Ahsanullah University of Science and Technology (AUST)
Department of Mechanical and Production Engineering

LABORATORY MANUAL

For the students of

Department of Mechanical and Production Engineering

2rd Year, 2nd Semester

Student Name :

Student ID :

Department of Mechanical and Production Engineering
Ahsanullah University of Science and Technology (AUST)

IPE 2216: Measurement, Instrumentation and Control Sessional
Credit Hour: 1.5

Objective:

To get familiar with different types of measuring procedures and control equipment. Designing concepts of sampling plan, hypothesis testing.

General Instructions:

1. Attend to the lab 5 minutes prior to the scheduled time and be prepared for the experiment.
2. Students must be prepared for the experiment prior to the class.
3. Report of an experiment must be submitted in the next class.
4. Report should be submitted in the following week during the sessional time.
5. Write report on one side of an 80 gram A4 paper and follow the following format
    a) Top sheet
    b) Objective
    c) Apparatus
    d) Figure
    e) Data Sheets
    f) Sample calculation
    g) Result
    h) Graph
    i) Discussion
        i) Discuss the graphs and results
        ii) Discuss about the experimental setup if it could be improved
        iii) Discuss the different parameters that could affect the result
        iv) Discuss any assumption made
        v) Discuss any discrepancies in the experimental procedure and result
        vi) Discuss what you have learnt and the practical application of this knowledge
    j) Finally, add the data sheet with the report.

<u>**Marks Distribution:**</u>

Total Marks		
Report	Attendance and Viva	Quiz
40	10	50

Experiment No: 01

Experiment Name: Study and determination of angles using the Two-Ball Method, Four-Ball Method, and Bevel Protractor with Vernier.

1(a) Determination of angles using the Two-Ball Method, Four-Ball Method

THEORY:

Measuring the taper angle of internal or external conical surfaces can be challenging when direct access is limited. In such cases, the two-ball and four-ball methods provide effective indirect techniques. The Two-Ball Method is used for internal tapers. Two balls of different diameters are placed inside the tapered hole, and depth readings are taken from a reference surface. Using trigonometric calculations, the included angle of the taper can be determined. This method is simple and practical, though not highly precise. The Four-Ball Method is used for external tapers. Pairs of large and small balls are placed symmetrically on the taper. The height difference between the setups is measured using a flat reference plate and a depth micrometer. From this, the taper angle is calculated. These ball-based methods are especially useful for approximate measurement of tapers in recessed or inaccessible areas where standard tools cannot be applied.

Fig. 1.1: 3D View of a Conical Taper (Internal Taper Geometry)

Calculation:

$$\boldsymbol{\theta = 2 \cdot \sin^{-1} \left(\frac{(d_2 - d_1) - (R - r)}{R - r}\right)} \quad \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where:

- d_2, d_1 = depth measurements with large and small balls
- R, r = radii of the large and small balls respectively
- θ = included taper angle

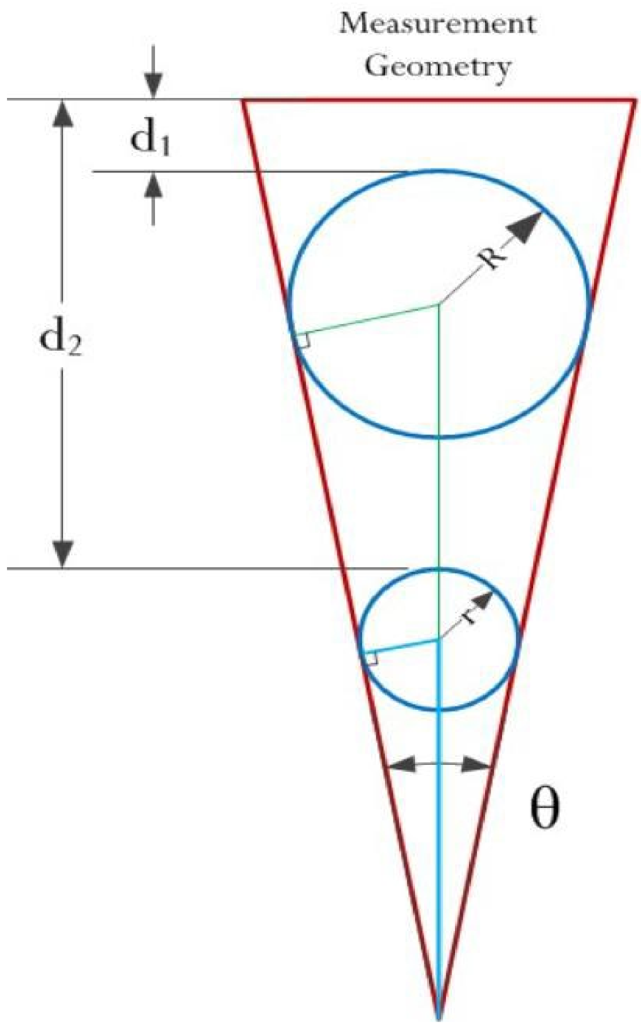


Fig. 1.2: Measurement Geometry of 2 Ball Angle Measurement Technique.

Ahsanullah University of Science and Technology

Department of Mechanical and Production Engineering

IPE 2216

Datasheet

Experiment 1a

Name of the Student:
Student ID:

Radius of small ball, r = mm

Radius of large ball, R = mm

Depth recorded from the top to small ball, d_2 = mm

Depth recorded from the top to large ball, d_1 = mm

Result:

Included tapper angle, θ =

Signature of Course Teacher

1(b) Determination of angles using Vernier Bevel Protractor.

Objectives:

- Learn and understand different parts of Vernier Bevel Protractor
- Know the use and working principle of Vernier Bevel Protractor
- Understand the use of Vernier Bevel Protractor

Vernier Bevel Protractor:

It is also called universal bevel protractor. It is one of the simplest instruments for angular measurement. It is a direct type of angular measuring instrument. The range of this instrument is 0 to 360 degrees i.e. it can measure angles up to 360 degrees which any other angular measuring instrument cannot measure. It also has two arms (fixed blade and adjustable blade), which can be set along the faces and a circular scale to indicate the angle between them. Workpiece is set in between these two arms (two blades, fixed blade and adjustable blade), and the difference of two scale (main scale and Vernier scale) gives accurate measurement. Main parts of bevel protractor are-

- Fixed base blade and a circular body is attached to it
- Adjustable blade
- Blade clamp
- Scale magnifier lens
- Acute angle attachment

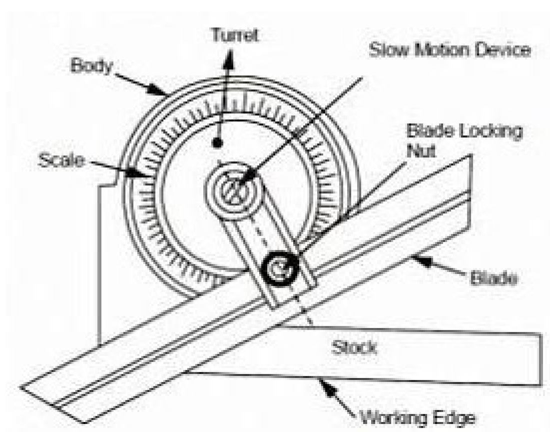


Fig. 1.3: Vernier Bevel Protractor

Note that, magnifying lens has been provided for easy reading of the instrument. Main scale is circular and is graduated in degrees on the circular body. Main scale graduations are all around the circular body which is attached to fixed base blade. Fixed base blade also called as stock is attached to circular body of bevel protractor as shown in Fig. 1.3. Once the reading is fixed, blade clamp fixes the reading. Blades are about 150 mm long or 300 mm long, 13 mm thick. Its ends are beveled at 45 degrees and 60 degrees. Vernier scale is also marked on turret which can rotate all over the fixed body. Adjustable can pass through the slot provided in turret. So as the turret rotates, adjustable blade also rotates full 360 degrees. There are 12 graduations of Vernier scale starting from 0 to 60 degrees on both sides of zero of Vernier scale.

How to read Vernier scale:

- If the indicator on the Vernier is corresponding to that on the main scale, then directly read on the main scale.
- If the zero indicator on the Vernier indicates rightward of the zero indicator on the main scale, read on the right side of the Vernier. Example of Fig. 3.2 shows that 15 degree on the right side of the Vernier is directly in correspondence with the main scale so the reading is $12^{o}\ 15'$.
- If the zero indicator of the Vernier indicates on the left side of the zero indicators on the main scale, read on the left side of the Vernier.

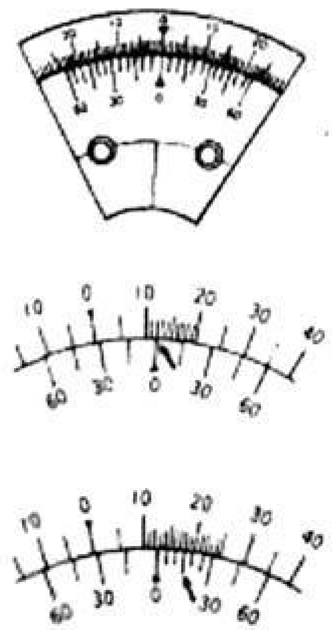


Fig. 1.4: How to Read Vernier Scale

Least count of Vernier Bevel Protractor:

$$\text{Least count of Vernier Bevel Protractor} = \frac{\text{Smallest division on the main scale}}{\text{Total no of division on the Vernier scale}} \quad \text{.........(ii)}$$

$$= 1^{o} \text{ (equal to } 60'\text{) i.e. } \frac{60}{12}$$

$$= 5 \text{ minutes (written as } 5'\text{)}$$

Application of Vernier Bevel Protractor:

The bevel protractor can be used in the following applications-

- For checking V-block
- For measuring acute angle

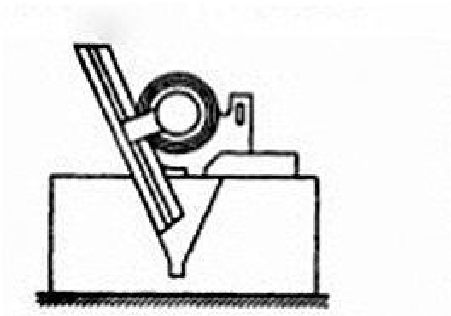


Fig. 1.5: Checking V-block

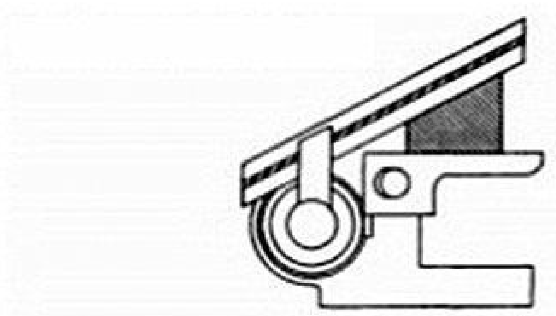


Fig. 1.6: Measuring acute angle

Assignment:

1. What is the difference between the Two-Ball and Four-Ball methods?

2. Why is the Two-Ball method used instead of a bevel protractor for internal tapers?

Experiment No: 02

Experiment Name: Measurement of torque of a rotating shaft using Torsion Meter, Strain Gauge Torque Transducer.

Objective: To measure torque of a rotating shaft using a Torsion Meter, Strain Gauge Torque Transducer.

Apparatus: Torsion Meter, Strain Gauge Torque Transducer.

Theory:

Torque:

Torque is the tendency of a force to rotate an object about an axis, fulcrum, or pivot. (or) Torque is defined as a force around a given point, applied at a radius from that point.

An engine produces power by providing a rotating shaft which can exert a given amount of torque on a load at a given speed. The amount of torque the engine can exert usually varies with speed.

Facts about calculations:

1. Power (the rate of doing work) is dependent on torque and rpm.

2. Torque and rpm are the measured quantities of engine output.

3. Power is calculated from torque and rpm, by the following equation:

$$P = \text{Torque } (T) \times \text{Speed}(\omega) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where,

P = Power (watts), T = Torque (Nm), ω = Angular Speed (rad/s)

Torsion Meter:

The deflection measuring system is called torsion meter. An instrument for determining the torque on a shaft, and hence the horse power of an engine by measuring the amount of twist of a given length of the shaft. When a shaft is connected between a driving engine and driven load, a twist (angular displacement) occurs on the shaft between its ends. This angle of twist is measured and calibrated in terms of torque.

Construction of Mechanical Torsion Meter:

The main parts of the mechanical torsion meter are as follows: A shaft which has two drums and two flanges mounted on its ends as shown in the diagram. One drum carries a pointer and other drum has a torque calibrated scale. A stroboscope is used to take readings on a rotating shaft.

