Lab Manual

CISE-312

Instrumentation Engineering

Department of Systems Engineering

College of Computer Science and Engineering

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Table of Contents

Lab No.	Title	Page No.
1	Wheatstone Bridge	3
2	MTM001-03 trainer: Acquisition of Physical Phenomenon	11
3	MTM001-03 trainer: Study of the characteristics of Capacitor Level Sensor for Level Measurement of a Liquid in a Tank	20
4	MTM001-03 trainer: Study of the characteristics of a Piezoresistive Sensor for Pressure Measurement of a Liquid in a Tank	26
5	MTM001-03 trainer: Study of the characteristics of Resistance Temperature Detector (RTD)	31
6	MTM001-03 trainer: Study of the characteristics of a Thermistor	35
7	MTM001-03 trainer: Study of the characteristics of a Thermocouple	39
8	MTM001-03 trainer: Study of the characteristics of an Electromagnetic Flow meter	43
9	MTM001-03 trainer: Study of the characteristics of a Paddle Wheel Flow meter	48
10	MTM001-04 trainer: Study of the characteristics of a Photo reflective sensor for Speed Measurement	53
11	MTM001-04 trainer:Study of the characteristics of a Magnetic Proximity sensor for Speed Measurement	60
12	MTM001-04 trainer: Study of the characteristics of a DC Tachometer	68
13	TecQuipment hardware: Study of the characteristics of Linear and Rotary Potentiometer	72
14	TecQuipment hardware: Study of the characteristics Reed Switch	83
15	TecQuipment hardware: Study of the characteristics of Reflective Beam Sensor	84
16	TecQuipment hardware: Study of the characteristics Four Bit Optical Encoder	86
17	TecQuipment hardware: Introduction to Speed Control	88

Lab 1

THE WHEATSTONE BRIDGE

CONTENT

The basic behaviour of a Wheatstone Bridge is introduced. The advantages of bridge measurement techniques over simple Ohm's Law methods are investigated.

EQUIPMENT REQUIRED

Qty	Designation	Description
1	TK2941M	Measurements Package
1	–	Power Supply, ±15V dc *(eg Feedback PS446)*
1	–	Decade Resistance 1Ω to 100kΩ
1	–	* DC Voltmeter 15V
1	–	* Centre zero dc milliammeter
1	–	Resistor – 100Ω, 1W
1	–	Resistor – 1kΩ, 1/8W
1	–	Resistor – 10kΩ, 1/8W

* Alternatively multimeters may be used.

PRACTICALS

2.1 The basic Wheatstone Bridge

THE WHEATSTONE BRIDGE

OBJECTIVES

When you have completed this assignment you will:

- Know the principle of operation of the basic Wheatstone Bridge.
- Know how to measure resistances using a Wheatstone Bridge.

KNOWLEDGE LEVEL

Before starting this assignment you should:

- Understand the theory and application of Ohm's Law
- Be familiar with the operation of series/parallel dc circuits and potential divider circuits.

The Wheatstone Bridge

INTRODUCTION

The Wheatstone Bridge

A method of determining resistance which was not direct reading has many sources of error. A direct reading method with few error sources would be of great advantage.

A way of determining resistance value which only requires one meter is shown in the circuit of fig 4.2.1.

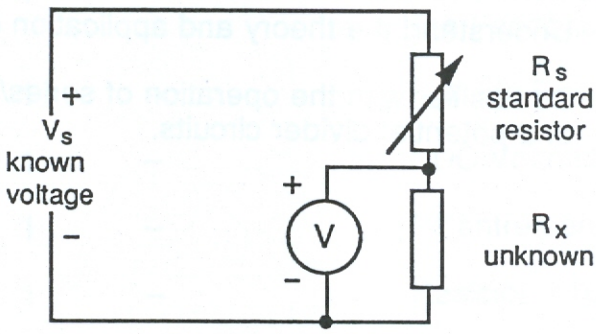

Fig 4.2.1 Basic one meter measurement

Here, the unknown resistance, R_X, is used in a potential divider circuit with a known standard resistor R_S connected across a known source voltage V_S.

By the potential divider formula:

$$V = \frac{R_x}{R_s + R_x} . V_s$$

therefore $$R_x = \frac{V}{V_s - V} . R_s$$

This circuit suffers from some disadvantages.

Obviously R_S, the standard resistor, must be known precisely.

The voltmeter V must have a resistance very much greater than R_X for accurate results.

The method does not lead to direct reading of the result.

When all the circuit values are known precisely, the final accuracy still depends ultimately on the accuracy of the meter indication.

It would be advantageous to find a method which does not have these drawbacks. Consider the circuit of fig 2.2.

Here, there are two voltage sources of $+V_S$ and $-V_S$ volts. R_S is a variable calibrated standard resistor and R_X is the unknown resistance.

M is a centre-zero meter.

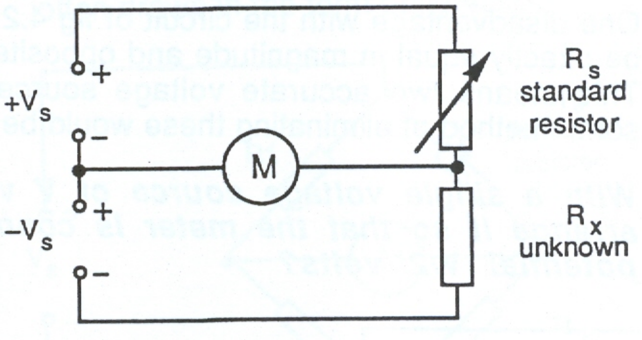

Fig 4.2.2 Centre zero reading

Question 2.1 — ***In the circuit of fig 4.2.2 when will the meter read zero?***

Question 2.2 — ***Assuming Rs has a calibrated scale, what will be the relationship between the resistance Rx and the indicated value of Rs?***

Question 2.3 — ***Can you think of a more sensitive way of determining the zero position of the meter?***

Consider the circuit in fig 4.2.3. With the switch closed the meter needle will be at its zero position. When the switch is open any current flowing through the meter will cause the needle to move, and it is possible to detect very small movements of the needle. This method then gives a very sensitive indication of the zero position.

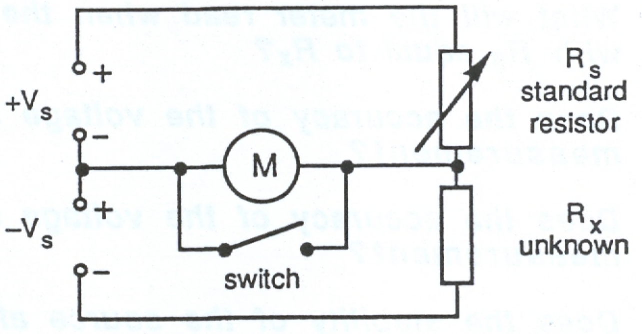

Fig 4.2.3 Sensitive zero position

Question 2.4 ***Does the accuracy of resistor measurement using the circuit of fig 4.2.3 depend on the accuracy of the meter?***

Question 2.5 ***Does the resistance of the meter affect the accuracy of measurement?***

One disadvantage with the circuit of fig 4.2.3 is that $+V_S$ must be exactly equal in magnitude and opposite in polarity of $-V_S$. This means two accurate voltage sources are needed, so some method of eliminating these would be useful.

Question 2.6 ***With a single voltage source of V volts how can you arrange it so that the meter is connected to a point of potential V/2 volts?***

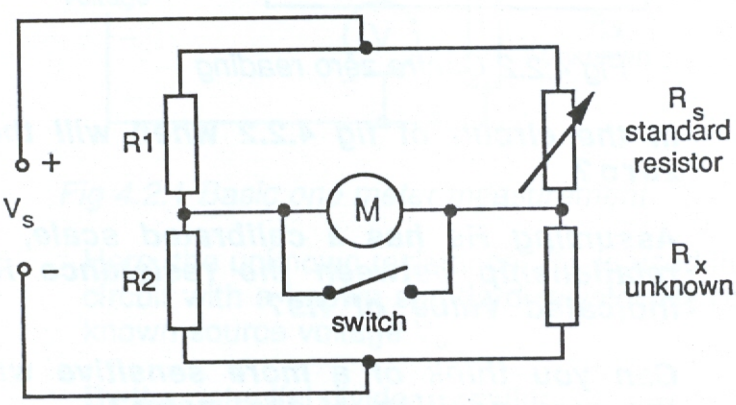

Fig 4.2.4 Centre zero but with single supply

Consider the circuit in fig 4.2.4.

With R_1 equal to R_2 the potential of the lefthand connection to the meter will be V/2 and with R_S equal to R_X the potential on the righthand end of the meter will also be V/2.

Question 2.7 ***What will the meter read when the switch is open with R_S equal to R_X?***

Question 2.8 ***Does the accuracy of the voltage source affect the measurement?***

Question 2.9 ***Does the accuracy of the voltage source affect the measurement?***

Question 2.10 ***Does the stability of the source affect the measurement?***

The Wheatstone Bridge

Question 2.11

Is it the absolute values of R_1 and R_2 that determine the accuracy of measurement of R_x, or is it the ratio accuracy that does so?

R_1 and R_2 are often called the Ratio Arms of the circuit and the circuit as a whole is called a Wheatstone Bridge. It is more often drawn in the form of fig 4.2.5.

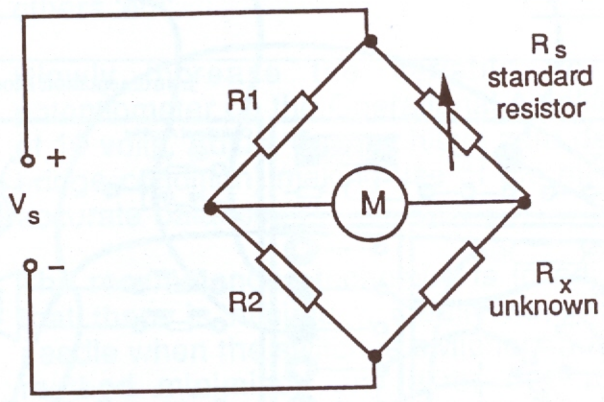

Fig 4.2.5 Circuit of Wheatstone Bridge

The Wheatstone Bridge

PRACTICAL 2.1

The Basic Wheatstone Bridge

Let us investigate the circuit. Set up your module as in fig 4.2.6. This corresponds to the circuit of fig 4.2.4 with $R_1 = 10k\Omega$ and $R_2 = 10k\Omega$. Use the external decade box for R_S.

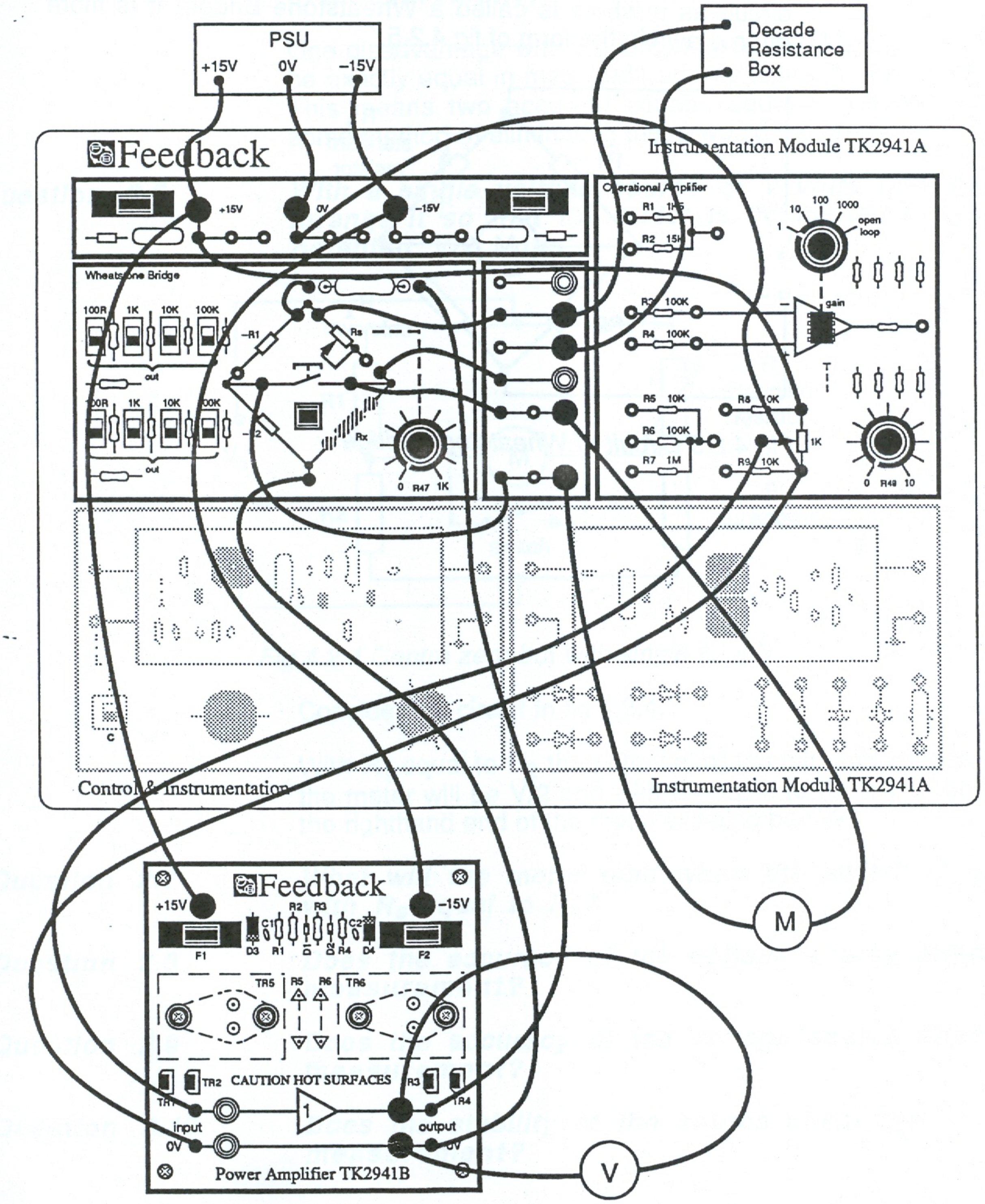

Fig 4.2.6 Wheatstone Bridge Connections

An extra 220Ω resistor is included in the module circuit in series with the Wheatstone Bridge to limit the current in event of a short circuit when connecting and using the Wheatstone Bridge.

Connect a resistor of about 100Ω across the R_x terminals.

On the Wheatstone Bridge set switches SW3 and SW7 'in'; all others 'out'.

Slowly increase the variable dc voltage, using the potentiometer on the Operational Amplifier, to give a supply V_S of 10 volts. Adjust R_S to achieve zero deflection (ie a balanced bridge condition) making use of the meter switch to obtain an accurate balance.

The recommended technique is to adjust R_S to a value such that there is minimum, ideally no, movement of the meter needle when the switch is switched in and out. The use of this method minimises any error due to the meter set-zero adjustment.

Read off the value of R_S from the resistance box.

Record your results in your own copy of fig 4.2.7.

Disconnect the 100Ω resistor and substitute a 1000Ω resistor for R_X. Repeat the balancing procedure and read the new value of R_S.

Repeat the procedure for an R_X of 10kΩ.

R_1	R_2	R_X	R_S
10kΩ	10kΩ	100Ω 1kΩ 10kΩ	
10kΩ	1kΩ	100Ω 1kΩ 10kΩ	
1kΩ	10kΩ	100Ω 1kΩ 10kΩ	

Fig 4.2.7

Lab 2

Acquisition of Physical Phenomenon

Objective:

1. To introduce the student to the principles of computer-based signal acquisition of physical phenomena using **DAQ**.

1. Introduction

Computer-based measurement systems are used in a wide variety of applications: laboratories, field services and on manufacturing plant floors. These systems act as general-purpose measurement tools that are well suited for measuring voltage signals. Many real-world sensors and transducers require signal conditioning before a computer-based measurement system can effectively and accurately acquire these signals. The front-end signal conditioning system can include functions such as signal amplification, attenuation, filtering, electrical isolation, simultaneous sampling, and multiplexing. In addition, many transducers require excitation currents or voltages, bridge completion, linearization, or high amplification for proper and accurate operation. Therefore, most computer-based measurement systems include some form of signal conditioning in addition to plug-in data acquisition DAQ devices.

2. Theory

Data acquisition involves gathering signals from measurement sources and digitizing the signal for storage, analysis, and presentation on a personal computer (PC). Data acquisition (DAQ) systems come in many different forms of flexibility when choosing your system. Scientists and engineers can choose from PCI, PXI, CompactPCI, PCMCIA, USB, Firewire, parallel, or serial ports for data acquisition in test, measurement,

and automation applications. There are five components to be considered when building a basic DAQ system:

1. Transducers and sensors
2. Signals
3. Signal conditioning
4. DAQ hardware
5. Driver and application software

a. Transducers

Data acquisition begins with the physical phenomenon to be measured. This physical phenomenon can be the temperature in a room, the intensity of a light source, the pressure inside a chamber, the force applied to an object, or many other phenomena. An effective DAQ system can measure all of these different phenomena. A transducer is a device that converts a physical phenomenon into a measurable electrical signal, such as voltage or current, or frequency. The ability of a DAQ system to measure different phenomena depends on the transducers ability to convert the physical phenomena into a signal measurable by the DAQ hardware. Transducers are synonymous with sensors in DAQ systems. There are specific transducers for many different applications, such as measuring temperature, pressure, or fluid flow. The table below shows a short list of the transducers used in the **Process Variables Measurement** and the phenomena they can measure.

Different transducers have different requirements for converting the physical phenomena into a measurable signal. Some transducers may require excitation in the form of voltage or current or may require additional components such as resistive networks to produce a signal. Other sensors provide the data acquisition system with electrical signals

that might need amplification, scaling, linearization, and manipulation to convert them to physical quantities.

Table 1: Transducers and Sensors used in Process Variables Measurement Trainer

Phenomena	Transducer	Signal
Temperature	Thermocouple	mV signal
	RTD	Ohm
	Thermistor	Ohm
Level	Capacitance Level Meter	4 – 20 mA
Fluid Flow	Electromagnetic Flow Meter	4 – 20 mA
	Paddle Wheel Flow Meter	4 – 20 mA
Pressure	Piezoresistive Transducer	4 – 20 mA

As an example, the Thermocouple used in the **Process Variable Measurement Trainer** are J-Type Thermocouples, they provide a **mV** signal that corresponds to Temperature, this signal needs some kind of amplification and conversion to find the corresponding temperature. The Thermocouples are connected to the Universal AI-9219 Module that converts the **mV** signal to its corresponding temperature. In addition, the AI module performs some kind of filtering and CJC (Cold Junction Compensation). Other kinds of transducers, such as a **Level Meter**, and a **Pressure Sensor** have their own signal converting algorithms. Such transducers are called transmitters. These transmitters have microprocessors that convert the raw electrical signal (**mV**, **µV**, **µA**, **Frequency**, etc…) and convert it to a scaled industrial standard signal, such as: 0 – 20 **mA**, 4 – 20 **mA**, 0 – 10 **V**, 0 – 5 **V**, etc… These signals are all linearized to the measuring range of the sensor. Some sensors have more than one measuring range and others can even be taught other measuring ranges. As an example, the **Level Meter** (, figure 1) has a measuring range of 0 – 30 **cm**. The transmitter delivers a 4 **mA** signal if the object level reads 0 **cm** and 20 **mA** if the object level reads 30 **cm**.

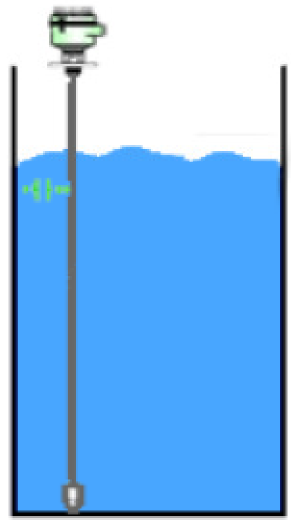

Figure 1: Capacitor Probe Level Meter

All the sensors used in the **MTM001-03 Process Variables Measurement Trainer** have their own conversion equations; these equations can be found in the **Explanation Box** in the front panel of each experiment.

b. Signals

The appropriate transducer converts the physical phenomena into measurable signals. However, different signals need to be measured in different ways. For this reason, it is important to understand the different types of signals and their corresponding attributes. Signals can be categorized into two groups:

i. Analog
ii. Digital

i. Analog Signals

An analog signal can be of any value with respect to time. A few examples of analog signals include voltage, temperature, pressure, sound,

and load. The three primary characteristics of an analog signal include level, shape, and frequency, as shown in figure 2.

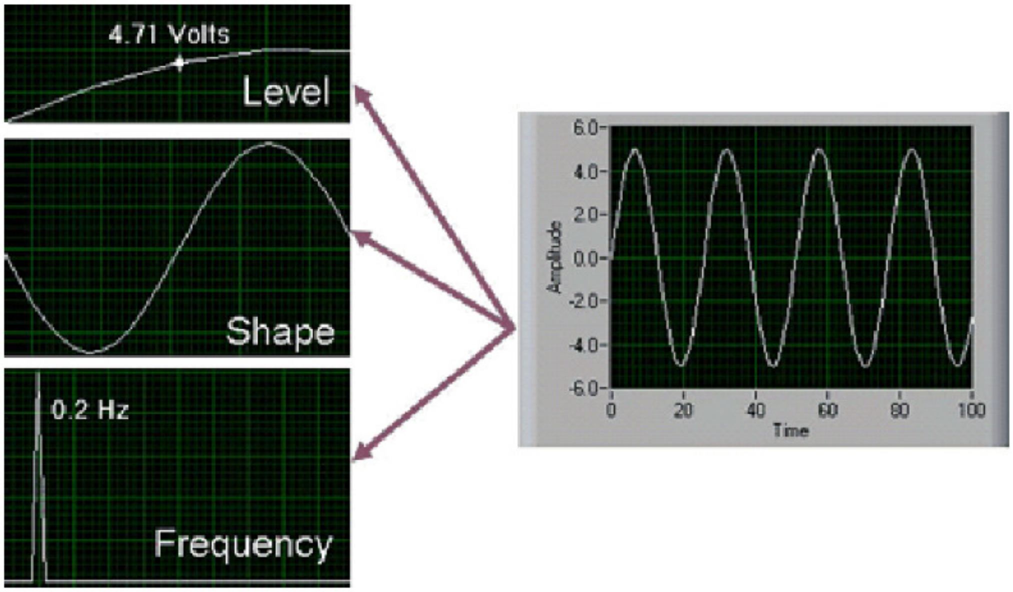

Figure 2: Characteristics of Analog Signals

A. Level:

Since analog signals can take on any value, the level gives vital information about the measured analog signal. The intensity of a light source, the temperature in a room, and the pressure inside a chamber are all examples that demonstrate the importance of the level of a signal. When measuring the level of a signal, the signal generally does not change quickly with respect to time. However, the accuracy of the measurement is very important. A DAQ system that yields maximum accuracy should be chosen to aid in analog level measurements.

B. Shape:

Some signals are named after their specific shape – sine, square, saw tooth, and triangle. The shape of an analog signal can be as important as the level, because measuring the shape of an analog signal allows further analysis of the signal, including peak values, DC values, and slope.

