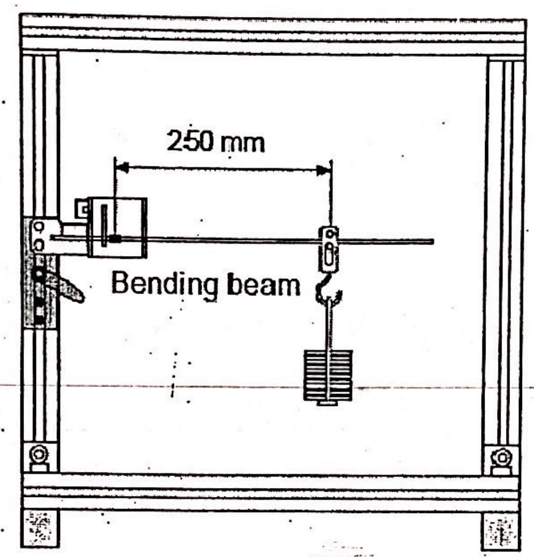
The University of Jordan

Faculty of Engineering & Technology

Mechanical Engineering Department



Engineering Measurements Lab

University Of Jordan
Faculty of Engineering and Technology
Mechanical Engineering Department

Measurement Lab.

EXPERIMENT 5 :

SINE BAR & ANGULAR MEASURMENTS

Student Name :
Student No. :

GROUP (   )

SINE BAR & ANGULAR MEASURMENTS

OBJECTIVES:

To familiarize student with the use of bevel protractor, vernier protractor, clinometer and sine bar for measuring angles.

APPARATUS:

1) Plain bevel protractor.
2) Vernier protractor.
3) Clinometer.
4) Sine bar.
5) Block gauges.
6) Specimen A & B.
7) Granite plate.

THEORY:

Bevel Protractor:

When two surfaces are at any angle other than 90°, the angle between them must be tested with some form of protractor. Instruments for this purpose may have a scale of degrees, enabling the angle to be read off, or they may consists of gauge which must be set to the angle before use. And the Bevel Protractor fig. (1) is an example of this second variety of gauges, and must be set to the correct angle before use.

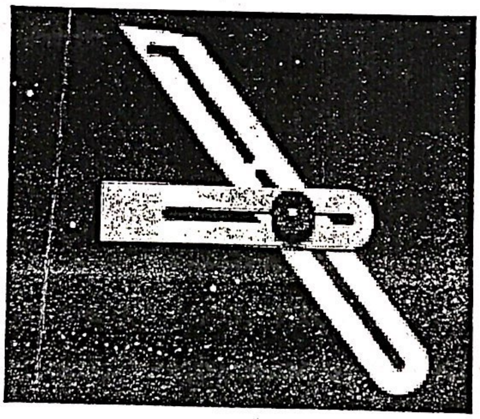


Fig. (1) bevel protractor

The Plain Bevel Protractor:

Consists mainly from main scale, movable arm and fixed nut, see fig(2). Its main scale is divided into 180 division, each division equals 1°, thus accuracy =+0.5° and total revolution can be measured = 180°.

NOTE: °=degree, '= minute.

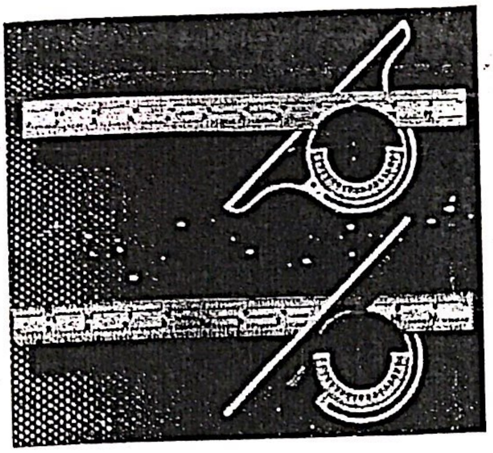


Fig. (2) Plain bevel protractor

Vernier Protractor:

The main scale of this device is divided up into degrees from 0 to 90° each way. The vernier scale is divided up to that 12 of its division occupying the same space as 23° on the main scale, thus 1 vernier division =23/12= 1.92 degree on main scale. The instrument therefore allows settings to 5 min of angle to be obtained, so we use it to get accurate readings. This device has a movable arm, plate blade, fixed nut and vernier scale, see fig. (3).

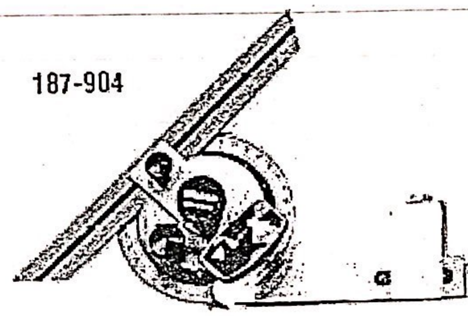


Fig. (3) Vernier protractor

Reading the vernier protractor:

1- Read of directly from the scale the number of whole degrees between 0 on the main scale and 0 on the vernier scale.
2- Count in the same direction the number of divisions from the 0 on the vernier scale to the first line on it that is level with a line on the main scale. As each division on the vernier scale represents 5', the number of these divisions multiplied by 5 will be the number of minutes to be added to the whole number of degrees. Actually the multiplication is not necessary, as it has been done on the scale. In fig. (4) notice that the number of the whole degrees is 85 degrees, and the mark on the vernier representing 30 minutes is level. The reading is therefore 85° 30'.

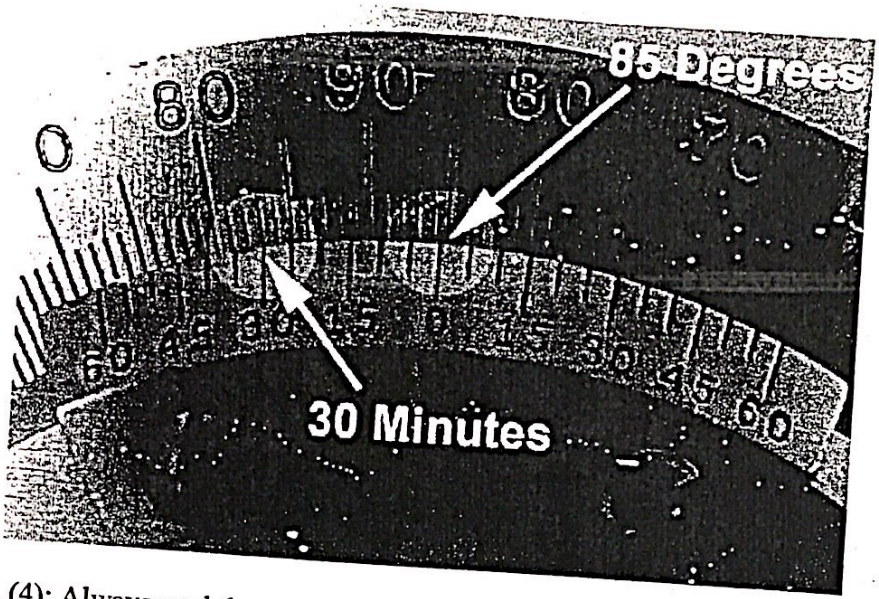


Fig. (4): Always read the vernier in the same direction that you read the dial.

The Clinometer:

The clinometer is a special case of the application of the spirit level. In this instance the level is mounted in a ratable body carried in a housing, one face of which forms the base of the instrument. A main use of the instrument is the measurement of the included angle of two adjacent faces of a work piece. Thus, in use, the instrument base is placed on one face and rot table body is adjusted until a zero reading of the bubble is obtained. The angle of rotation necessary to bring this about is then shown on an angular scale moving against an index.
A second reading is taken in a similar manner on the second face of the work piece, the included angle between the faces being the difference the first and the second readings. Depending upon the type of instrument used, reading direct to 1 min are obtained, and up to range of movement of 90°, see fig. (5).
Main Scale =360°.
Vernier scale: full revolution= 1° = 60 min, so each division on vernier scale = 1 min.

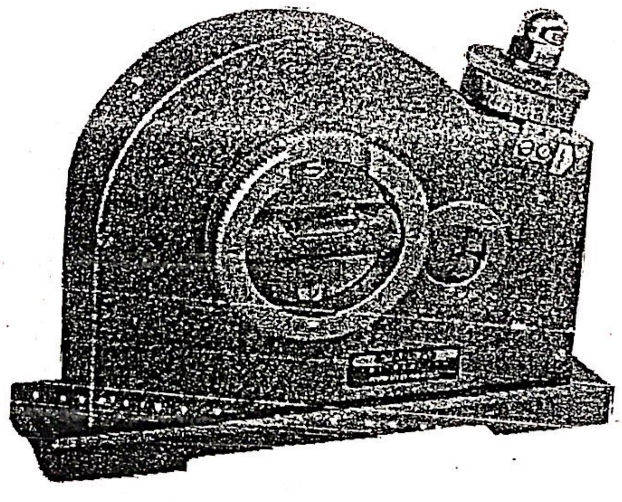


Fig. (5) Clinometer

Reading the clinometer:

1- Measure the angle γ of the component provided with the plate and the vernier protractors. Enter the values in table.

2- To measure the angle γ of the component with the clinometers:

a. Place the component on the table and mark it around.

b. But the clinometer on to of the component and the same axis, of the specimen.

3- To determine the inclination of the clinometer, the bubble unit is leveled by releasing the worm and turning the degrees graduated wheel:

a. Finer adjustment is made with the knurled micrometer knob.

b. Note the readings in degrees and minutes.

c. Take second reading by keeping the clinometer in the same direction but reverse the component.

Sine Bar:

The bar is essentially a hardened steel beam mounted on two hardened cylinders. The high degree of accuracy and precision available for length measurement in the form of gauges blocks may be utilized for angle measurements. The center distance between the two cylinders = 200 mm. Hence, if the difference in height of the cylinder can be accurately measured, possibly with gauge block stack, a right angle triangle is available from which an applied rate value of the angle can be calculated, using the Trigonometrically ratio.

Thus, when θ = angle to be measured then

$$\sin\theta = \frac{side\_opposite\_the\_angle}{Hypotenuse}$$

See fig.(6), you can see that sinθ= h/l

So, probable error = dθ $= \pm\left(\frac{dH}{H}+\frac{dL}{L}\right)\tan\theta$

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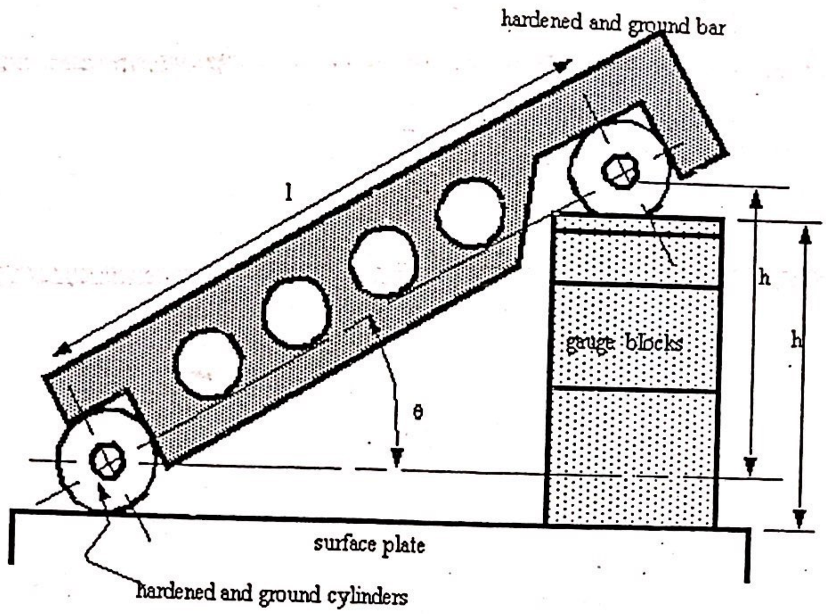

l = distance between centres of ground cylinders (typically 5" or 10")
h = height of the gauge blocks
θ = the angle of the plate

$$\theta = \operatorname{asin}\left(\frac{h}{l}\right)$$

Fig. (6) Sine bar

Gauge blocks can provide lengths only in small steps and it may not possible to build a gauge pile to the exact height required for a given angle and we use a dial indicator to make sure that we are at the exact height. The error is small but its magnitude depends on the step change of gauge block set.
To insure that the compound angle error is not introduced, the axis of the work must always be parallel to the axis of the sine bar.

PROCEDURE:

First of all clean the component and remove the burrs if there is any, also make sure that the surface plate is nice and clean. In order to avoid compound angle error care must be taken in aligning the work piece with the sine bar axis.
Set up the sine bar and work piece as shown up in fig. (6), so that the upper surface of the work piece is approximately parallel with the table surface. Take the series of readings along its upper surface with the dial gauge. The readings are not constant, increase or decrease the gauge block height until the DTI has same readings at both ends.
Finally add the gauge block increments to work out the value of h.

CALCULATIONS:

Calculate the probable error that can occur in measuring the angle with following individual errors.

e.g. Accumulated gauge block error from calibration certificate +0.00001 mm.
Sine bar cylinders center distance error –0.00005 mm.

DISCUSSION:

Discuss the personal skills required, overall time taken in measurement and suggest whether you would use the sine bar for one component or on a production line.