Operation of Mechanical Torsion Meter:

One end of the shaft of the torsion meter is connected to the driving engine and its other end to the driven load. An angle of twist is experienced by the shaft along its length between the two flanges which is proportional to the torque applied to the shaft. A measure of this angle of twist becomes a measure of torque when calibrated. The angulartwist caused is observed on the torque calibrated scale corresponding to the position of the pointer. As the scale on the drum is rotating, reading cannot be taken directly. Hence a stroboscope is used. The stroboscope's flashing light is made to fall on the scale and the flashing frequency is adjustedtill a stationary image is obtained. Then the scale reading is noted.

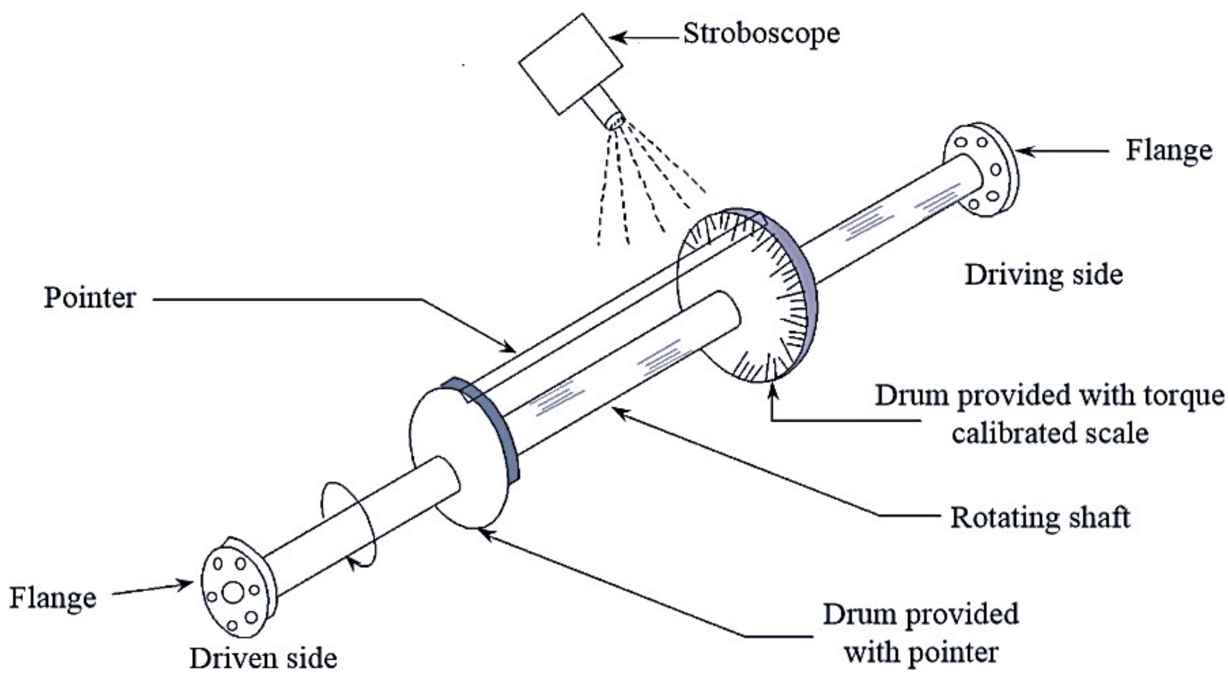


Fig 2.1: Measurement of Torque by Torsion Meter

Strain Gauge Torque Transducer:

The strain monitoring system is called Torque Meter (or) Strain Gauge Torque Transducer. A TorqueSensor is a transducer that converts a torsional mechanical input into an electrical output signal.

Torque Sensor, are also commonly known as a Torque Transducer. Torque is measured by either sensing the actual shaft deflection caused by a twisting force, or by detecting the effects of this deflection. The surface of a shaft under torque will experience compression and tension, as shown in figure below.

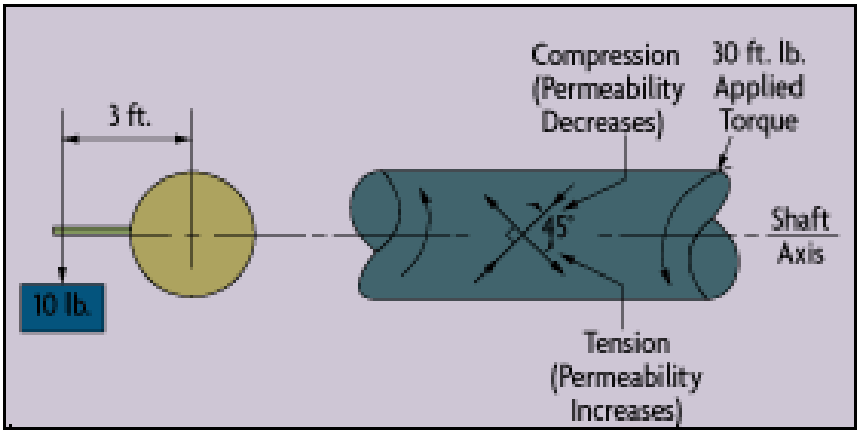


Fig. 2.2: Measurement of Torque by Torque Transducer

To measure torque, strain gage elements usually are mounted in pairs on the shaft, one gauge measuring the increase in length (in the direction in which the surface is under tension), the other measuring the decrease in length in the other direction. A strain gage can be installed directly on a shaft. Because the shaft is rotating, the torque sensor can be connected to its power source and signal conditioning electronics via a slip ring. The strain gage also can be connected via a transformer, eliminating the need for high maintenance slip rings. The excitation voltage for the strain gage is inductively coupled, and the strain gage output is converted to a modulated pulse frequency as shown in figure. Maximum speed of such an arrangement is 15,000 rpm.

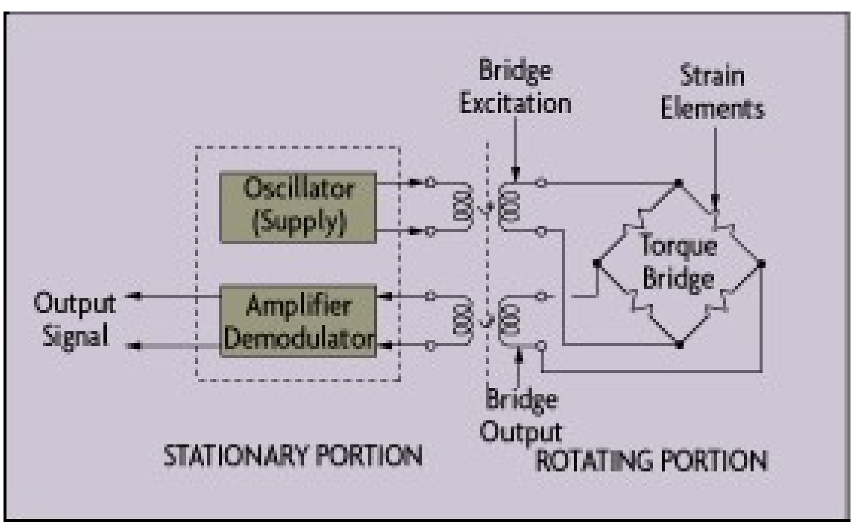


Fig. 2.3: Working Principle of Torque Transducer

Procedure:

1. Connect one end of the torsion meter shaft to the driving engine and the other end to the driven load, ensuring the pointer and scale are visible.
2. Start the engine to rotate the shaft, which causes an angle of twist along its length proportional to the applied torque.
3. Observe the pointer on the rotating scale indicating the angle of twist.
4. Direct the stroboscope light onto the scale and adjust its flashing frequency until the scale appears stationary. Note the reading on the torque-calibrated scale corresponding to the pointer position, which gives the applied torque.
5. Repeat the process if multiple readings are required.

Observations & Calculations:

Table 2.1: Average Torque Measurement of a Rotating Shaft

SL. No.	Power (KW)	Shaft Speed (RPM)	Shaft Speed (rad/s)	Twisting angle	Torque (N.m)	Torque (Average) (N.m)
1	45	277		2.1°		
2	45	253		2.3°		
3	45	292		1.9°		

Conclusion: Hence the torque of a rotating shaft is ……………

Assignments:

1. Draw Torque (N.m) vs Speed(rpm) and Torque (N.m) vs Angle of Twist (°)
2. Explain the working principle of Torque Transducer
3. If we know the shear modulus, polar moment of inertia, and length of the shaft, how do we calculate Torque from the angle of twist?

Experiment No: 03

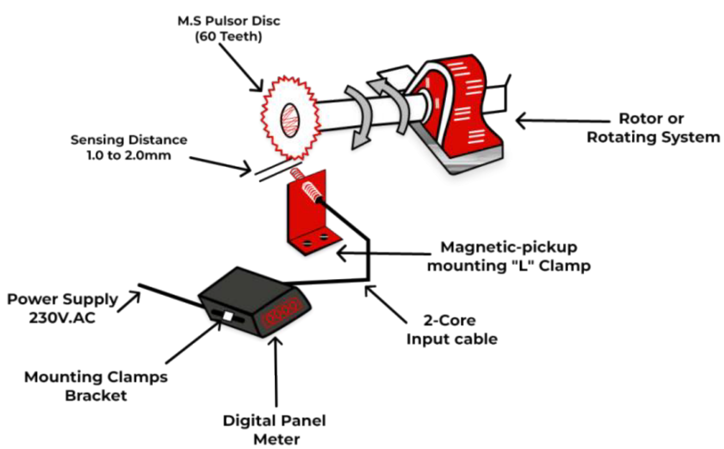
Experiment Name: Speed measurement of an electrical motor shaft using a non-contact type pick-ups (Magnetic or Photoelectric).

Objective: To measure the speed of a motor shaft with the help of non-contact type pick-ups (Magnetic or Photoelectric).

Apparatus: Photoelectric Pick-up

Theory:

Magnetic Pickup Tachometer: A coil wound on a permanent magnet, not on an iron core, enablesus to measure the rotational speed of the systems by using the electromagnetic induction principle (The voltage is induced in the coil around to a magnetic subject to change in the magnetic field). As the shaft rotates, the teeth pass in front of the pickup and produce a change in the field resistance of the magnetic circuit. The density of a magnetic field increases and decreases as each tooth approaches and leaves away from the end of the bar magnet per second. In the construction of a variable reluctance sensor, we use a ferromagnetic gearwheel. As the gearwheel rotates, a changein magnetic flux takes place in the pickup coil, which further induces voltage. This change in magnitude is proportional to the voltage induced in the sensor.



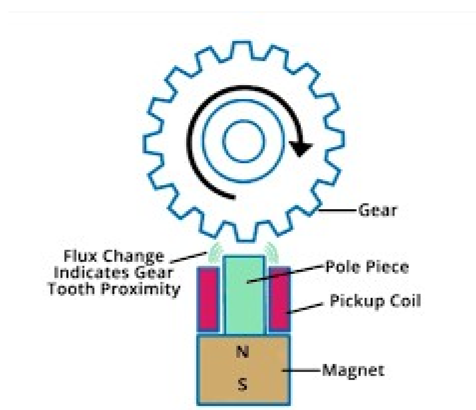


Fig. 3.1: Speed Measurement by Magnetic Pickup Tachometer

Number of pulses per second, f = reading of digital meter / gating period

Speed, N = (number of pulses per second, f / number of teeth, T) x 60 (rpm)

Photoelectric Tachometer: It consists of a opaque disc mounted on the shaft whose speed is to be measured. The disc has a number of equivalent holes around the periphery. On one side of the disc, there is a source of light (L) while on the other side there is a light sensor (may be a photosensitive device or photo-tube) in line with it (light-source). On the rotation of the disc, holes and opaque portions of the disc come alternately in between the light source and the light sensor. When a hole comes in between the two, light passes through the holes and falls on the light sensor, with the result that an output pulse is generated. But when the opaque portion of the disc comes in between, the light from the source is blocked and hence there is no pulse output.

Thus, whenever a hole comes in line with the light source and sensor, a pulse is generated. These pulses are counted/ measured through an electronic counter. The number of pulses generated depends upon the following factors: i. The number of holes in the disc; ii. The shaft speed. Since the number of holes is fixed, therefore, the number of pulses generated depends on the speed of the shaft only. The electronic counter may therefore be calibrated in terms of speed ~r.p.m.).