Signals where shape is of interest generally change rapidly with respect to time, but system accuracy is still important. The analysis of heartbeats, video signals, sounds, vibrations, and circuit responses are some applications involving shape measurements.

C. Frequency:

All analog signals can be categorized by their frequency. Unlike the level or shape of the signal, frequency cannot be directly measured. The signal must be analyzed using software to determine the frequency information. This analysis is usually done using an algorithm known as the Fourier Transform.

When the most important piece of information is frequency, then it is important to include both accuracy and acquisition speed. Although the acquisition speed for acquiring the frequency of a signal is less than the speed required for obtaining the shape of a signal, the signal must still be acquired fast enough so that the pertinent information is not lost while the analog signal is being acquired. The condition that stipulates this speed is known as the Nyquist Sampling Theorem. Speech analysis, telecommunication, and earthquake analysis are some examples of common applications where the frequency of the signal must be known.

2.2.2 Digital Signals

A digital signal cannot take on any value with respect to time. Instead, a digital signal has two possible levels: high and low. Digital signals generally conform to certain specifications that define characteristics of the signal. Digital signals are commonly referred to as Transistor-to-Transistor Logic (TTL). TTL specifications indicate a digital signal as low when the level falls within 0 to 0.8 Volts, and the signal as high when the level falls between 2 to 5 Volts. The useful information that can be

measured from a digital signal includes the state and the rate, as shown in figure 3.

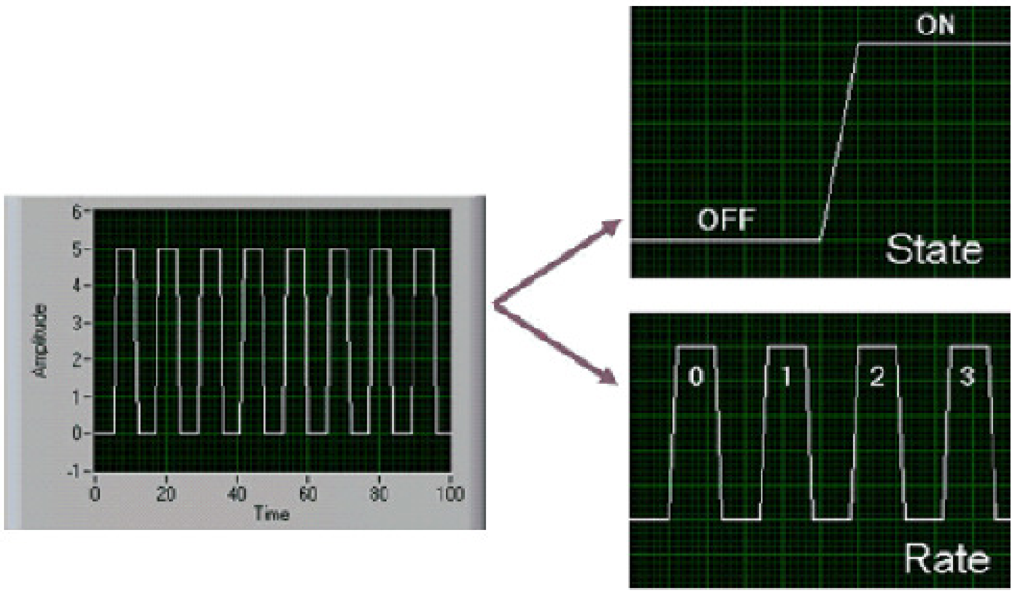

Figure 3: Characteristics of Digital Signals

A. State:

Digital signals cannot take on any value with respect to time. The state of a digital signal is essentially the level of the signal – on or off, high or low. Monitoring the state of a switch – open or closed – is a common application showing the importance of knowing the state of a digital signal.

B. **Rate:**

The rate of a digital signal defines how the digital signal changes state with respect to time. An example of measuring the rate of a digital signal includes determining how fast a motor shaft spins. Unlike frequency, the rate of a digital signal measures how often a portion of a signal occurs. A software algorithm is not required to determine the rate of a signal.

2.3. Signal Conditioning

Sometimes transducers generate signals too difficult or too dangerous to measure directly with a DAQ device. For instance, when dealing with high voltages, noisy environments, and extreme high and low signals, or simultaneous signal measurement, signal conditioning is essential for an effective DAQ system. Signal conditioning maximizes the accuracy of a system; it allows sensors to operate properly, and guarantees safety. It is important to select the right hardware for signal conditioning. Signal conditioning accessories can be used in a variety of applications including:

1. Amplification
2. Attenuation
3. Isolation
4. Bridge Completion
5. Simultaneous Sampling
6. Sensor Excitation
7. Multiplexing

Other important criteria to consider with signal conditioning include packaging (modular versus integrated), performance, I/O count, advanced features, and cost.

3. DAQ Hardware:

The DAQ hardware acts as the interface between the computer and the outside world. It primarily functions as a device that digitizes incoming analog signals so that the computer can interpret them. Other data acquisition functionality includes:

1. Analog Input/Output
2. Digital Input/Output
3. Counter/Timers

4. Multifunction – a combination of analog, digital, and counter operations on a single device

The platform we're using for the acquisition of the different signals in the **MTM001-03 Process Variables Measurement Trainer** is the National Instruments CompactDAQ. The NI cDAQ is an eight-slot NI CompactDAQ chassis designed for small, portable, mixed-measurement test systems. Combine the cDAQ with up to eight NI C Series I/O modules for a custom analog input, analog output, digital I/O, and counter/timer measurement system. With CompactDAQ, all of the intelligence, advanced control, and analysis capabilities of LabVIEW can be embedded in a small modular package suitable for industrial environments.

a. Driver and Application Software:

Software transforms the PC and the DAQ hardware into a complete data acquisition, analysis, and display system. Without software to control or drive the hardware, the DAQ device will not function or perform properly. The majority of DAQ applications use driver software. Driver software is the layer of software that directly programs the registers of the DAQ hardware, managing its operation and its integration with the computer resources, such as processor interrupts, DMA, and memory. Driver software hides the low-level, complicated details of hardware programming, providing the user with an easy-to-understand interface or a stand-alone application program. The increasing sophistication of DAQ hardware, computers, and software continues to emphasize the importance and value of good driver software. Properly selected driver software can deliver an optimal combination of flexibility and performance, while significantly reducing the time required developing the DAQ application.

Lab 3

Study of the characteristics of Capacitor Level Sensor for Level Measurement of a Liquid in a Tank

Objective:

1. To know what is a **Capacitance Level Sensor**.
2. To know how to convert the Capacitance Level Sensor Signal into Level and find the calibration equation

Apparatus: MT001-003 Multi0Process Variable Measurement Trainer

Theory: Capacitance *C*, of a capacitor is described by the following equation:

$$C = \frac{\epsilon A}{d}$$

Where

$$\epsilon = \epsilon_o \epsilon_r$$

$\epsilon_o$is the dielectric constant of air and ϵ_r is the relative dielectric constant of the medium. *A* is the area of the plates of a capacitor and *d* is the distance between the two plates of a capacitor.

In order to understand the working principle of a capacitance probe level sensor, consider figure 1, which show a capacitance probe level sensor inserted into a tank with conduction walls. As indicated, Wall of the tank and the probe constitute two plates of a capacitor. Any change of liquid level in the tank causes the change of dielectric medium between the two plates and thus changes the capacitance, giving a measure of the liquid level.

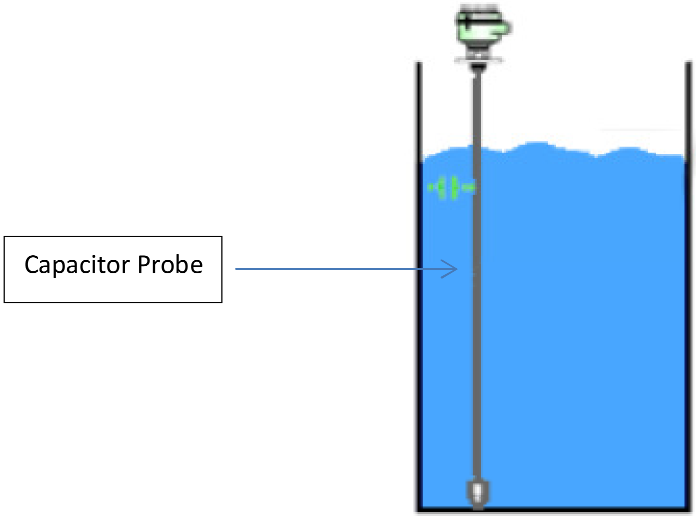

Figure 1: Capacitor Probe in a conducting Tank

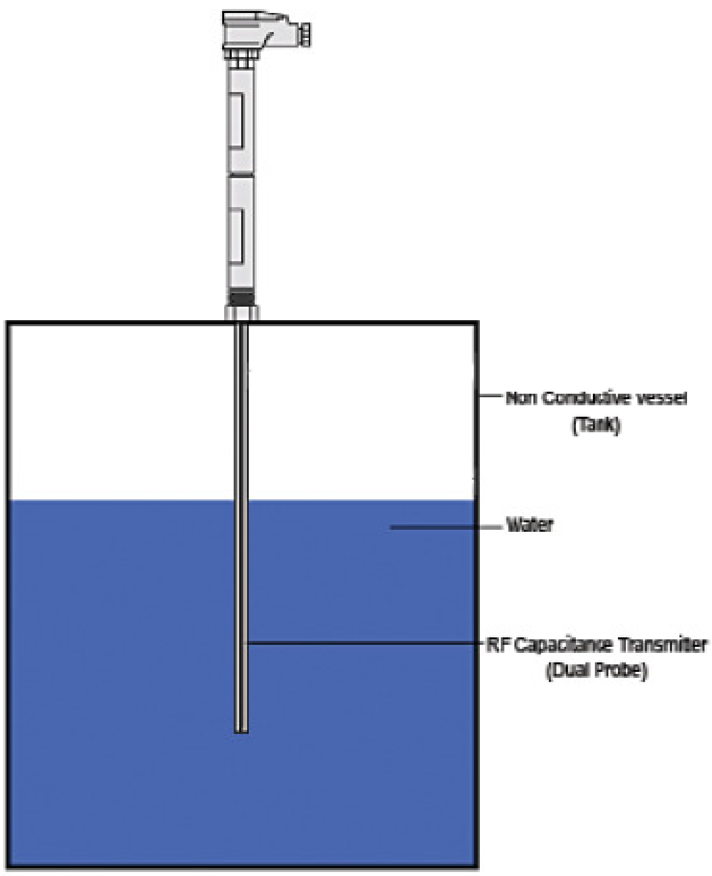

Figure 2: Dual Capacitor Probe in a non-conducting Tank

It should be noted that since the tanks in MT003-001 are made of Plexiglas which is a non-conducting material, therefore the scheme of

figure 1 cannot be used. Instead as seen in figure 2, a dual capacitor probe consisting of two concentric cylinders is used. The two concentric cylinders constitute the two plates of a capacitor and a change of liquid level between the two plates causes an ultimate change in the capacitance which is then calibrated into level of the liquid in the tank.

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 3.
2. Make sure that **Tank2** is almost empty.
3. Observe the reading of the Level in **cm** and the Current in **mA**.
4. Turn the **Pump** ON by pressing the Pump picture in the front panel.
5. Observe the **Level – Current graph**, and see the change of level and current with the change of water level.
6. Press **[Hold Values]** button to take a reading. The reading will appear in the **Held Values Table**.

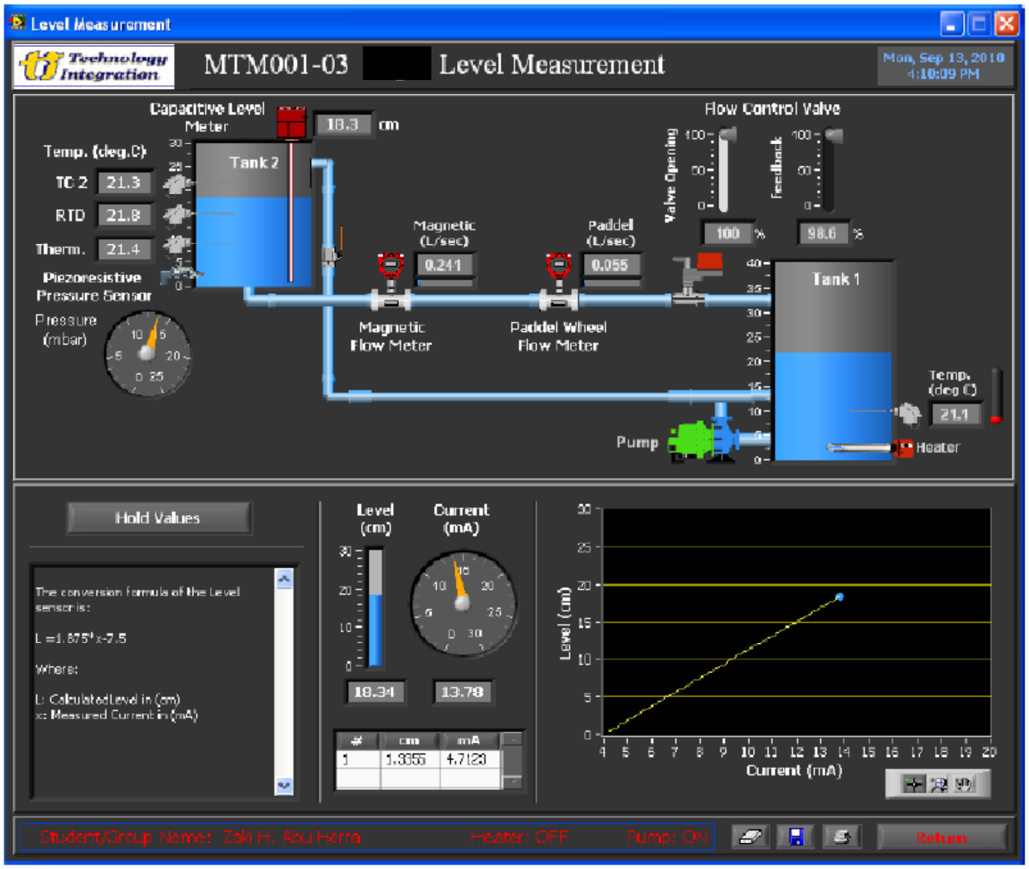

Figure 3: Level Measurement Experiment Window

7. Observe how the **Feedback Slide** responds to the change in the **Valve Opening Slide**.
8. Wait until the **Flow Control Valve** reaches the **"Fully Closed"** state (when the **Feedback** slide almost reaches **0** and the **Flow meters indicators** read **0 l/s**).
9. Turn the **Pump** OFF by pressing the Pump picture in the front panel.
10. The level in **Tank2** should not change.
11. Take the reading of the water level from the ruler at the front side of the tank, the level from the level sensor indicator and the current reading and write them down
    a. Water Level from ruler = ………………….(**cm**)

b. Water Level from sensor = ………………..(**cm**)

c. Current reading = ………………………….(**mA**)

a. Compare the reading of the ruler with the reading of the sensor, are they the same? If no, why?

12. Observe the plot in the **Level- Current graph**, is it Linear?
13. Take the current(**mA**) reading which you have taken above (step 11) and apply it in the following equation:

    $\boldsymbol{L=1.875*I-7.5}$ Where:

    L: *Calculated Level (***cm***)*

    I: *Current (***mA***)*
14. Compare the calculated level from the above equation with the level of the sensor you have taken in step 14, are they the same?
15. Observe the plot in the **Level – Current graph**, is it Linear?
16. Does the level transformation equation mentioned in step 17 describe the behavior of this plot? If not, why?
17. Change the state of the **Flow Control Valve** to **"Fully Open"** by dragging the **Valve Opening slide** to **100%**. Observe the change in the value of the **Feedback Slide**.
18. Observe the **Level – Current graph**, and see the change of level and current with the change of water level.
19. Notice that the **Flow Meter** should start measuring the Flow.
20. Wait until **Tank2** becomes almost empty.
21. Press **[Save]** button if you want to save the experiment.
22. Press **[Clear Chart]** button if you want to clear the chart(s).
23. Stop the process and press **[Return]** to go back to the **"Process Variables Experiments"** screen.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the liquid level and the current with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Level vs Current) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB
4. Plot the **Hold Value Table** readings for both increasing and decreasing values of level on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 4

Study of the characteristics of Piezo-resistive Pressure Sensor for Pressure Measurement of a Liquid in a Tank

Objective:

1. To know what is a **Piezo-resistive Pressure Sensor**.
2. To know how to convert the Piezo-electric Pressure Sensor Signal into Pressure and find the calibration equation

Apparatus: MT001-003 Multi0Process Variable Measurement Trainer

Theory: Pressure *P* is defined as the force *F* exerted per unit area *A*.

$$P = \frac{F}{A}$$

The SI unit for pressure is *Pascal* (N/m^2). Other commonly used units are *Pounds per square inch (psi), atmospheric pressure (atm.) and mmHg etc*

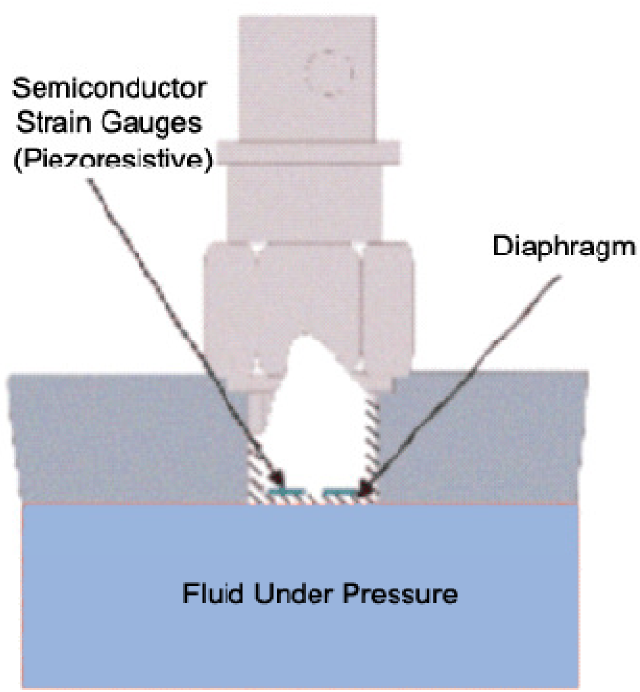

Figure 1: A Piezo-resistive pressure sensor

Figure 1 show a piezo-resistive sensor measuring the pressure of a fluid at certain point in a tank. The Piezo-resistive effect describes the changing electrical resistance of a material due to applied mechanical stress. Diaphragm of the sensor experiences a pressure due to which its resistance is changed, thereby changing the voltage across it when connected to an electric circuit.

Pressure Measurement: The natural output of a pressure transducer is a voltage. Most strain based pressure transducers will output a small **mV** voltage. This small signal requires several signal conditioning considerations. Additionally, many pressure transducers will output a conditioned 0-5**V** signal or 4-20 **mA** current. Both of these outputs are linear across the working range of the transducer. For example both 0 **V** and 4 **mA** correspond to a 0 pressure measurement. Similarly, 5 volts and 20 **mA** correspond to the Full Scale Capacity or the maximum pressure the transducer can measure. The 0-5**V** and 4-20 **mA** signals can easily be measured by Multi-function Data Acquisition (DAQ) hardware.

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 2.
2. Study the front panel carefully and observer the buttons on the screen.
3. Make sure that **Tank2** is almost empty.
4. Observe the reading of the pressure in **mbar** and the current in **mA**.
5. Turn the **Pump** ON by pressing the **Pump** picture in the front panel.

6. Observe the **Pressure – Current graph**, and see the change of pressure and current with the change of level.

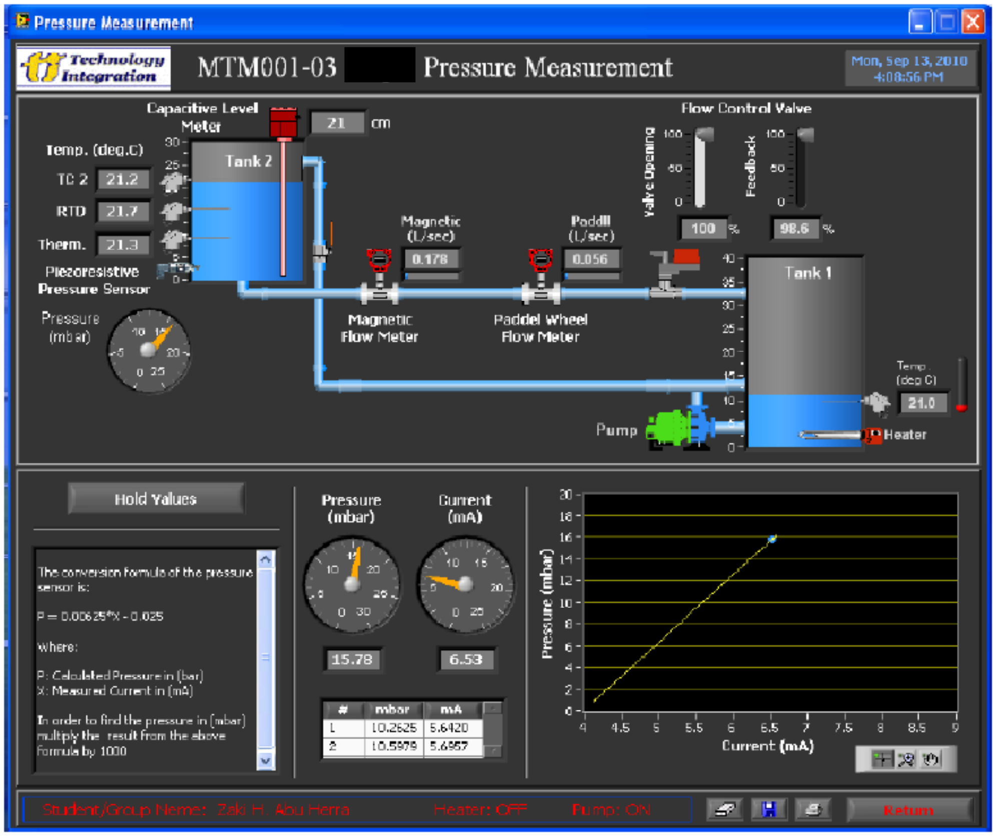

Figure 2: Pressure Measurement Experiment Window

7. Press **[Hold Values]** button to take a reading. The reading will appear in the **Held Values Table**.
8. Close the **Flow Control Valve** by dragging the **Valve Opening Slide** to **0%**.
9. Observe how the **Feedback Slide** responds to the change in the **Valve Opening Slide**.
10. Wait until the **Flow Control Valve** reaches the **"Fully Closed"** state (when the **Feedback** slide almost reaches 0 and the **Flow meters indicators** read 0 **l/s**).
11. Turn the **Pump** OFF by pressing the Pump picture in the front panel.

12. Notice that the Level in **Tank2** should not change.

Note: Make sure to measure the level of the water from the center of the sensor and above, don't measure the level under the sensor because the sensor measures the water pressure that is above.