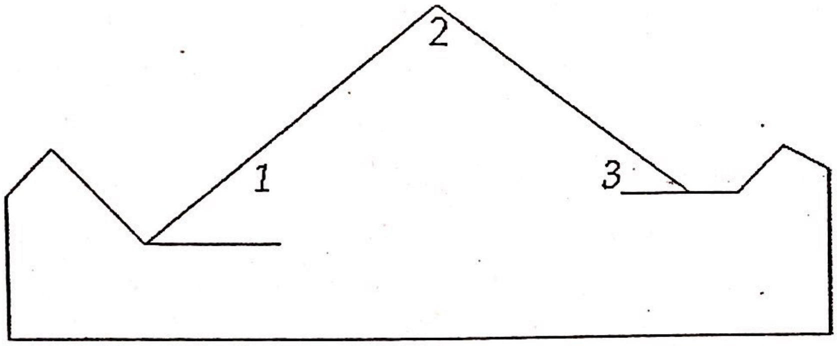

Fig. (7) The specimen

RESULTS:

Equipment used	Angle 3			Angle 2			Angle 1			Accuracy	
	deg	min	sec	deg	min	sec	deg	min	sec	min	sec
Plate Protractor											
Vernier Protractor											
Clinometer											
Sine Bar											

32° 31'

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Course Outline

Course Name: Engineering Measurements lab.
Course Number: 904424
Credit Hours: 1
Semester: Summer Semester 2011-2012
Instructor: Eng.Ahmad Bani yaseen
E-mail: a.baniyaseen@ju.edu.jo
Class Schedule: 12:40 – 15:40 Monday, Wednesday, sec: 1
Text Book: Lab. Manual Sheet.

Objectives:

The purpose of this laboratory is to expose the students to the measurement tools and equipments and to provide them training in using these instruments in order to strengthen and deepen their understanding of the principles of these subjects.

References:

1. Holman, J. P., Experimental Methods for Engineers. 7th Ed. McGraw-Hill.
2. Doebelin, E. O., Measurement Systems: Application and Design. 4th Ed. McGrawHill.
3. Figliola and Beasley, Theory and Design for Mechanical Measurements. 2nd Ed. Wiley.
4. Beckwith, Buck, and Marangoni, Mechanical Measurements. 3rd Ed. Addison Wesley.
5. Cheremisinoff, N. P. and Cheremisinoff P. N., Flow Measurement for Engineers and Scientists., Marcel Dekker, New York.
7. Jain, Er. R. K., Mechanical and Industrial Measurements. 8th Ed. Khanna Publishers, Delhi.
8. Dally, J. W., Riley, W. F., and McConnell, K. G., Instrumentation for Engineering Measurements, Wiley.

Remarks:

I. Minimum Student Materials

Lab. Manual, class handouts, engineering calculator.

II. Minimum College Facilities

Lab. with white board and projection facilities; library; computer facilities.

III. Attendance:

Attendance of classes is obligatory. Absence must be verified according to the university's regulation.

Grading:

1. Reports 20%
2. Mid Exam 30%
3. Quizzes 10%
4. Final Exam 40%

Experiments Schedule

Week	Group A	Group B
02-Mon (18/6/12)	Linear measurement	Autocollimator
02-Wed (20/6/12)	Autocollimator	Linear measurement
03- Mon (25/6/12)	Strain Gauges	Power & Torque
03- Wed (27/6/12)	Power & Torque	Strain Gauges
04- Mon (2/7/12)	Flow measurement	RTD & Thermistor
04- Wed (4/7/12)	RTD & Thermistor	Flow measurement
04- Thu (5/7/12)	Mid-term Exam	
05- Mon (9/7/12)	Thermocouple	Block Gauges
05- Wed (11/7/12)	Block Gauges	Thermocouple
07- Wed (25/7/12)	Final Exam	

OBJECTIVE:

To familiarize the student with the types, applications of calipers, micrometers & measurements.
At the completion of this experiment, the student will be able to:

- Get familiar to the variety of the linear measurement tools, and know the type of a measurement tool needed to achieve a certain measurement.
- Students will seek more efficient means of measure.
- Take linear measurements with a certain accuracy depending on the instrument being used
- Clean, care for and store calipers, micrometers and dial indicators.

APPARATUS:

a) Vernier caliper
b) Dial caliper
c) External micrometer
d) 2-point inside micrometer

I. Calipers:

General definition of a caliper:

1. An instrument consisting essentially of two curved hinged legs, used to measure thickness and distances. Often used in the plural.

2. A large instrument having a fixed and a movable arm on a graduated stock, used for measuring the diameters of logs and similar objects.

3. A vernier caliper.

General specifications & functions of a caliper:

- All Stainless Steel construction
- Used to measure inside dimensions
- Used to measure outside dimensions
- Used to measure step dimension
- Convenient thumbscrew to lock a measurement in place
- *Accuracy equation*

$$Accuracy = \frac{\text{1 division main scale}}{\text{no. of divisions on vernier scale}}$$

Two types of calipers are to be discussed in this experiment:

(1.1).The vernier caliper :

The Vernier Caliper shown in fig. (1.1.1) is a precision instrument that can be used to measure internal and external distances extremely accurate.

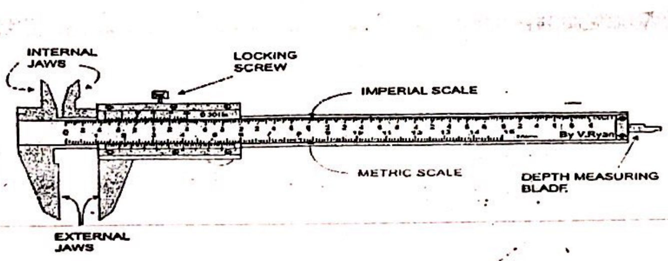


Fig. (1.1.1):a Vernier Caliper

Description:

- A vernier caliper has two scales, a *main* scale and a *vernier* scale.
- These two scales move past each other, usually on a slide.
- When the measurement is taken, the zero point of the vernier scale lies at the true datum of the measurement.
- Main scale (on the larger, fixed portion of the caliper) gives the most significant digits of your reading.
- The vernier scale (on the smaller moving portion of the caliper) gives the least significant digits in the reading and

subdivides a mark on the main scale into 10, 20, 50 subdivisions.

- Notice that ten tick marks in the sliding scale are the same width as nine ticks marks on the fixed scale.
- The smallest division on a scale is the least count of it. On the fixed scale (main scale) the least count is 1 mm, while on the sliding scale (vernier scale) the least count is .02 mm (50 divisions to represent 1 cm).
- Most direct reading calipers have an arrow sliding blade attached to the sliding jaw. it permits the dial caliper to be used as an efficient and accurate depth gauge.

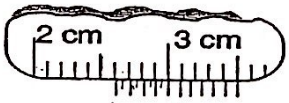
How to use &read a vernier caliper:

To start:

- Place the object between the calipers jaws.
- Close the jaws gently on the part to be measured.
- When you are measuring a round cross sectional parts, make sure that the axis of this object is perpendicular to the caliper, to ensure measuring the full diameter.
- Lock the final locking screw ,and remove the object

Then:

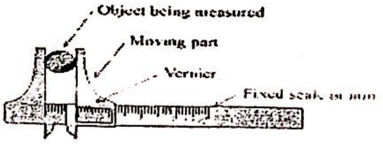
- Read the centimeter mark on the fixed scale to the left of the 0-mark on the vernier scale. (2 cm on caliper seen below).
- Find millimeter mark on the fixed scale that is just to the left of the 0-mark on the vernier scale. (2.6 cm).
- Look along the ten marks on the vernier scale and the millimeter marks on the adjacent fixed scale, until you find the two that most nearly line up. Here it is (0.04 cm).
- To get the correct reading, simply add this found digit to your previous reading. (2.64 cm).
- If two adjacent tick marks on the sliding scale look equally aligned with their counterparts on the fixed scale, then the reading is half way between two marks. If the 4th and 5th looked to be equally aligned with their counter parts then the reading is (26.45±.05) mm.
- If the reading is a nice number such as (2, 6, 9….etc.) don't forget to place the zero decimal after the reading plus to the error introduced (I.e. 2.000±.05).
- Example:

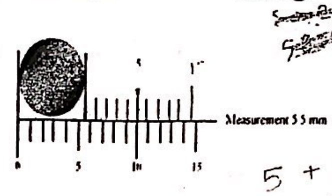


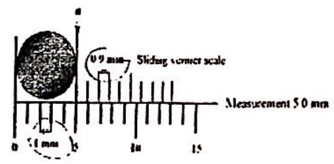
Reading: 2.64

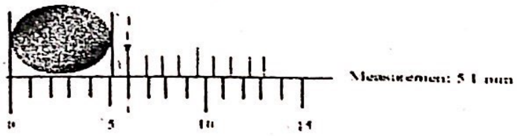
The vernier caliper is an extremely precise measuring instrument , the reading error is (1/20) mm=0.05 mm

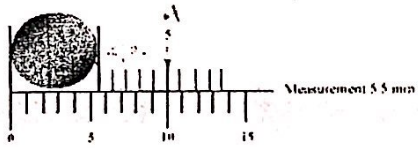
- Note: for inside readings ,the thickness of the jaws must be added to the scale reading.
-
- Fig. (1.1.2): Further examples on using a Vernier Caliper.











- Fig. (1.1.3): Further examples on using a Vernier Caliper.

(1.2)Dial caliper:

It can be described as a modified vernier caliper with gauges, which allows us to have a direct reading. It can be also provided with a digital indicator.

Because it is easier to read, the direct reading dial caliper is gradually replacing the standard vernier caliper.

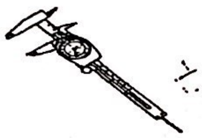


Fig. (1.2.1) :Dial Caliper

Description:

- Dial calipers are manufactured is inch &/or metric standards, and are available with digital readouts.
- A dial indicator, the hand of which is attached to a pinion is mounted on the sliding jaw.
- For metric dial caliper one revolution of the hand represents 2mm of travel, depending on the manufacturer. Therefore, each dial graduation represents .02mm maximum discrimination. Other type with 5mm move/rev & maximum of 0.05 mm.
- Most direct reading calipers have an arrow sliding blade attached to the sliding jaw (and dial).it permits the dial caliper to be used as an efficient and accurate depth gauge as introduced later
- The beam scale on the dial caliper is graduated only into 5mm and 10mm increment.
- The caliper dial is graduated into 100 dimensions.

How to use &read a dial caliper:

- Place the object between the calipers jaws.
- Close the jaws gently on the part to be measured.
- When you are measuring a round cross sectional parts, make sure that the axis of this object is perpendicular to the caliper, to ensure measuring the full diameter.
- Get the most significant digit from the main scale let us say (2.4 cm),then look at the dial gauge to take the least significant digits (as 1 division on the dial indicator equals .02 mm)so if we had 67 divisions on the dial then the least significant digit is = 67 *.02 = 1.28 mm.
- Finally to get your reading add the most and least significant , and take into considerations units, 24mm+1.28mm = 25.28mm ±0.05mm

How to care the calipers?
Regardless of what type you use:

1. Wash your hands before use.
2. Wipe the calipers components.
3. Do not drop or otherwise mishandle the caliper.

(1.3) Alignment principle:

Abbe's principle states that:
"The maximum accuracy may obtain when the standard scale and the work piece being measured are aligned on the same line measurement." When the contact points of a micrometer are away from the axis of the graduations, as shown in the example, measurement error (e) will become significant. This case, a special attention must be paid to the measuring force.

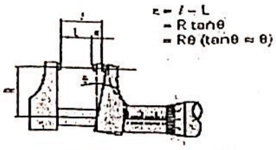


Fig. (1.3.1): abbe's principle

2.Micrometers:

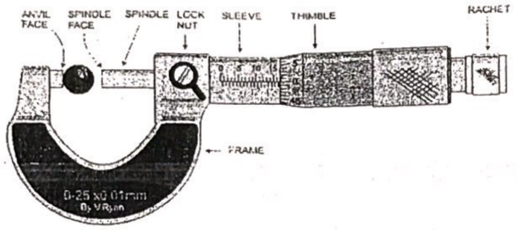


Fig.: (2.0.1): The micrometer calipers

A micrometer is a widely used device in mechanical engineering for precisely measuring thickness of blocks, outer and inner diameters of shafts and depths of slots.

Micrometers have several advantages over other types of measuring instruments like the vernier, like:

- It measures greater precision than the caliper, but smaller ranges of lengths
- The vernier caliper does not give such accurate readings as micrometer because:
  1. It is difficult to obtain a correct feel due to its size and weight.
  2. The scales are difficult to read even with the aid of magnifying glass

Description:

- The tick marks along the fixed barrel of the micrometer represent halves of millimeters.
- One revolution of the knob exposes another tick mark on the barrel consequently the jaws will open another half millimeter.
- The moving barrel of the micrometer has 50 tick marks rapped around each tick mark represent 0.01 mm.
- Pitch, is the distance from point on one thread to a corresponding point on the next thread.
- Lead, is the distance to a thread advances axially in one compete revolution to turn.
- $$accuracy = pitch \times \frac{\text{no.of divs. On vernier scale}}{\text{no.of divs. On thimble scale}}$$
- Before using the micrometer, its accuracy must be verified.(as will be in the next section.).

Accuracy verification of a micrometer:

- Zero-checking:

zero checking is one way to determine the accuracy of a zero to one-2.54cm micrometer. Zero checking is exactly what it sounds like.