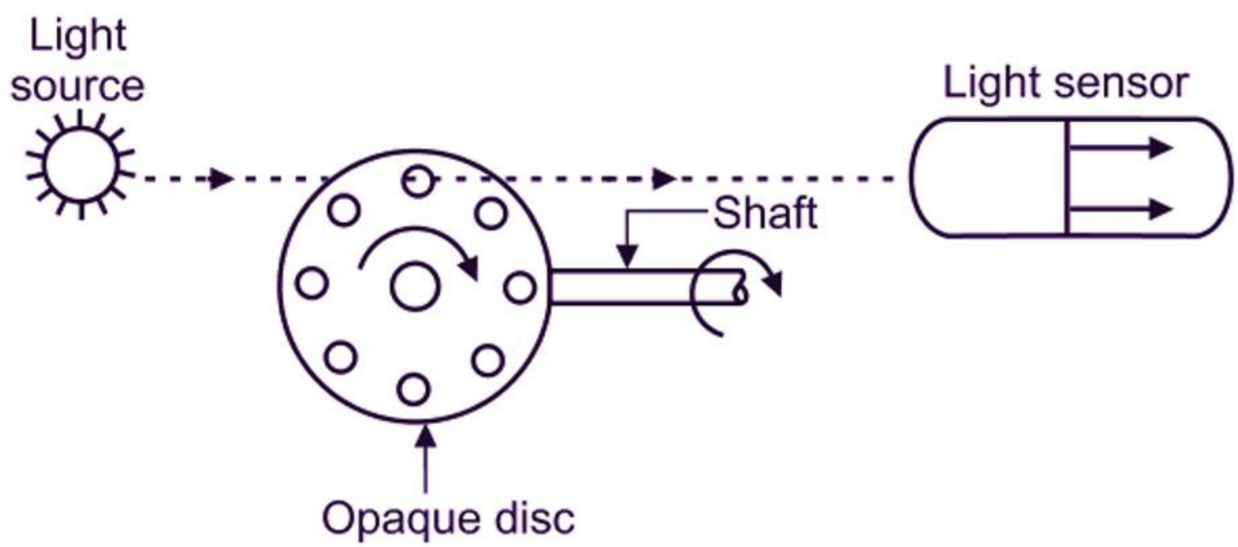


Fig. 3.2: Speed Measurement by Photoelectric Tachometer

Pickups: There are electric tachometer consists of a transducer which converts rotational speed into an electrical signal coupled to an indicator. The transducer produces an electrical signal in proportion to speed. The signal may be in the analog form or in the form of pulses. Tachometer or pickups of this type produce pulses form a rotating shaft without being mechanically. connected to it. As the energy produced by these devices is not sufficient to actual an indicator directly, amplifiers of sufficient sensitivity are employed. The various types of non-contact pick-ups are optical pickups or photoelectric or photoconductive cell.

• Inductive pick up

• Capacitive pick up

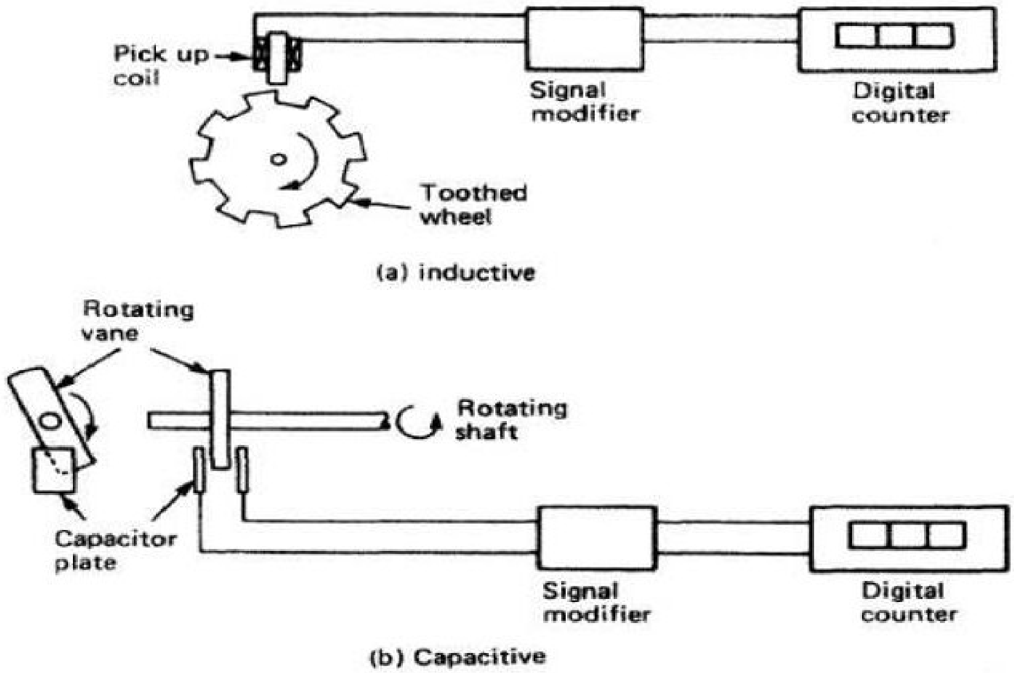


Fig. 3.3: Pickup Tachometer (a) Inductive (b) Capacitive

Here, we will measure the speed by Photoelectric Tachometer. As they don't have moving parts so speed upto 3 million rpm. These are available in a variety of designs using the principle of shaft rotation to interrupt a beam of light falling on a photoelectric or photo conductive cell. The pulse thus obtained are first amplified & then either fed to an electric counter, or shaped to an along signaland connected to the indicator. A bright white spot is made on the rotating shaft. A beam of lightoriginating from the tachometer case hits the white spot & the reflected light falls on photoconductive cell inside the case, producing pulse in transistorized amplifier, which is turn, causes the indicator to deflect which is measure of speed of the shaft.

Procedure:

1. Connect the circuit & CRO with the required apparatus & switch on the supply.

2. Adjust the speed of the DC motor by the knob and wait for some time till the motor attains the maximum speed at corresponding knob position.

3. Measure the frequency (t) from output wave on CRO.

4. Find the speed of the motor by the given formula.

Observations & Calculations:

Table 3.1: Speed Measurement of Motor Shaft

SL. No.	t_{CRO} (ms)	$t_{actual}=1.8\times t_{CRO}$ (ms)	$f=1/t_{actual}$ (Hz)	$N=(f/T)\times 60$ (rpm)	Speed (Average)
1	2				
2	2.2				
3	1.9				

For observation 1:

Formula used: - Speed (rpm) = Frequency x 60 / No. of segments.

Calculations: - At knob position (A) RPM, N = $\frac{\text{Frequency, f}}{\text{No.of teeth of segments, T}}$ x 60 ……….(i)

Where f = $\frac{1}{t}$ ……………...(ii)

t = time period of one cycle of output wave

= 1.8 x 2 ms = 3.6 x 10^{-3} s [on CRO, correction factor= 1.8] and

f = $\frac{1}{3.6\ x10^{-3}}$ = 2.77 x 10^2 Hz

T =60.

Therefore, R.P.M = ($\frac{2.77 \text{ x } 10^2}{60}$) x 60 = 277 rpm

Conclusion: Hence the Speed of position = ……… rpm

Assignments:

1. Why are non-contact pick-ups preferred over mechanical tachometers at very high speeds?
2. Analyze one advantage of photoelectric pick-ups over magnetic pick-ups.
3. Compare between inductive and capacitive pick-ups. Interpret how environmental factors such as dust, oil, or temperature affect their performance.
4. Derive the formula of N = $\frac{60f}{T}$, where N=Speed, f= Pulse Frequency and T= No. of Teeth

Experiment No: 04

Experiment Name: Study of the working principle of the Bourdon Pressure Gauge and checking the calibration of a gauge in a deadweight pressure

Objective:

- To measure the pressure of gases or liquids accurately using a Bourdon Pressure Gauge.
- To calibrate the gauge for reliable and precise pressure readings in monitoring and control applications.

Theory:

Many types of gauge are available for measurement of pressure. The most simple form is a manometer tube, in which the rise of level of a liquid indicates the static head, this being converted to pressure by multiplying by the liquid density. An example of a much more sophisticated instrument is a pressure transducer, in which the pressure is used to deflect a diaphragm. The deflection causes an electrical signal to be generated by some means such as an electric resistance strain gauge, and this signal is displayed, typically in digital form, as the corresponding pressure. The response is rapid, being typically 1 ms, and the display can be remote from the point of measurement. The Bourdon gauge (named after its inventor Eugene Bourdon) uses the deflection of a tube of oval cross-section to cause a pointer to move over a scale. Its response time is therefore long, being of the order of 1 second. Moreover, the distance between the measuring point and the gauge is limited by the practicable length of the capillary line connecting the gauge to the sensing point. Nevertheless, because of its simplicity and low cost, and the large selection of pressure ranges which are available, the Bourdon gauge is widely used in engineering practice. All pressure gauges, of whatever type, need to be calibrated. If the required accuracy is low, then a standard calibration obtained from a sample of the particular model will suffice. For higher accuracy, a manufacturer will take special care and will supply a calibration certificate for an individual gauge. As the calibration may change over a period, repeat calibrations will be needed from time to time. For the highest accuracy. transducers and gauges are sometimes calibrated before each use. The normal calibration procedure is to load the gauge with known pressures using a dead weight tester using oil. The present experiment, however, works satisfactorily with water instead of oil.

Description of Apparatus:

The Bourdon pressure gauge shown in Fig 3 .1 has a transparent dial through which the construction may be viewed. It consists essentially of a thin-walled tube of oval cross-section. which is bent to a circular arc encompassing approximately 270°. It is rigidly held at one end. where the pressure is admitted. The other end is free to move

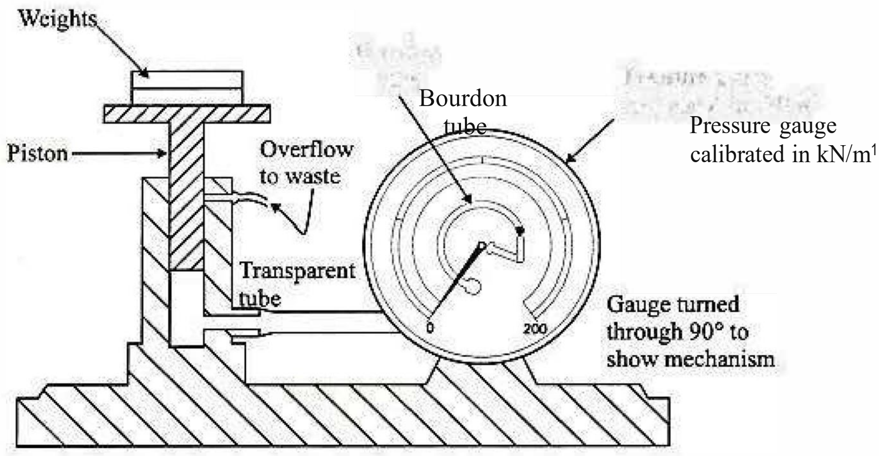


Fig. 4.1: Experimental Setup for Pressure Gauge Calibration

and is sealed. When pressure is applied, the tube tends to straighten, so that the free end moves slightly. This movement operates a mechanism which drives a pointer round the graduated dial, the movement of the pointer being proportional to the applied pressure. The construction of the dead weight tester is also shown in Fig 3.1. A cylindrical piston. free to move vertically in a closely-fitting cylinder, is loaded with known weights. The space below the piston is filled with water, and the pressure is transmitted by the water to the gauge under test through a transparent hose. The pressure generated by the piston is easily found in terms of the total weight supported and the cross-sectional area of the piston. Pressure gauge calibrated in KN/m^2.

Procedure:

The weight of the piston. and its cross-sectional area, should be noted. To fill the cylinder, the piston is removed, and water is poured into the cylinder until it is full to the overflow level. Any air trapped in the tube may be cleared by tilting and gently tapping the apparatus. In point of fact, a small amount of air left in the system will not affect the experiment, unless there is so much as to cause the piston to bottom on the base of the cylinder. The piston is then replaced in the cylinder and allowed to settle. A spirit level placed on the platform at the top of the piston may be used to ensure that the cylinder stands quite vertically.

Weights are now added in convenient increments, and at each increment the pressure gauge reading is observed. A similar set of results is then taken with decreasing weights. To guard against the piston sticking in the cylinder, it is advisable to rotate the piston gently while the pressure gauge is being read.

Observations & Calculations:

Weight of piston =0.5 kg

Cross-sectional area =244.8 mm^2

Table 4.1 True Pressures and Gauge Readings

Total Load Including Piston Weight (Kg)	Total Load Including Piston Weight (N)	True Pressure (KN/m^2)	Gauge Reading: Increasing Pressure (KN/m^2)	Gauge Reading: Decreasing Pressure (KN/m^2)

Graph:

Discussions:

Assignments:

1. What suggestions have you for improving the apparatus?
2. No correction has been made for the difference in elevation of the piston of the dead weight tester and of the pressure gauge. If the center of the gauge were 200 mm higher than the base of the piston. Should a correction be made, and if so. how big would it be?
3. What alterations would you make to the dimensions of the piston if it were? Desired tocalibrate a gauge with a full scale reading of3500 kN/m^2 using the same weights?