13. Take the level of the water in **Tank2** and the reading of the pressure sensor in (**mbar**) and write them down.

    a) Water Level = ……………………………………(**m**)
    b) Pressure from the Pressure sensor = …………(**mbar**)

    Use the below equation to find the actual Pressure $P=\rho g h$ Where:

    P: *Pressure Calculated* **(pascal)**

    : *Water Density* **(kg/m3)**

    g: *Gravity Acceleration* **(m/s2) = 9.81**

    h: *Water Level* **(m)**

14. Divide the calculated pressure on (1∗105) to convert it to **bar**.
15. Compare the result with the value you have taken above. 17.
16. Compare the calculated pressure value with the actual pressure value that you have taken from the **Held Values table**, is it the same?
17. Observe the transformation equation and the **Pressure-Current graph**, and answer the following questions:
    a) Is the equation Linear? If no, why?
    b) Does the plot in the **Pressure-Current graph** represent the transformation equation? If no, why?

18. Change the state of the **Flow Control Valve** to **"Fully Open"** by dragging the **Valve Opening slide** to **100%**.
19. Observe the change in the value of the **Feedback Slide**. 20.

20. Observe the **Pressure – Current graph**, and see the change of pressure and current with the change of level.
21. Notice that the **Flow Meter** should start measuring the Flow.
22. Wait until **Tank2** becomes almost empty.
23. Press **[Save]** button if you want to save the experiment.
24. Press **[Clear Chart]** button if you want to clear the chart(s).
25. Stop the process and press **[Return]** to go back to the **"Process Variables Experiments"** screen.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the liquid pressure and the current with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Level vs Current) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB
4. Plot the **Hold Value Table** readings for both increasing and decreasing values of pressure on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 5

Study of the characteristics of Resistance Temperature Detector (RTD)

Objective:

1. To know what is a **RTD**.
2. To know how to convert the RTD Signal into Temperature and find the calibration equation

Apparatus: MT001-003 Multi-Process Variable Measurement Trainer

Theory:

RTDs or **Resistance Temperature Detectors** are electrical resistors that change resistance as temperature changes. With all common types of RTD, the resistance increases as temperature increases, this is referred to as Positive Temperature coefficient (PTC). RTDs are manufactured using several different materials as the sensing element. The most common by far is the Platinum RTD. Platinum is used for several different reasons including high temperature rating, very stable, and very repeatable. Other materials used to make RTDs are nickel, copper, and nickel-iron. These materials are becoming less common now, due to the reduction of the cost of platinum RTDs.

RTDs are commonly categorized by their nominal resistance at 0 °C. Typical nominal resistance values for platinum thin-film RTDs include 100 and 1000 **Ω**. In MTT a PT100 RTD is used. In order to measure temperature with the RTD, you only need to measure the resistance of the RTD, and then substitute the resistance value in the following equation:

$$T = \frac{R_0 - R}{-0.5\left(R_0 A + \sqrt{{R_0}^2 A^2 - 4R_0 B(R_0 - R)}\right)}$$

Where:

T = *Calculated temperature in (*^{o}**C***)*

Ro = *RTD nominal resistance at 0*^{o}**C***, for PT100, Ro=100 (***Ohm***)*

R = *Measured resistance (***Ohm***)*

A = *3.90802×10-3*

B = *-5.80195×10-7*

The above equation gives the temperature in ^{o}**C**. The value of **Ro**, **A**and**B** differs from one type of RTD to another.

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 1.
2. Study the front panel carefully and observe the buttons on the screen.
3. Notice the 4 different tabs on the front panel; **Thermocouple**, **RTD, Thermistor** and **Trends.** Press **RTD.**
4. Make sure that **Tank2** is almost empty.
5. Turn the **Heater** ON by pressing the **Heater** picture in the front panel.
6. Keep taking readings by pressing the tab **Hold Value** while heater is ON.
7. Wait until the Temperature go up between **(7-10)** degrees from the initial temperature.
8. Turn the **Heater** OFF by pressing on the **Heater** picture in the front panel (**Cooling Mode**).

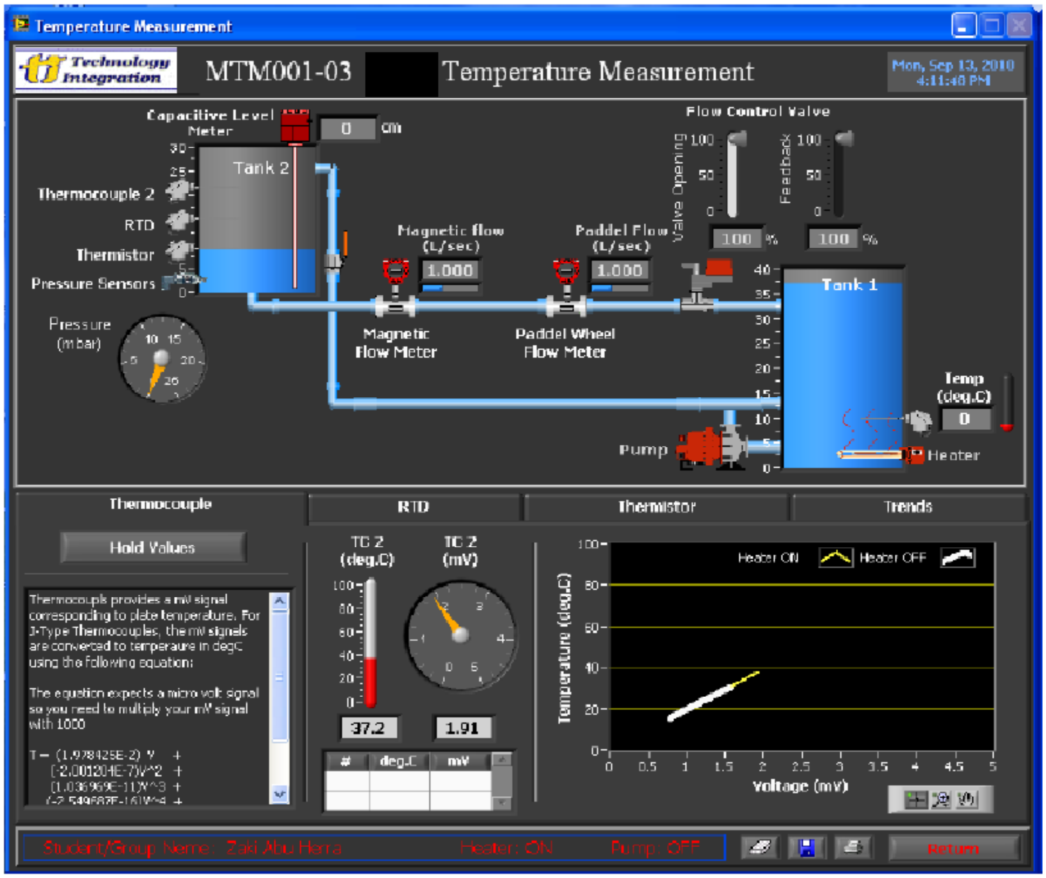

Figure 1: Temperature Measurement Window

9. Turn the **Pump** on by pressing the **Pump** picture on the front panel.
10. Keep taking readings by pressing **[Hold Values]** button.
11. Press **[Clear Chart]** button if you want to clear the chart(s).
12. Press **[Return]** button to return to the **"Process Variables Experiments"** screen.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the Temperature and the Voltage with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Temperature vs Voltage) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB
4. Plot the **Hold Value Table** readings for both increasing and decreasing values of pressure on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 6

Study of the characteristics of Thermistors

Objective:

1. To know what is a **Thermistor**.
2. To know how to convert the Thermistor Signal into Temperature and find the calibration equation

Apparatus: MT001-003 Multi-Process Variable Measurement Trainer

Theory:

Thermistors, like RTDs, are thermally sensitive semiconductors whose resistance varies with temperature. Thermistors are manufactured from metal oxide semiconductor material encapsulated in a glass or epoxy bead. Also, thermistors typically have much higher nominal resistance values than RTDs (anywhere from 2,000 to 10,000 **Ω**) and can be used for lower currents. Each sensor has a designated nominal resistance that varies proportionally with temperature according to a linearized approximation. Thermistors have either a negative temperature coefficient (NTC) or a positive temperature coefficient (PTC). The first, which is more common, has a resistance that decreases with increasing temperature while the latter exhibits increased resistance with increasing temperature. Thermistors typically have a very high sensitivity (~200 **Ω/°C**), making them extremely responsive to changes in temperature. Though they exhibit a fast response rate, thermistors are limited in their use up to the 300 °C temperature range. This, along with their high nominal resistance, helps to provide precise measurements in lower-temperature applications. In **MTM001-03** we use an NTC thermistor which has a temperature range from 13-85 ^{o}C. In order to measure

temperature with the thermistor, you only need to measure the resistance of the thermistor, and then substitute the resistance value in the following equation :

$$T = \frac{1}{a + bln(R) + c[\ln(R)]^3}$$

Where:

T *: Calculated temperature in (***Kelvin***)*

R*: Measured resistance in (***Ohm***)*

a, b *and* **c** *are Steinhart-Hart Constants that have the following values*

a = *1.2407635*10-3*

b = *2.3612017*10-4*

c = *8.97975*10-8*

Using the above equation you will get the temperature in **Kelvin**. The value of **a**, **b** and **c** differs from one type of thermistor to another.

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 1.
2. Study the front panel carefully and observe the buttons on the screen.
3. Notice the 4 different tabs on the front panel; **Thermocouple**, **RTD, Thermistor** and **Trends.** Press **Thermistor.**
4. Make sure that **Tank2** is almost empty.
5. Turn the **Heater** ON by pressing the **Heater** picture in the front panel.
6. Keep taking readings by pressing the tab **Hold Value** while heater is ON.
7. Wait until the Temperature go up between **(7-10)** degrees from the initial temperature.

8. Turn the **Heater** OFF by pressing on the **Heater** picture in the front panel (**Cooling Mode**).

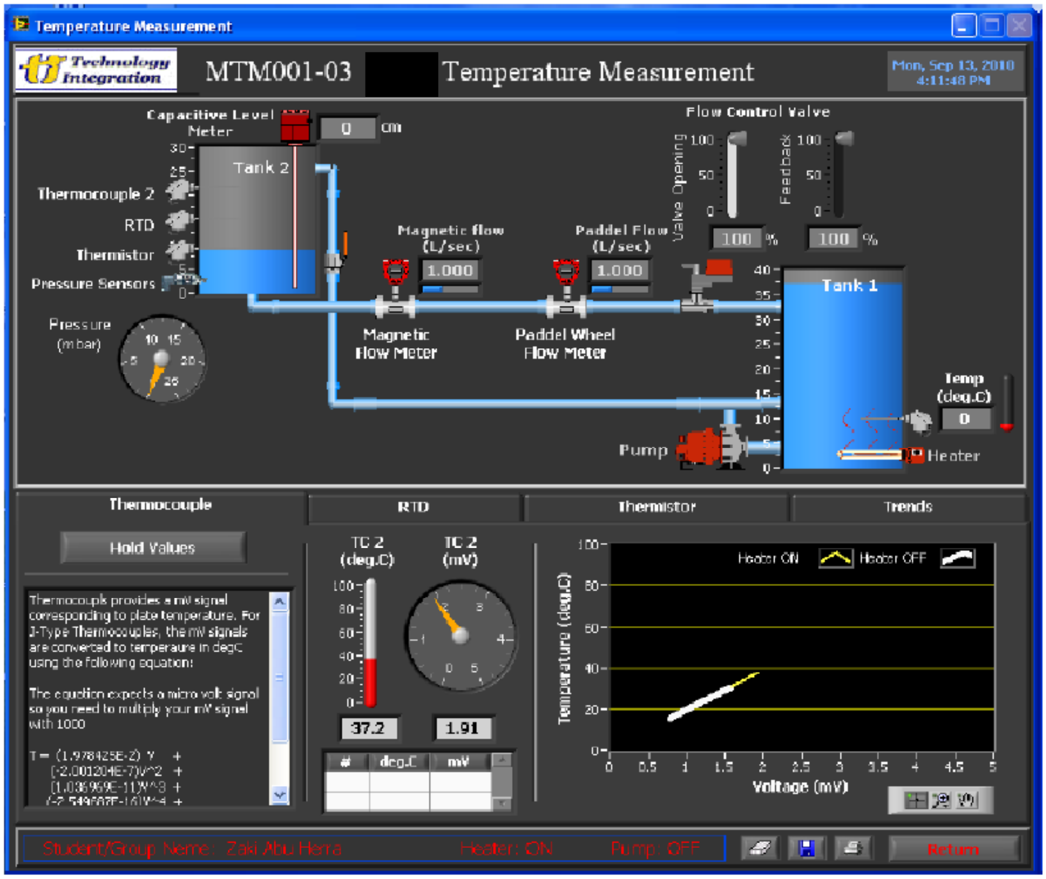

Figure 1: Temperature Measurement Window

9. Turn the **Pump** on by pressing the **Pump** picture on the front panel.
10. Keep taking readings by pressing **[Hold Values]** button.
11. Press **[Clear Chart]** button if you want to clear the chart(s).
12. Press **[Return]** button to return to the **"Process Variables Experiments"** screen.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the Temperature and the Voltage with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Temperature vs Voltage) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB
4. Plot the **Hold Value Table** readings for both increasing and decreasing values of pressure on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 7

Study of the characteristics of Thermocouples

Objective:

1. To know what is a **Thermocouple**.
2. To know how to convert the Thermocouple Signal into Temperature and find the calibration equation

Apparatus: MT001-003 Multi-Process Variable Measurement Trainer

Theory:

Thermocouple (TC) is created whenever two dissimilar metals touch and the contact point produces a small open-circuit voltage as a function of temperature. This thermoelectric voltage is known as the **Seebeck voltage**, named after Thomas Seebeck, who discovered it in 1821. The TC has been the popular choice over the years for a variety of reasons. Thermocouples are relatively inexpensive and can be produced in a variety of sizes and shapes. They can be of rugged construction and can cover a wide temperature range. However, TCs produce a very small microvolt output per degree change in temperature that is very sensitive to environmental influences. Electromagnetic interference (EMI) from motors and electrical distribution and especially radio frequency interference (RFI) from walkie-talkies can produce dramatic errors in measuring circuits in these instruments. As mentioned above any two dissimilar metals may produce a TC, however, there are some standard thermocouples which have calibration tables and assigned letter-designations which are recognized worldwide, Such as, J-type (Iron / Constantan), K-type (Chromel / Alumel), E-type (Chromel / Constantan), N-type (Nicrosil / Nisil), B-type (Platinum / Rhodium), R-type (Platinum

/ Rhodium) and S-type (Platinum / Rhodium). In order to select the suitable TC for an application, sensitivity and temperature range should be taken into consideration, because each one of these thermocouples has a different temperature range and sensitivity. Further details and operation of TCs can be found in the text book.

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 1.
2. Study the front panel carefully and observe the buttons on the screen.
3. Notice the 4 different tabs on the front panel; **Thermocouple**, **RTD, Thermistor** and **Trends.** Press **Thermistor.**
4. Make sure that **Tank2** is almost empty.
5. Turn the **Heater** ON by pressing the **Heater** picture in the front panel.
6. Keep taking readings by pressing the tab **Hold Value** while heater is ON.
7. Wait until the Temperature go up between **(7-10)** degrees from the initial temperature.
8. Turn the **Heater** OFF by pressing on the **Heater** picture in the front panel (**Cooling Mode**).

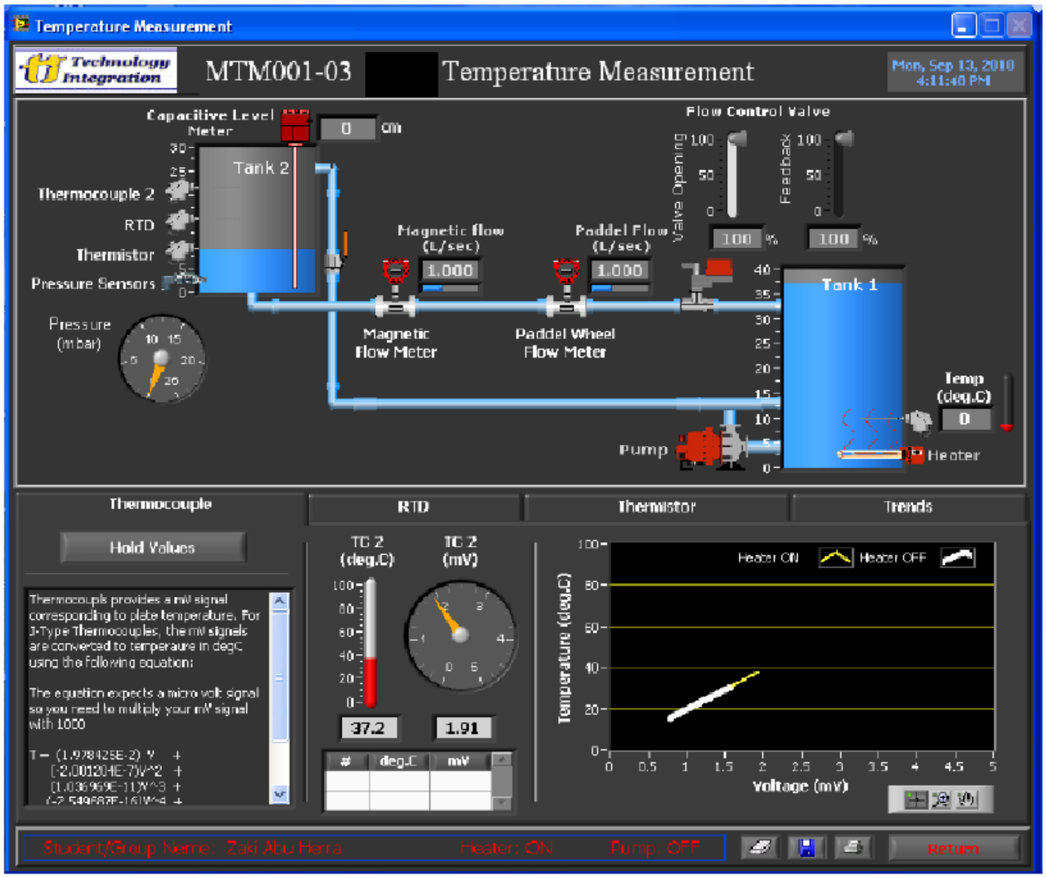

Figure 1: Temperature Measurement Window

9. Turn the **Pump** on by pressing the **Pump** picture on the front panel.
10. Keep taking readings by pressing **[Hold Values]** button.
11. Press **[Clear Chart]** button if you want to clear the chart(s).
12. Press **[Return]** button to return to the **“Process Variables Experiments”** screen.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the Temperature and the Voltage with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Temperature vs Voltage) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB
4. Plot the **Hold Value Table** readings for both increasing and decreasing values of pressure on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 8

Study of the characteristics of Electromagnetic Flowmeter

Objective:

1. To know what is an **Electromagnetic Flowmeter**.
2. To know how to convert the Electromagnetic Flowmeter. Signal into Flow rate and find the calibration equation

Apparatus: MT001-003 Multi-Process Variable Measurement Trainer

Theory:

An **Electromagnetic Flow Meter** is a volumetric flow meter which does not have any moving parts and is ideal for wastewater applications or any dirty liquid which is conductive or water based. Magnetic flow meters don't work in non-aqueous solutions, neither with hydrocarbons, nor distilled water. Magnetic flow meters are also ideal for applications where low pressure drop and low maintenance are required.

Principle of Operation

The operation of a magnetic flow meter is based upon **Faraday's Law**, which states that: **"The voltage induced across any conductor as it moves at right angles through a magnetic field is proportional to the velocity of that conductor."**

Faraday's Formula:

E is proportional to **V** X **B** X **C**

where;

E = *voltage generated in a conductor*

V = *velocity of the conductor*

B = *magnetic field strength*

D = *length of the conductor*

To apply this principle to flow measurement with a magnetic flow meter, it is necessary to state that the fluid being measured must be electrically conductive for the Faraday principle to be applies successfully.

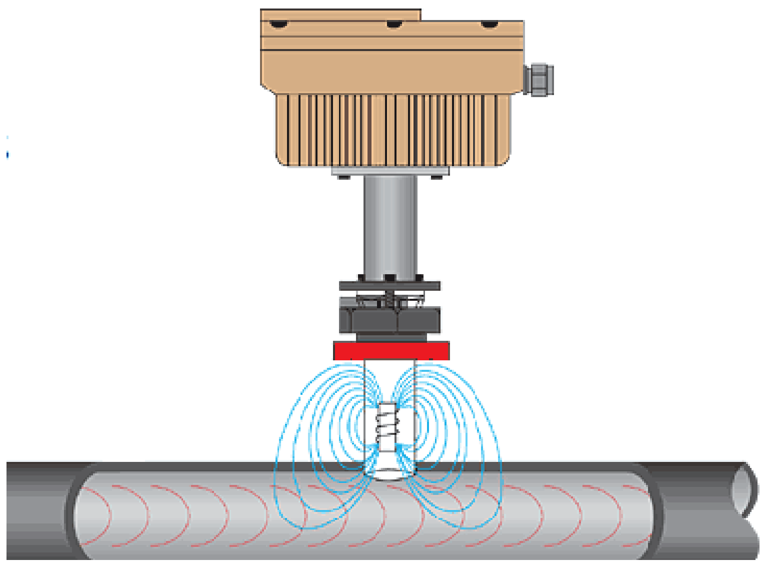

Figure 1: Electromagnetic Flowmeter Operation Priciple

As applied to the design of magnetic flow meters, Faraday's Law indicates that signal voltage **(E)** is dependent on the average liquid velocity **(V)** the magnetic field strength **(B)** and the length of the conductor **(D)** (which in this instance is the distance between the electrodes). Here the magnetic field is considered as the measuring element of the magnetic flow meter, it can be seen that the measuring element is exposed to the hydraulic conditions throughout the entire cross-section of the flow meter. (Figure 1) Where to use Magnetic Flow meters? Where there is High percentage of solids, obstructionless measurement, very corrosive liquids, and conductive liquids.

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 2.