Zero checking is the condition where, the display of a zero to one-inch micrometer should show zero.

The steps are as follows.

1. Turn the thimble of the micrometer until the spindle is snug against the anvil.
2. Fine-tune the contact between the spindle and anvil with the ratchet stop until it clicks.
3. Check the reading.
4. If the reading is zero, the micrometer is ready to be used for measuring.

   If the reading u got does not equal zero(due to our capabilities of sight), use the following steps to correct the gage, then read the micrometer and subtract this offset from all the measurements been taken.

- Calibration:

Calibration is the process for insuring the accuracy of gages. The process involves a gage block and the micrometer. A gage block is a block made from steel that is cut to size with in a millionth of an (inch\cm). Gage blocks come in various sizes and are used to check the accuracy of measuring devices such as a micrometer.

If the reading you get from the micrometer is the gage block's dimension, you may begin using the micrometer for measuring. The micrometer may also be checked for calibration using other gage blocks within its range.

Using other blocks that fall within the range of the gage will test the gage's accuracy from one end of the spindle to the other. This may also uncover problems and explain why the gage is loosing accuracy. In the event that the display and the gage block dimension do not correspond, you will need to re-calibrate the micrometer.

Types of micrometers:

There are three types of micrometers based on their application:

- External micrometer
- Internal micrometer
- Depth micrometer

An external micrometer is typically used to measure wires, spheres, shafts and blocks.

An internal micrometer is used to measure the opening of holes, and a depth micrometer typically to measure depths of slots and steps.

How to use &read a Micrometer:

To start:

- Use the ratchet knob (cap) to close the jaws gently on the object to be measured. When the ratchet clicks the jaws are closed sufficiently.

Then:

To read the distance between the jaws of a micrometer:

- Get the reading from the fixed barrel ,while(1 div. = .5 mm), divisions
- Get the reading of the moving barrel while (1 div. = .01 mm)
- To get the final reading simply add the two reading, and take into consideration the units

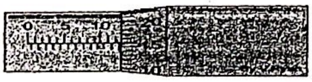
Using Fig. (2.0.1) seen below:

1. Read the scale on the sleeve. The example clearly shows12 mm divisions.

2. Still reading the scale on the sleeve, a further ½ mm (0.5) measurement can be seen on the bottom half of the scale. The measurement now reads 12.5mm.

3. Finally, the thimble scale shows 16 full divisions (these are hundredths of a mm).

The final measurement is 12.5mm + 0.16mm = 12.66 ± 0.005 mm



SLEEVE READS FULL mm = 12.00
SLEEVE READS ½ mm = 0.50
THIMBLE READS = 0.16
TOTAL MEASUREMENT = 12.66mm

Fig. (2.0.1)

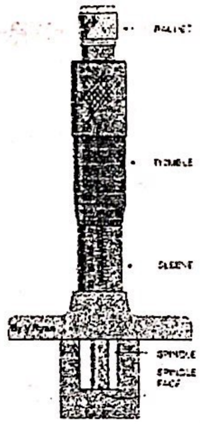
How to care the micrometers:

- Before work makes sure that the object to be measured is fixed stationary (not moving).
- Avoid over tightening the micrometer. Such abuse to the micrometer will only do damage to the micrometer, or any other gage you may be using.
- Great care must be taken in using the micrometer caliper; A ratchet knob is provided for closing the caliper on the object being measured without exerting too much force.
- While you are using a micrometer, it would be mostly recommended to hold the frame with one hand and turning the knurled sleeve with the other hand.
- Damage can be caused to a micrometer if it is dropped. So it is recommended to make sure that the micrometer is in a safe place when it is not being used.
- Before you store a micrometer back the spindle away from the anvil wipe all exterior surfaces with a clean glove.

(2.1)THE DEPTH GAUGE MICROMETER:

Definition:

The depth gauge micrometer is a precision measuring instrument, used by engineers to measure depths of holes, slots, and recesses, the distance of stepped faces from each other and similar applications.



Description:

- Each revolution of the ratchet moves the spindle face 0.5mm towards the bottom of the blind hole.
- Fig (2.1.1) below shows how the depth gauge is used. The ratchet is turned clockwise until the spindle face touches the bottom of the blind hole. The scales are read in exactly the same way as the scales of a normal micrometer. (Refer to the example about fig (2.0.1).

Fig (2.1.1): depth-gauge micrometer

(2.2) two-point inside micrometers

this micrometer is used for measuring the internal dimensions and graduated in 100's of a mm, this micrometer is available in two designs: fig(2.2.1)

1. One with jaws similar to vernier caliper and with a scale reading backwards.
2. The second is a straight bar with a micrometer barrel this type can b obtained with several interchangeable rods which allow a wide range of measurements.

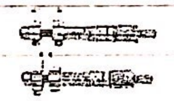


Figure (2.2.1): 2-point inside micrometer

Description:

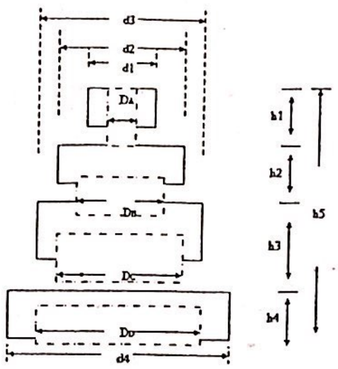
- This type of micrometer used for measuring inside diameters.
- The same principle application as for other micrometer.
- The reading of two point inside micrometer is taken in a similar manner are that of the depth micrometer.
- The reading increase as the thimble is screwed.

PROCEDURE:

- Inspect the tool to be used before using.
- Check its accuracy and zero alignment.(determine an offset).
- Clean the specimen to be used, with a soft cloth.
- Hold the tool in a proper way to start measuring.
- Take abbe's principle into consideration before taking a reading.
- Measure the dimensions of the specimen shown below with each of the following measuring devices (If it is possible):

  _Vernier Caliper, Dial. Caliper outside micrometer, 2-point inside micrometer &depth micro meter
- Make sure not to drop the measuring tool.
- Record you readings in table 1

After measurements are taken ,make sure to leave the measuring device clean, and in a safe place



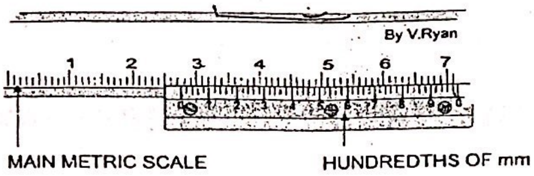
RESULTS:

Measuring instrument	D1	D2	D3	D4	Da	Db	Dc	Dd	H1	H2	H3	H4	H5
Vernier caliper	19.1	[illegible]	[illegible]	41	[illegible]	8.4			10.1				
dial													
Outside micrometer	19.15												
2-point depth													

Table 1

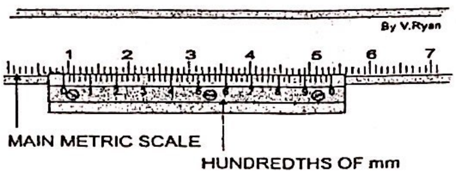
Dial : (15) cm 15.4

QUESTION 1:



answer:

QUESTION 2:



answer:

DISCUSSION & CONCLUSIONS :

Caliper:

1. Does the vernier caliper conform to abbe's principle of alignment? Why?

2. Calculate the error of a vernier caliper?

3. What is the function of the sliding blade of the caliper?

4. what is a direct reading instrument, does that apply to the caliper?

5. What are the sources of error in reading a caliper?

6. What could happen if the locking screw is not used when measuring a distance with the vernier caliper?

7. Is the reading taken from a caliper in an inside measurement of an object is final? In this case is the caliper considered to be a comparator?

8. Is the vernier line standard or end standard?

9. What are the advantages of the vernier caliper over the micro meter?

Micrometers:

1. Draw a simple diagram representing the depth gauge micrometer and label the important parts.

2. How many screw threads are in each micrometer?

3. Does the external micrometer Obeys the abbe's principle? How?

4. What is the total length approached by the moving barrel when it rotates a complete revolution?

5."over tightening the micrometer, will only do damage to the micrometer, or any other gage you may be using." Explain.

4. Can this micro. Be used as comparators?

5. the accuracy of the micrometer depends on the accuracy of the screw threads, explain?

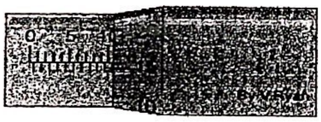
6. What are the factors governing the estimated reading?

7. What are the sources of error in reading a micrometer?

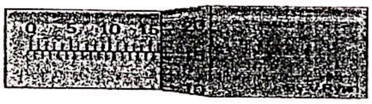
8. Is the spindle rotating or non rotating type? Name disadvantages of rotating type?

EXTRA EXCERSISES:

1. What s the reading indicated by the following micrometers?



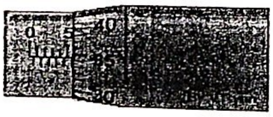
answer:



answer:

answer:

2. What s the reading indicated by the following calipers?



The Resistance Temperature Detector (RTD) Characteristics

Objectives:

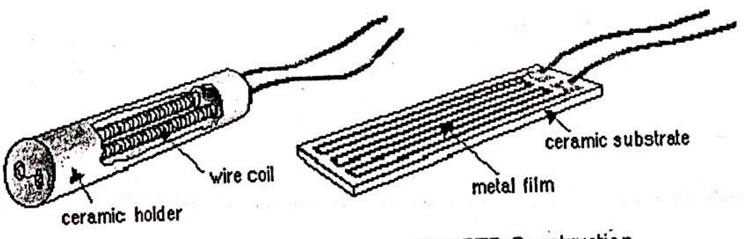
1. To know what is an RTD.
2. To know how to convert the RTD resistance reading to temperature.
3. To understand the characteristics of the RTD.

Introduction:

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.

RTD's 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 RTD's are nickel, copper, and nickel-iron. These materials are becoming less common now, because the cost of platinum RTD's is coming down.

RTDs are constructed using one of two different manufacturing configurations. Wire-wound RTDs are created by winding a thin wire into a coil. A more common configuration is the thin-film element, which consists of a very thin layer of metal laid out on a plastic or ceramic substrate. Thin-film elements are cheaper and more widely available because they can achieve higher nominal resistances with less platinum. To protect the RTD, a metal sheath encloses the RTD element and the lead wires connected to it.



Wire RTD Construction   Film RTD Construction

Figure (1): RTD Constructions

They are popular because of their stability; RTDs exhibit the most linear signal with respect to temperature of any electronic temperature sensor. However, they are generally more expensive than alternatives because of the careful construction and use of platinum. RTDs are also characterized by a slow response time and low sensitivity, and, because they require current excitation, they can be prone to self-heating.

Theory:

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 TMT 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

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

Where :

T : Calculated temperature in (^{o}C).
R_o : RTD nominal resistance at 0 °C, R_o=100 Ω.
R : Measured resistance (Ω).
$A = 3.90802\times10^{-3}$
$B = -5.80195\times10^{-7}$

The above equation will give you the temperature in °C. The value of R_o, A & B differs from one type of RTD to another.

Experiment Procedure:

1. Refer to running procedure in Thermocouple Experiment.
2. Choose Experiment 2: "**RTD Characteristics**".

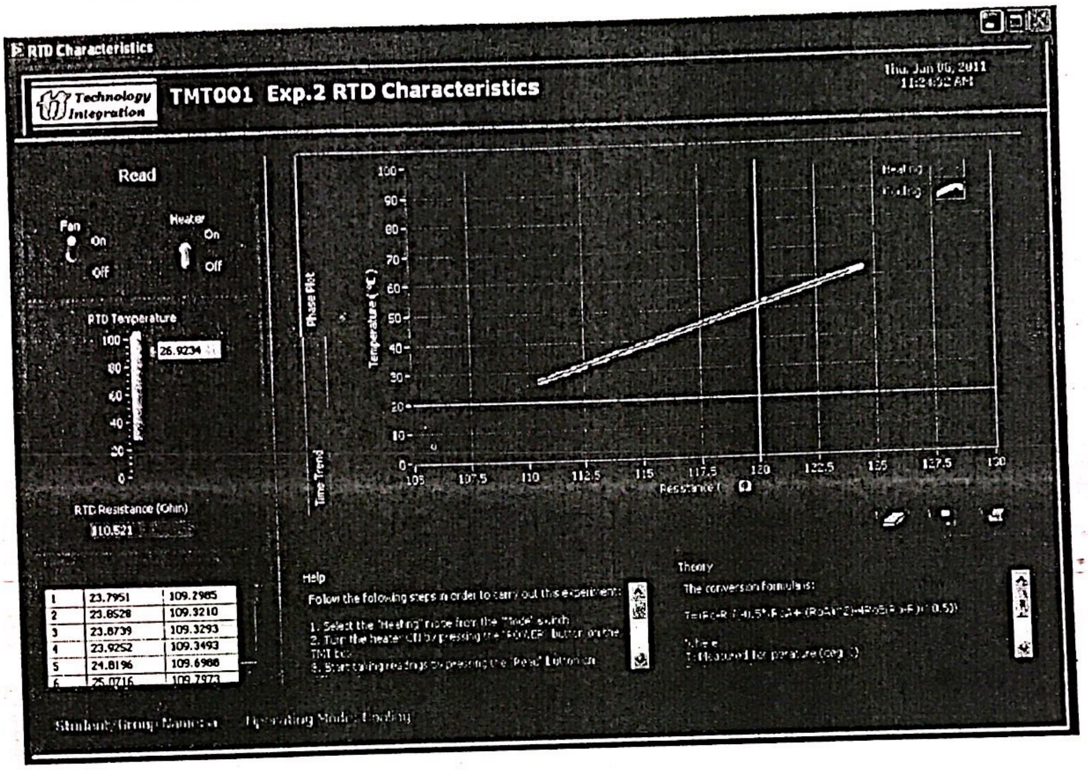


Figure (2): RTD Characteristics Experiment.