Experiment No: 05

Experiment Name: Use of a Resistance Thermometer, and apply it the measurement of temperature of a subject.

Objective: To understand the working principle and calibration method of a Resistance Thermometer for accurate temperature measurement.

Theory:

Resistance Thermometers may be called as RTDs (resistance temperature detectors), PRT's (platinum resistance thermometers), or SPRTs (standard platinum resistance thermometers). These thermometers operate on the principle that electrical resistance changes in pure metal elements relative to temperature. The traditional sensing element of a resistance thermometer consists of a coil of small-diameter wire wound to a precise resistance value. The most common material is platinum, although nickel, copper, and nickel-iron alloys compete with platinum in many applications. Platinum is preferred over other metals because it has a high coefficient of resistance and is uniform over a large range of temperatures (300-1200 °C). For temperatures greater than 1200 °C, the resistance vs. temperature graph for platinum no longer remains a straight line; thus, the formula for calculating resistance changes. It does not react with oxygen. The relative change in resistance with temperature (temperature coefficient of resistance) for platinum varies very slightly with temperature change. Other elements like Nickel and Copper cannot be used because (i) Nickel, the amount of change in resistance per degree of change in temperature becomes very nonlinear at temperatures over 300 °C (572 °F).

(ii) Copper has a very linear resistance temperature relationship, but it oxidizes at moderate temperatures and cannot be used over 150 °C (302°F).

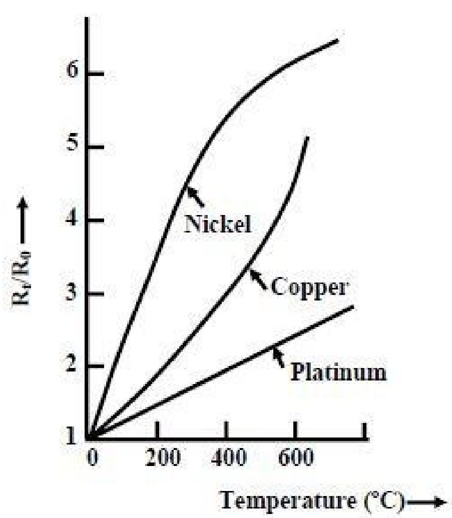


Fig. 5.1: Variation of Resistance with Temperature for Various Metals

In Industries, we have to measure temperatures in the range 200-1200 °C, and the temperature range of a clinical thermometer is 35-42 °C. Hence, we need resistance thermometers to measure high temperatures.

Structure of Resistance Thermometer

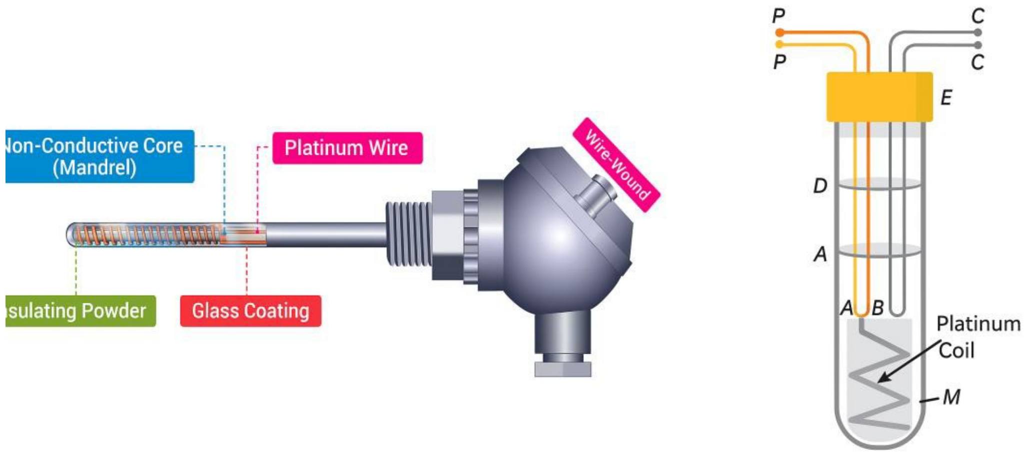


Fig. 5.2: Structural Diagram of a Resistance Thermometer

It consists of a fine platinum wire wound on a mica frame. The wire is wound non-inductively to avoid self-induction in the platinum. The mica is used as an insulator and placed at the ends of the tube. The RTD construction design may be enhanced to handle shock and vibration by including compacted magnesium oxide (MgO) powder inside the sheath. MgO is used to isolate the conductors from the external sheath and each other. MgO is used due to its dielectric constant, rounded grain structure, high-temperature capability, and chemical inertness. The ends of the copper wire arc connected to points A and B from which two platinum wire leads run along the length of the glass tube and are connected to two terminals. A set of compensating lead run parallel to these and arc connected to the terminals fixed on the cap of the tube. This compensating wire CC is connected to reduce the effect of resistance of the copper wire PP on the thermometer. Both two copper wires PP and CC are the same in length and thickness, thus they have the same resistance.

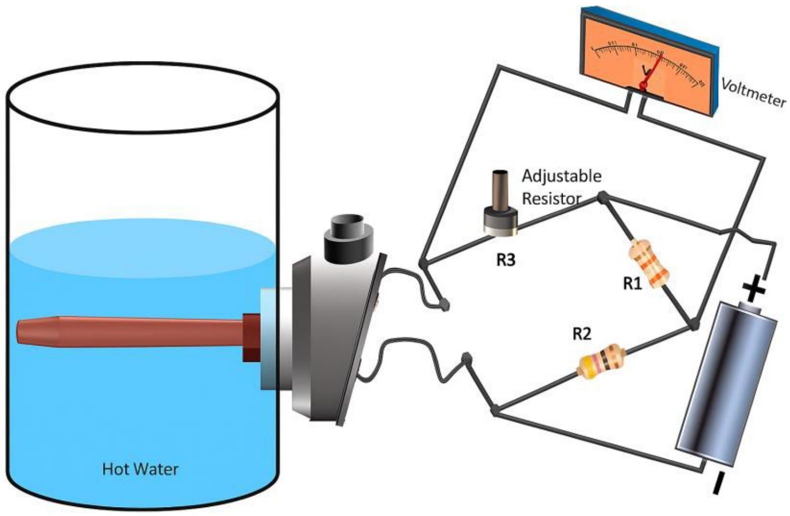


Fig. 5.3: Schematic Diagram of Experiment

There are commonly three wiring configurations are available for RTD.

Two-wire configuration

A 2-wire RTD is the most basic configuration, consisting of a sensing element with a single lead wire connected to each end. This setup makes it the simplest and most cost-effective RTD configuration available. However, because the lead wire resistance is included in the total resistance measurement, it can introduce significant errors, particularly in applications with long cable runs.

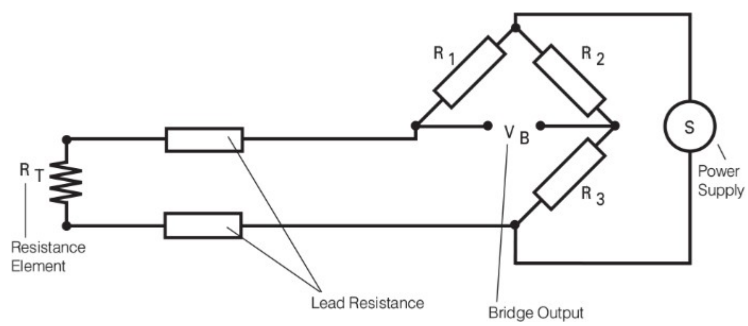


Fig. 5.4: 2-wire RTD Construction

Pros: High accuracy and reliability

Cons: Requires stopping flow for installation or removal

Application: Short-distance applications where high precision is not critical, such as basictemperature monitoring

Three-wire configuration

A 3-wire RTD is the most commonly used configuration in industrial applications. It features two wires connected to one side of the RTD element and a single wire on the other. This design helps compensate for lead wire resistance by assuming that both lead wires have the same resistance.

While this assumption generally holds true in controlled environments, minor inaccuracies may still arise if wire lengths or resistances are unequal.

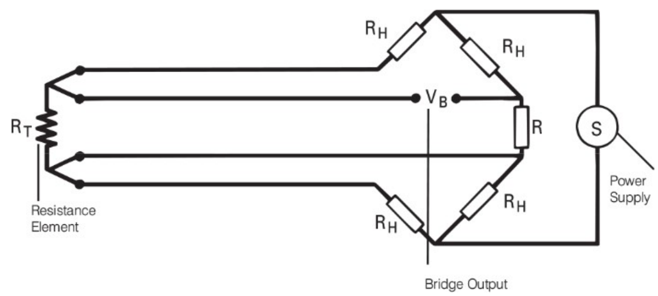


Fig. 5.5: 3-Wire RTD Construction

Pros: Cost-effective and easy to install

Cons: Lead wire resistance is includedin the measurement – leading to potential inaccuracies, particularly with longer cable runs.

Application: Short-distance applications where high precision is not critical, such as basic temperature monitoring.

Four-wire configuration

A 4-wire RTD is the most accurate configuration, designed to completely eliminate the effects of lead wire resistance. It utilizes two wires on each end of the RTD element, allowing precise resistance measurement by using a separate pair of wires for excitation and measurement. This configuration is commonly used in laboratory and high-precision industrial applications where measurement errors must be minimized.

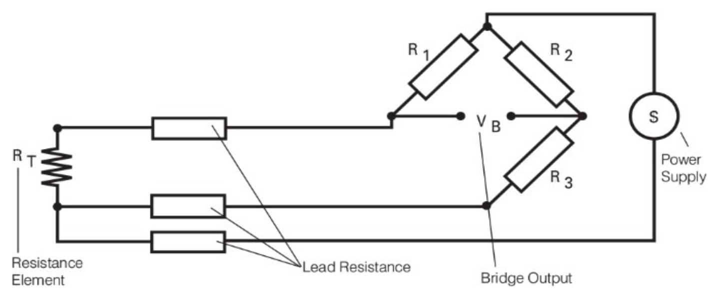


Fig. 5.6: 4-Wire RTD Construction

Pros: Provides the highest accuracy by completely compensating for lead wire resistance.

Cons: More complex wiring and higher cost.

Application: High-precision applications such as laboratory research, calibration systems, and critical industrial processes.

Selecting the appropriate RTD configuration depends on the application's accuracy requirements, wiring complexity, and budget. A 2-wire RTD may be sufficient for shorter runs or less critical measurements, while a 3-wire setup balances accuracy and cost for many industrial applications. For the highest precision, a 4-wire RTD is preferred, though it requires more complex wiring and higher installation costs.

Working Principle

The platinum resistance thermometer (PRT) works on the basis that as temperature is increased, the resistance also increases linearly with it, i.e.

$$R_T \propto T \quad \text{………..(i)}$$

The Callendar-Van Dusen equation is used to calculate the temperature of an RTD (Resistance Temperature Detector) based on its resistance measurement. It's a polynomial equation(ii) that accounts for the non-linear relationship between resistance and temperature. The general form is

$$R_T = R_0\left[1 + AT + BT^2 + CT^3(T-100)\right]\ (-200\,^\circ\mathrm{C} < T < 0\,^\circ\mathrm{C}),$$
$$R_T = R_0\left[1 + AT + BT^2\right]\ (0\,^\circ\mathrm{C} \le T < 850\,^\circ\mathrm{C}).$$

Here, R_T is the resistance at temperature T, R_0 is the resistance at 0 °C, and the constants are:

$$A = 3.9083 \times 10^{-3}\ ^\circ\mathrm{C}^{-1},$$
$$B = -5.775 \times 10^{-7}\ ^\circ\mathrm{C}^{-2},$$
$$C = -4.183 \times 10^{-12}\ ^\circ\mathrm{C}^{-4}.$$

For positive temperature, solution of the quadratic equation (iii) yields the following relationship between temperature and resistance:

$$T = \frac{-A + \sqrt{A^2 - 4B\left(1 - \frac{R_T}{R_0}\right)}}{2B}. \quad \text{……………..(iii)}$$

Then for a four-wire configuration with a 1 mA precision current source, the relationship between temperature and measured voltage V_T is:

$$T = \frac{-A + \sqrt{A^2 - 40B(0.1 - V_T)}}{2B} \quad \text{……………..(iv)}$$

To avoid complexity, as the relative change associated with resistance per degree change in temperature for Pt is small, we can neglect the higher-order terms and consider a linear approximation, i.e.

$$R(T) = R_0\,(1 + \alpha T) \quad \text{………….(v)}$$

$$T = \frac{1}{\alpha}\left(\frac{R(T)}{R_0} - 1\right) \text{ .... (vi)}$$

In the above equation, the constant term associated with temperature (α) is called the "temperature coefficient of resistance". R_o is the y-intercept of R vs T graph, and it is the resistance of platinum wire at 0°C. The temperature coefficient of resistance can be calculated by dividing the slope by R_o.