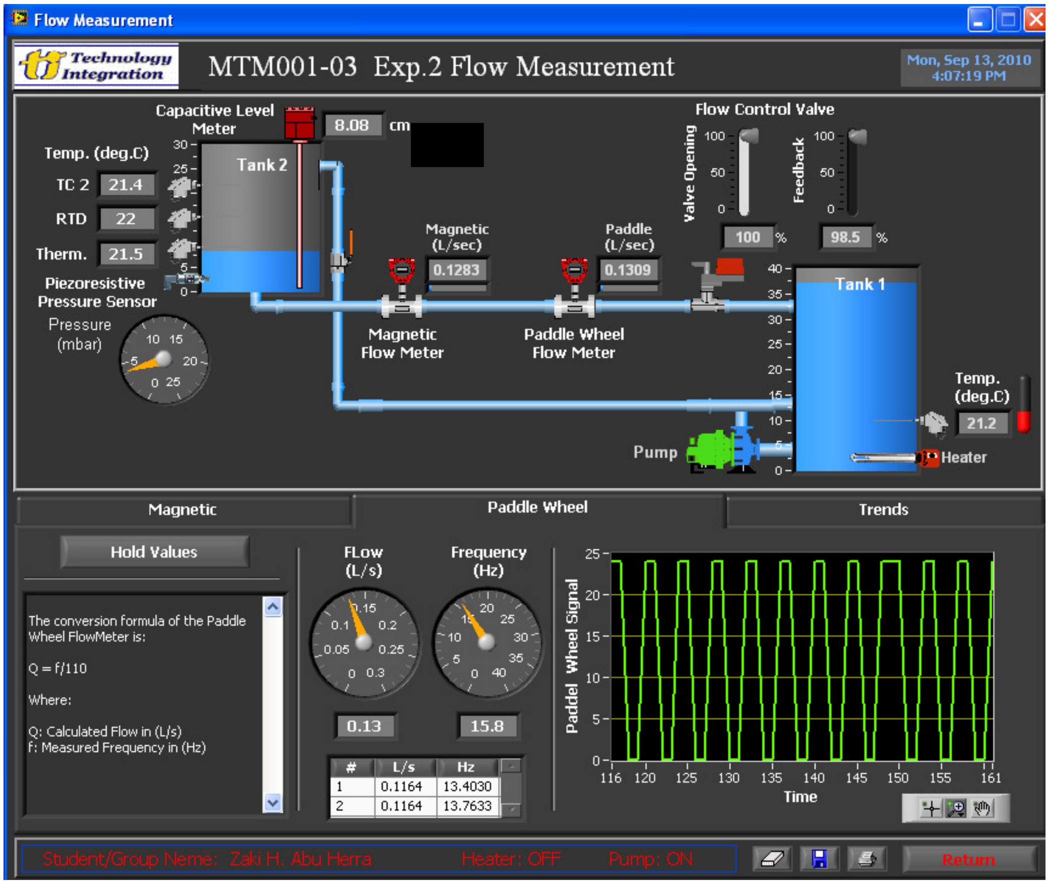

Figure 2: Flow-rate Measurement Window

2. Study the front panel carefully.
3. observe the buttons on the screen.
4. Make sure that **Tank2** is almost empty.
5. Observe the readings of the **Flow Meters** on the front panel.
6. Press the **[Magnetic]** tab.
7. Close the **Flow Control Valve** by dragging the **Valve Opening Slide** to **0%**.
8. Observe how the **Feedback Slide** responds to the change in the **Valve Opening Slide**.
9. Wait until the **Flow Control Valve** reaches the **“Fully Closed”** state (when the **Feedback** slide almost reaches **0**).

10. Turn the **Pump** ON by pressing the Pump picture in the front panel.
11. Wait until the water level in **Tank2** reaches 20 **cm**.
12. Turn the **Pump** OFF by pressing the Pump picture in the front panel.
13. Open the **Flow Control Valve** by dragging the **Valve Opening Slide** to **100%**.
14. Observe the readings of the **Feedback Slide** and the readings of the**Flow Meters**.
15. Press the **[Hold Values]** button when the **Feedback Slide** reaches **25%**, **50%** &**75%** of its value, and write the values below:

Held Value 25%

Level = ……………………………….**cm**

Flow = …………………………………**L/s**

Current = ……………………………**mA**

Held Value 50%

Level = ……………………………….**cm**

Flow = …………………………………**L/s**

Current = ……………………………**mA**

Held Value 75%

Level = ……………………………….**cm**

Flow = …………………………………**L/s**

Current = ……………………………**mA**

16. From the previous step take the **Current** reading in **mA** for the value of **25%** and apply it in the following equation:

$$Q = 0.0507 \times I - 0.0203$$

Where:

Q :*Calculated Flow (***L/s***)*

I :*Current (***mA***)*

17. Compare the calculated flow in step 15 with the measured flow in step 16.
18. Repeat the same steps (16-17) for the values of **50%** and **75%**.
19. Press **[Clear Chart]** button if you want to clear the chart(s).
20. Stop the process and press **[Return]** to go back to the **"Process Variables Experiments"** screen.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the Flowrate and the Current with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Flow rate vs Current) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB
4. Plot the **Hold Value Table** readings for both increasing and decreasing values of pressure on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 9

Study of the characteristics of Paddle Wheel Flowmeter

Objective:

1. To know what is an **Paddle Wheel Flowmeter**.
2. To know how to convert the Electromagnetic Flowmeter. Signal into Flow rate and find the calibration equation

Apparatus: MT001-003 Multi-Process Variable Measurement Trainer

Theory: **Paddle Wheel Flow Meters** as the name state they have a paddle wheel that is perpendicular to the flow path. The rotor axis is positioned to limit contact between the paddles and the flowing media. There are many different types of paddle wheel flow meters. Examples include gas flow meters, air flow meters liquid flow meters, and water flow meters. A Water flow meter is designed to measure the flow rate of water. Paddle wheel flow meters carry physical, media and operating specifications, and differ in terms of output options and features. Pipe diameter, mounting style and end fittings are important physical specifications to consider when selecting paddle wheel flow meters. Pipe diameter is the diameter of the pipe to be monitored.

The Paddle wheel Flow meter (sensor) is made up of a transducer and a measuring finger with a paddle wheel which paddles contain magnets. The sensor detects the rotation of the paddle wheel & generates a signal which frequency **(F)** is proportional to the flow rate **(Q)**. The proportionality factor is called **(K)** factor; its value is specific to each fitting. Sensing very low flow rates, fast response with good repeatability,

direct and accurate volumetric flow measurement are some of many advantages for using the Paddle Wheel flow meter.

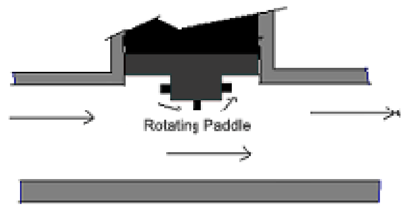

Figure 2 - Paddle Wheel Flow Meter

Experiment Procedure:

1. Open the "MT001-003 Level Measurement" window as shown in figure 2.

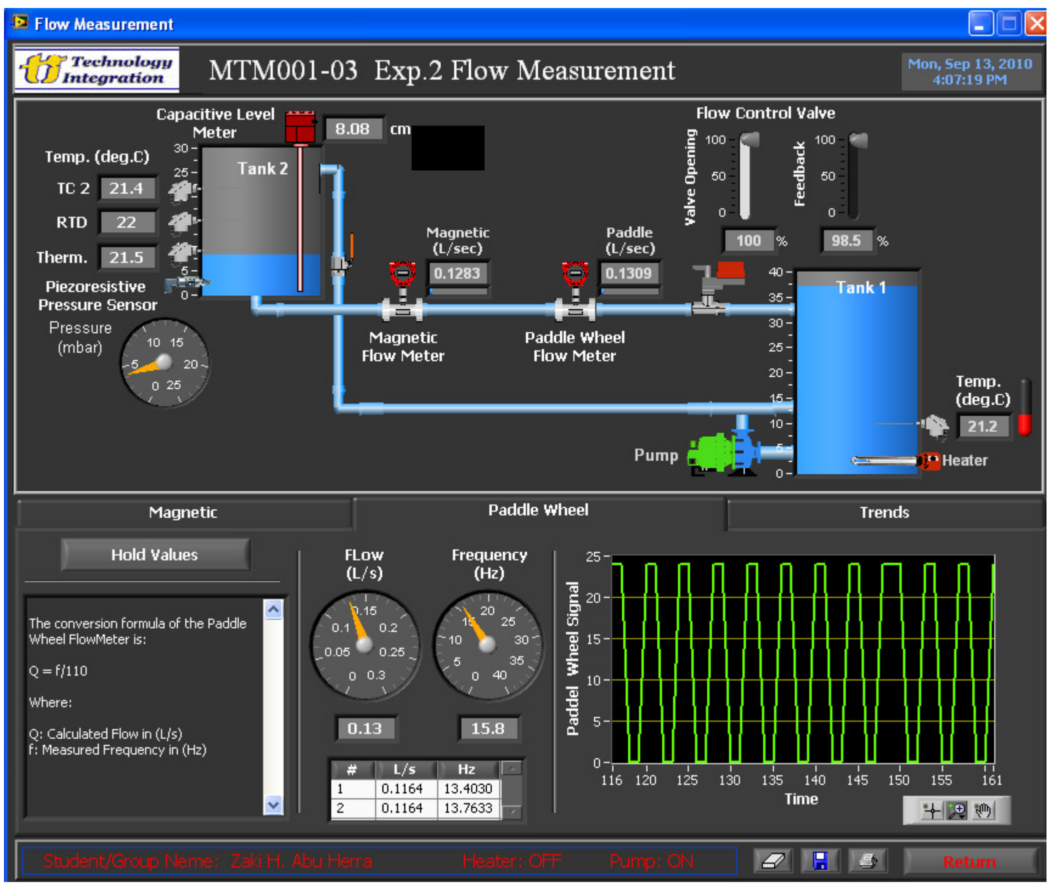

Figure 2: Flow-rate Measurement Window

2. Study the front panel carefully.
3. Observe the buttons on the screen.
4. Make sure that **Tank2** is almost empty.
5. Observe the readings of the **Flow Meters** on the front panel.
6. Press the **[Paddle Wheel]** tab.
7. Close the **Flow Control Valve** by dragging the **Valve Opening Slide** to **0%**.
8. Observe how the **Feedback Slide** responds to the change in the **Valve Opening Slide**.
9. Wait until the **Flow Control Valve** reaches the **"Fully Closed"** state (when the **Feedback** slide almost reaches **0**).
10. Turn the **Pump** ON by pressing the Pump picture in the front panel.
11. Wait until the water level in **Tank2** reaches 20 **cm**.
12. Turn the **Pump** OFF by pressing the Pump picture in the front panel.
13. Open the **Flow Control Valve** by dragging the **Valve Opening Slide** to **100%**.
14. Observe the readings of the **Feedback Slide** and the readings of the **Flow Meters**.
15. Press the **[Hold Values]** button when the **Feedback Slide** reaches **25%**, **50% &75%** of its value, and write the values below:

Held Value 25%

Level = …………………………………..**cm**

Flow = …………………………………**L/s**

Frequency = ……………………………**Hz**

Held Value 50%

Level = …………………………………..**cm**

Flow = …………………………………**L/s**

Frequency = ……………………………**Hz**

Held Value 75%

Level = ………………………………..**cm**

Flow = …………………………………**L/s**

Frequency = ……………………………**Hz**

From the previous step take the **Current** reading in **mA** for the value of **25%** and apply it in the following equation:

$$Q = \frac{110}{f}$$

Where:

Q: *Calculated flow (***L/s***)*

f: *frequency (***Hz***)*

1. Compare the calculated flow in step 15 with the measured flow in step 16.
2. Repeat the same steps (16-17) for the values of **50%** and **75%**.

Non-Linearity and Hysteresis Analyses using MATLAB

1. Obtain the linear relationship between the Flowrate and the Frequency with the values taken from the **Hold Value Table** using MATLAB
2. Plot the line (Flow rate vs Frequency) obtained in step 1. Also plot the readings obtained from **Hold Value Table** on the same figure for comparison.
3. Evaluate maximum nonlinearity at full scale deflection using MATLAB

4. Plot the **Hold Value Table** readings for both increasing and decreasing values of pressure on the same figure and observe the hysteresis, if any.
5. Evaluate maximum hysteresis at full scale deflection using MATLAB

Lab 10

Photoelectric Characteristics

Introduction:

The number and variety of light-operated or light-controlled devices and equipment produced is tremendous. Photoelectric controls and sensors are only a small part of this vast product spectrum. Photoelectric sensors includes; thru-beam, retroreflective scan, and diffuse scan sensors. Important parameters to consider when looking for photoelectric sensors include sensing mode, detecting range, position measurement window, minimum detectable object, and response time. Sensing modes can be presence or absence and position measurement.

Objectives:

- To know what is a **Photoelectric Sensor**.
- To know how to convert the Photoelectric Signal into Speed.

Theory:

Photoelectric Sensor

Photoelectric presence sensors utilize photoelectric emitters and receivers to detect presence, absence, or distance of target objects.

Reflective and retroreflective scan are two names for the same technique. The emitter and receiver are in one unit. Light from the emitter is transmitted in a straight line to a reflector and returns to the receiver. A normal or a corner-cube reflector can be used. When a target blocks the light path the output of the sensor changes its state. When the target no longer blocks the light path the sensor returns to its normal state. Our photoelectric sensors emits a light directed towards the shaft when it sees the reflective tape (which is placed over the shaft) it gives a signal (the tape acts as the reflector) otherwise it changes its state; each signal means that the shaft has completed one turn.

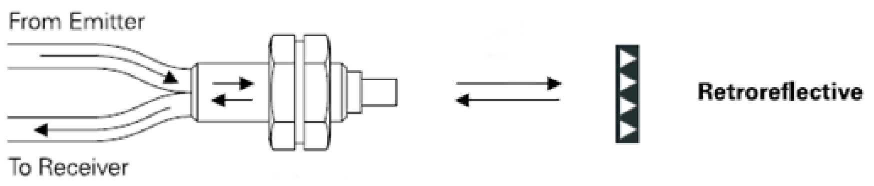

Figure 38 - Photoelectric sensor

Experiment Procedure:

1. Refer to **Running the Experiments** procedure in page 80.

1. From the **"Welcome to MTM001-04"** screen choose **[Speed Measurement Trainer]** button**.**

2. From the **"Speed Measurement Experiments"** screen choose Experiment 1: **[Photoelectric Sensor Characteristics]**.

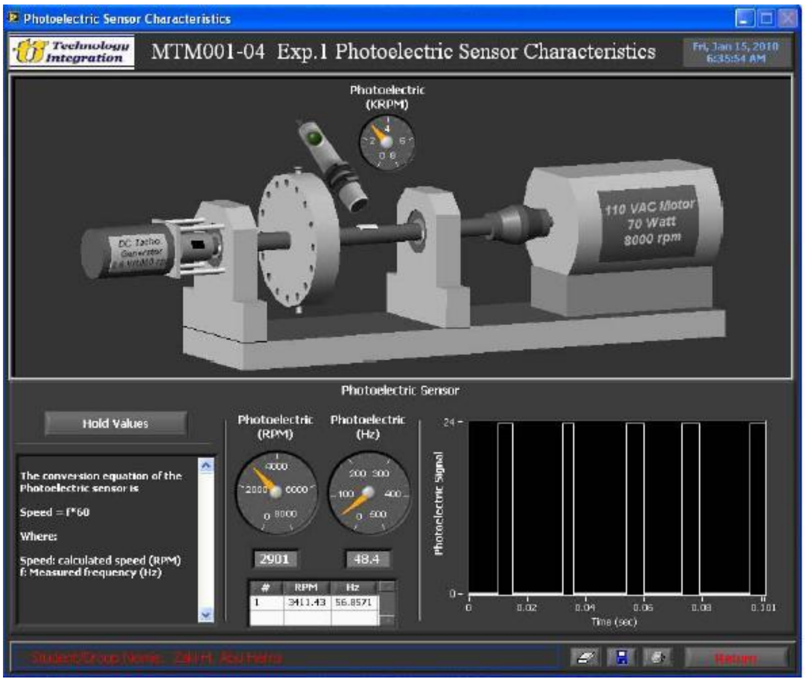

Figure 39 - Photoelectric characteristics Experiment Screen

3. Study the front panel carefully and observe the buttons on the screen.

4. Make sure the **Speed Measurement Trainer** is turned ON by pressing the **[Power]** button on the electrical box.

5. On the digital screen of the **VFD (variable frequency driver)** the word **"Stop"** will appear.

6. To start the motor, press the **[Start]** button on the **VFD**. The **VFD** reading will be **"H 50.0",** and it will start going down until it reaches **"H 0.0"**.

TIP:

The minimum frequency of the VFD is "H 0.0"; this frequency will not start the motor, in order to start the motor you have to increase the frequency.

7. Press the **[UP]** button on the **VFD** to increase the frequency, keep increasing until the motor starts slowly.

8. Observe how the status **LED** on the "**Photoelectric"** sensor turns ON when the reflective tape faces the sensor, and turns OFF when it goes away from the sensor.

9. Can you predict the shape of the signal produced from the **Photoelectric** sensor? Draw it down.

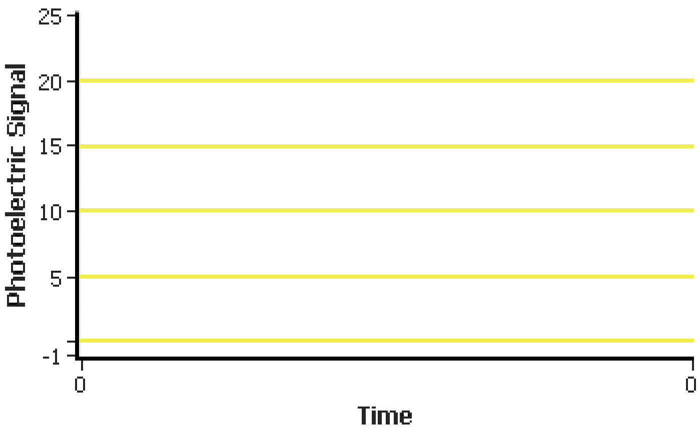

Figure 40 - Photoelectric vs. Time Graph

10. Do you expect the signal produced from the sensor to be periodic? Why?

11. If the signal is periodic, what does each cycle of the signal represent?

12. Observer the front panel of the **"Photoelectric Sensor Characteristics"** experiment carefully.

13. On the chart appears on the front panel of the experiment, you will see the actual signal produced from the **Photoelectric** sensor.

14. Compare the signal on the chart with the signal you have drawn in step 9.

15. Press the **[Hold Values]** button to save the current speed (**RPM**) and frequency (**Hz**). Write the values down:

    Speed=………………….. (**RPM**)
    Frequency=……………… (**Hz**)

16. From step 15 take the Frequency and find the period of the signal using the following equation:

$$T = \frac{1}{f}$$

Where:

T=*Period (s)*
f= *Frequency (Hz)*

17. Is the period (**T**) that you have calculated in the previous step reflected in the **Photoelectric-Time** graph?

18. Apply the frequency that you have taken from step 15 in the following equation to find the rotating speed of the shaft:

$$rotating\ speed = f * 60$$

Where:

Rotating speed = *the rotating speed of the shaft (**RPM**)*
f = *Frequency (**Hz**)*

19. Compare the calculated speed from the previous step with the speed you have taken in step 15.

20. Increase the speed of the motor by pressing the **[UP]** button on the **VFD** until it reaches 40 Hz. Observe the behavior of the **LED** on the sensor, and the signal and the shaft speed behavior in the front panel.

21. Press the **[Hold Values]** button and write the values down:

    Speed=………………. (**RPM**)
    Frequency=…………... (**Hz**)

- To study the **"sensing distance"** of the sensor, do the following steps:

22. Turn the motor OFF by pressing the **“Stop”** button on the **VFD**; observe how the frequency goes down till it reaches the minimum frequency and the motor goes OFF.

23. Wait till the motor stops completely, and then open the cover of the setup.

24. Adjust the **Shaft Position** so that the reflective tape faces the photoelectric sensor and the status **LED** on the on the sensor turns ON.

25. Increase the distance between the sensor and the tape by dragging the sensor backwards (rotate the sensor CCW), without changing the position of the shaft.

26. Is the status **LED** on the **Photoelectric sensor** still on? Why?

27. Close the cover of the setup.

28. Press the **[Start]** button on the **VFD**, and increase the frequency till it shows 40 Hz.

29. Wait 2-3 seconds then press **[Hold Values]** button and write the values down:

    Speed=………………. (**RPM**)
    Frequency=………….. (**Hz**)

30. Compare the held values in step 29 with the held values in step 21. Is there any difference between the values?

31. Does changing the distance affect the response of the sensor?

32. Turn the motor OFF by pressing the **[Stop]** button on the **VFD**.

33. If the width of the reflective tape changed (increased or decreased) how will it affect the signal? Draw the signal below.

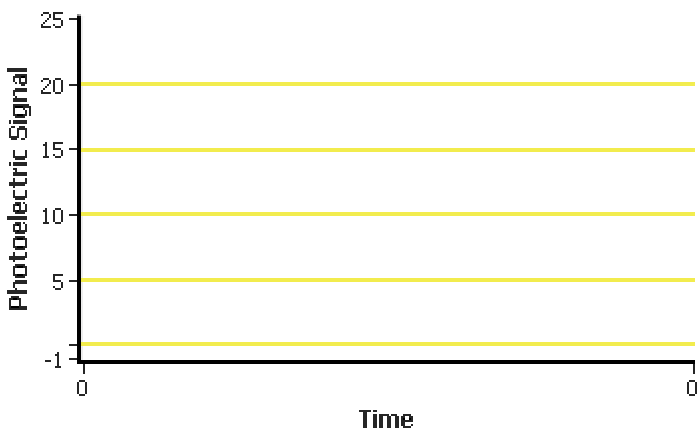

Figure 41 - Photoelectric Vs. Time Graph

34. Turn the trainer OFF by pressing the **[Power]** button on the electrical box.

35. Press **[Save]** button if you want to save the experiment.

36. Press **[Clear Chart]** button if you want to clear the chart(s).

37. Press **[Return]** button to return to the "**Speed Measurement Experiments"** screen.

Lab 11

Electromagnetic Proximity Characteristics

Introduction:

An **Electromagnetic proximity sensor** is a sensor able to detect the presence of nearby objects without any physical contact, it is widely used in the modern high speed process control environment for the detection, positioning and counting of ferrous and non-ferrous metal objects.
Important specifications for Electromagnetic proximity sensors include operating distance, repeatability, field adjustable and minimum target distance. Advantages include insensitivity to water, oil, dirt, non metallic particles, target color, or target surface finish, and the ability to withstand high shock and vibration environments.

Objectives:

- To know what is an **Electromagnetic Proximity Sensor**.
- To know how to convert the Electromagnetic Proximity Signal into Speed.

Theory:

Electromagnetic (Inductive) Proximity Sensor

Electromagnetic (Inductive) proximity sensors respond to ferrous and non-ferrous metal objects. They will also detect metal through a layer of non-metal. An Electromagnetic (inductive) sensor consists of an oscillator circuit (the sensing part) and an output circuit including a switching device (transistor or thyristor), all housed in a resin encapsulated body. An essential part of the oscillator circuit is the inductance coil creating a magnetic field in front of the sensing face. When the magnetic field is disturbed, the output circuit responds

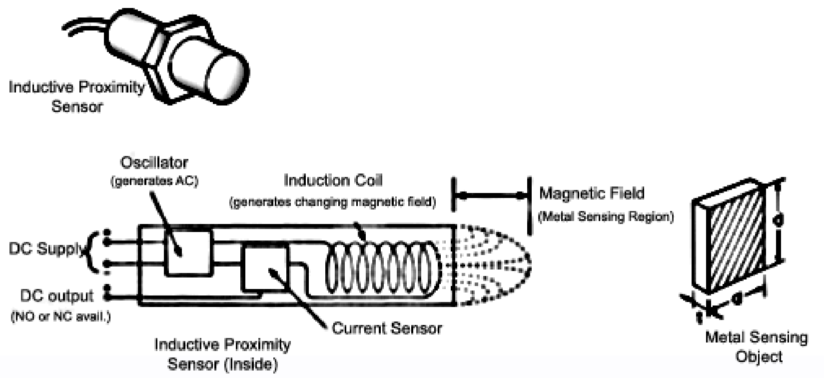

Figure 42 - Proximity Sensor

by either closing the output switch (normally open version type NO) or by opening the output switch (normally closed version type NC).