3. Study the front panel carefully and observe the buttons on the screen.
4. Turn the **Heater** ON by pressing ON the **Heater Switch** on the screen (Heating Mode).
5. Start taking readings by pressing **[Read]** button over different temperature values.
6. The acquired readings appear on the Temperature-Resistance graph as **red** points.
7. Compare the read temperature with the temperature of the **glass thermometer.** Is it the same temperature? Why?

....
....
....

8. Turn the **Heater** OFF by pressing OFF the **Heater Switch** on the screen.

9. Turn the **Fan** ON by pressing ON the **Fan Switch** on the screen (Cooling Mode).

10. Start taking readings by pressing **[Read]** button on different temperature values.

11. The acquired reading appears on the Temperature-Resistance graph as **white** points.

12. Is the cooling curve the same as the heating curve? Why?
....
....
....

13. Notice the Temperature vs. Resistance curve and answer the following questions:

14. 1 Is the curve linear?
   a) Yes
   b) No

14. 2 Does the RTD equation in the "**Theory**" window describe the curve on the Temperature-Resistance graph? If your answer is "No", what is the difference and why?
....
....
....

15. Choose one of the readings taken before from the **Readings Table** and write down its Resistance (Ω) and Temperature (°C) readings:

   15. 1 Current Resistance (Ω) ....
   15. 2 Current temperature (°C)........................
   15. 3 Apply the current resistance in the RTD equation
   15. 4 Write down the Calculated temperature (°C).....................
   15.5 Compare the calculated temperature with the current temperature.

Conclusions

1. ....
....
2. ....
....
3. ....
....
4. ....
....

Thermistor characteristics

Objectives:

1. To know what is a **Thermistor.**
2. To know how to convert the Thermistor resistance reading to temperature.
3. To understand the characteristics of the Thermistor.

Introduction:

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, 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 for 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 TMT001 we use an NTC thermistor which has a temperature range from 13-85 °C.

Theory:

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

$$T = \frac{1}{a + b(lnR) + c(lnR)^3}$$

Where :

T : Calculated temperature in (K)
R: Measured resistance in (Ω)
a, b and c are Steinhart-Hart Constants that have the following values
$a = 1.2407635*10^{-3}$
$b = 2.3612017*10^{-4}$
$c = 8.97975*10^{-8}$

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

Experiment Procedure:

1. Refer to running procedure in Thermocouple Experiment.
2. Choose Experiment 3: "**Thermistor Characteristics**".

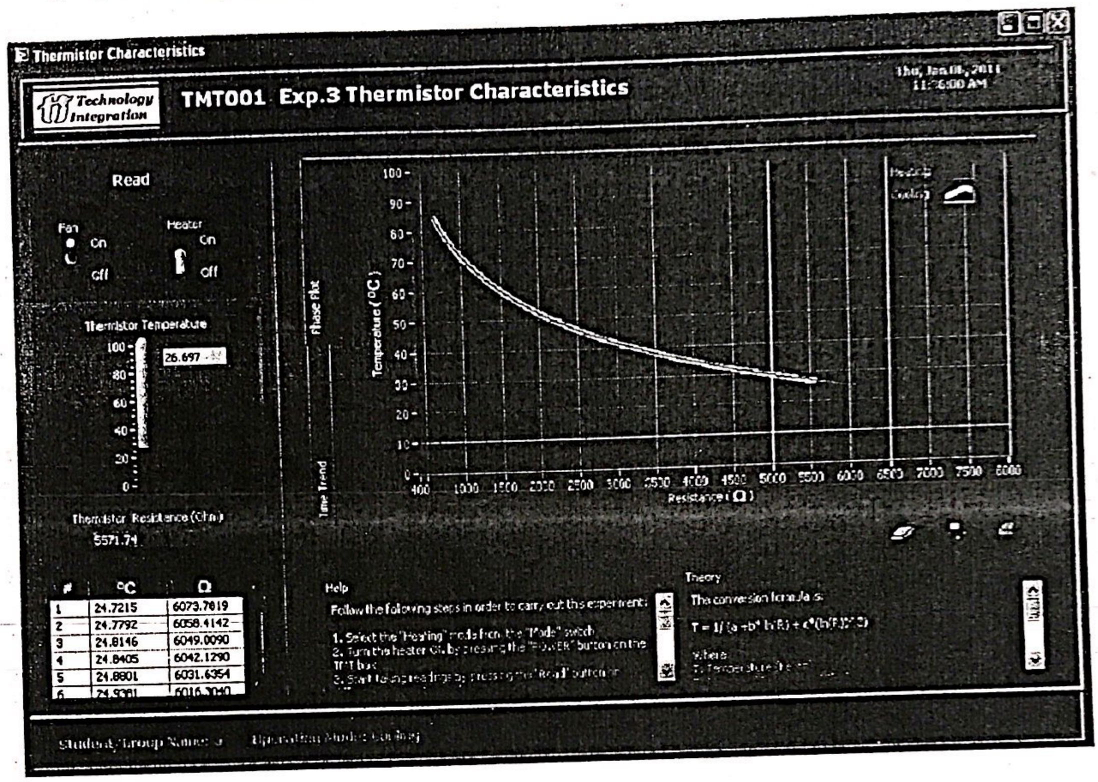


Figure (1): Thermistor Characteristics Experiment

3. Study the front panel carefully and observe the buttons on the screen.
4. Turn the **Heater** ON by pressing ON the **Heater Switch** on the screen (Heating Mode).
5. Start taking readings by pressing **[Read]** button over different temperature values.
6. The acquired readings appear on the Temperature-Resistance graph as **red** points.
7. Compare the read temperature with the temperature of the **glass thermometer**. Is it the same temperature? Why?
   ....
   ....
   ....
8. Turn the **Heater** OFF by pressing OFF the **Heater Switch** on the screen.
9. Turn the **Fan** ON by pressing ON the **Fan Switch** on the screen (Cooling Mode).

10. Start taking readings by pressing **[Read]** button on different temperature values.

11. The acquired reading appears on the Temperature-Resistance graph as **white** points.

12. Is the cooling curve the same as the heating curve? Why?
    ....
    ....
    ....

13. Notice the Temperature vs. Resistance curve and answer the following questions:

14. 1 Is the curve linear?
    a) Yes
    b) No

14. 2 Does the Thermistor equation in the "**Theory**" window describe the curve on the Temperature-Resistance graph? If your answer is "No", what is the difference and why?
    ....
    ....
    ....

15. Choose one of the readings taken before from the **Readings Table** and write down its Resistance (Ω) and Temperature (°C) readings:

    15. 1 Current Resistance (Ω) ....
    15. 2 Current temperature (°C)..........................
    15. 3 Apply the current resistance in the Thermistor equation
    15. 4 Write down the Calculated temperature (°C).......................
    15.5 Compare the calculated temperature with the current temperature.

Conclusions

1. ....
   ....
2. ....
   ....
3. ....
   ....
4. ....
   ....

Thermometers Comparison

Introduction:

As mentioned before, temperature is one of the most important phenomena that needed to be measured in real life applications; consequently there are more than 20 different types of thermometers these days. These thermometers have different specifications, such as measuring method, temperature range, linearity, stability, repeatability, accuracy and response time…etc.

Thermocouples, RTDs and Thermistors, are the most common thermometers in real life applications. Engineer chooses the suitable thermometer according to the specification of the application. In this experiment, you will be able to compare the behavior and the characteristics of these thermometers.

Experiment Procedure:

1. Refer to running procedure in Thermocouple Experiment.
2. Choose Experiment 4:" **Thermometers Comparison**".

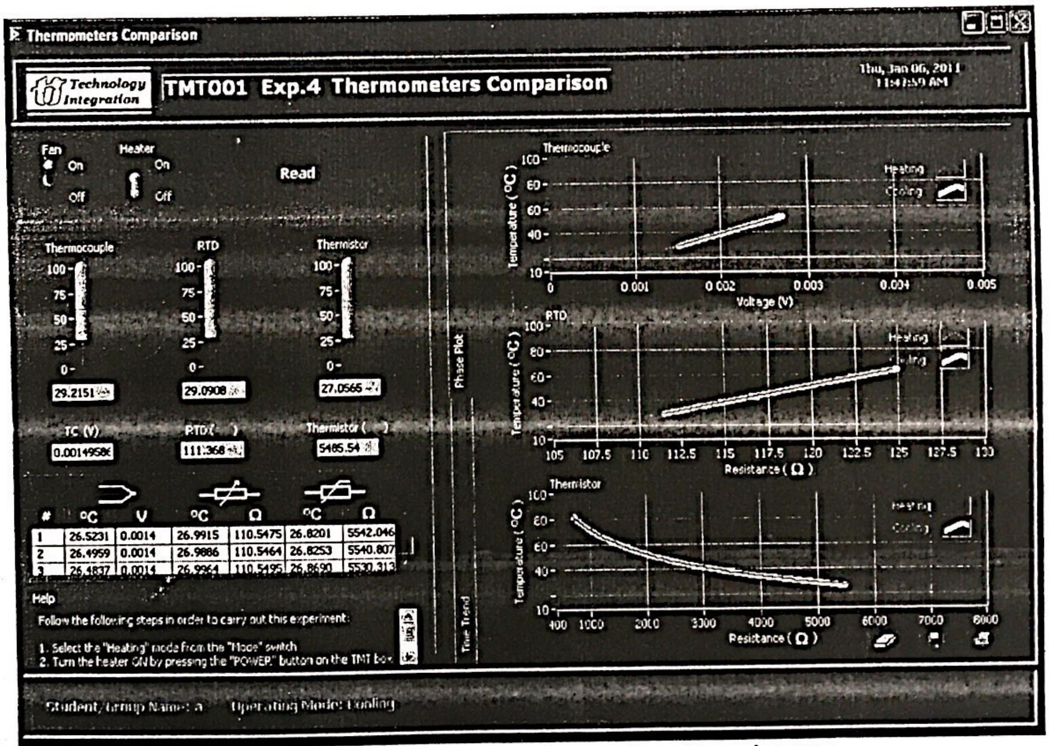


Figure (1): Thermometers Comparison Experiment.

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

4. Turn the **Heater** ON by pressing ON the **Heater Switch** on the screen (Heating Mode).

5. Start taking readings by pressing **[Read]** button over different temperature values.

6. The acquired readings appear on the Temperature-Resistance graph as red points.

7. Compare the read temperature values with the temperature of the glass thermometer.

8. Which thermometer has the closest readings compared to the glass thermometer readings:

   a) Thermocouple
   b) RTD
   c) Thermistor

9. Turn the **Heater** OFF by pressing OFF the **Heater Switch** on the screen.

10. Turn the **Fan** ON by pressing ON the **Fan Switch** on the screen (Cooling Mode).

11. Start taking readings by pressing [Read] button on different temperature values.

12. The acquired readings appear on the Temperature-Voltage (or Resistance) graph as white points.

13. Are the cooling curves of the thermometers the same as the heating curves? Why?

   ....
   ....
   ....

14. Notice the Temperature-Voltage (or Resistance) curves and the Temperature-Time curves (on the Trends tab) and answer the following questions:

14. 1 Which one of the thermometers has the fastest response time?

   a) Thermocouple
   b) RTD
   c) Thermistor

14. 2 Which one of the thermometers has the slowest response time?

   a) Thermocouple
   b) RTD
   c) Thermistor

15. Depending on this and the previous experiments assign the suitable thermometer for the following applications and explain why:

15. 1 An application with a wide temperature range (**above 1000°C**).

....

15. 2 An application that needs a good response time (**temperature range is up to 500°C**) .

....

15. 3 An application that needs accurate readings and fast response time (**temperature range is up to 80°C**).

....

15. 4 An application that needs a repetitive sensor (**temperature range is up to 500°C**).

....

15. 5 An application that has electromagnetic fields (**temperature range is up to 500°C**).

....

15. 6 An application in which the wires length of the sensor does not affect the temperature readings (**temperature range is up to 500°C**).

....

15. 7 An application in which the wires length of the sensor does not affect the temperature readings (**temperature range is up to 50°C**).

....

Thermocouple Characteristics

Objectives:

1. To know what is a **Thermocouple.**
2. To know how to convert the thermocouple voltage readings to temperature.
3. To understand the characteristics of the thermocouple.

Introduction:

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, 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.

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 different temperature range and sensitivity.

In the experiment two J type thermocouples are used. The first one is used for the experiments, and the other one is used with temperature controller to control the temperature of the hot plate.

Theory:

To measure a thermocouple Seebeck voltage, you cannot simply connect the thermocouple to a voltmeter or other measurement system, because connecting the thermocouple wires to the measurement system creates additional thermoelectric circuits.