Table 5.1: Resistance Thermometer Types

RTD Type	Resistance in ohms (Ω) at 0°C
Pt_{100}	100
Pt_{500}	500
Pt_{1000}	1000

Procedure:

1. Connect all wires and instruments as shown in the Wheatstone Bridge. Place standard resistors P and Q in gaps 1 and 2. Place a rheostat in gap 3.
2. Place both the Platinum Resistance Thermometer (RTD) and a normal thermometer into a beaker filled with water.
3. Connect the RTD in gap 4.
4. Connect a galvanometer to the bridge setup to detect any unbalance.
5. Adjust the rheostat until the galvanometer shows zero deflection. This means the bridge is balanced.
6. Once the bridge is balanced, calculate the resistance of the RTD using the known values of P, Q, and rheostat.

$$\frac{R_{\text{RTD}}}{Q} = \frac{R_{\text{rheostat}}}{P}$$

7. Calculate temperature by using the equation (1)
8. Check the temperature from the standard thermometer and compare it with the RTD-calculated temperature.
9. Find the error

$$\text{Error} = T_{\text{RTD}} - T_{\text{actual}}$$

$$\text{Percentage Error} = \frac{\text{Error}}{T_{\text{actual}}} \times 100\%$$

Data Table and Calculation:

Table 5.2: Temperature Measurement Using Resistance Thermometer

SL. No.	Actual Water Temperature (ºC)	Measured Resistance of RTD (Ω)	Measured Temperature (ºC)	% Error
1.	0			
2.	20			
3.	40			
4.	60			
5.	80			
6.	100			

Graph:

Discussions:

Assignments:

1. Why is platinum commonly used in resistance thermometers instead of other metals?
2. What are the advantages and disadvantages of 2-wire, 3-wire, and 4-wire RTD configurations.

Experiment No:06

Experiment Name: Study and operation of a Programmable Logic Controller (PLC)

Objective: To learn basics of PLC, logic diagrams, Boolean algebraand ladder logic diagrams.

PLC:

- PLCs are the solid state member of computer family.
- It is a special form of microprocessor-based controller that uses programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic in order to control machines and processes.
- It uses integrated circuit instead of electromechanical devices to implement control.
- A PLC monitors inputs, makes decisions based on its program, and controls outputs to automate a process or machine.
- PLCs are similar to computers, but whereas computers are optimized for calculation and display tasks, PLCs are optimized for control tasks and the industrial environment.

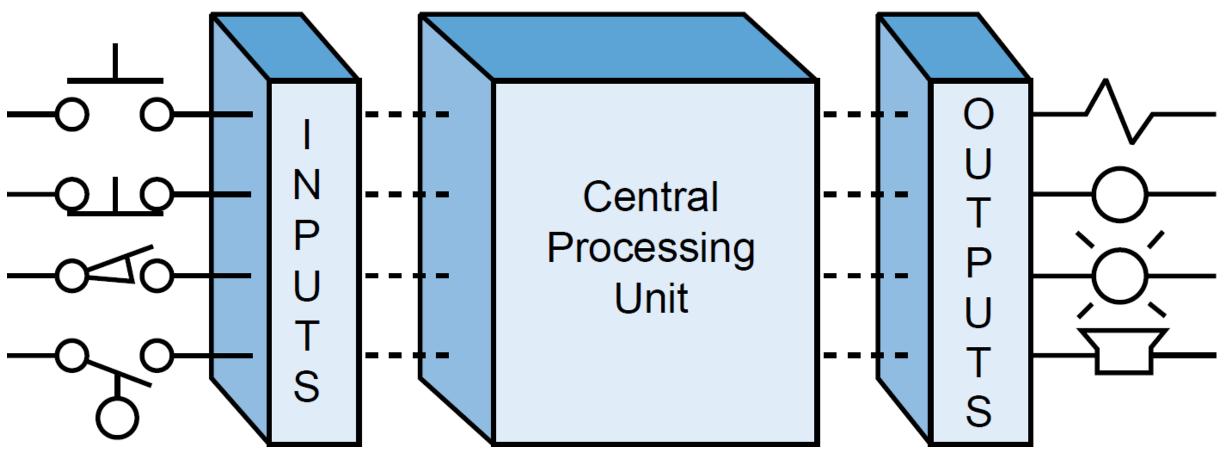


Fig. 6.1: PLC Schematic

Features of PLC:

- Rugged design; suitable for harsh industrial environments against high temperature variations, dust and vibrations.

- Industry standard I/O interfaces; capable of communicating with other PLCs, computers and intelligent devices.
- Industry standard programming languages; easily learned and understood. Programming is primarily concerned with logic, timing, counting and switching operations.
- Field programmable.
- Reduces hard wiring and wiring cost.
- Monitoring, error checking and diagnostics capability.
- Competitive in both cost and space requirements.

Applications of PLC:

- Manufacturing/Machining
    1. Assembly machines
    2. Boring
    3. Cranes
    4. Energy demand
    5. Grinding
    6. Injection/blow molding
    7. Material conveyors
    8. Metal casting
    9. Milling
    10. Painting
    11. Plating
    12. Tracer lathe
    13. Welding
- Metals
    1. Blast furnace control
    2. Continuous casting
    3. Rolling mills
    4. Soaking pit
- Mining
    1. Bulk material conveyors
    2. Loading/unloading
    3. Ore processing
    4. Water/waste management
- Lumber/Pulp/Paper
    1. Batch digesters
    2. Chip handling

Major Components: PLC consists of five major sections:

1. Power Supply
2. Memory
3. Central Processing Unit (CPU)
4. I/O Interface
5. Programming Section

Principles of Operation:

- An input accepts a variety of digital or analog signals from various field devices or sensors and converts them into a logic signal that can be used by the CPU.
- These field devices may be discrete or analog input devices, such as,
    1. Limit switches
    2. Pressure transducers
    3. Push buttons
    4. Motor starters
    5. Solenoids, etc.
- The CPU makes decisions and executes control instructions based on program instructions in memory.
- During its operation, the CPU completes three processes:
    1. It reads, or accepts, the input data from the field devices via the input interfaces
    2. It executes, or performs, the control program stored in the memory system, and
    3. It writes, or updates, the output devices via the output interfaces.
- This process of sequentially reading the inputs, executing the program in memory and updating the outputs is known as scanning.

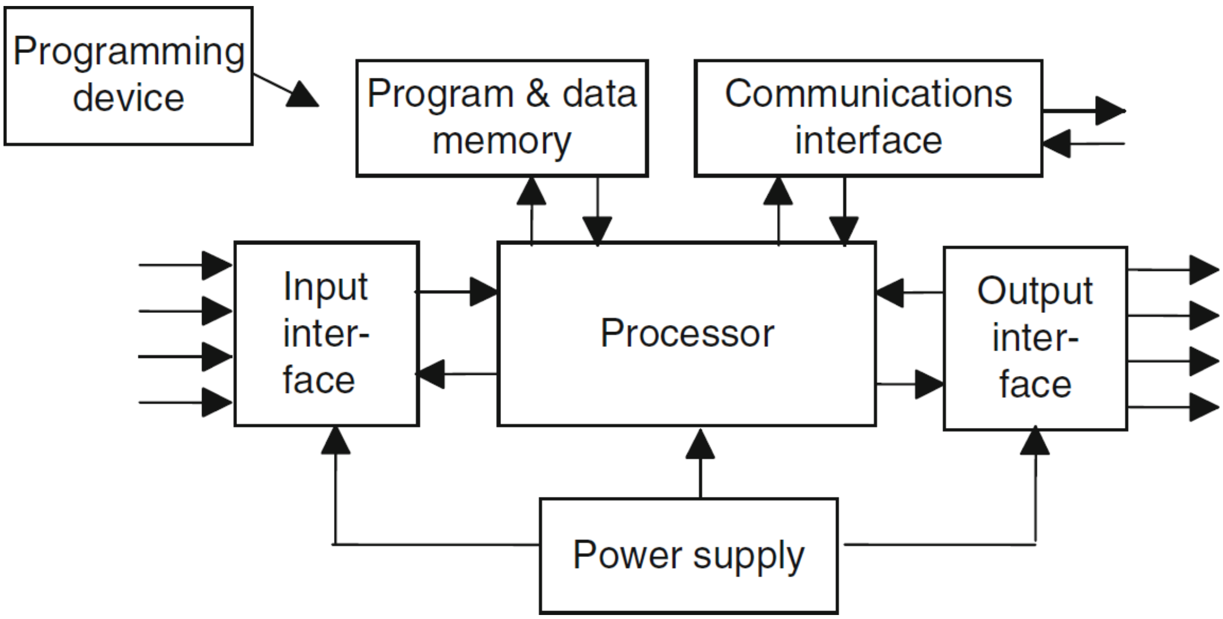


Fig. 6.2: Process Flow Diagram of PLC

- Output modules convert control instructions from the CPU into a digital or analog signal that can be used to control various field devices or actuators.
- A programming devices (programmer), usually a personal computer or a manufacturer's miniprogrammer unit, is required to enter the control program or instructions into memory.
- These instructions determine what the PLC will do for a specific input.
- An operator interface device allows process information to be displayed and new control parameters to be entered.

The system power supply provides all the voltages required for the proper operation of the various central processing.

PLC Programming Languages:

- There are five PLC programming languages;
    1. **Ladder Diagram(LAD):** Graphic language derived from circuit diagram of directly wired relay controls
    2. **Function Block Diagram (FBD)** :Functions & functions block are represented graphically and interconnected into networks.
    3. **Instruction List (IL):** Textual assembler-type language consisting of an operator and an operand.
    4. **Structured Text (ST)**: High level language based on Pascal.
    5. **Sequential Function Chart (SFC):** A language resource for the structuring of sequence-oriented control programs.

Ladder Diagram:

- Ladder diagram is type of graphic language for automatic control systems it had been used for a long period since World War II.
- The use of ladder programming involves writing a program in a manner to drawing a switching circuit.
- Originally there are only few basic elements available such as Normally Open or contact, Normally Closed or contact, output coil, timers and counters.

Ladder Programming Conventions:

- When a ladder diagram contains a functional block, contact instructions are used to represent the input conditions that drive the block's logic.
- A functional block can have one or more enable inputs that control its operation. In addition, it can have one or more output coils, which signify the status of the function being performed.