Electromagnetic (Inductive) proximity sensors generate an electromagnetic field and detect the eddy current losses induced when the metal target enters the field. The field is generated by the coil, which is used by a transistorized circuit to produce oscillations. The target, while entering the electromagnetic field produced by the coil, will decrease the oscillations due to eddy currents developed in the target. If the target approaches the sensor within the so-called "sensing range", the oscillations cannot be produced anymore: the detector circuit generates then an output signal controlling a relay or a switch.

Experiment Procedure:

1. Refer to **Running the Experiments** procedure in page 80.

2. From the **"Welcome to MTM001-04"** screen choose **[Speed Measurement Trainer]** button**.**

3. From the **"Speed Measurement Experiments"** screen choose Experiment 2: **[Electromagnetic Proximity Characteristics]**.

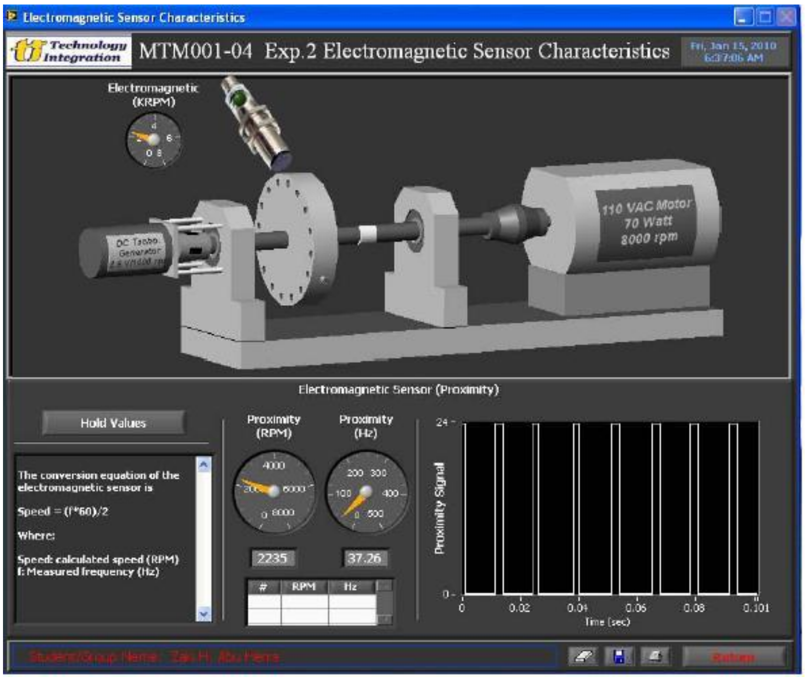

Figure 43 - Electromagnetic Proximity Sensor Experiment Screen

4. Study the front panel carefully and observe the buttons on the screen.

5. Make sure the **Speed Measurement Trainer** is turned ON by pressing the **[Power]** button on the **electrical box**.

6. On the digital screen of the **VFD (variable frequency driver)** the word **"Stop"** will appear.

7. To start the motor, press the **[Start]** button on the **VFD**. The **VFD** reading will be **"H 50.0",** and it will start going down until it reaches **"H 0.0".**

TIP:

The minimum frequency of the VFD is "H 0.0"; this frequency will not start the motor, in order to start the motor you have to increase the frequency.

8. Press the **[UP]** button on the **VFD** to increase the frequency, keep increasing until the motor starts slowly.

9. Observe how the status **LED** on the **"Electromagnetic"** sensor turns ON when one of the two screws on the circumference of the rotating disk faces the sensor, and turns OFF when it goes away from the sensor.

10. Can you predict the shape of the signal produced from the **"Electromagnetic"** sensor? Draw it down.

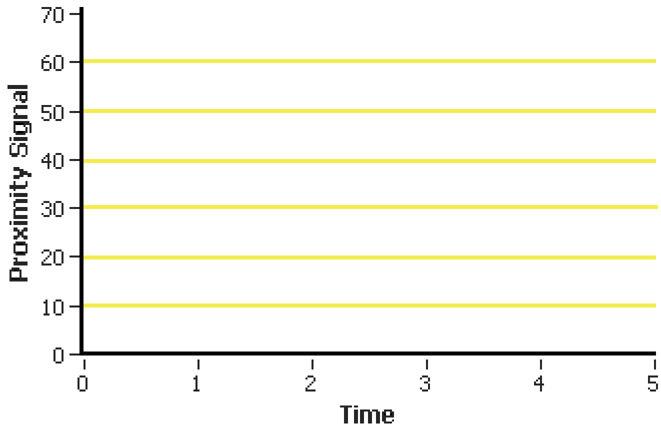

Figure 44 - Proximity vs. Time Graph

11. Do you expect the signal produced from the **Electromagnetic sensor** to be periodic? Why?

12. If the signal is periodic, what does each cycle in the signal represent?

13. Observe the front panel of the **"Electromagnetic Sensor Characteristics"** experiment carefully.

14. From the chart in the front panel, you can see the actual signal produced from the **Electromagnetic sensor**.

15. Compare the Signal in the chart with the signal you have drawn in step 10.

16. Press the **[Hold Values]** button to save the current speed (**RPM**) and frequency (**Hz**). Write the values down:

    Speed=………………….. (**RPM**)
    Frequency=……………… (**Hz**)

17. From step 16 take the Frequency and find the period of the signal using the following equation:

$$T = \frac{1}{f}$$

Where:

T=*Period (s)*
f= *Frequency (Hz)*

18. Is the period (**T**) that you have calculated in the previous step reflected in the **Electromagnetic-Time** graph?

19. Compare the calculated frequency with the frequency you have taken in step 16.

20. Apply the frequency you have calculated in the following equation to find the rotating speed of the shaft.

$$\textbf{rotating speed} = \textbf{f} * \textbf{60}$$

Where:

Rotating speed = *the rotating speed of the shaft (**RPM**)*
f = *Frequency (**Hz**)*

21. Compare the calculated speed from the previous step with the speed you have taken in step 16.

22. Increase the speed of the motor by pressing the **[UP]** button on the **VFD** until it reaches 40 Hz. Observe the behavior of the **LED** on the sensor, and the signal and the shaft speed behavior in the front panel.

23. Press the **[Hold Values]** button and write the values down:

    Speed=………………. (**RPM**)
    Frequency=…………... (**Hz**)

24. Turn the motor OFF by pressing the **"Stop"** button on the **VFD**; observe how the frequency goes down till it reaches the minimum frequency and the motor goes OFF.

25. Wait till the motor stops completely, and then open the cover of the setup.

26. Remove one of the Screws from the disk.

27. Close the cover of the setup

28. Can you predict how this will affect the signal of the sensor? Explain why? Draw the expected signal.

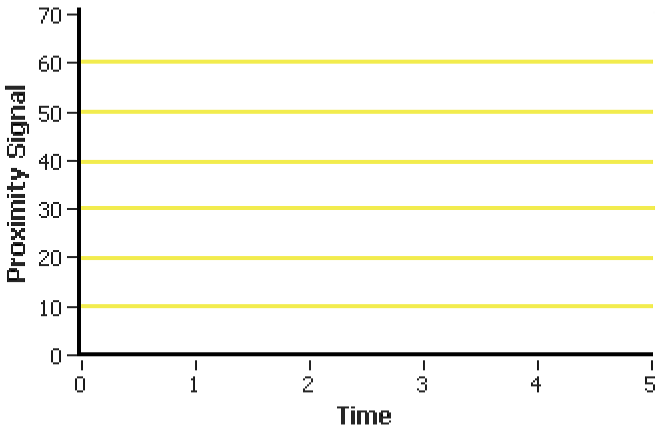

Figure 45 - Proximity vs. Time Graph

Important Note:

Removing one of the screws will cause the system to be unbalanced and it will vibrate when the motor starts rotating, so try not to keep it running for a long time.

29. Press the **[Start]** button on the **VFD**, and increase the frequency till it reaches 40 Hz.

30. Wait 2-3 seconds then press **[Hold Values]** button and write the values down:

    Speed=……………….. (**RPM**)
    Frequency=………….. (**Hz**)

31. Find the period interval in seconds, and apply it in the following equation to find the frequency of the signal:

$$f = \frac{1}{T}$$

Where:

f = *signal frequency* (***Hz***)
T = *signal period* (***second***)

32. Turn the motor OFF by pressing the **[Stop]** button on the **VFD**.

33. Compare the calculated frequency with the frequency you have taken in step 29.

34. Apply the frequency you have calculated in the following equation to find the rotating speed of t he shaft.

$$\textbf{\textit{rotating speed}} = f * 60$$

Where:

Rotating speed = *the rotating speed of the shaft* (***RPM***)
f = *Frequency* (***Hz***)

35. Compare the calculated speed from the previous step with the speed you have taken in step 29.

36. Make sure that the **motor** has stopped completely, open the cover of the setup and return the screw you have removed earlier (step 25) to its original position.

- To study the **"sensing distance"** of the sensor, do the following steps:

37. Adjust the shaft position so that one of the screws faces the **Electromagnetic sensor**, and the status **LED** on the sensor turns ON.

38. Increase the distance between the sensor and the tape by dragging the sensor backwards (rotate the sensor CCW), without changing the position of the shaft.

39. Is the status **LED** on the **"Electromagnetic"** sensor still ON? Why?

40. Close the cover of the setup.

41. Press the **[Start]** button on the **VFD**, till it reaches 40 Hz.

42. Wait 2-3 seconds then press **[Hold Values]** button and write the values down:

    Speed=………………. (**RPM**)
    Frequency=………….. (**Hz**)

43. Compare the held values in the previous step with the held values in step 29. Is there any difference between the values?

44. Does changing the distance affect the response of the sensor?

45. Turn the motor OFF by pressing the **[Stop]** button on the **VFD**.

46. Turn the trainer OFF by pressing the **[Power]** button on the **electrical box**.

47. Press **[Save]** button if you want to save the experiment.

47. Press **[Clear Chart]** button if you want to clear the chart(s).

48. Press **[Return]** button to return to the "**Speed Measurement Experiments"** screen.

Lab 12

D.C. Tachometer Generator Characteristics

Introduction:

A **Tachometer** (also called a revolution-counter, rev-counter, or RPM gauge) is an instrument that measures the rotation speed of a shaft or disk, as in motor or other machine.
Tachometers are widely used in industrial applications to measure the angular speed of rotating machinery. In most industrial settings, a tachometer is very good and feasible to be used, this type of sensor is inexpensive, rugged, and can be easily mounted and used as a part of a tachometer system; they are commonly installed in sports cars, large trucks, airplanes and ships to measure engine speed.

Objectives:

- To know what is a **D.C. Tachometer Generator**.
- To know how to convert the D.C. Tachometer Signal into Speed.

Theory:

D.C. Tachometer Generator

Tachometer generators are small DC generators that output a voltage in proportion to the rotational speed of a shaft. They are capable of measuring speed and direction of rotation, but not position.

D.C. Tachometer generators calculate the angular speed (which is the time rate of change of angular position of the object) of a rotating speed directed in the direction of the axis about which the object is turning in rpm (revolutions per minute) like the engine shaft in a car, thus providing useful information as how fast and hard the engine is working.
Measurements can be relative or absolute; in the Relative case the measurements are taken with respect to the base of the item being measured. The idea of this is to generate a pulse or a sine wave whose frequency is proportional to the angular velocity.

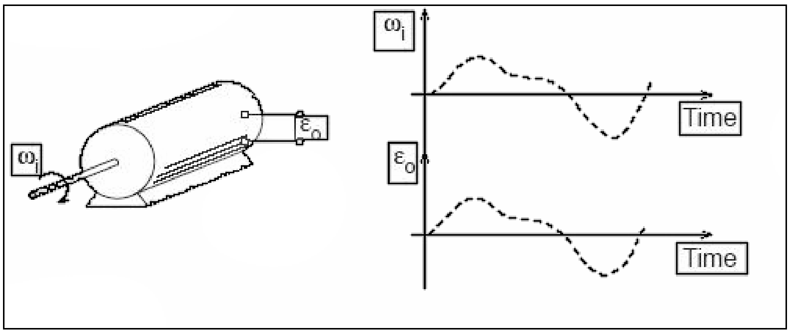

Figure 46 - D.C. Tachometer Generator

Experiment Procedure:

1. Refer to **Running the Experiments** procedure in page 80.

2. From the **"Welcome to MTM001-04"** screen choose **[Speed Measurement Trainer]** button**.**

3. From the **"Speed Measurement Experiments"** screen choose Experiment 3: **[DC Tachometer Generator Characteristics]**.

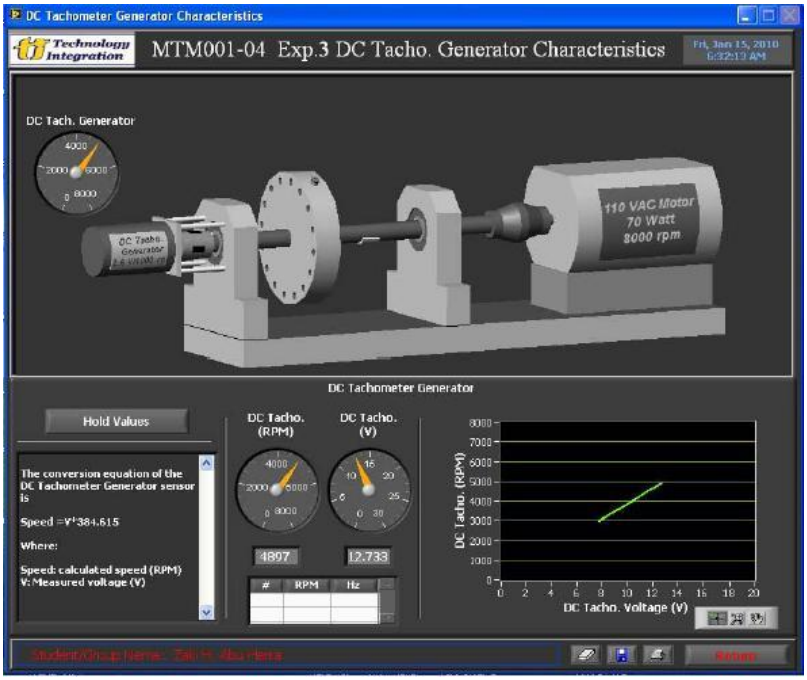

Figure 47 - DC Tachometer Generator Characteristics Experiment Screen

4. Study the front panel carefully and observe the buttons on the screen.

5. Make sure the **Speed Measurement Trainer** is turned ON by pressing the **[Power]** button on the **electrical box**.

6. On the digital screen of the **VFD (variable frequency driver)** the word **"Stop"** will appear.

7. To start the **motor**, press the **[Start]** button on the **VFD**. The **VFD** reading will be **"H 50.0",** and it will start going down until it reaches **"H 0.0".**

TIP:

The minimum frequency of the VFD is "H 0.0"; this frequency will not start the motor, in order to start the motor you have to increase the frequency.

8. Press the **[UP]** button on the **VFD** to increase the frequency, keep increasing until the motor starts slowly.

9. Wait 2-3 seconds then press **[Hold Values]** button and write the values down:

   Speed=………………. (**RPM**)
   Voltage=…………… (**V**)

10. Apply the voltage reading from the previous step in the following equation

$$\boldsymbol{rotating\ speed = 384.62 * V}$$

   Where:

   Rotating speed: *shaft rotating speed (**RPM**)*
   V: *voltage from the DC tachometer (**V**)*

11. Compare speed result in the previous step with the speed in step 9.

12. Increase the Speed of the motor by pressing the **[UP]** button on the **VFD**.

13. Observe the plot on the **Speed-Voltage graph**; does it represent the equation in step 10?

14. Turn the trainer OFF by pressing the **[Power]** button on the electrical box.

15. Press **[Save]** button if you want to save the experiment.

16. Press **[Clear Chart]** button if you want to clear the chart(s).

17. Press **[Return]** button to return to the "**Speed Measurement Experiments"** screen.

Lab 13-17: TecQuipment sensors and Instrumentation hardware

This chapter contains a series of experiments supporting the theory given previously. Ideally they should be performed on the TecQuipment Sensors and Instrumentation System hardware. However, it may be possible to perform the experiments using similar components to those described here. Because the specifications of these components may vary, results are not included. Figure 13.1 shows the TecQuipment Sensors and Instrumentation System hardware.

The experiments assume a knowledge of basic electrical engineering principles. To gain full benefit from these experiments, read and understand at least Chapter 2, Chapter 3, Chapter 9 and Chapter 10.

Each experiment has a number of questions at the end. After completing the experiment, try and answer these, even if you need to take further measurements or revise the topic. You may also benefit from using the results obtained, observations made and the answers given to the questions to write a report on each experiment. In the report, include any theory you feel supports the comments and conclusions you give. If possible, suggest any changes to the experiment that would improve the quality of the results and widen the scope of the experiment.

For all experiments, switch on the equipment for a minimum of 5 minutes prior to any settings being made or any results taken. This will ensure that any drift in the circuits due to thermal effects will be kept to a minimum.

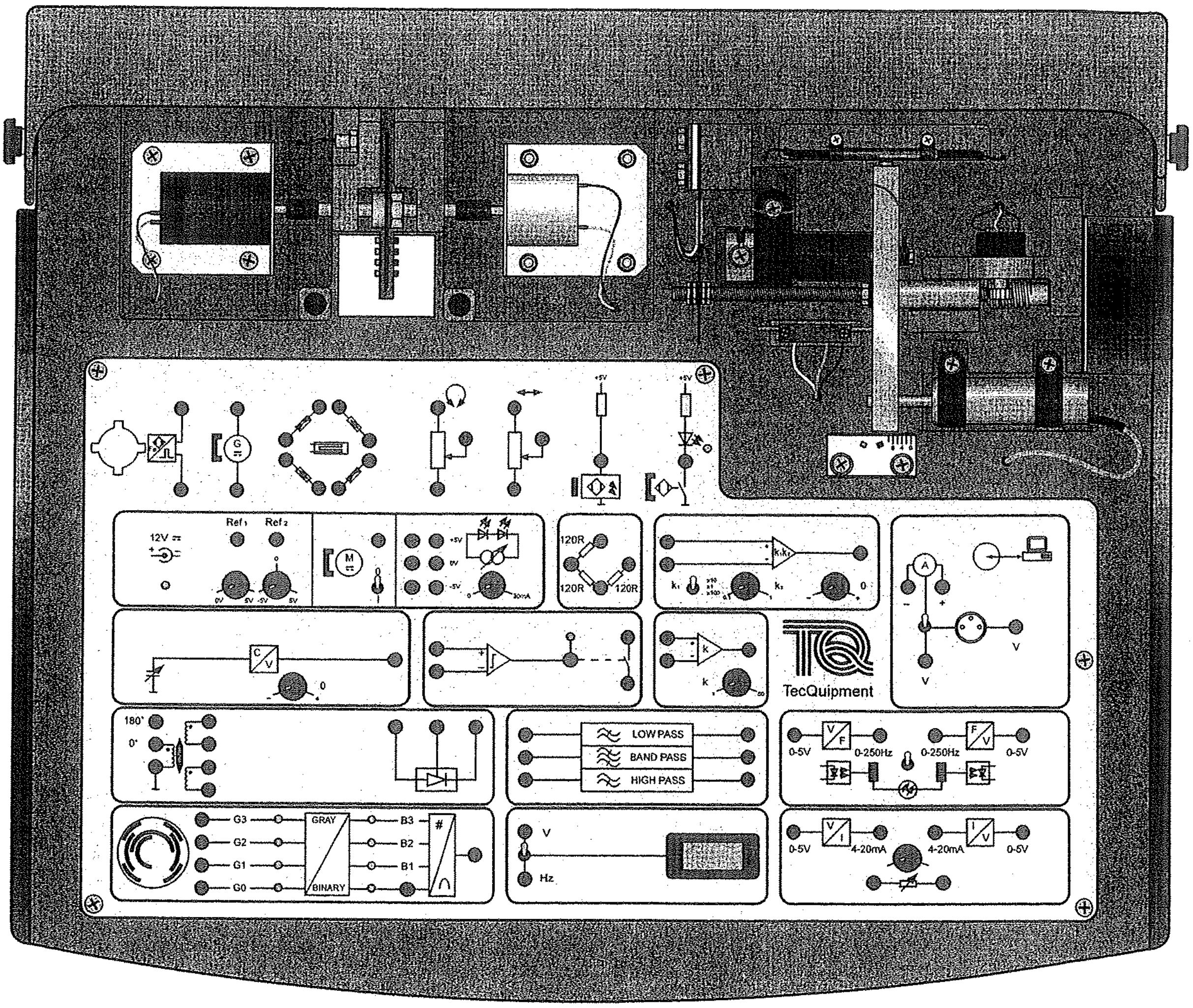

Figure 13.1 TecQuipment sensors and instrumentation hardware

Sensor specifications and familiarisation

This section describes the sensors, signal conditioning equipment and power supplies needed to perform the experiments. They are as on the TecQuipment SIS hardware. If you intend to perform the experiments on other equipment, it should be of a similar specification.

To gain the full benefit of the experiments, it is worthwhile spending some time becoming familiar with each element. Consider how the components are constructed and positioned within a measurement system, and how they respond to changes in the measurand. In later experiments we will be returning to these circuits and devices and investigating them in more detail as well as putting them to practical use.

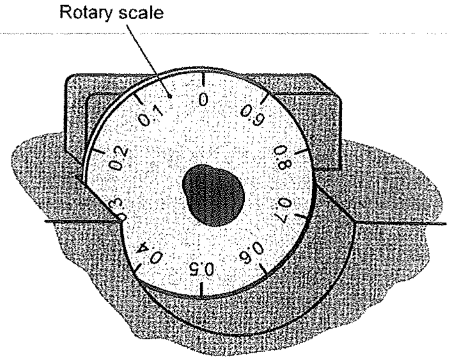

Figure 13.3 Rotary scale

The linear assembly

Figure 13.2 shows the linear assembly. It is used for experiments which study sensing linear motion. It consists of rotary scale which produces a linear motion which can be detected by various sensors connected to it. This linear motion can be left or right, by manually turning a scaled control, shown in Figure 13.3.

The rotary scale of the linear assembly is scaled 0 to 0.9. One complete revolution of the scale moves the linear assembly ±1 mm. Clockwise moves it to the right and anticlockwise to the left. The rotary scale may therefore be used to indicate linear movement with a resolution of ±0.05 mm. The maximum range of movement possible with the linear assembly is 9 mm or ±4.5 mm.

The range of movement of the linear assembly is limited at each end of its travel. Do not apply any undue force to move the assembly beyond these limits. Permanent damage to the equipment may result if excess force is used.

The measurement interval used in all the later experiments on linear motion is 1 mm. This is one complete revolution of the rotary scale. The following sensors are mounted on the linear assembly.