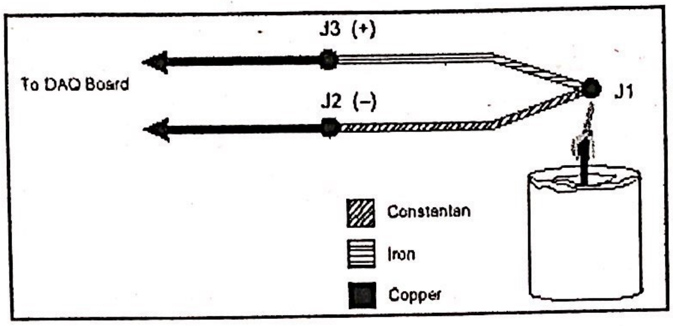


Figure (1): Thermocouple connection

Consider the circuit illustrated in Figure 1, in which a J-type thermocouple is in a candle flame that has a temperature you want to measure. The two thermocouple wires are connected to the copper leads of the measurement device. Notice that the circuit contains three dissimilar metal junctions J1, J2, and J3. J1, the thermocouple junction, generates a Seebeck voltage proportional to the temperature of the candle flame. J2 and J3 each have their own Seebeck coefficient and generate their own thermoelectric voltage proportional to the temperature at the measurement device terminals. To determine the voltage contribution from J1, you need to know the temperatures of junctions J2 and J3 as well as the voltage-to-temperature relationships for these junctions. You can then subtract the contributions of the parasitic junctions at J2 and J3 from the measured voltage at junction J1.

Thermocouples require some form of temperature reference to compensate for these unwanted parasitic "cold" junctions. The most common method is to measure the temperature at the reference junction with a direct-reading temperature sensor and subtract the parasitic junction voltage contributions. This process is called **cold-junction compensation.** You can simplify computing cold-junction compensation by taking advantage of some thermocouple characteristics.
By using the **Thermocouple Law of Intermediate Metals** and making some simple assumptions, you can see that the voltage a data acquisition system measures depends only on the thermocouple type, the thermocouple voltage, and the cold-junction temperature. The measured voltage is in fact independent of the composition of the measurement leads and the cold junctions, J2 and J3.

According to the Thermocouple Law of Intermediate Metals, illustrated in Figure 2, inserting any type of wire into a thermocouple circuit has no effect on the output as long as both ends of that wire are the same temperature, or isothermal.

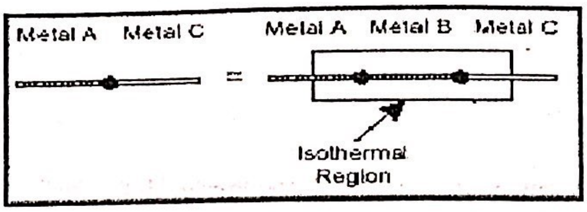


Figure (2): Thermocouple Law Intermediate Metals.

Consider the circuit in Figure 3. This circuit is similar to the previously described circuit in Figure 1, but a short length of constantan wire has been inserted just before junction J3 and the junctions are assumed to be held at identical temperatures. Assuming that junctions J3 and J4 are the same temperature, the Thermocouple Law of Intermediate Metals indicates that the circuit in Figure 3 is electrically equivalent to the circuit in Figure 1. Consequently, any result taken from the circuit in Figure 3 also applies to the circuit illustrated in Figure 1.

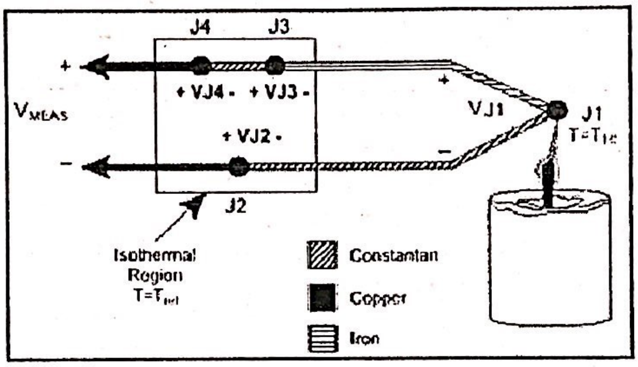


Figure (3): Intermediate Materials effect In Isothermal region.

In Figure 3, junctions J2 and J4 are the same type (copper-constantan); because both are in the isothermal region, J2 and J4 are also the same temperature. Because of the direction of the current through the circuit, J4 contributes a positive Seebeck voltage, and J2 contributes an equal but opposite negative voltage. Therefore, the effects of the junctions cancel each other, and the total contribution to the measured voltage is zero. Junctions J1 and J3 are both iron-constantan junctions, but may be at different temperatures because they do not share an isothermal region. Being at different temperatures, junctions J1, J3 both produce a Seebeck voltage, but with different magnitudes. To compensate for the cold junction J3, its temperature is measured and the contributed voltage is subtracted out of the thermocouple measurement.

Experiment Procedure:

1. Run the **TMT001** Software.
2. A screen named "**Welcome to TMT001**" will appear, containing three buttons: **[Information]**, **[Run the Experiments]** and **[Quit]**.
3. The "**Welcome screen"** is shown in the figure below:

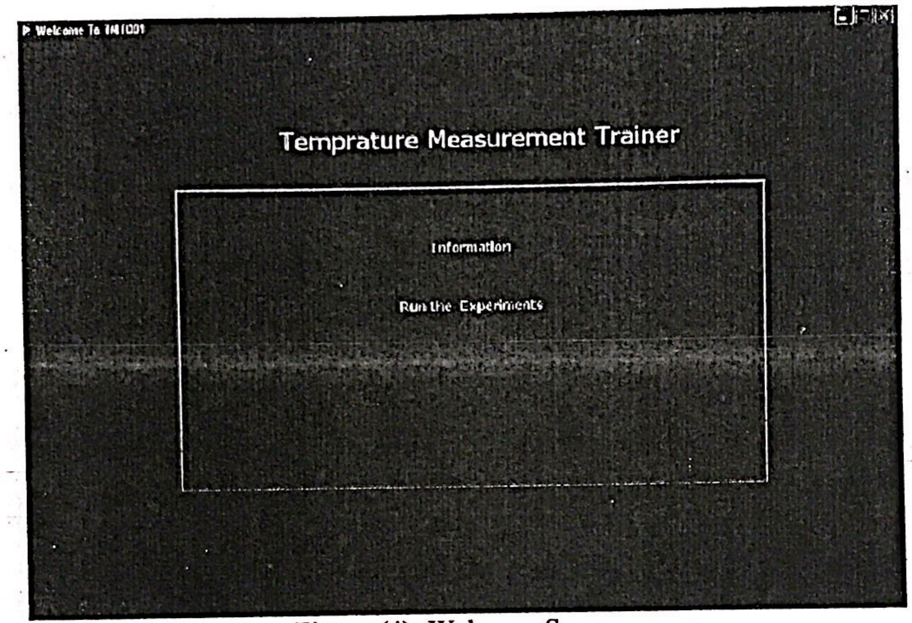


Figure (4): Welcome Screen.

4. Press the **[Information]** button to go to the Information screen.
5. The "**Information Screen**" is shown in the figure below:

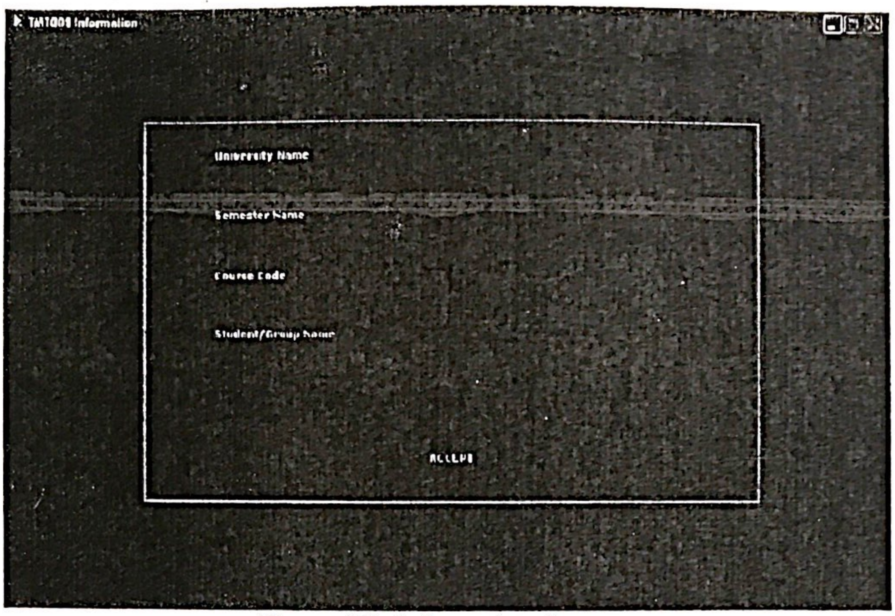


Figure (5): Information Screen.

6. Fill in the fields with your information, Press the **[Accept]** button and a confirmation message will appear asking you to press **[Accept]** the information you have entered, or **[Cancel]** if you need to go back to change anything. Pressing **[Accept]** will let you go back to the "**Welcome Screen**".
7. Press **[Run the Experiments]** button to go to the "**Experiments screen**".
8. The "**Experiments Screen**" is shown in the figure 6, containing four experiments; **Thermocouple Characteristics**, **RTD Characteristics**, **Thermistor Characteristics** and **Thermometers Comparison**.

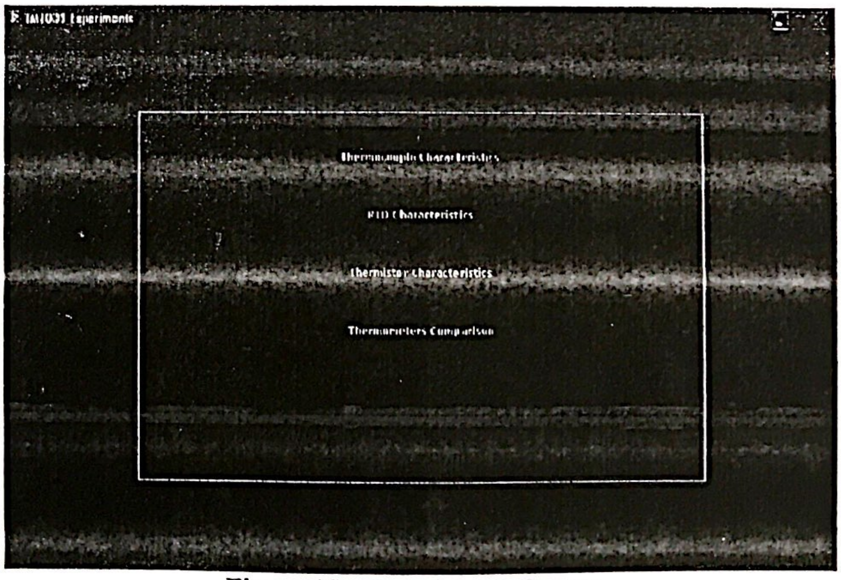


Figure (6): Experiments Screen.

9. Choose Experiment 1: **"Thermocouple Characteristics".**
10. Study the front panel carefully and observe the buttons on the screen.

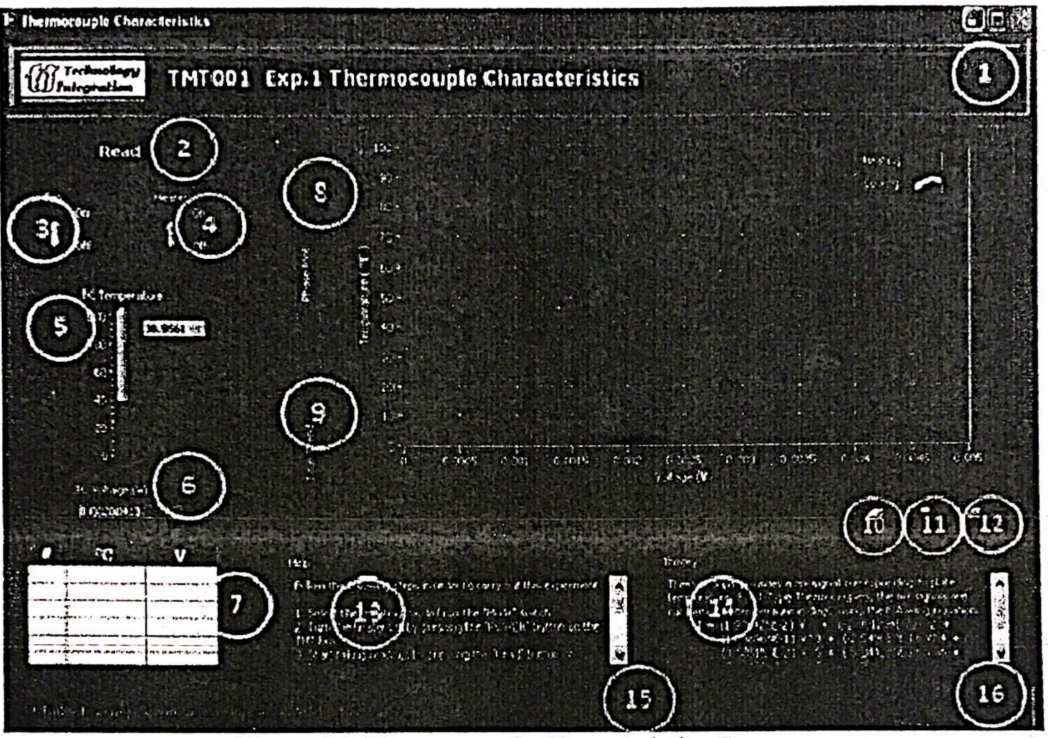


Figure (7): Thermocouple Characteristics Screen.