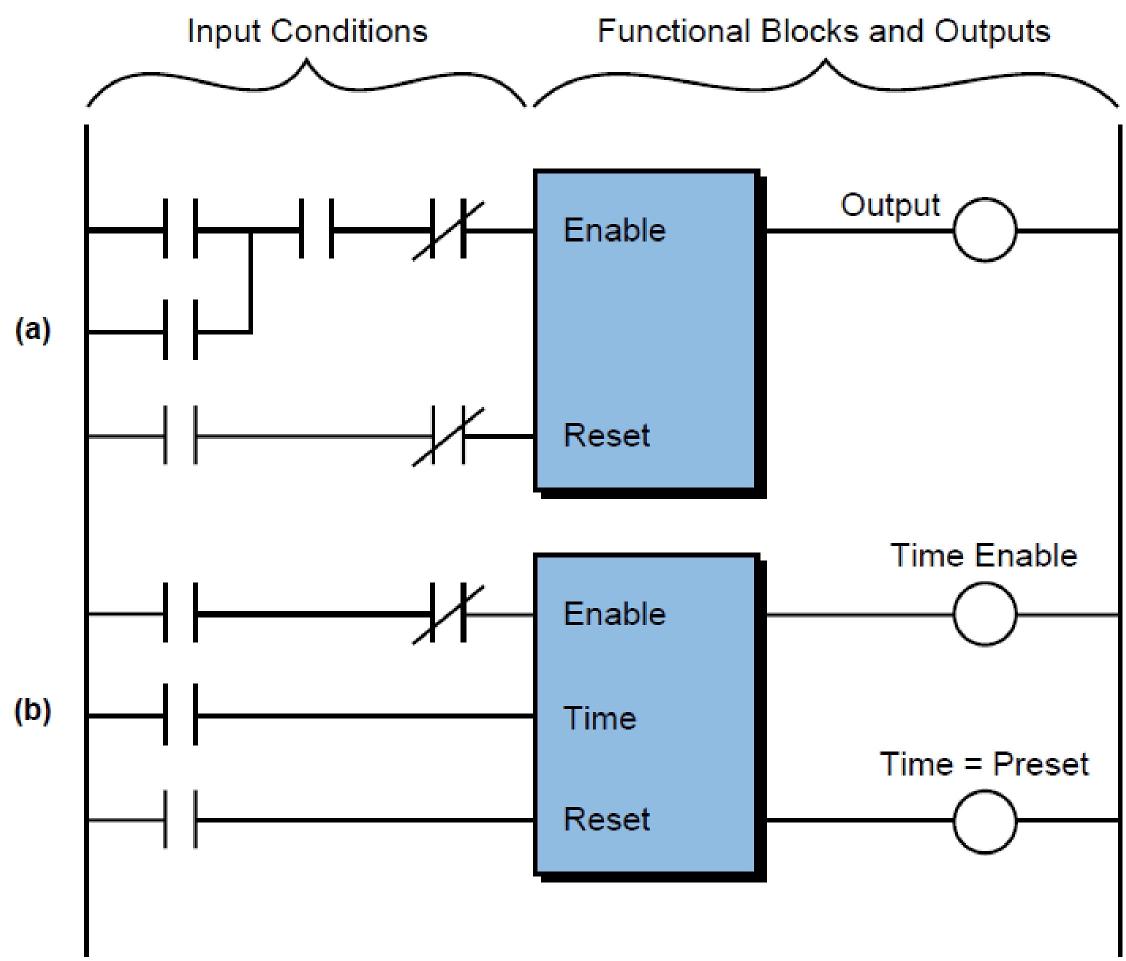
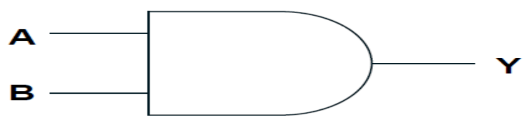


Fig. 6.3: Ladder Programming Conventions

Logical Functions:

AND Gate



AND Gate

AND Truth Table		
Inputs		Output
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

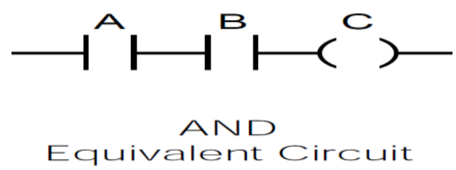
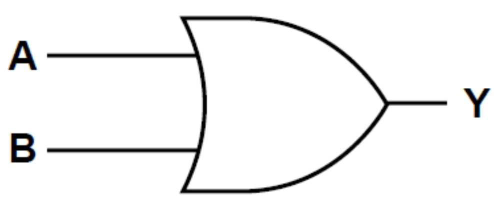


Fig. 6.4: AND Gate Symbol, Truth Table and Equivalent Circuit

OR Gate:

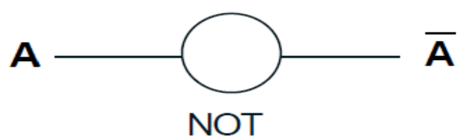


OR Gate

OR Truth Table		
Inputs		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Fig. 6.5: OR Gate Symbol and Truth Table

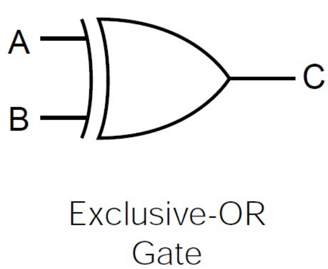
NOT Gate:



NOT Truth Table	
Input	**Output**
A	**Ā**
0	1
1	0

Fig. 6.6: NOT Gate Symbol and Truth Table

XOR Gate:



A	B	C
0	0	0
0	1	1
1	0	1
1	1	0

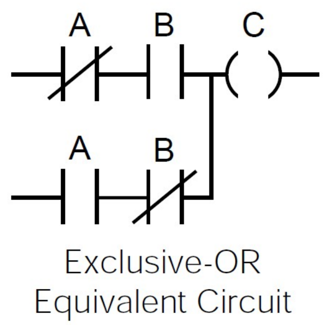
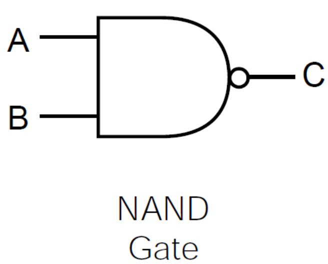


Fig. 6.7: XOR Gate Symbol, Truth Table and Equivalent Circuit

NAND Gate:



A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

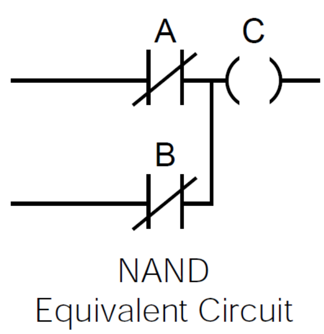


Fig. 6.8: NAND Gate Symbol, Truth Table and Equivalent Circuit

NOR GATE:

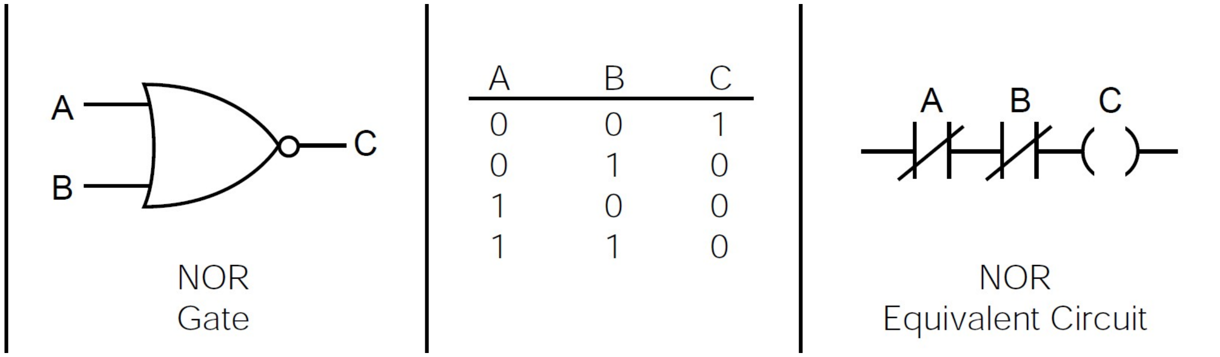
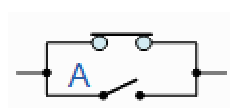
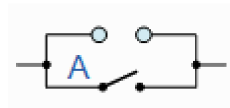
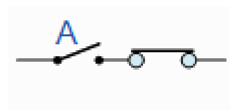
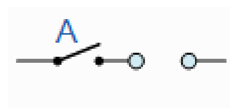
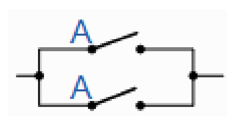
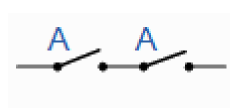
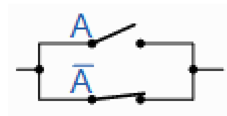
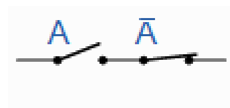
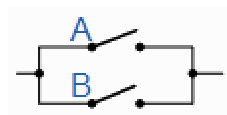
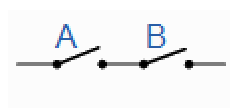


Fig. 6.9: NOR Gate Symbol, Truth Table and Equivalent Circuit

Table 6.1: Laws of BOOLEAN Algebra

Boolean Expression	Description	Equivalent Switching Circuit	Boolean Algebra Law or Rule
A + 1 = 1	A in parallel with closed = "CLOSED"		Annulment

A + 0 = A	A in parallel with open = "A"		Identity
A . 1 = A	A in series with closed = "A"		Identity
A . 0 = 0	A in series with open = "OPEN"		Annulment
A + A = A	A in parallel with A = "A"		Idempotent
A . A = A	A in series with A = "A"		Idempotent
NOT A = A'	NOT NOT A (double negative) = "A"		Double Negation

$A + A' = 1$	A in parallel with NOT A = "CLOSED"		Complement
$A . A' = 0$	A in series with NOT A = "OPEN"		Complement
$A+B = B+A$	A in parallel with B = B in parallel with A		Commutative
$A.B = B.A$	A in series with B = B in series with A		Commutative
$(A+B)' = A'.B'$	invert and replace OR with AND		de Morgan's Theorem
$(A.B)' = A'+B'$	invert and replace AND with OR		de Morgan's Theorem

Assignment:

1. Draw the following logic diagrams

a. A.(B+C ')= Output

b. A ' (B+C) = Output

2. Prove that, A+BC = A.B + A.C according to BOOLEAN algebra.

3. Show the ladder logic diagrams for the three fundamental logic expressions (AND,OR, NOT)

Experiment No: 07

Experiment Name: Study and operation of a Pneumatic Control System (Pneumatic Trainer); Electro-pneumatic Control System; Derivative Pressure Control System.

(a) Pneumatic Control System (Pneumatic Trainer)

Objective: The objective of the experiment is to get acquainted with different types of control systems, components of pneumatic control system and its application.

Pneumatic Control System: Pneumatics is a branch of engineering that makes use of gas or pressurized air. Pneumatic systems used extensively in industry are commonly powered by compressed air or compressed inert gases. A centrally located and electrically powered compressor powers cylinders, air motors, and other pneumatic devices. A pneumatic system controlled through manual or automatic solenoid valves is selected when it provides a lower cost, more flexible, or safer alternative to electric motors and actuators.

Factory-plumbed pneumatic-power users need not worry about poisonous leakage, as the gas is usually just air. Smaller or stand-alone systems can use other compressed gases that present an asphyxiation hazard, such as nitrogen—often referred to as OFN (oxygen-free nitrogen) when supplied in cylinders.

Any compressed gas other than air is an asphyxiation hazard—including nitrogen, which makes up 78% of air. Compressed oxygen (approx. 21% of air) would not asphyxiate, but is not used in pneumatically-powered devices because it is a fire hazard, more expensive, and offers no performance advantage over air.

Portable pneumatic tools and small vehicles, such as Robot Wars machines and other hobbyist applications are often powered by compressed carbon dioxide, because containers designed to hold it such as soda stream canisters and fire extinguishers are readily available, and the phase change between liquid and gas makes it possible to obtain a larger volume of compressed gas from a lighter container than compressed air requires. Carbon dioxide is an asphyxiate and can be a freezing hazard if vented improperly. Some other common uses of pneumatic system are lifts, bus doors etc.

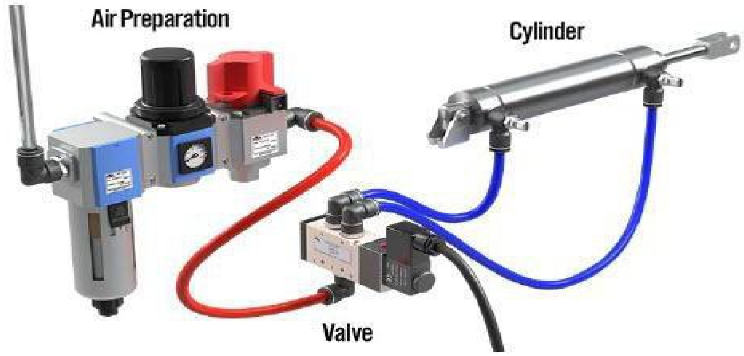


Fig. 7.1: Basic Pneumatic System

Comparison to hydraulics:

Advantages of pneumatics:

- Simplicity of design and control—Machines are easily designed using standard cylinders and other components, and operate via simple on-off control.
- Reliability—Pneumatic systems generally have long operating lives and require little maintenance. Because gas is compressible, equipment is less subject to shock damage. Gas absorbs excessive force, whereas fluid in hydraulics directly transfers force. Compressed gas can be stored, so machines still run for a while if electrical power is lost.
- Safety—There is a very low chance of fire compared to hydraulic oil. Newer machines are usually overload safe.

Advantages of hydraulics:

- Liquid does not absorb any of the supplied energy.
- Capable of moving much higher loads and providing much higher forces due to the incompressibility.
- The hydraulic working fluid is basically incompressible, leading to a minimum of spring action. When hydraulic fluid flow is stopped, the slightest motion of the load releases the pressure on the load; there is no need to "bleed off" pressurized air to release the pressure on the load.
- Highly responsive compared to pneumatics.
- Supply more power than pneumatics.
- Can also do many purposes at one time: lubrication, cooling and power transmission.