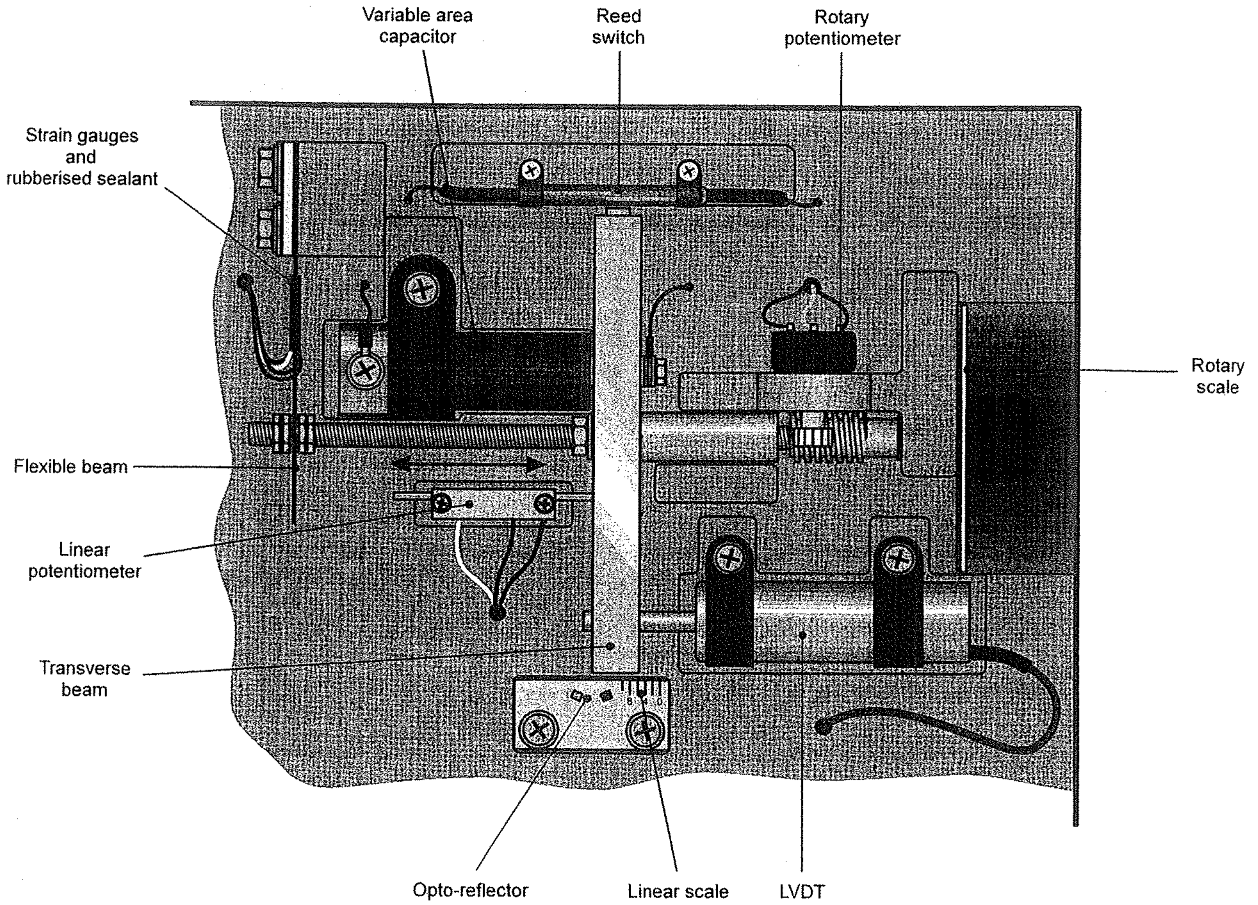

Figure 13.2 Linear assembly

Strain gauges and the flexible beam assembly

This is a sub-assembly of the linear assembly. It comprises a flexible beam which is deflected when the linear assembly is moved. Four foil type bonded resistance strain gauges are attached to the flexible beam. Two are tensioned when the beam is strained in one direction, because they are on the outside of the curvature of the beam. The other two are in compression when the beam is moved in the same direction, because they are on the inside of the curvature of the beam. When the beam is strained in the opposite direction this action reverses.

The strain gauges have a resistance of 120 Ω and a gauge factor: 2.12 (nominal). For protection the they are coated with a transparent rubberised sealant. Figure 13.4 shows the section of the front panel which accesses the strain gauges.

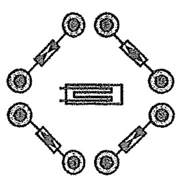

Figure 13.4 Strain gauge section of the front panel

Linear potentiometer

The linear potentiometer has a total resistance of 10 kΩ. Its maximum displacement (stroke) is 10 mm. It has a ±0.4% linearity and a ±10% tolerance.

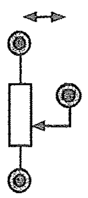

Figure 13.5 Linear potentiometer section of the front panel

Figure 13.5 shows the section of the front panel which accesses the linear potentiometer.

Rotary potentiometer

The rotary potentiometer is rated at 10 kΩ. The resistor material is conductive plastic. It has a linearity of ±2% and a tolerance of ±20%. It rotates 340° (or ±170°) through a worm and wheel gearing arrangement to the linear assembly. The gear ratio produces 0.0833 (one twelfth) of a revolution of the rotary potentiometer shaft for each complete rotation of the calibrated scale. For the full 9 mm movement of the linear assembly the shaft of the rotary potentiometer will rotate through 270°. Figure 13.6 shows the section of the front panel which accesses the rotary potentiometer.

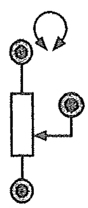

Figure 13.6 Rotary potentiometer section of the front panel

Linear variable differential transformer (LVDT)

The LVDT has six access wires, two for the primary winding and two for each of the secondary windings. It requires a 3 kHz, 5 V supply. Its linearity is ±0.5% and sensitivity ±75 mV/mm.

The plunger of the LVDT is rigidly attached to the linear assembly. The body of the LVDT is fixed to the chassis of the hardware module. When the linear assembly is moved there is relative motion between the body of the LVDT and the link connecting to its soft iron core.

The supply to the primary winding and output signals from the two secondary windings are available at the phase sensitive detector block on the front panel (see later).

Variable area capacitor

A variable area capacitor comprising an outer cylinder attached to the chassis of the hardware module, and a second sliding cylinder attached to the linear assembly. They are mounted and aligned such that the inner cylinder is partially inserted into the outer cylinder. The inner cylinder is covered with a plastic material to act as an insulator and also as a dielectric.

When the linear assembly is moved to the left, the inner cylinder enters the static outer cylinder to increase the area of overlap and decrease it when moved to the right.

The variable area capacitor is accessed via the capacitance to voltage converter.

Reed switch

The reed switch is the normally open type. It consists of rhodium contacts mounted in a hermetically sealed glass tube. The contacts close or open when a magnet, mounted in the end of the adjacent transverse beam, is moved to be in close proximity and then moved away. An LED illuminates when the contacts are closed. The circuit must be complete for current to flow through the LED to cause it to illuminate.

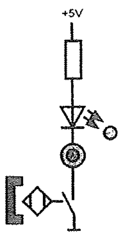

Figure 13.7 Reed switch section of the front panel

Figure 13.7 shows the section of the front panel which accesses the reed switch. It is rated 80 VA, 1.3 A d.c. or a.c. maximum, switching voltage 250 V a.c. rms., pull-in range 40 to 45 AT, breakdown voltage 800 V d.c. The resistor limits the maximum amount of current which can flow through the switch.

Reflective optical beam sensor

This sensor comprises a light emitting diode (LED) and a phototransistor. This is mounted adjacent to the reflective surface of the end of the transverse beam of the linear assembly. Changes in position of the linear assembly affect the amount of light reaching the phototransistor.

An adjacent scale, marked in 1 mm steps, gives an approximate indication of the linear assembly position and relative movement. For accurate measurements always use the rotary scale though be sure not to lose count of the number of turns.

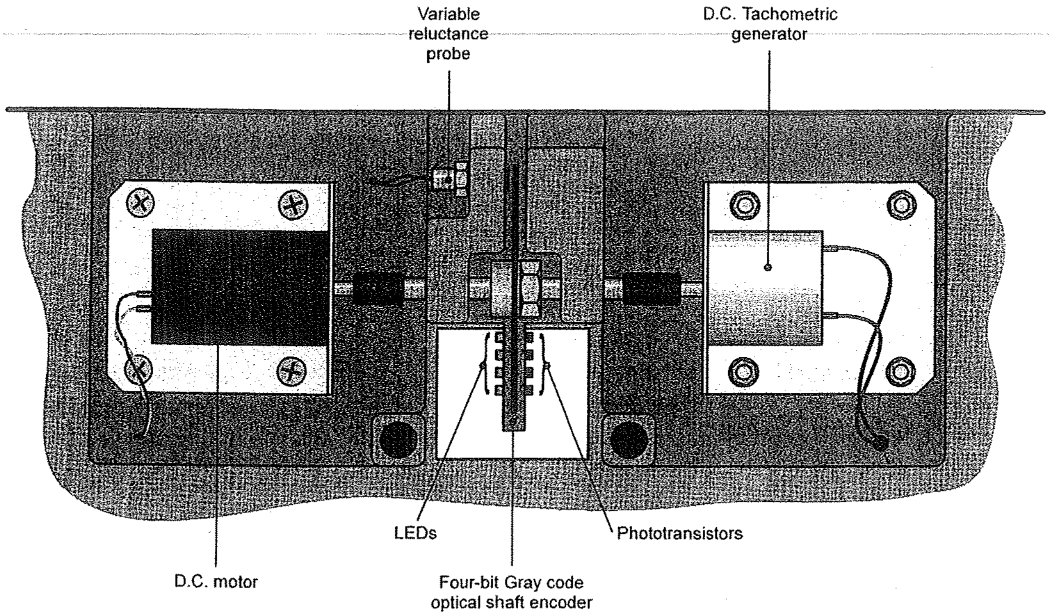

Figure 13.8 The rotary assembly

The opto-reflector shield allows investigations into the effect of background levels of light and how this affects the sensitivity of the system. Figure 13.9 shows the section of the front panel which accesses the rotary potentiometer.

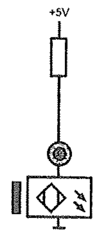

Figure 13.9 reflective optical section of the front panel

The rotary assembly

The rotary assembly comprises a horizontal shaft with a number of sensors attached, as shown in Figure 13.8. These are for measurement of rotational speed and position. The d.c. motor drives the shaft at various selected speeds, from 0 to 209.5 rad.s^{-1} (0 to 2000 revolutions per minute). The output voltage or frequency of the rotational sensors may be measured using the panel mounted digital voltmeter (DVM) to provide the information against which to calibrate the individual speed sensors.

Speed may be set manually or automatically using closed-loop control with one of the speed sensors providing the feedback signal.

With Ref_2 connected to the motor input and the selector switch set to '1' the speed of the motor may be varied in terms of both speed and direction of rotation. Setting the selector to '0' disables the motor supply.

Access to the d.c. motor may be made at the appropriate socket located in the power supply section (see later).

D.C. tachometric generator

A permanent magnet d.c. tachometric generator producing a nominal output of 2.5 ±0.25 V per 104.7 rad.s^{-1} (1000 revolutions per minute). With the motor driven at different speeds the output from the tachometric generator may be displayed on the digital volt meter. The polarity indicates the direction of rotation. Figure 13.10 shows the section of the front panel which accesses the d.c. tachometric generator.

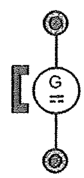

Figure 13.10 The d.c. tachometric generator

Four-bit encoder

The four-bit encoder consists of metal disc with a four-bit Gray scale formed by a series of slots. Four pairs of LEDs and phototransistors are mounted on either side of the disc, as illustrated in Figure 13.11.

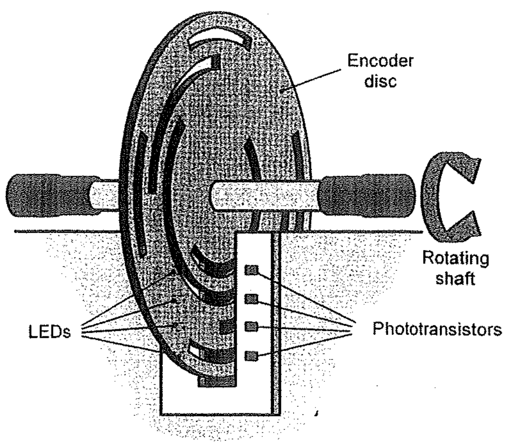

Figure 13.11 Four-bit encoder

The sequence of 'highs' and 'lows' at the outputs of the four phototransistors are indicated by four LEDs on the front panel. This digital information is then processed by the Gray to digital converter into an analogue signal. This provides information on the angular position of the disc, its speed of rotation and direction of rotation.

An indexing mark on the edge of the encoder disc indicates position zero when all bits are low. Access to the four-bit encoder is via the decoder section of the front panel (see later).

Optical tachometer

The optical tachometer uses the least significant bit (LSB), of the encoder to produce a pulsed output. The frequency of this output is directly proportional to the rotational speed of the shaft.

Access to the optical tachometer may be made in the decoder section of the front panel (see later).

Variable reluctance probe

The variable reluctance proximity sensor is an encapsulated sensor comprising a steel outer body supporting a permanent magnet with a coil wound around it. Each complete revolution of the rotary disc produces four pulses at the output terminals.

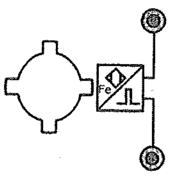

Figure 13.12 The variable reluctance probe

Figure 13.12 shows the section of the front panel which accesses the variable reluctance probe.

The signal conditioning circuits

The signal conditioning circuits on the hardware module are a selection of electronic circuits designed to condition raw signals from the sensors into a suitable form. This is usually a d.c. voltage level for data acquisition or control purposes.

Differential amplifier

This is a dual input differential amplifier with variable gain and set zero controls. Figure 13.13 shows the section of the front panel which accesses the differential amplifier.

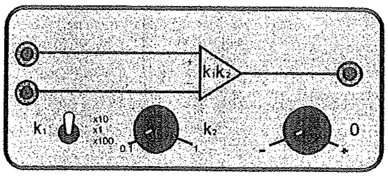

Figure 13.13 The differential amplifier

The range switch allows gain k_1: ×1, ×10, ×100. The gain k_2 is continuously variable between 0.1 and 1.0. The amplifier gain is the product of these two settings, namely $k_1 \times k_2$, giving an overall range of gains of 0.1 to 100.

The output voltage of this amplifier is given by:

$$V_{out} = (V_{+ve} - V_{-ve}) \times k_1 \times k_2 + V_{off}$$

The set zero control offsets the output signal in the range ±5 V. To ensure that no offsets are present, it must be calibrated. To do this, short circuit the two inputs with one of the patching leads supplied. Set the gains, k_1 and k_2, to minimum. Observe the output signal using the DVM set to read volts (V). If there is an offset, adjust the set zero until it is removed. Increase the gains to maximum and zero the output of the differential amplifier as indicated by the DVM.

If the 'set zero' control is moved it will be necessary to repeat the calibration procedure.

Capacitance to voltage converter

This is an a.c. capacitance to voltage converter with a built in 80 kHz oscillator. An external capacitance connected across the input forms one arm of an a.c. bridge. A set zero control is included to reduce any offset in the output signal to zero. Figure 13.14 shows the section of the front panel which accesses the capacitance to voltage converter.

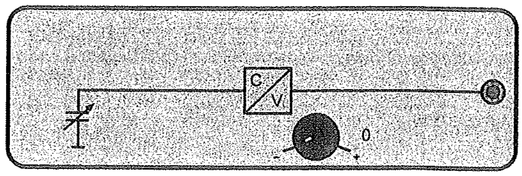

Figure 13.14 The capacitance to voltage converter

The supply to the capacitor cannot be measured. The oscillator is only used with the capacitor and the permanently wired connections are made with screened leads to minimise noise. The output voltage is directly proportional to the capacitance.

Comparator

The comparator provides a comparison between two signals such that the output is either 'high' or 'low'. This depends on which is more positive. An LED at its output indicates when the output is 'high'. Figure 13.15 shows the section of the front panel which accesses the comparator.

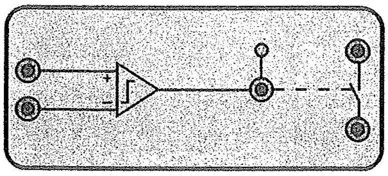

Figure 13.15 The comparator

If the voltage on the positive input is greater than the voltage on the negative input, the output voltage will be high. At all other times the output voltage will be low. The output allows the comparator to control the supply to devices such as the d.c. motor or compatible external device. The supply is either on or off depending upon the relative magnitudes of the input signals.

Phase sensitive detector

The phase sensitive detector is dedicated for use with the LVDT. It produces a d.c. output signal proportional to the phase of the input compared to a reference signal. Figure 13.16 shows the section of the front panel which accesses the phase-sensitive detector.

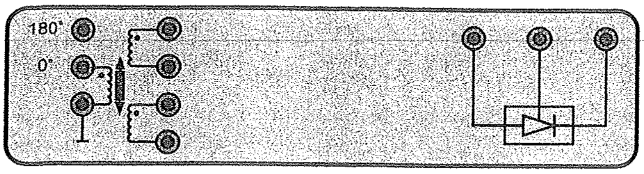

Figure 13.16 The phase-sensitive detector

It includes a 5 V (peak) 3 kHz oscillator to energise the LVDT primary winding as well as providing 0° and a 180° references.

Four-bit decoder

The four-bit decoder is used with the four-bit Gray scale encoder. It gives rotary position measurements with a resolution of 22.5° (360°/16). Figure 13.17 shows the section of the front panel which accesses the four-bit decoder.

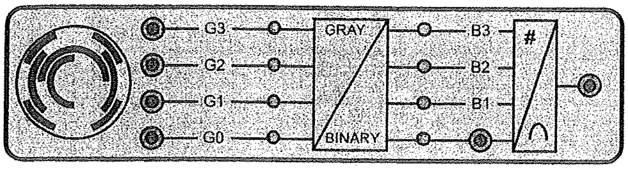

Figure 13.17 The four-bit decoder

The decoder inputs the four individual bits of data directly from the Gray scale encoder. The status of each bit is indicated by an LED. The decoder converts these into a binary code using a Gray to binary converter, again the status of each bit being indicated by an LED. The binary code is then converted by a four-bit digital to analogue converter (DAC) into an analogue signal in the range of 0 to 5 V. This corresponds to a complete revolution of the shaft. With the four-bit resolution of the encoder this signal will comprise a series of 16 steps corresponding to angular positional changes of 3.6 radians (22.5°).

The disc may be manually rotated to observe the effect on the output states, as indicated by the LEDs. The variable current source located in the power supply section may be used to vary the level of illumination of the LEDs to investigate performance under varying levels of ambient light.

Filters

The filters remove unwanted frequencies from a signal. Filter options are: low pass, band pass and high pass. Figure 13.18 shows the section of the front panel which accesses the filters.

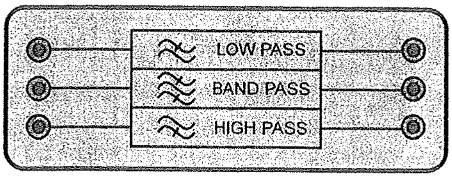

Figure 13.18 The filters

Summing amplifier

This is a differential amplifier like the one described earlier. The summing amplifier provides an error signal for control applications. amplifier with one non-inverting (+) and one inverting (–) input. The output is the difference between the two inputs. A rotary gain control varies the gain of the amplifier in the range of 1 to 50.

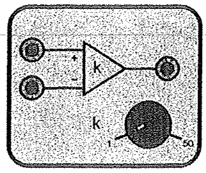

Figure 13.19 The summing amplifier

Figure 13.19 shows the section of the front panel which accesses the summing amplifier.

Voltage to frequency (V to F) and frequency to voltage (F to V) converters

The V to F converter converts an input signal in the range 0 to 5 V into a corresponding frequency of 0 to 250 Hz. The F to V converter converts a 0 to 250 Hz signal at its input into a 0 to 5 V signal at its output. The connection between the V to F and F to V circuits is made using a patching lead. The V to F and F to V circuits may be used together or separately.

An optical link between the V to F and F to V circuits, selected by an adjacent toggle switch, allows the frequency modulated signals to be transmitted through a fibre optic cable connecting the two converters as an alternative to a conductor. An LED and phototransistor at the sending and receiving end provide the electrical to light and light to electrical conversions.

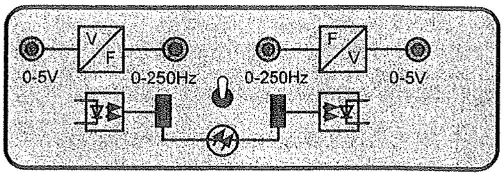

Figure 13.20 The voltage to frequency and frequency to voltage converters

Figure 13.20 shows the section of the front panel which accesses the V to F and F to V converters.

The output frequency from the V to F converter is given by:

$F_{out} = V_{in} \times 50$

The output voltage from the frequency to voltage converter is given by

$V_{out} = F_{in} \times 50$

Voltage to current (V to I) and current to voltage (I to V) converters

The V to I and I to V converter illustrates data transmission using current sources to overcome losses in a cable when using analogue voltage signals. A voltage input to the V to I converter in the range 0 to 5 V produces a current output of 4–20 mA. A current input to the I to V converter in the range 4 to 20 mA produces a voltage output signal in the range of 0 to 5 V. Figure 13.21 shows the section of the front panel which accesses the V to I and I to V converters.

A 0 to 500 Ω variable resistance simulates a length of cable between the source and the receiver. The converters can be used to send and receive data using external sensors, with a maximum resistance of approximately 300 Ω.

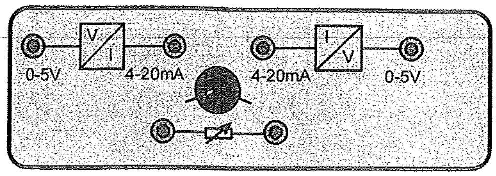

Figure 13.21 The voltage to current and current to voltage converters

Bridge completion resistors

The bridge completion resistors are set of three 120 Ω precision resistors used with one or more of the strain gauges. Figure 13.22 shows the section of the front panel which accesses the bridge completion resistors.

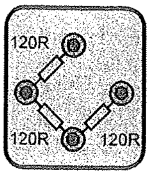

Figure 13.22 The bridge completion resistors

Panel meter

The panel meter is a three-and-a-half-digit digital voltage and frequency meter. Its ranges are 0 to ± 10 V in 10 mV steps; or 0 to 500 Hz, accuracy ±1%. Figure 13.23 shows the section of the front panel which accesses the panel meter.

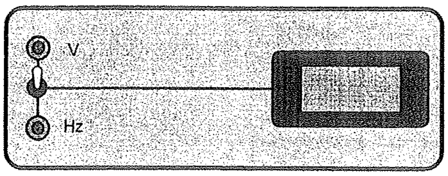

Figure 13.23 The panel meter

PC interface

The PC interface connects the hardware to a PC if data acquisition software is used. It consists of a twelve bit analogue to digital and digital to analogue converter with a sampling frequency up to 10 kHz. It provides one analogue to digital (A to D) input and one digital to analogue (D to A) output. Figure 13.24 shows the section of the front panel which accesses the PC interface.