1) **Current Date and Time Indicator.**
2) **Read Button:** To read and plot the current temperature and voltage (resistance) of the current thermometer (here it is the **Thermocouple**).
3) **Fan Switch:** To turn the Fan ON or OFF.
4) **Heater Switch:** To turn the Heater ON or OFF.
5) **Thermometer Temperature (°C):** Displays the current temperature of the current thermometer.
6) **Thermometer Voltage (Resistance):** Displays the current voltage (resistance) of the current thermometer.
7) **Readings Table:** Displays the current Temperature and Voltage (resistance) readings taken each time the **[Read]** button is pressed.
8) **Phase Plot:** Contains the Temperature vs. Voltage (Resistance) graph which displays the readings that have been taken by the user. Each point represents the Thermometer Temperature (°C) with its corresponding Voltage (V) or Resistance (Ohm).

9) **Time Trend:** Contains the Temperature vs. Time graph which displays the temperature profile of the thermometer.
10) **Clear Chart Button:** To clear the Phase Plot graph.
11) **Save Report Button:** To save a report, the report will be saved in the **"Temperature Trainer Files"** folder on the desktop.
12) **Print Report Button:** To print a report, the report will be printed using your default printer.
13) **Help Window:** Displays the procedures needed to carry out the experiment
14) **Theory Window:** Displays the conversion theory of the thermometer of the current experiment (how to change from voltage (resistance) to temperature).
15) **Status Bar:** Displays the current Student/Group name as well as the current operating mode (Heating or Cooling).
16) **Quit Button:** To quit from this experiment and return to the **"Experiments"** window.

11. Turn the **Heater** ON by pressing ON the **Heater Switch** on the screen (Heating Mode).
12. Start taking readings by pressing **[Read]** button on different temperature values.
13. The acquired readings appear on the **Temperature-Voltage graph** as red points.
14. Compare the read temperature with the temperature of the **glass thermometer.** Is it the same temperature? Why?

....
....
....
....

15. Turn the **Heater** OFF by pressing OFF the **Heater Switch** on the screen.
16. Turn the **Fan** ON by pressing ON the **Fan Switch** on the screen (Cooling Mode).
17. Start taking readings by pressing **[Read]** button over different temperature values.
18. Notice that the acquired reading appears on the **Temperature-Voltage graph** as white points.
19. Is the cooling curve the same as the heating curve? Why?

....
....
....

20. In order to save the readings you have taken, press **[Save Report]** button, your report will be saved on your desktop in a folder named **Temperature Trainer Files.**
21. To print the report, press **[Print Report]** button.

22. Notice the **Temperature vs. Voltage** curve and answer the following questions:

22.1 Is the curve linear?
a) Yes
b) No

22.2 Does the thermocouple equation in the **"Theory"** window describe the curve on the **Temperature vs. Voltage graph**? If your answer is "No", what is the difference and why?
....
....

23. Choose one of the readings taken before from the **Readings Table** and write down its Voltage (V) and Temperature (°C) readings:

23.1 Current Voltage (V) ....
23.2 Current temperature (°C).......................
23.3 Apply the current voltage in the thermocouple equation below

$$T = V(1.978425 * 10^{-2}) + V^2(-2.001204 * 10^{-7}) + V^3(1.036969 * 10^{-11}) + V^4(-2.549687 * 10^{-16}) + V^5(3.585153 * 10^{-21}) + V^6(-5.344285 * 10^{-26}) + V^7(5.099890 * 10^{-31})$$

Where: T : Calculated temperature in (°C)
V : Thermocouple voltage in microvolt ($V*10^6$)

23.4 Write down the Calculated temperature (°C)....................
23.5 Compare the calculated temperature with the current temperature.

24. Press **[Clear Chart]** button if you want to clear the chart.
25. Press **[Quit]** button to return to the **"Experiments"** window.

Conclusions

1. ....
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2. ....
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3. ....
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4. ....
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The Resistance Temperature Detector (RTD) Characteristics

Objectives:

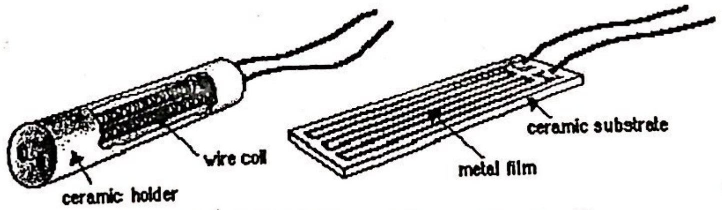
1. To know what is an RTD.
2. To know how to convert the RTD resistance reading to temperature.
3. To understand the characteristics of the RTD.

Introduction:

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.

RTD's 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 RTD's are nickel, copper, and nickel-iron. These materials are becoming less common now, because the cost of platinum RTD's is coming down.

RTDs are constructed using one of two different manufacturing configurations. Wire-wound RTDs are created by winding a thin wire into a coil. A more common configuration is the thin-film element, which consists of a very thin layer of metal laid out on a plastic or ceramic substrate. Thin-film elements are cheaper and more widely available because they can achieve higher nominal resistances with less platinum. To protect the RTD, a metal sheath encloses the RTD element and the lead wires connected to it.



Wire RTD Construction   Film RTD Construction

Figure (1): RTD Constructions

They are popular because of their stability; RTDs exhibit the most linear signal with respect to temperature of any electronic temperature sensor. However, they are generally more expensive than alternatives because of the careful construction and use of platinum. RTDs are also characterized by a slow response time and low sensitivity, and, because they require current excitation, they can be prone to self-heating.

Theory:

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 TMT 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

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

Where :

T : Calculated temperature in (°C).
R_o : RTD nominal resistance at 0 °C, R_o=100 Ω.
R : Measured resistance (Ω).
$A = 3.90802 \times 10^{-3}$
$B = -5.80195 \times 10^{-7}$

The above equation will give you the temperature in °C. The value of R_o, A & B differs from one type of RTD to another.

Experiment Procedure:

1. Refer to running procedure in Thermocouple Experiment.
2. Choose Experiment 2: "**RTD Characteristics**".

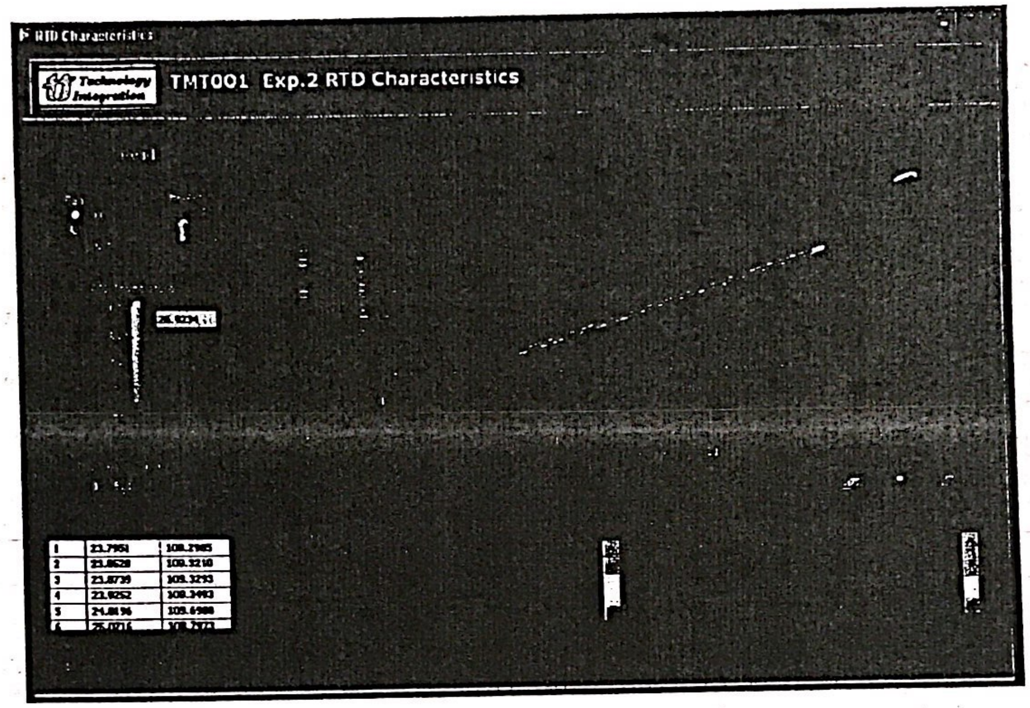


Figure (2): RTD Characteristics Experiment.

3. Study the front panel carefully and observe the buttons on the screen.
4. Turn the **Heater** ON by pressing ON the **Heater Switch** on the screen (Heating Mode).
5. Start taking readings by pressing **[Read]** button over different temperature values.
6. The acquired readings appear on the Temperature-Resistance graph as **red** points.
7. Compare the read temperature with the temperature of the **glass thermometer.** Is it the same temperature? Why?

....
....
....

8. Turn the **Heater** OFF by pressing OFF the **Heater Switch** on the screen.

9. Turn the **Fan** ON by pressing ON the **Fan Switch** on the screen (Cooling Mode).

10. Start taking readings by pressing **[Read]** button on different temperature values.

11. The acquired reading appears on the Temperature-Resistance graph as **white** points.

12. Is the cooling curve the same as the heating curve? Why?

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13. Notice the Temperature vs. Resistance curve and answer the following questions:

14. 1 Is the curve linear?
    a) Yes
    b) No

14. 2 Does the RTD equation in the "**Theory**" window describe the curve on the Temperature-Resistance graph? If your answer is "No", what is the difference and why?

....
....
....

15. Choose one of the readings taken before from the **Readings Table** and write down its Resistance (Ω) and Temperature (°C) readings:

    15. 1 Current Resistance (Ω) ....
    15. 2 Current temperature (°C).........................
    15. 3 Apply the current resistance in the RTD equation
    15. 4 Write down the Calculated temperature (°C).....................
    15.5 Compare the calculated temperature with the current temperature.

Conclusions

1. ....
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2. ....
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3. ....
   ....
4. ....
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FLOW MEASUREMENT
(Venturi meter, Orifice Plate and Rotameter)

OBJECTIVES

- To study the characteristics and applications of various flow measuring device (venturi meter & orifice plate).
- To calculate the volume flow rate of water from the pressure difference of both venturi and orifice devices.
- To compare between theoretical and actual volumetric flow rate through the discharge coefficient concept.
- To know how rotameter works.

INTRODUCTION

The measurement of fluid flow is important in applications ranging from measurements of blood-flow rates in human artery to the measurement of liquid oxygen in a rocket.

The selection of the proper instrument for a particular application is governed by many variables, including cost. Flow-rate-measurement devices frequently require accurate pressure and temperature measurements in order to calculate the output of the instrument.

The most widely used flow metering principle involves placing a fixed area flow restriction of some type in the pipe or duct carrying the fluid. This flow restriction causes a pressure drop that varies with the flow rate.

Thus, measurement of the pressure drop by means of a suitable differential-pressure pick up allows flow rate measurement.

Each of the flow measurement devices inherently has its own advantages and disadvantages. Some of those instruments are:

- **The Venturi Meter**

In the venturi meter (shown in figure (1) below) the fluid is accelerated through a converging cone of angle 15-20° and the pressure difference between the upstream side of the cone and the throat is measured and provides the signal for the rate of flow.

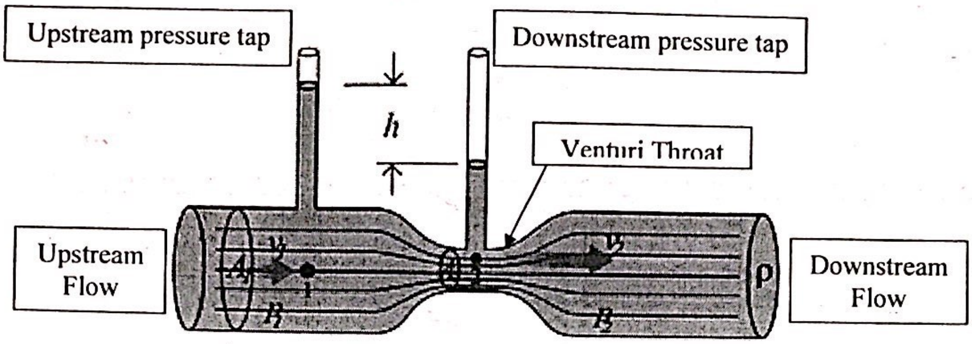


Figure (1) : The Venturi meter operation.

The fluid slows down in a cone with smaller angle (5-7°) where most of the kinetic energy is converted back to pressure energy. Because of the cone and the gradual reduction in the area there is no "vena contracta". The flow area is at minimum at the throat.

High pressure and energy recovery makes the venturi meter suitable where only small pressure heads are available.
A discharge coefficient Cv- of 0.975 may be taken as standard, but the value varies noticeably at low values of the Reynolds' number.