Components of a Pneumatic Control System:

1. Sensor: A sensor is like a brain of a control system. It does not execute an action but it signals the actuator when to execute the required actions and accordingly it runs the total systems. There are several types of sensors like light sensor, proximity sensor, motion sensor etc.

2. Actuator: The actuator is like the hand or leg of a control system. It executes the required action in response to the signal of the sensor. There are two types of actuators used in a pneumatic system

a. Single Acting Cylinder (SAC): It has only one port for inlet and outlet of gas or air. It has a restoring force (spring) to come back to its initial position without any impact of air. It can be operated with a single 3 port valve.

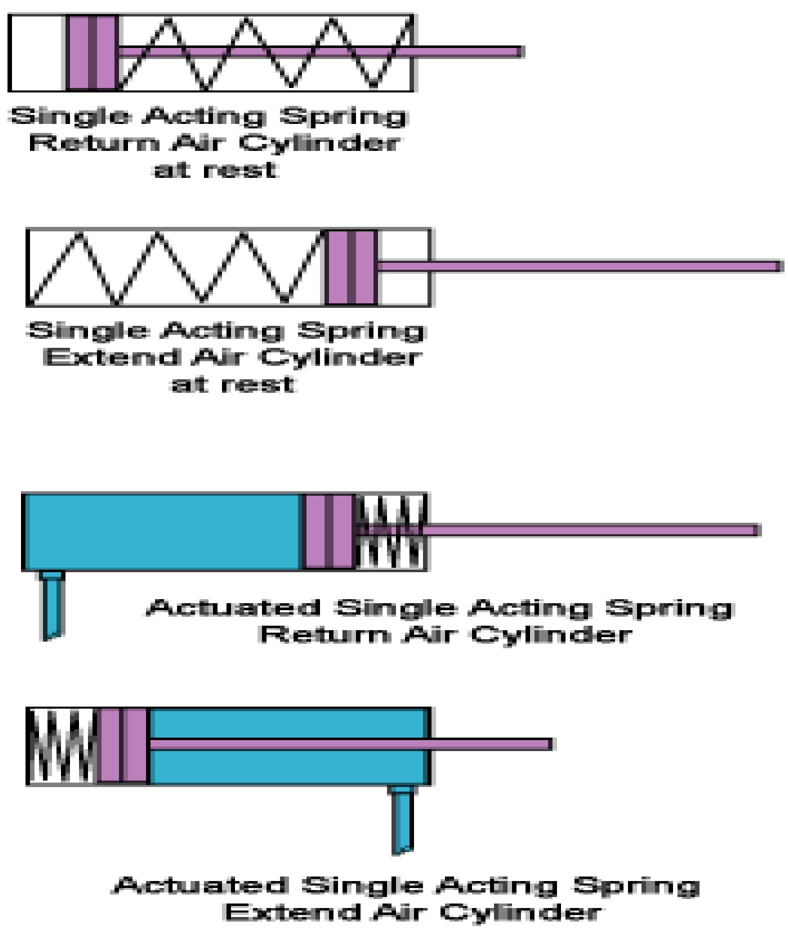


Fig. 7.2: Single Acting Cylinder

b. Double Acting Cylinder (DAC): It has two ports, one inlet and one outlet port for air in andout. It has no restoring force attached to it. To operate a double acting cylinder, two 3-port valvesor a single 5-port valve is required.

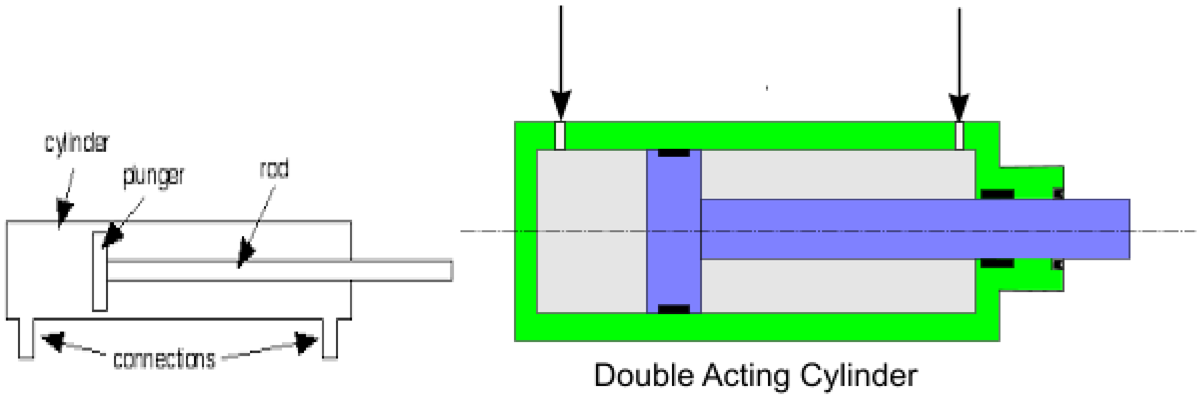


Fig. 7.3: Structural Diagram of DAC

3. Valves: Two types of valves are used to operate the actuators of a pneumatic system.

a. 3-Port valve: It has only three ports along with a maximum of one connection between themand one port always open. A 3-Port valve can be lever operated or push/pull switch operated. In any position of the lever/switch if port 1 is connected to port 2 then in the other position port 2will be connected to port 3 leaving port 3 open in one position and port 1 open in the next. Thefollowing figures show a lever operated and a push-pull operated 3 port valves.

Fig. 7.4: 3-Port Valve

b. 5-Port valve: It has 5 ports along with a maximum of two connections between them and two ports always open. A port can be lever operated or push/pull switch operated. The advantage of a 5-Port valve is that it can handle a DAC on its own whereas in case of 3-Port valves two are simultaneously required to be operated to handle a DAC. Moreover a 5-Port valve can be used as a 3-Port valve as well.

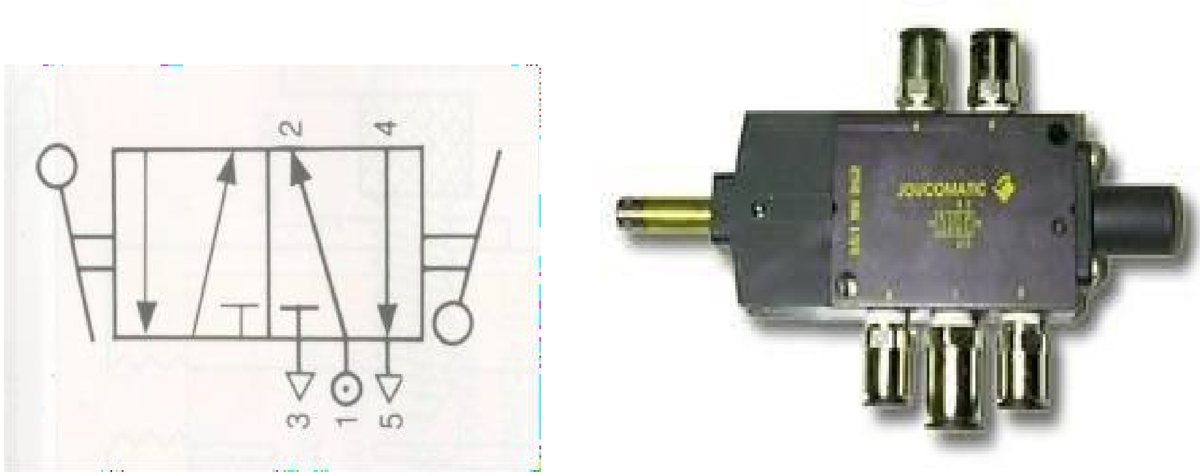


Fig. 7.5: 5-Port Valve

In your control you will be demonstrated the actions of a pneumatic system through a pneumatic trainer which uses air as power input.