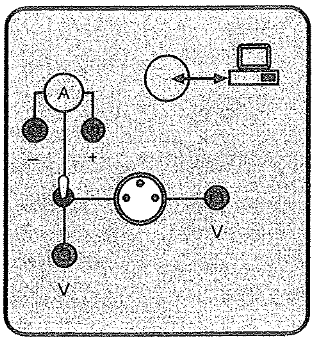

Figure 13.24 The PC interface

The input is switchable for a voltage input in the range ±5 V, with a resolution of ±2.5 mV, or a current input in the range ±500 mA, with a resolution of ±0.25 mA.

Power supply section

This section provides the supplies needed by the sensors, signal processing circuits and the d.c. motor. The supplies available are: variable 0 to 5 V (Ref_1); variable ±5 V d.c. (Ref_2); and fixed d.c. supplies of +5 V, −5 V and 0 V (two of each). It also includes a variable 0 to 30 mA current source for the LED sensors in the encoder and reflective optical beam sensors. Figure 13.25 shows the section of the front panel which accesses the power supplies.

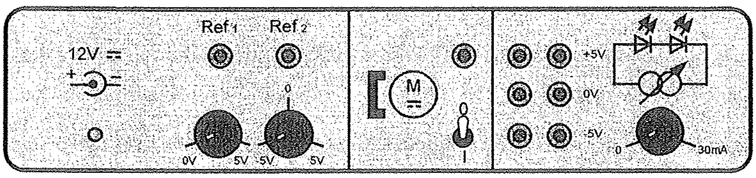

Figure 13.25 The power supplies

the linear and rotary potentiometer

On completion of this experiment you will:

- Understand how linear and rotary potentiometers may be attached to a system to measure displacement.
- Have produced a calibration graph of both types of device and make judgements on linearity, repeatability, accuracy and sensitivity.
- Appreciate the sources of errors in potentiometric circuits.

Part (a): the linear potentiometer

This part of the experiment investigates the linear potentiometer measuring linear displacement.

Make the connections shown in Figure 13.36. This corresponds to the schematic in Figure 13.37.

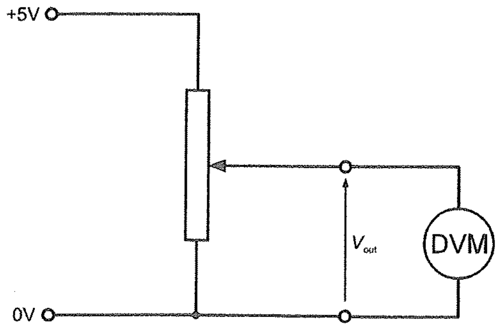

Figure 13.37 Linear potentiometer

Move the linear assembly to the right by rotating the manual control clockwise until it reaches the end stop. Carefully adjust the dial until the zero aligns with the edge of the moulding.

In steps of 1 mm (one complete rotation of the rotary scale) move the linear assembly to the left over its full range of travel. Record corresponding meter readings to complete the table in Figure 13.39. Adjust the control in one direction only throughout the procedure.

Displacement (mm)	Output (V)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

Figure 13.39 Results table for potentiometer experiments

Plot a graph of your results. Comment on the shape of the graph and measure its slope and intercept with the vertical axis. Hence give the equation which governs this measurement system.

With the linear assembly in mid position, determine the minimum amount of movement (the resolution) that can be detected by the meter.

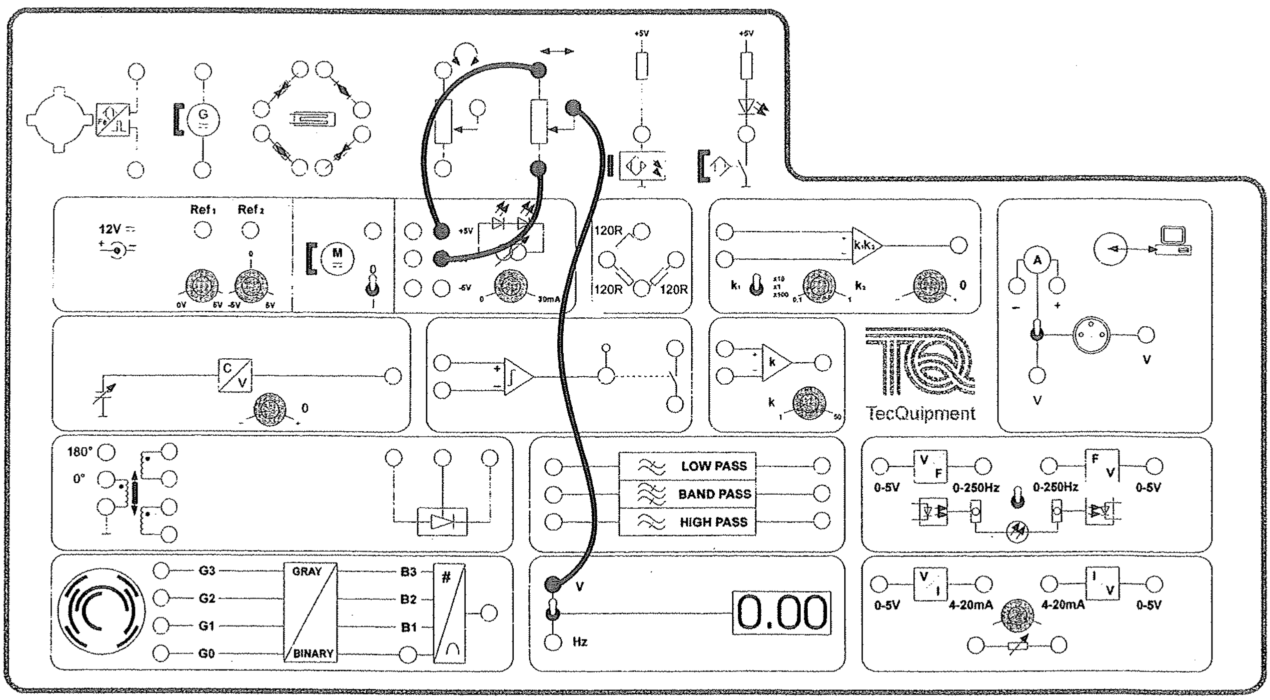

Figure 13.38 Connection diagram for linear potentiometer

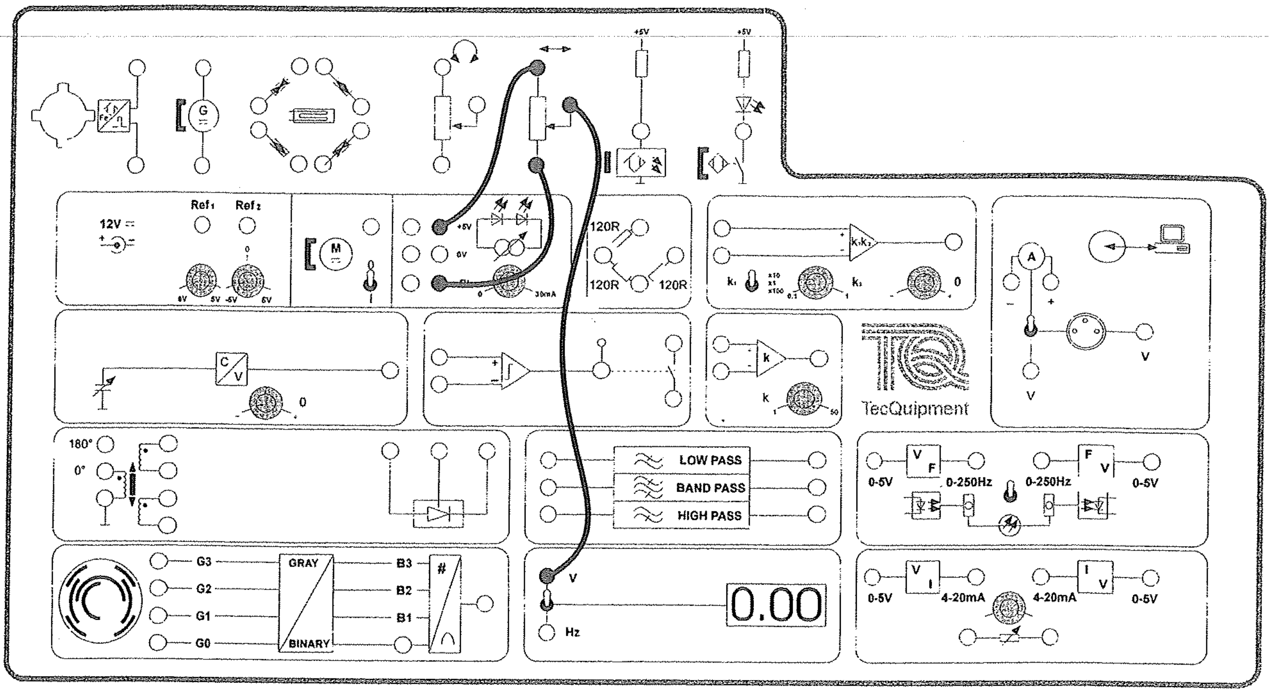

Figure 13.40 Linear potentiometer bipolar connection diagram

Connect the equipment as shown in Figure 13.40. This corresponds to the schematic diagram shown in Figure 13.41. Notice the supply is bipolar, from –5 V to +5 V.

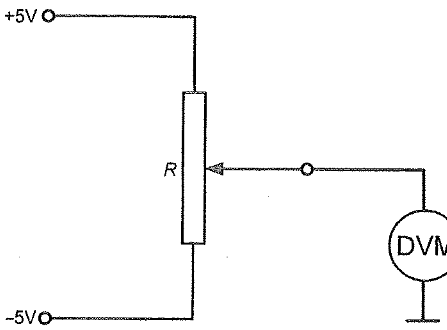

Figure 13.41 Linear potentiometer with bipolar supply

Repeat the previous procedure moving the linear assembly from the right to the left. Tabulate corresponding values of displacement and meter reading. Plot a graph of your results.

Comment on the shape of the graph and measure its slope and intercept with the vertical axis. Hence give the equation which governs this measurement system.

With the linear assembly adjusted to be in mid position determine the resolution of the system.

The circuit shown in Figure 13.42 shows the output from the potentiometer connected to an input (+) of a differential amplifier. An external reference voltage, Ref_2, is connected to the other input (–). The object here is to use the reference voltage to remove any offset in the output signal when the linear assembly is in the starting position.

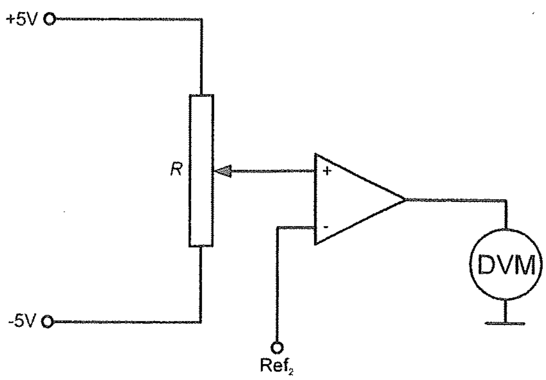

Figure 13.42 Linear potentiometer with differential amplifier

Connect the equipment as shown in Figure 13.43. This corresponds to the schematic in Figure 13.42.

With the amplifier gain set to unity, adjust Ref_2 so the meter reading is zero at the starting position.

Repeat the previous procedure and tabulate your results. From this. plot a graph.

Comment on the shape of the graph and measure its slope and intercept with the vertical axis. Hence give the equation which governs this measurement system.

With the linear assembly adjusted to be in mid position determine the resolution of the system.

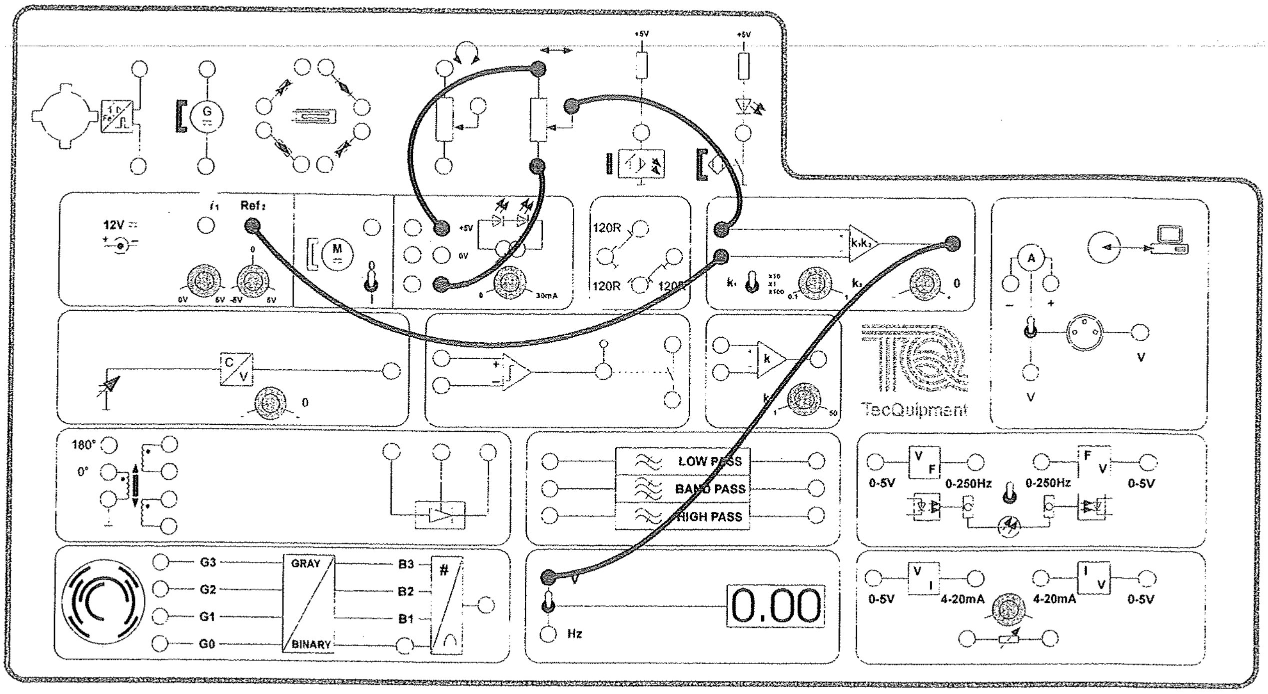

Figure 13.43 Linear potentiometer with differential amplifier connection diagram

Part (b): the rotary potentiometer

The rotary potentiometer illustrates the conversion of linear motion into rotary motion, in this example by the use of a worm and wheel arrangement. Although the shaft is caused to rotate by the movement of the linear assembly the final motion delivered to the potentiometer is actually rotary.

While moving the linear assembly over its full range of movement visually inspect the effect this has on the shaft of the rotary potentiometer in terms of the angle moved through. Also observe any relative movement between the worm and wheel arrangement which would cause errors in measurement.

Connect the equipment as shown in Figure 13.44. The schematic for this circuit is as Figure 13.42.

Repeat the previous procedure and tabulate your results. Plot a graph and comment on its shape. Measure the slope of the graph and intercept with the vertical axis. Hence give the equation which governs this measurement system.

With the linear assembly adjusted to be in mid position determine the resolution.

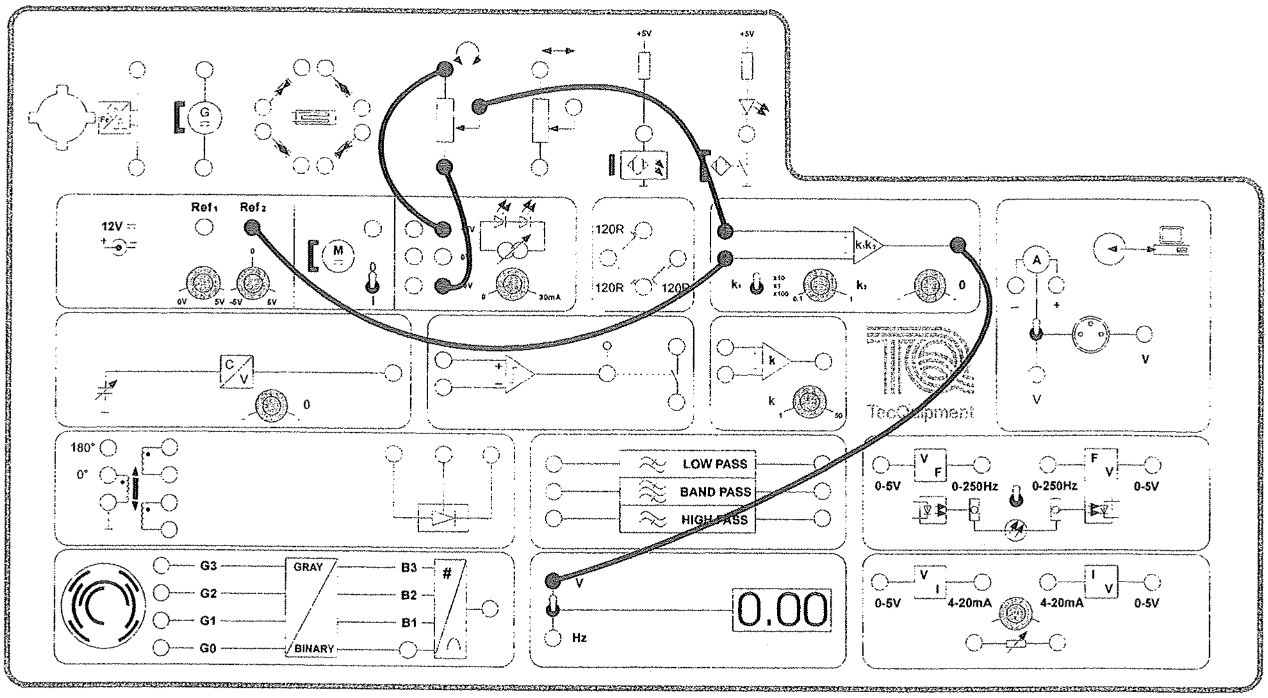

Figure 13.44 Rotary potentiometer with differential amplifier connection diagram

Questions

Answer the following questions, making additional measurements if necessary. It may be helpful to refer to the theory given in Chapters 3, 9 and 10.

1. In the experiments, a variable reference voltage was used to zero the output signal at the start position. How else could zeroing the output voltage at the starting point have been achieved? Hint: Not all solutions need to be electrical.
2. In the SIS, a worm and wheel arrangement is used to convert linear motion into rotary motion. Describe, with the aid of diagrams, two other methods which could achieve this same effect.
3. For each experiment, for both the linear and rotary potentiometers, none gave an output voltage equal to the actual supply voltage. Why should this be the case?
4. Could the rotary potentiometer be used to make measurements of rotary displacements greater than 360°?
5. If the meter used to display the output signal of the circuit shown in Figure 13.38 has an impedance of 5 kΩ, what effect would this have on the output signal when the wiper is at the centre point of the resistance (equidistant from points A and B)? Refer to the specifications for the linear potentiometer given earlier.

the reed switch

On completion of this experiment you will:

- Understand the functionality of the reed switch.
- Appreciate how and where a reed switch may be positioned within a system to measure proximity.
- Determine the resolution, repeatability and hysteresis of the reed switch system.
- Be aware of any limitations of the reed switch for measuring proximity.

This experiment investigates the operation of a reed switch in sensing the proximity of a magnet. Make the connection shown in Figure 13.59. Figure 13.60 shows this circuit schematically.

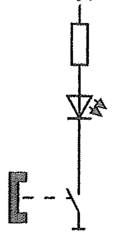

Figure 13.60 Schematic representation of the reed switch

Set the meter to read volts (V). Move the linear assembly to the right by rotating the manual control clockwise until it reaches the end stop. Carefully adjust the dial until the zero aligns with the edge of the moulding.

In steps of 1 mm move the linear assembly to the left over its full range of travel. Record corresponding meter readings and tabulate your results as in Figure 13.61. Adjust the control in one direction only throughout the procedure.

Where a contact closure occurs between readings return to that displacement range and, using smaller steps, determine the repeatability of the measurement, the resolution and the hysteresis.

Displacement (mm)	Output (volts)	Contacts open or closed
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		

Figure 13.61 Results table

Questions

Answer the following questions, making additional measurements if necessary. It may be helpful to refer to the theory given in Chapters 3, 9 and 10.

1. Over the full range of movement of the linear assembly, how many times did the contact close? Explain why this was so.
2. How could the reed switch be mounted so that only one closure occurs for the same range of displacements?
3. In the SIS a permanent magnet initiates the reed switch action. What would be the effect if an electromagnet were to be used instead?
4. What would be the effect of either decreasing or increasing the strength of the magnet?

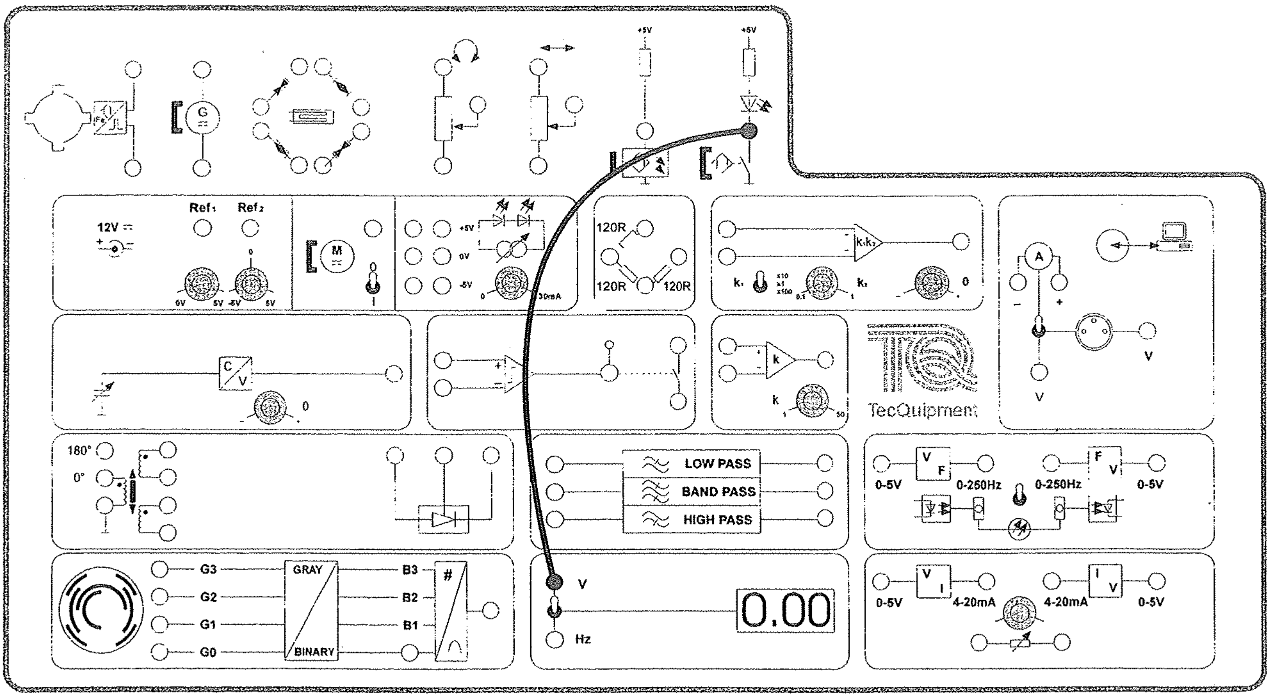

Figure 13.59 Reed switch connection diagram

the reflective optical beam sensor

On completion of this experiment you will:

- Understand how a reflective optical beam sensor may be positioned within a system to measure proximity.
- Experience how to minimise the effects of background light on the sensitivity of the system.
- Appreciate the limitations of the reflective optical beam sensor for measuring displacement.