- The pressure recovery is much better for the venturi meter than for the orifice plate.
- The venturi tube is suitable for clean, dirty and viscous liquid and some slurry services.
- Pressure loss is low.
- Typical accuracy percent is ±i of full range.
- Required upstream pipe length 5 to 20 diameters.
- Viscosity effect is high
- Relative cost is medium

- **The Orifice Plate**

The orifice meter shown in figure (2) below, consists of a flat orifice plate with a circular hole drilled in it. There is a pressure tap upstream from the orifice plate and another just downstream. There are in general three methods of placing the taps. The coefficient of the meter depends upon the position`n of taps.

- Flange location - Tap location 1 inch upstream and 1 inch downstream from face of orifice.
- Vena contracta location - Tap location 1 pipe diameter (actual inside) upstream and 0.3 to 0.8 pipe diameter downstream from face of orifice.
- Pipe location - Tap location 2.5 times nominal pipe diameter upstream and 8 times nominal pipe diameter downstream from face of orifice.

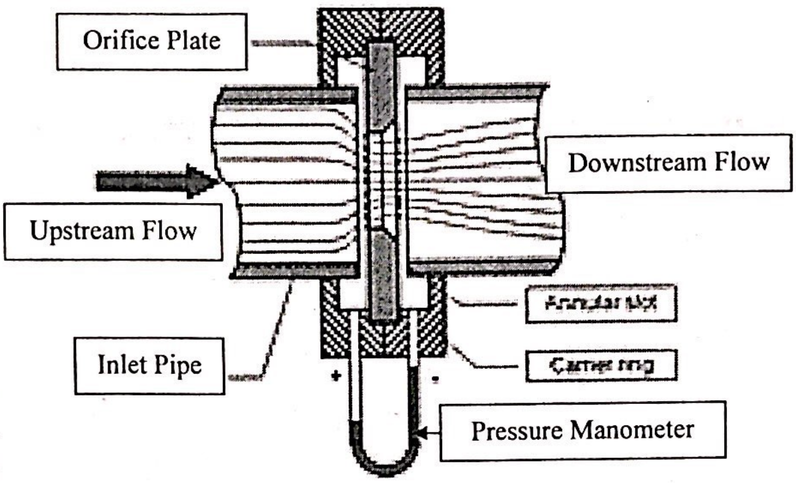


Figure (2) : The Orifice Plate operation.

The discharge coefficient - *Co* - varies considerably with changes in area ratio and the Reynolds' number. A discharge coefficient - *Co* - of 0.60 may be taken as standard, but the value varies noticeably at low values of the Reynolds number.

The pressure recovery is limited for an orifice plate and the permanent pressure loss depends primarily on the area ratio. For an area ratio of 0.5, the head loss is about 70 -75% of the orifice differential.

- The orifice meter is recommended for clean and dirty liquids and some slurry services.
- The pressure loss is medium
- Typical accuracy is ±2 to ±4 of full scale
- The required upstream diameter is 10 to 30
- The viscosity effect is high.
- The relative cost is low.

Application of Energy Principle to Tube-Type Flow meters

The energy equation can be used to derive the venturi meter (shown in figure (3) below) equation by assuming general case not horizontal and due to its short length, there is no head loss, hf = 0.

Although these assumptions were made to simplify the derivation, the final results will be identical for any orientation of the venturi meter.

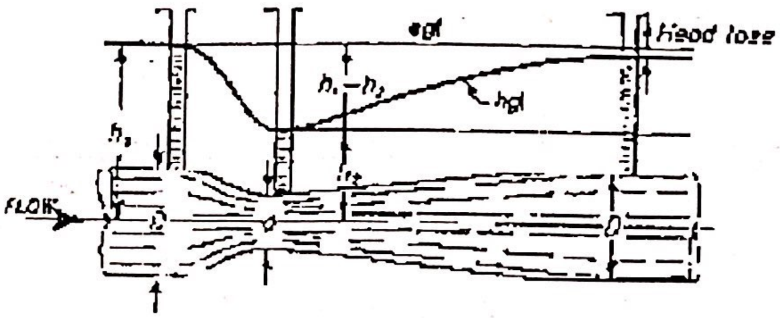


Figure (3): The Venturi meter.

Thus:

$$\frac{P_1}{\gamma}+z1+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+z2+\frac{V_2^2}{2g}$$

By the continuity equation for the approach and throat sections:

$$V1\ A1 = V2\ A2$$

Either VI or V2 can be solved for in terms of the other; for example:

$$VI = V2\ (A2/A1)$$

Substituting this result into the energy equation results in:

$$\frac{P_1-P_2}{\gamma}+(z1-z2)=\frac{V_2^2-V_1^2}{2g}$$

Solving for V2:

$$V_2=\sqrt{2g\frac{\left[\frac{P_1-P_2}{\gamma}+(z1-z2)\right]}{1-\left(\frac{A_2}{A_1}\right)^2}}$$

Taking the square root of both sides and multiplying both sides by A2 results in the theoretical discharge equation:

$$\dot{Q}_{Th} = A_2 \sqrt{2g \frac{\left[\frac{P_1 - P_2}{\gamma} + (z1 - z2)\right]}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

To obtain actual discharge, a coefficient, Cd, added to compensate for velocity distribution and for minor losses not accounted for in the energy equation yields:

$$\dot{Q}_{Th} = C_d A_2 \sqrt{2g \frac{\left[\frac{P_1 - P_2}{\gamma} + (z1 - z2)\right]}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

APPARATUS

Figure (4) below, shows the apparatus, it equipment consists of:

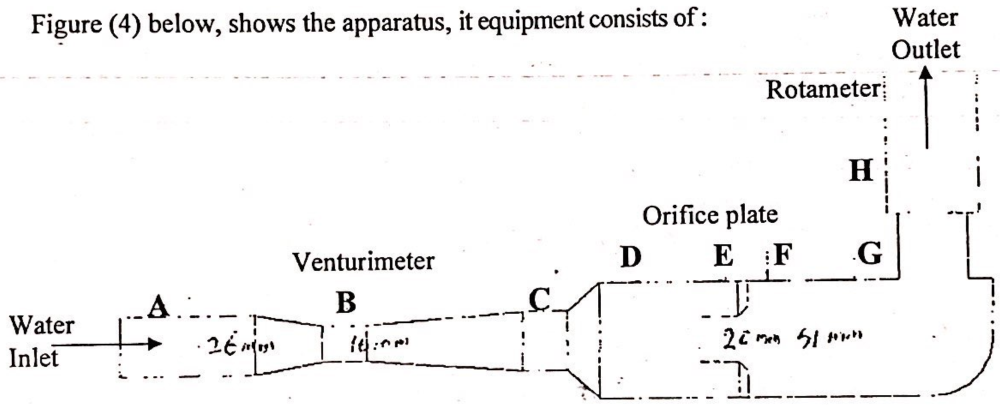


Figure (4): Explanatory Diagram of the Flow Measuring Apparatus

1. A Perspex venture meter; a long gradually converging section followed by a throat then by a long diverging section.
2. Orifice plate meter; this meter made from a brass plate with a hole of reduced diameter through which the fluid flows, is mounted between two pressure tapped Perspex flanges (E) and (F).
3. Right angled bend, in which we can derive bend loss coefficient from pressure tapped (G) and (H).
4. Rotameter; this consists of a transparent tapered tube in which a float takes up an equilibrium position.
5. Control valve in which water returns to the hydraulic bend and weight tank.

- Pressure measurement are made at venture entry (A), venture throat (B),venture exit (C),orifice entry (D), tapped Perspex flanges (E) & (F), right-angled pressure tapped (G) & (H),and rotameter pressure drop (II) & (I).
- Calibration characteristics for the rotameter in figure (5).

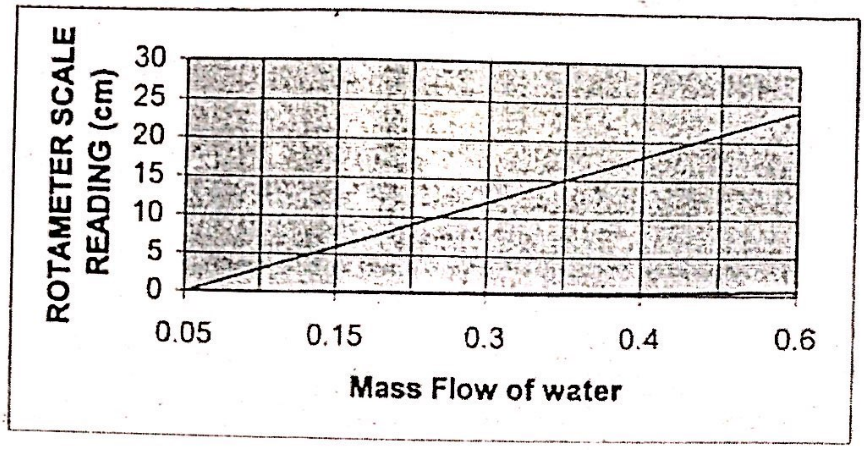


Figure (5) : Rotameter calibration curve.

The flow measuring apparatus is connected to the hydraulic bench water supply and the control valve is adjusted until the rotameter is about at mid-position in its calibrated tapered tube. Air is removed from the manometer tubing by flexing it.

The pressure within the manometer reservoir is now varied and the flow rate decreased until, with no flow, the manometer height in all tubes is about 280 mm. The apparatus is now ready to operate:

1- Switch on the main power supply of the bench.
2- Open water inlet valve.
3- Put 2.5 kg mass on the weight hanger and notice the hanger movement (measure time required to fill water in the tank) and record it in table (3).
4- Record the pressure head at points A, B, C, D, E, F, G, H, and I in table (2).
5- Notice the rotameter reading.
6- Change valve setting and repeat above steps.

REQUIREMENTS

1. Calculate the discharge coefficient for both the venture and orifice plate for each flow rate.
2. Calculate Reynolds number for each flow rate.
3. Fill table (4) of the values you get in 2&3.
4. Plot the discharge coefficient against Re for both the venture tube and the orifice plate.
5. Check the accuracy of the rotameter.

6. How does the rotameter operate?
7. Show the difference between venture and orifice by filling table (l).
8. Comment on your results.

Table (1) : Comparison between flow measurement devices

	Venturi meter	Orifice plate
Accuracy		
Pressure Loss		
Pressure recovery		
Cost		
Space		

Table (2) : Data observed for flow measurement devices

Manometer Level (mm H2O)								
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**

venture entry (A), venture throat (B),venture exit (C),orifice entry (D), tapped Perspex flanges (E) & (F), right-angled pressure tapped (G) & (H), and rotameter pressure drop (II) & (I)

Table (3) : Observed Data for Rotameter and mass collected

Float Height (cm)	Mass flow rate (kg/s)	Mass of water collected (kg)	Time needed (sec)

Table (4) : Final results.

Volume flow rate (m^3/s)	Reynolds' Number	Discharge Coefficient for Venturi (Cv)	Discharge Coefficient for Orifice (Co)

University Of Jordan
Faculty of Engineering and Technology
Industrial Engineering Department

Measurement Lab.

EXPERIMENT 2 :

BLOCK GAUGES

Student Name :
Student No. :

GROUP (   )

OBJECTIVES:

-To familiarize students with types and applications of block gauges.
- To be able to calibrate linear measurements tools.
- Learn the correct ways of using them in measurements.
- Learn how to maintain them in the correct shape

INTRODUCTION:

In industrial applications maximum accuracy must be met in order to produce reliable products.
What is the most accurate way to measure 5mm distance?
Using a steel rule, caliber, or micrometer?
When maximum accuracy needed the use of ordinary measuring tools is not a good approach, there for some other ways is introduced to give more accuracy such as block gauges.

Block gauges are practical length standards of industry. A modern end standard consists fundamentally of a block (slip) or bar of steel or cemented carbide -generally hardened- whose end faces are lapped flat and parallel within a few tenth of a micrometer.

There are two types of length standards:

1. Line standard or Engraved scale:

In which the unit length is defined as being the distance suitably engraved lines. Like the ruler you can measure 1cm or 1.5 cm that is the whole distance is divided into sub measurements units.

2. End standard:

In which the unit of length is defined as being the distance between the end faces of the standard, these take the form of either slip, so the whole piece can measure 5mm for example but not 4.5 mm.

Gauge blocks are good examples of end standards. The name end standards indicate that these consist of sets of standard blocks or bars, and to have the desired measurement we have to build a required length from the blocks. And they have the following characteristics:
-End standard are highly accurate
-End standard have a built in datum because there measuring faces are flat and parallel
-The accuracy of end and line standard is affected by the temperature they are calibrated at 20 °C.
-They are made in high-grade cast steel.

As motioned earlier, block gauges are standard bars made of hardened steel, which is heat treated. Its accuracy is 0.0005 mm. Its calibrated conditions: 20°c, 1 atm, and 60% relative humidity, they are specially machined and therefore they have the following characteristics

1) Straightness
2) Flatness: the surfaces are made by a very accurate process named lapping therefore they are flat to a very high degree

3) Parallelism: each tow surfaces or two lines are parallel to a very high degree.

But there is four types of block gauges differ by the degree of there accuracy, quality and roughness.

Grades of gauge blocks:

1. 00
2. Calibration: this grade provides the highest level of accuracy required in normal engineering practice and is intended for calibrating other blocks in conjunction with suitably accurate comparators. They are used where tolerance are 2 micrometer or less and are not intended for generally gauge inspection.
3. 0
4. I
5. II

When the grades get larger the tolerance get larger and the price cheaper, the best and most expensive of all is grade 00.