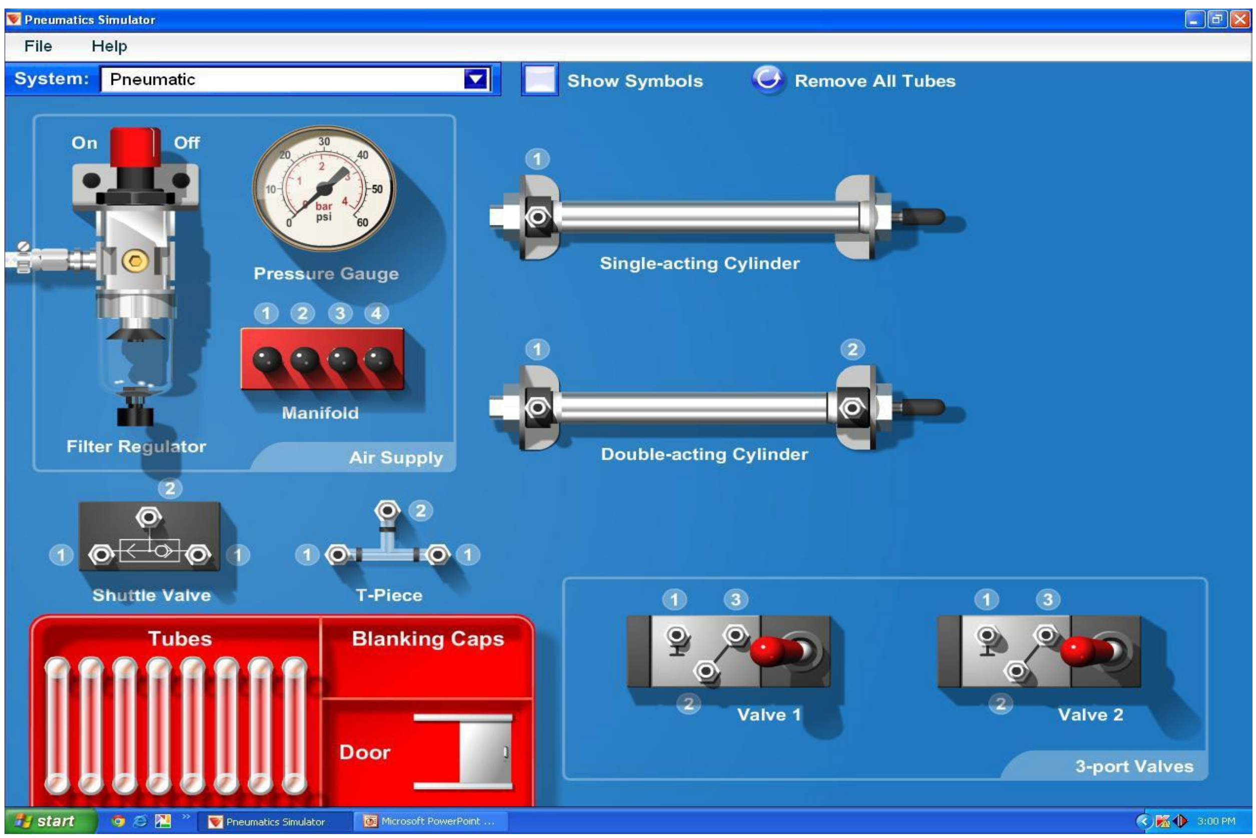


Fig. 7.6: Pneumatic Trainer Simulation

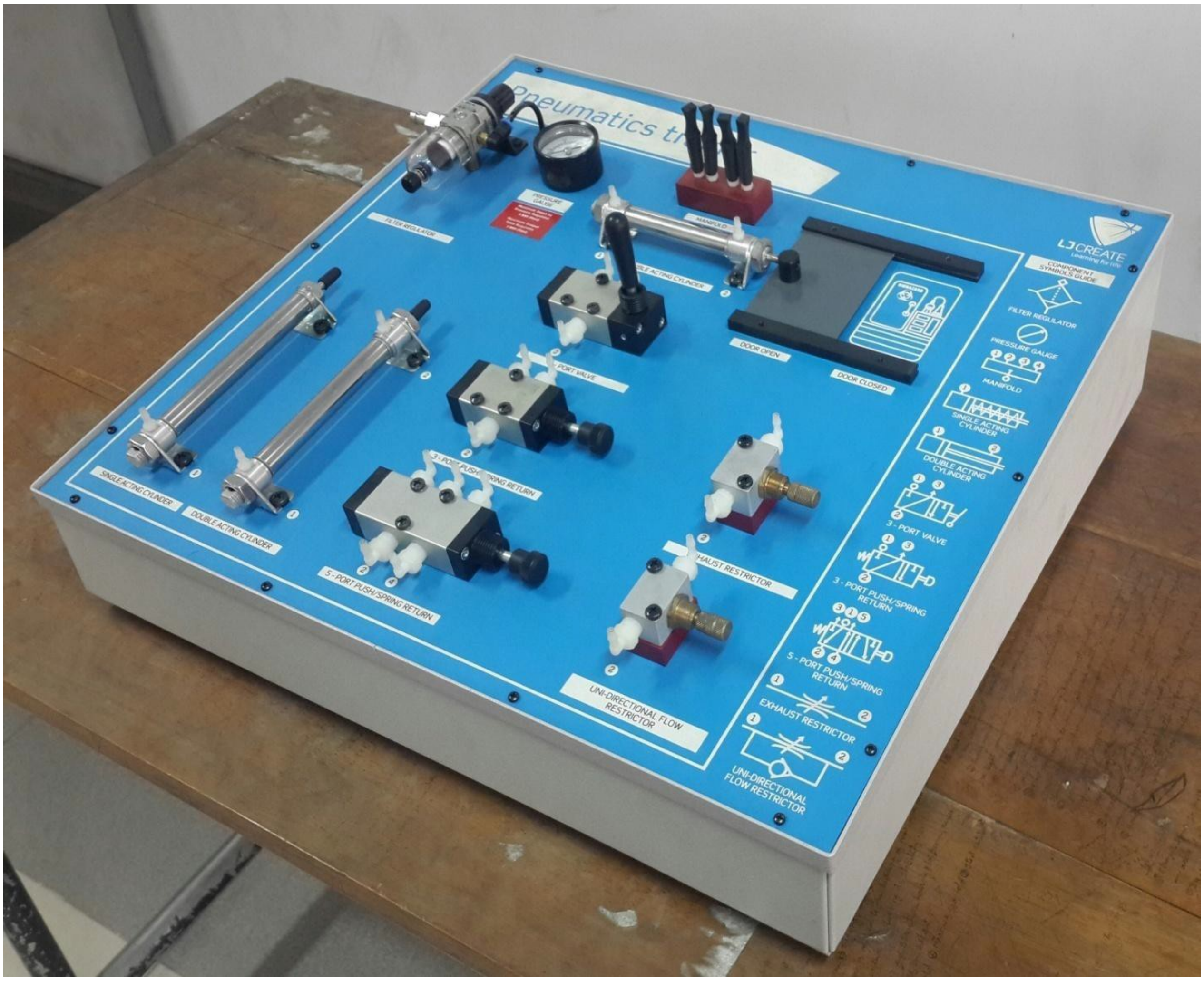


Fig. 7.6: Pneumatic Trainer

Assignment:

1. What are the advantages of a pneumatic system over a hydraulic one?

2. If you are driving a car on highway would you recommend a pneumatic break system in it? Why?

3. Is there any way a DAC can be operated with a single 3-port valve? If yes/no, why?

(b) Electro-pneumatic Control System

Objective: The purpose of this experiment is to get exposure to a practical implementation of combination of pneumatic control system and PLC logics.

Electro-pneumatic control: An electro pneumatic control system uses compressible fluid as its input power and facilitates automation through the use of PLC logics. So, it is actually a combination of a pneumatic and an electronic system.

In this experiment you will be illustrated an action of the electro-pneumatic trainer which will be powered by the pneumatic trainer shown in previous experiment. And several logic gates will be used to design a circuit which will facilitate the disposal of two different items in two different bins. The pneumatic trainer has 3 cylinders to push the object to be disposed. One solenoid valve to take pneumatic input and power the cylinders and three sensors (Dispenser sensor, Check point sensor and transparency sensor). There is a PLC board attached to it to design the circuit to perform required actions. The sequence of operations can be controlled both manually and automatically. The following diagrams shows the Electro-Pneumatic trainer of this experiment

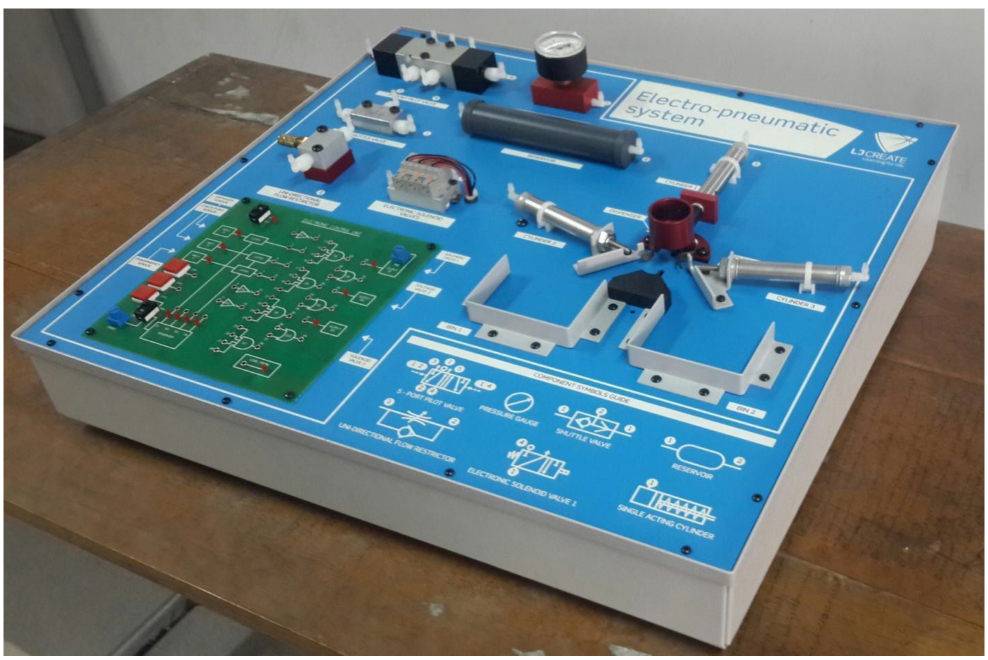


Fig. 7.7: Electro-pneumatic Trainer

Experimental details will be taught in the lab experiment. And the simulation of the device will also be illustrated during the experiment.

Assignments

1. Draw the logic diagram of the that was designed in this experiment.

2. Draw the block diagram of the solenoid valve used in this experiment

(c) Proportional Integral Derivative Pressure Control System

Objective: The objective of this experiment is to learn the mechanism of PID control system and its industrial applications.

Theory: A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a desired set point and a measured process variable and applies a correction based on proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D) which give their name to the controller type. The controller attempts to minimize the error over time by adjustment of a control variable u(t), such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_P e(t) + K_d \frac{de(t)}{dt} + K_I \int_0^t e(t)\,dt \quad \text{.........................(i)}$$

where K_P , K_I and K_d , all non-negative, denote the coefficients for the proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D). In this model:

- P accounts for present values of the error. For example, if the error is large and positive, the control output will also be large and positive.
- I accounts for past values of the error. For example, if the current output is not sufficiently strong, the integral of the error will accumulate over time, and the controller will respond by applying a stronger action.
- D accounts for possible future trends of the error, based on its current rate of change

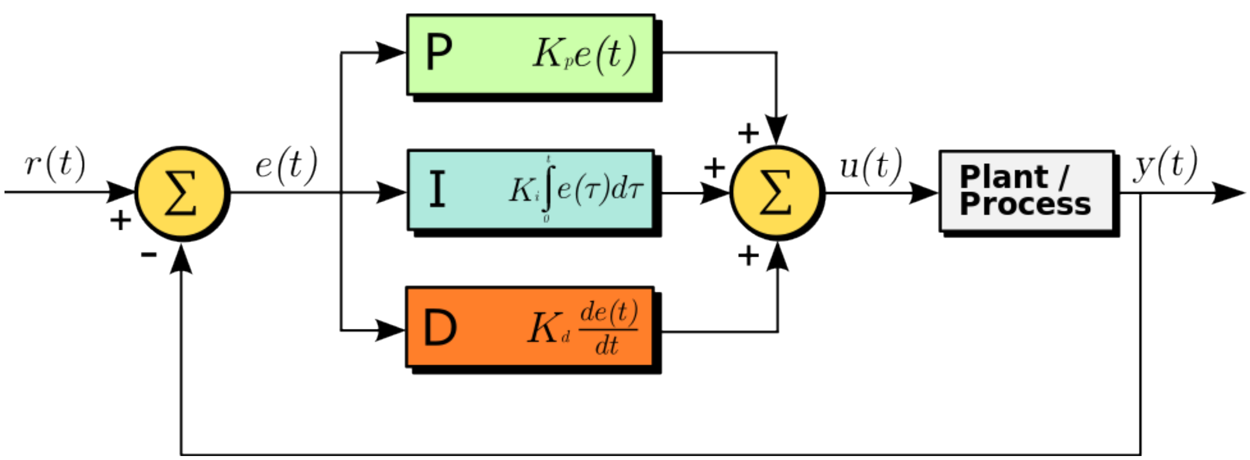


Fig. 7.8: A schematic of PID control system

As a PID controller relies only on the measured process variable, not on knowledge of the underlying process, it is broadly applicable. By tuning the three parameters of the model, a PID controller can deal with specific process requirements. The response of the controller can be described in terms of its responsiveness to an error, the degree to which the system overshoots a set point, and the degree of any system oscillation. The use of the PID algorithm does not guarantee optimal control of the system or even its stability.

Some applications may require using only one or two terms to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller is called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value.

For discrete-time systems, the term PSD (proportional-summation-difference) is often used.

Proportional Term: The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain constant.

The proportional term is given by,

$P_{out} = K_P e(t)$ …………..(ii)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

Integral Term: The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (K_i) and added to the controller output.

The integral term is given by

$I_{out} = K_I \int_0^t e(t)\,dt$ ……………….(iii)

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value (see the section on loop tuning).

Derivative Term: The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

The derivative term is given by,

$$D_{out} = K_d \frac{de(t)}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(iv)}$$

Derivative action predicts system behavior and thus improves settling time and stability of the system. An ideal derivative is not causal, so that implementations of PID controllers include an additional low-pass filtering for the derivative term to limit the high-frequency gain and noise. Derivative action is seldom used in practice though – by one estimate in only 25% of deployed controllers because of its variable impact on system stability in real-world applications.

Loop Tuning: Tuning a control loop is the adjustment of its control parameters (proportional band/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Stability (no unbounded oscillation) is a basic requirement, but beyond that, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, and more sophisticated techniques are the subject of patents; this section describes some traditional manual methods for loop tuning.

Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple (and often conflicting) objectives such as short transient and high stability are to be achieved. PID controllers often provide acceptable control using default tunings, but performance can generally be improved by careful tuning, and performance may be unacceptable with poor tuning. Usually, initial designs need to be adjusted repeatedly through computer simulations until the closed-loop system performs or compromises as desired.

Some processes have a degree of nonlinearity and so parameters that work well at full-load conditions don't work when the process is starting up from no-load; this can be corrected by gain scheduling (using different parameters in different operating regions).

There are two types of tuning system,

Manual Tuning: the parameters are manually controlled to optimize the output and the other is software controlled where the parameters are controlled by the software to get the desired set point for both input and output control loop.

Experimental Device: The pressure control device we use in our experiment is PCT 53 pressure control device. It is software operated and the parameters can be manually or automatically controlled.

Fig. 7.9: PID Pressure Control Device

The software simulates the graphical representation of pressure change with time along with the numerical values of the set parameters and set point. There are four valves in the device along with a solenoid valve, one input valve, one output valve and an emergency valve to protect air entrapping.

Limitations of PID: While PID controllers are applicable to many control problems, and often perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications, and do not in general provide optimal control. The fundamental difficulty with PID control is that it is a feedback control system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. While PID control is the best controller in an observer without a model of the process, better performance can be obtained by overtly modeling the actor of the process without resorting to an observer.

PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control setpoint value. They also have difficulties in the presence of non-linearities, may trade-off regulation versus response time, do not react to changing process behavior (say, the process changes after it has warmed up), and have lag in responding to large disturbances.

The most significant improvement is to incorporate feed-forward control with knowledge about the system, and using the PID only to control error. Alternatively, PIDs can be modified in more minor ways, such as by changing the parameters (either gain scheduling in different use cases or adaptively modifying them based on performance), improving measurement (higher sampling rate, precision, and accuracy, and low-pass filtering if necessary), or cascading multiple PID controllers.

Another problem faced with PID controllers is that they are linear, and in particular symmetric. Thus, performance of PID controllers in non-linear systems (such as HVAC systems) is variable. For example, in temperature control, a common use case is active heating (via a heating element) but passive cooling (heating off, but no cooling), so overshoot can only be corrected slowly – it cannot be forced downward. In this case the PID should be tuned to be overdamped, to prevent or reduce overshoot, though this reduces performance (it increases settling time).

Assignment:

1. Why is PID suboptimal in case of non-linearities?
2. What problems may arise if the differential part is missing in a PID?
3. What are the limitations of a PID?
4. Mention a few industrial applications of PID.