This experiment investigates the properties of the LED and phototransistor arrangement, and its use in sensing the proximity of the linear assembly.

Figure 13.62 shows the schematic arrangement between the LED and the phototransistor.

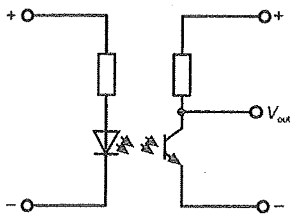

Figure 13.62 Schematic arrangement of the LED and phototransistor

Part (a): reflective optical sensor characteristics

Note that this experiment may be affected by the amount of background light surrounding the apparatus. If difficulties are found obtaining any change in output signal reduce the level of background light reaching the phototransistor.

Make the connection shown in Figure 13.63. Move the linear assembly to the right by turning the rotary scale clockwise until it reaches the end stop. Carefully adjust the dial until the zero aligns with the edge of the moulding.

Set the LED current level to maximum and the meter to read volts (V).

In steps of 1 mm move the linear assembly to the left over its full range of travel. Record corresponding meter readings and tabulate your results as in Figure 13.64. Adjust the control in one direction only throughout the procedure.

Repeat the procedure with the LED current setting at the '12 o'clock' position and then at the '9 o'clock' position. At each position observe the relative position of the end of the transverse beam and the output signal produced.

Displacement (mm)	Current at max. output (volts)	Output (volts) current at '12 o'clock'	Output (volts) current at '9 o'clock'
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			

Figure 13.64 Results table

On the same axes plot graphs of meter reading against displacement for the three LED current levels.

Use your results to find the optimum setting for the LED current.

Examine the effect of changing the level of background light using a portable lamp or by moving the experiment to be closer to a window.

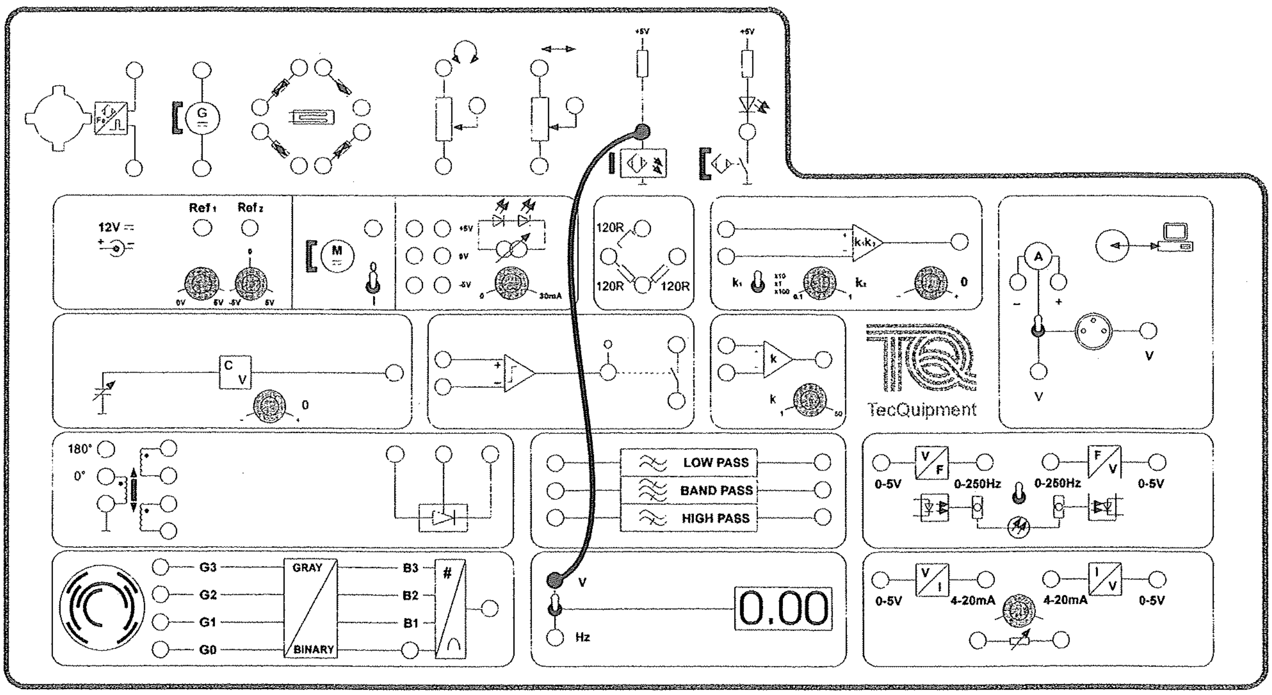

Figure 13.63 Connection diagram for the reflective optical sensor

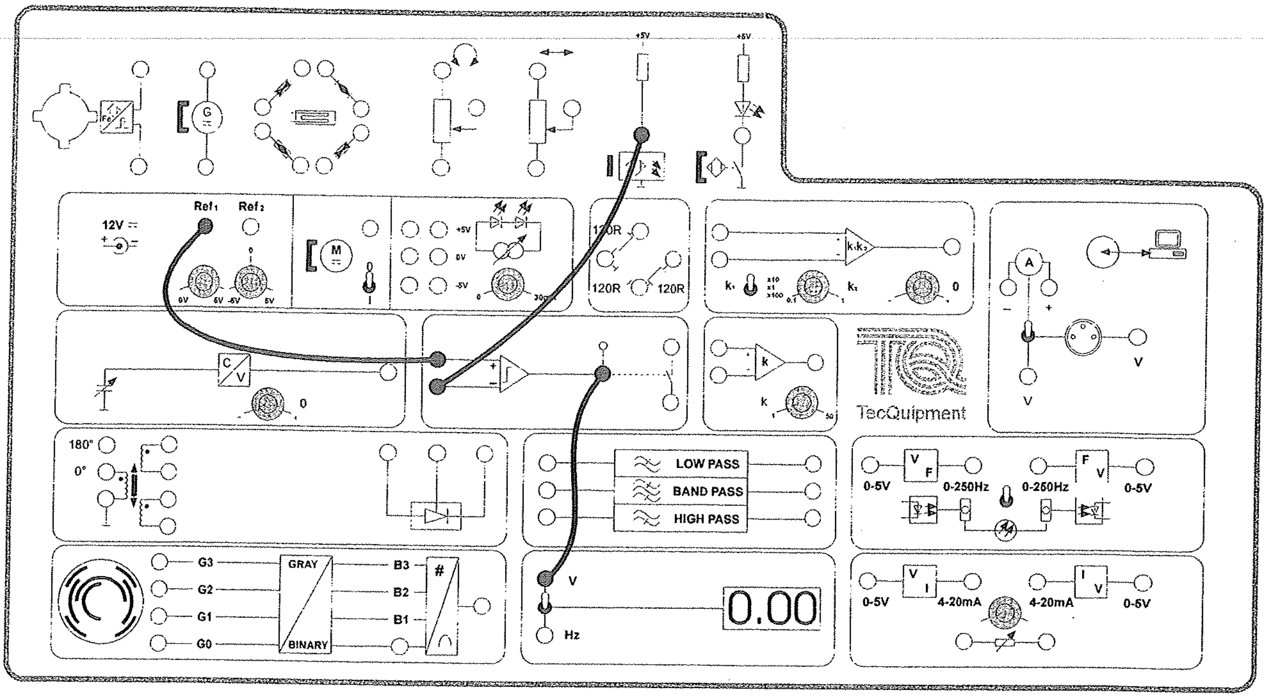

Figure 13.65 Connection diagram for reflective optical sensor with comparator

Part (b): using a comparator circuit

Modify the circuit to include the comparator at the output of the reflective optical beam sensor, as shown in Figure 13.65.

With the linear assembly moved to the right, adjust the setting of Ref_1 until the comparator indicator LED is off.

To investigate the effect on the reflective optical beam sensor of connecting the comparator to its output, repeat the previous procedure. Use the optimum LED current setting determined in Part (a). Tabulate your results as shown in Figure 13.66.

Displacement (mm)	Output (volts)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	

Figure 13.66 Results table

Determine the hysteresis and repeatability of the measurement system. Comment on your results and observations.

Questions

Answer the following questions, making additional measurements if necessary. It may be helpful to refer to the theory given in Chapters 3, 9 and 10.

1. What was the effect of varying the level of current flowing through the LED? What setting of the current control achieved optimum response? (It may be necessary to repeat the procedure at different current settings to obtain this value.)
2. What possible sources of error are there with this type of system? How could these errors be minimised?
3. Would you use an reflective optical system to measure the speed of rotation of a road wheel on a motor car? Give reasons for your answer.
4. What advantages are there in using a reflective optical beam sensor for proximity measurement compared with a reed switch.

Lab 16

the four-bit optical encoder

On completion of this experiment you will:

- Understand how optical encoders measure displacement and derive speed.
- Have produced a table of rotary position with respect to a Gray scale and binary scale.
- Have made judgements on such characteristics as linearity, repeatability, accuracy, sensitivity.
- Recognise the sources of errors in encoders.

Part (a): the Gray scale

This part of the experiment looks into rotary position measurement using the Gray scale encoder. No extra circuit connections are needed (they exist in the internal circuitry of the hardware module). The four bits at the input to the decoder section are taken direct from the phototransistors monitoring the slots in the encoder disc.

Rotate the current control in the power supply section fully clockwise. This sets the current flowing through the LED to maximum.

Manually rotate the encoder disc until the white indexing mark on the edge of the disc points forwards. At this point all the LED's in the decoder section will be off. This is the starting position, Position 0. Rotate the disc clockwise, as viewed from the left-hand side of the hardware module. Record when a Gray scale LED (G0 to G3) lights up, in a table as shown in Figure 13.85. Record the on state with a large cross or shade in the cell to show the LED is on. This will show the coding pattern of the whole encoder when completed.

When the table is complete comment on the Gray coded scale.

Part (b): the binary scale encoder

This part of the experiment produces the binary scale for a four-bit encoder.

All four bits of the Gray scale are processed by a Gray to binary converter to produce a four-bit binary number, indicated by LED's B0 to B3. This is the same binary number that would be obtained if the encoder disc was binary coded.

Rotate the disc to position 0. As in part (a), rotate the disc manually, this time recording the state of the binary LED's (B0 to B3). Tabulate your results as in Figure 13.86. Comment on the binary coded scale when completed.

Part (c): digital to analogue conversion

The four bits of the binary number are processed by a digital to analogue converter. This provides an analogue signal which corresponds to the value of the digital number and so also indicates the disc position.

This part of the experiment investigates the analogue signal obtained using a four-bit encoder and decoder, and digital to analogue converter.

Make the connection shown in Figure 13.87. Set the meter to read volts (V).

Manually rotate the disc to the starting position, Position 0. Rotate the disc clockwise, as viewed from the left-hand side of the hardware module. Each time an LED illuminates record the meter reading. Tabulate your results as in Figure 13.88.

Plot a graph of position against meter reading. Comment on your results.

Position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G0																
G1																
G2																
G3																

Figure 13.85 Gray scale encoder output

Position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B0																
B1																
B2																
B3																

Figure 13.86 Gray to binary encoder output

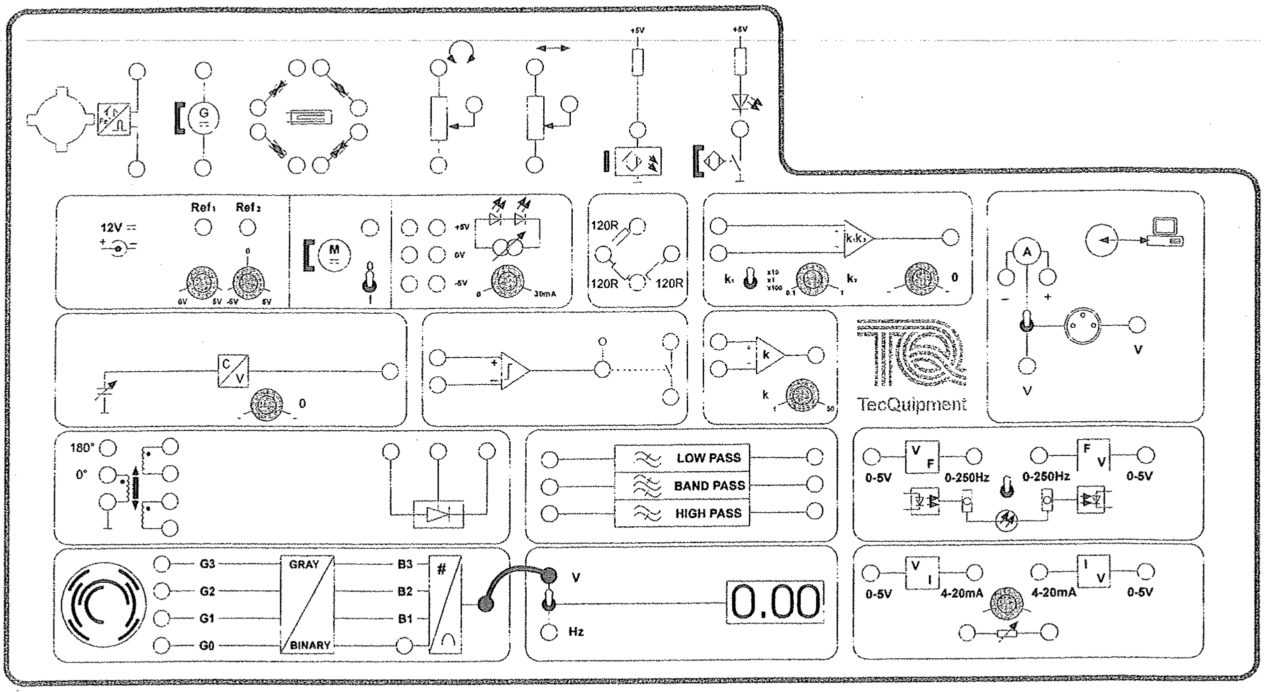

Figure 13.87 Digital to analogue conversion connection diagram

Disc position	Meter reading (V)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
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Figure 13.88 Results table

Questions

Answer the following questions, making additional measurements if necessary. It may be helpful to refer to the theory given in Chapters 3, 9 and 10.

1. What is the effect of increasing the number of bits in the digital encoder? Are there any limitations of how many bits are possible?
2. What is the resolution of an 8 bit encoder?
3. How can the encoder be used to measure speed of rotation?
4. What alternative sensors are available for measuring shaft position if the rotation is to be less than 360°? What are the advantages and disadvantages of these alternatives?

introduction to control

This experiment investigates the principles of open- and closed-loop control of a rotating body using, a d.c. tachometric generator to provide feedback. On completion of this experiment you will have:

- Investigated open-loop and closed-loop circuits for control of speed.
- Experienced the concepts of set point, error and control signal.

Part (a): open-loop control

In this part of the experiment a control signal is set manually to produce the speed required.

Set the meter to read voltage (V). This display will be used to monitor speed. Set the motor drive control switch to 0 and adjust Ref_1 to produce an indicated value of 2.5 volts.

Make the connections shown in Figure 13.101. Set the motor control switch to 1. Use the meter to measure the output voltage from the tachometric generator and compare this with the value of Ref_1. Calculate the difference or error.

Momentarily apply a load to the motor by pressing the push-button adjacent to the tachometric generator legend. Note the effect on the speed. Determine the value of the error, and comment on your results.

Part (b): closed-loop control

In this experiment the output variable is the speed of the d.c. motor. The output from the d.c. tachometric generator, the feedback signal, is compared with the reference voltage Ref_1 by the summing amplifier. This produces the error signal. The error signal is amplified by the controller to become the control signal. The control signal drives the motor and so determines the speed of rotation.

Set the motor drive switch to 0. Adjust Ref_1 to 2.5 volts and the differencing amplifier gain to minimum (1) by rotating the control fully anticlockwise.

Make the connections shown in Figure 13.102. Set the motor drive switch to 1. With the gain at (1) the error signal is supplied directly to the motor drive circuit.

Note the value of the tachometric generator signal indicated by the meter. How does this compare with the value from Part (a)? Note what happens to the error signal when the motor is loaded. Explain why this is so and comment on your observations.

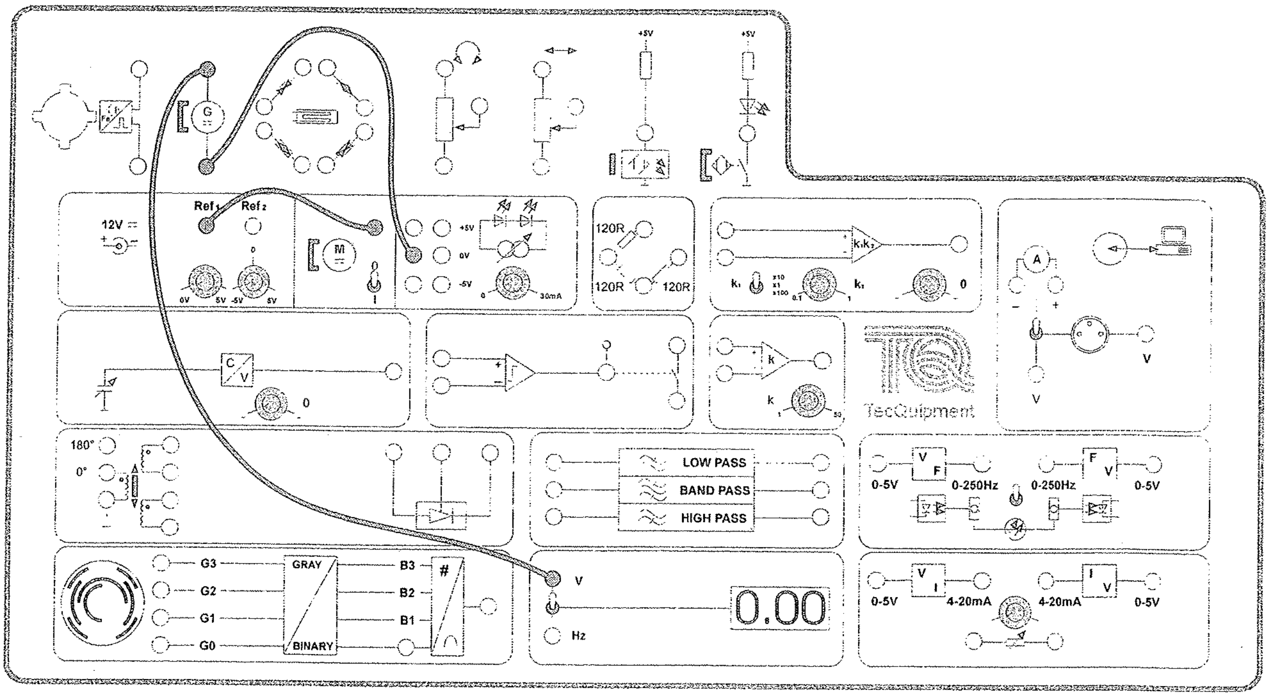

Figure 13.101 Open-loop control connection diagram

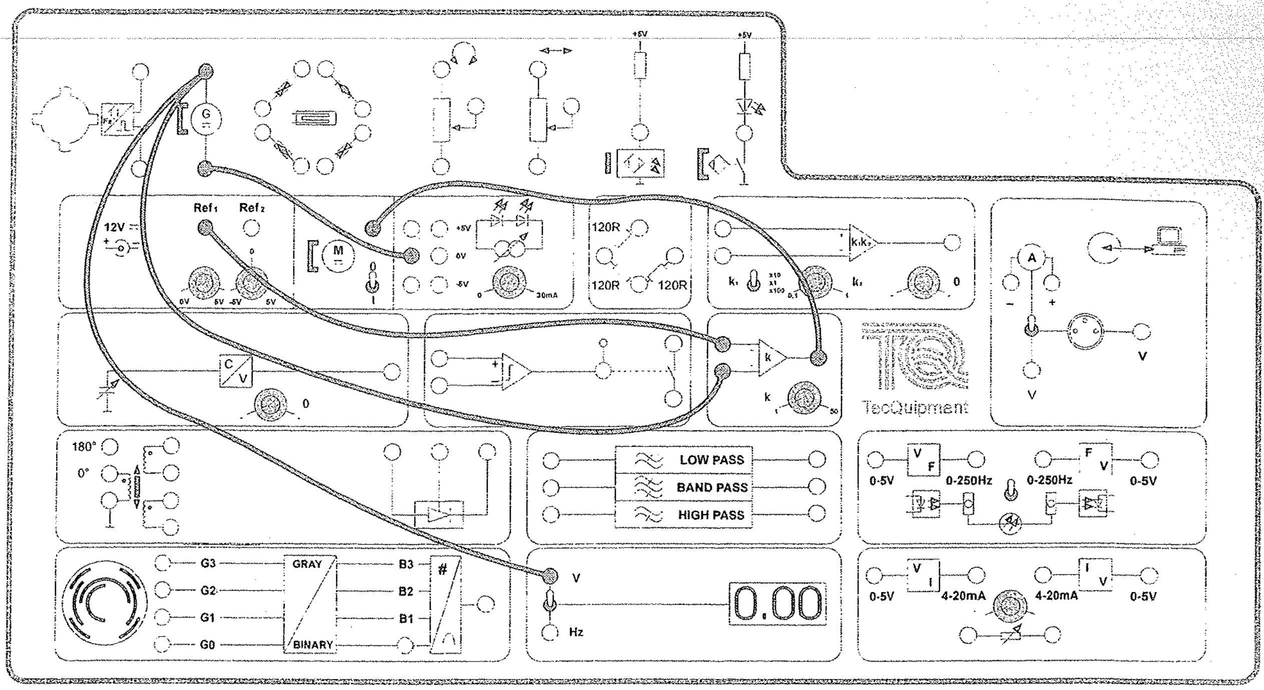

Figure 13.102 Closed-loop control connection diagram

Questions

1. In a closed-loop control system, can the error ever be zero?
2. What problems would you anticipate if you used the output signal from the digital to analogue converter as the feedback signal to control rotary position?
3. A reservoir of hot water in a process is to be maintained at a constant temperature. Any water drained from the tank is automatically replaced from a supply at a lower temperature. Describe a controller system which would maintain the temperature of water at the constant temperature with minimum error. State the devices you would use and why you have selected them. Include any considerations in the system design and component selection.

Summary

This chapter contains a structured series of experiments which illustrate the practical use and characteristics of a number of sensors. This is to support the theory given previously.

The experiments are ideally performed using the TecQuipment Sensors and Instrumentation System (SIS) hardware, but may be performed on similar equipment if available.

Further experimentation is possible, for example looking at proportional, integral and differential (PID) control. Also, the scope of the experiments can be expanded by interfacing to a PC and incorporating data acquisition software.

Because of variations in sensor specifications, characteristics and manufacturing tolerances, it has not been possible to provide experimental results here. However, if the experiments have been performed using the TecQuipment SIS hardware, typical results to all these experiments and answers to the questions in this chapter are given in the lecturer's guide which accompanies the product. Also supplied with the TecQuipment SIS are a student guide, an interactive CD-ROM, and automatic data acquisition software, making it a complete course in sensors and instrumentation.