K. A measurement of the output voltage therefore indicates the temperature directly in K. (e.g. At the temperature of 20 ° C (293 K) the output voltage will be 2.93 V). In the experiment temperature values are measured with I.C. transducer by measuring its output voltage.

4.2. The characteristics of a platinum R.T.D. transducer

- Connect the circuit as shown in Fig. 12.
- Adjust the control of variable resistor so that the voltage drop across the platinum R.T.D. is 0.108 V as indicated by the digital voltmeter.
- Now connect the +12V supply to the heater input and note the values of the voltage across the R.T.D. with voltmeter and temperature values in 30 second intervals.

4.3. The characteristics of an N.T.C. thermistor

- Connect the circuit as shown in Fig. 13.
- Now connect the +12V supply to the heater input and note the resistance and temperature values across the N.T.C. thermistor with voltmeter and thermocouple respectively, in 30 second intervals.

4.4. The characteristics of a K type thermocouple

- Connect the circuit as shown in Fig. 14.
- Set amplifier # 1 and fine gain control to 10.
- Connect the +12V supply to the heater input and note the values of thermocouple output voltage and the voltages representing the temperatures of the ʻʻhotʻʻ and ʻʻcold'' junctions of the thermocouple.

4.5. The characteristics of a strain gauge transducer

- Connect the circuit as shown in Fig. 15.
- Set amplifier # 1 and fine gain control to 10.
- Place a coin on the beam platform and note the output voltage.

- Repeat the process, adding further coins one at a time, noting the output voltage at each step.

4.6. The characteristics of an air pressure transducer

- Connect the circuit as shown in Fig. 17.
- Set amplifier # 1 and fine gain control to 10.
- Adjust the offset control of amplifier # 1 for zero output voltage. The unit is now calibrated zero for the current value of the atmospheric pressure.
- Set the Flow/Pressure control to Pressure and then switch the pump ON. The output voltage from the amplifier # 1 will increase. Note the value of this voltage.

5. CALCULATIONS

5.1. RTD Transducers

Table 5.1. The characteristics of platinium RTD transducer

t(s)	T_{IC}(°C)	R.T.D.(V)	R.T.D.exp.(Ω)	R.T.D.theo.(Ω)

RTD (Ω) = R_0 + 0.385 T (^{0}C)

(where R_0 = 100 Ω at 0^0C)

Draw Figure 5. 1. 1 T dependence of RTD ⟶ **RTD**$_{\text{theoretical}}$ (Ω) vs T_{IC}(°C)

Draw Figure 5. 1. 2 T dependence of RTD ⟶ **RTD** $_{\text{experimental}}$ (Ω)vs T_{IC}(°C)

Draw Figure 5. 1. 3 T RTD$_{\text{theoretical}}$ (Ω) **vs RTD** $_{\text{experimental}}$ (Ω)

5.2. NTC Transducers

Table 5.2. The characteristics of NTC thermistor

t(s)	T_{IC}(°C) T(K)	$R_{variable}$(Ω)	$R_{thermistor}$(Ω) ($R_{variable}$+1 Ω)	$R_{thermistor}$(Ω) (From the formula)

Experimental $R_{thermistor}$:

$R_{thermistor}$ (Ω) = $R_{variable}$ (Ω) + 1

Calculated $R_{thermistor}$:

$$R_2 = R_1 \cdot \exp\left(\frac{B}{T_2} - \frac{B}{T_1}\right)$$

Where R_1 : resistance at T_1 (K) R_2

: resistance at T_2 (K)

B : characteristic temperature (4350 K)

Draw Figure 5.2. T dependence of NTC ⟶ NTC (Ω) vs T_{IC}(°C)

5.3. "K" type Thermocouple

Table 5.3. The characteristics of "K" type Thermocouple

t(s)	T_{IC}(°C)	T(K) Hot Junction	M.C.(V) (OutputVoltage)	V_{REF} (V)	T_{ref}(K) (Cold Junction)	ΔT(K)

T_{ref} (K) = Ref (volt) x 100 (Cold junction)

Draw Figure 5.3. M.C. dependence of ΔT & $T_{hot.}$ ⟶ M.C. (V) vs ΔT & T_{hot} (K)

5.4. Strain Gauge Transducer

Table 5.4. The characteristics of strain gauge transducer

Number of coins	M.C.(V)

Draw Figure 5.4. ⟶ M.C. (V) vs Num. of coins

5.5. Air Pressure Transducer

Table 5.5. The characteristics of air pressure transducer

Pump	M.C.(V)
Pressure off	
Pressure on	

6. REFERENCES

- Curriculum Technical Manual LC Technical Publications Dept., ″ An Introduction to Transducers and Instrumentation ʻʻ, Vol:2, LC Technical Systems Inc.

7. DATA SHEET

Name Surname:

Group No:

Assistant: **Date:**

7.1. RTD Transducers

t(s)	**T_{IC}(ºC)**	**R.T.D.(V)**

7.2 NTC Transducers

t(s)	**T_{IC}(ºC)**	**$R_{variable}$(Ω)**

7.3. “K” type Thermocouple

t(s)	T_{IC}(ºC)	V_{REF} (V)	M.C.(V) (OutputVoltage)

7.4. Strain Gauge Transducer

Number of coins	M.C.(V)

7.5. Air Pressure Transducer

Pump	M.C.(V)
Pressure off	
Pressure on	