_*USING THE BLOCK GAUGES:*

Number of pieces in gauge blocks set can be:

1. 48 pieces in gauge block set
2. 87 pieces in gauge block set

The sizes found in 87 pieces gauge block set Grade II, which we use it in this experiment, are:

0.5, 1.0, 1.001-1.009 (by 0.001 steps),

1.10-1.19 (by 0.001 steps),

1.20-1.29 (by 0.001 steps),

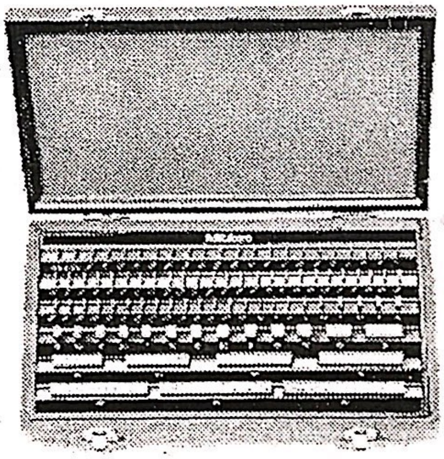
1.30-1.39 (by 0.001 steps),

1.40-1.49 (by 0.001 steps),

1.50, 2.0, 2.5, 3.0, 3.5, 4.0,

4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5,

8.0, 8.5, 9.0, 9.5, 10.0, 20.0,



30.0, 40.0, 50.0, 60.0, 70.0, 80.0, 90.0 and 100.0mm.

As can be seen from the figure the block gauges are fitted in a wooden box, for each of the blocks there is a special place with the length written on it.

Each block has two surfaces that have high lapping; you can distinguish them by noticing that they shine the most of the six faces The length is taken between these tow surfaces which are parallel.

- ***Instructions for wringing together two slip gauges:***

1. Surfaces must be clean and free from burrs They should be washed in petrol. benzene. carbon tetrachloride or other DE-greasing agents and wiped dry on a clean

cloth. Then be wiped with clean soft chamois leather. Slip gauges they should be held across one another at right angles and wiring them with a rotary motion; this reduces the amount of surface rubbing necessary.

2. A minute amount of grease or moisture must be present between the surfaces for them to wring satisfactory. Unless a very firm wring is obtained there is always the possibility that the wringing film maybe a micrometer thick.

- **Another way to assemble a gauge block:**

1. Remove the gauge blocks required from the protective case
2. Clean of the oil that they have been coated in using a special cleaner. It is acceptable to handle the blocks; in fact the oil from your hands will help them stick together.
3. One at a time, hold the blocks so that the faces just overlap, push the blocks together, and slide them until the faces overlap together. This will create a <u>vacuum</u> between the blocks that makes them stick together (this process is known as wringing).
4. Make required measurements with the gauge blocks, being careful not to damage the faces
5. Take the blocks apart, and apply the protective coating oil, and return them to their box.

In order to protect the blocks take the following points into consideration:
-Protect from dust, dirt and moister.
-Avoid magnetization.
-Handle lapped faces as little possible to prevent etching from finger acid; wipe all finger marks with chamöis leather.
-Always wipe faces immediately before use even when it continuous.
-Always replace clean gauges in their box and close it after use. If gauges are not in frequent use they should be coated to prevent corrosion.
-Do not handle gauges above open box, they mat cause damage to other gauges if dropped.

It was mentioned earlier that we have to build the desired length of the blocks; the following example explains the procedure:
-Build a 30.967 mm using the minimum number of blocks.

30.967
<u>- 1.007</u>
29.960
<u>-1.090</u>
28.870
<u>-1.370</u>
27.500
<u>-7.500</u>
20.000

So we 5 blocks are used to build the desired length.

APPARATUS:

- Set of block gauges
- Granite surface plate

EXPERIMENTAL PROCERUDE:

After being familiar with the blocks and the available rang of lengths complete the following procedure. .

1-Use minimum number of block gauges to build the following size length and complete table1.

Table 1:

# of gauges	59.876 mm	41.389 mm	9.999 mm
1st piece			
2nd piece			
3rd piece			
4th piece			
5th piece			
6th piece			

2-Complete the following table and Plot your results & determine the maximum error

Table 2:

Standard block gauge mm	Standard block gauge with error mm	Reading of micrometer
0.000	0+ 0.0005 0-0.0005	
3.000	3+ 0.0005 3-0.0005	
5.000	5+ 0.0005 5-0.0005	
10.000	10+ 0.0005 10-0.0005	
15.000	15+ 0.0005 15-0.0005	
20.000	20+0.0005 20-0.0005	

3-Take the piece which you want to measure its length and take its length by using vernier caliber (to take approximate length to easy the comparison)then we put it in a mechanical comparator and calibrate it to get error less than 0.01 mm. Now remove the piece and put block gauges until we reach the desire value. Then we take the reading of blocks.

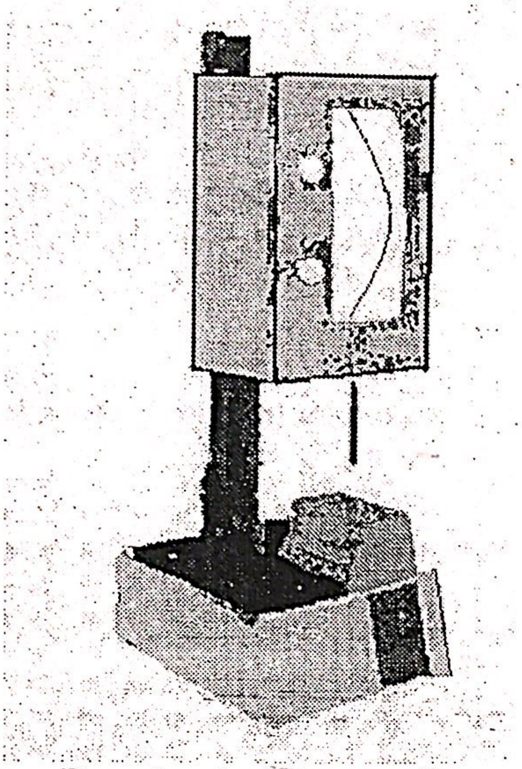


Figure 1 mechanical comparator

As seen in the figure the mechanical comparator is used to detect the correct number of blocks needed to the desired length, and it provides a rang of tolerance within the measurement is acceptable.

DISCUSSION:

1. State the difference between end standard and line standard? And state the reason that make the end standard more accurate?
2. Stat the difference between the different grades of the blocks.
3. What is the accuracy of the block gauges? How did you reach the answer?
4. Why do we always choose the minimum number of blocks combination?
5. Why do we bather ourselves with how the blocks should be attached to each other?
6. Suggest other applications for block gauges?
7. In the comparator measuring method what do we compare with?

University Of Jordan
Faculty of Engineering and Technology
Mechanical Engineering Department

Measurement Lab.

Experiment 2

Surface Texture

SURFACE TEXTURE

*INTRODUCTION:

Surface topography is of great importance in specifying the function of a surface. A significant proportion of component failure starts at the surface due to either an isolated manufacturing discontinuity or gradual deterioration of the surface quality. Typical of the former is the laps and folds which cause fatigue failures and of the latter is the grinding damage due to the use of a worn wheel resulting in stress corrosion and fatigue failure. The most important parameter describing surface integrity is surface roughness. In the manufacturing industry, surface must be within certain limits of roughness. Therefore, measuring surface roughness is vital to quality control of machining work piece. Below are the definition of surface roughness and its main measurement methods. . From a knowledge of the roughness amplitude and wavelength values expected from the surface, it is possible to select the appropriate instrument settings for a reliable roughness measurement.

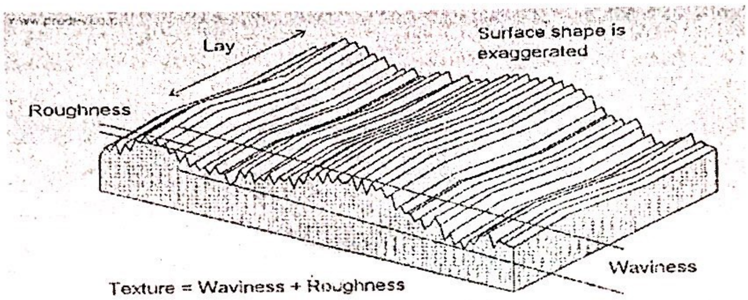


Fig.1 : Surface texture includes roughness and waviness. Many surfaces have lay: directional striations across the surface

*DEFINITIONS:

In any discussion of this type, we need to start with a few definitions. The important ones here are:
SURFACE TEXTURE is the local deviations of a surface from its ideal shape e.g perfect flat shape, perfect cylinderical shape, sherical shape etc. The measure of the surface texture is generally determined in terms of its roughness, waviness and Form ** In surface texture there are many factors that, when combined, characterise a surface's profile. For example:

- the microstructure of the material
- the action of the cutting tool
- the instability of the cutting tool on the material
- errors in the machine tool guideways
- Mainly, what affects the surface texture could be summarized in the speed of the cutting tool, feed rate & the depth of cut.

ROUGHNESS – a quantitative measure of the process marks produced during the creation of the surface and other factors such as the structure of the material. The action of the cutting tool, chemical action, polishing, lapping, and the structure of the material all contribute to the roughness of the surface.

WAVINESS – a longer wavelength variation in surface away from its basic form (e.g. straight line or arc). . It may result from such factors as machine or work deflection, vibration, chatter, heat treatment, or warping strains

**Because both process and machine induced irregularities occur simultaneously,roughness is superimposed over waviness.

LAY refers to the predominant direction of the surface texture. Ordinarily lay is determined by the particular production method and geometry used.Turning, milling, drilling, grinding, and other cutting tool machining processes usually produce a surface that has lay

PROFILE is, mathematically, the line of intersection of a surface with a sectioning plane which is (ordinarily) perpendicular to the surface. It is a two-dimensional slice of the three-dimensional surface. Almost always profiles are measured across the surface in a direction perpendicular to the lay of the surface. Shortly saying, it's the graphical representation of the surface.

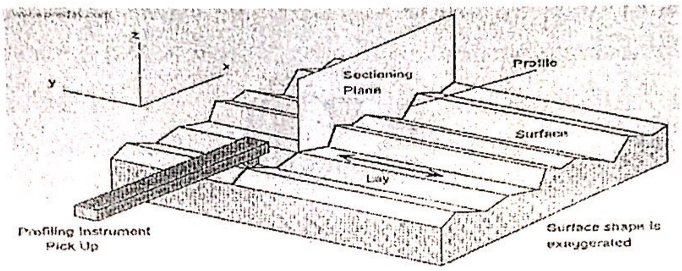


Fig.2 : A profile is a two-dimensional picture of a three dimensional surface that may be thought of as the result of a sectioning place cutting the surface. Profiles are ordinarily taken perpendicular to the lay.

CENTER LINE (Mean line) : mathematically it's poisoned in such a way that within the sampling length the sum of areas enclosed by the profile above & below the center line are equal.

FORM of a surface is the profile of the surface under consideration ignoring variations due to roughness and waviness. Deviations from the desired form result from clamping marks or sliding marks machining guide errors etc.

Ra - Average Roughness....The average roughness is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length Graphically, the average roughness is the area (shown below) between the roughness profile and its center line divided by the evaluation length (normally five sample lengths with each sample length equal to one evaluation length) This is the parameter that has been used universally for many years.

$$Ra = \sum A / L = \sum H / N$$

Where A = Area between the center line & the profile.
L= Sampling length.
H = Height of a point chosen from the profile with respect to the center line.
N = number of heights taken.

FILTERS are electronic or mathematical methods or algorithms which separate out different wavelengths and allow us to see only the wavelengths we are interested in.

CUT-OFF is a filter and is used as a means of separating or filtering the wavelengths of a component. Cut-offs have a numerical value that when selected will reduce or remove the unwanted wavelengths on the surface. For example, a roughness filter cut-off with a numeric value of 0.8mm will allow wavelengths below 0.8mm to be assessed with wavelengths above 0.8mm being reduced in amplitude; the greater the wavelength, the more severe the reduction. For a waviness filter cut-off with a numeric value of 0.8mm, wavelengths above 0.8mm will be assessed with wavelengths below 0.8mm being reduced in amplitude.

SAMPLE LENGTH : after the data has been filtered with a cut –off, we then sample it. Sampling is done by breaking the data into equal sample lengths. The sample lengths have the same numeric value as the cut-off. In other words, if you use a 0.8mm cut-off, then the filtered data will be broken down into 0.8mm sample lengths. These sample lengths are chosen in such a way that a good statistical analysis can be made of the surface. In most cases, five sample lengths are used for analysis.

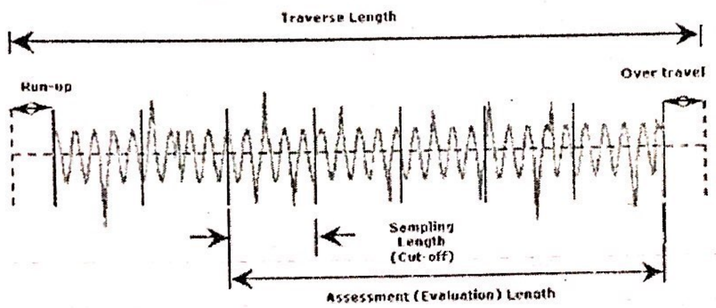


Fig.3 : Sample of surface profile

Rsk –(it's an amplitude parameter which's a measure of the vertical characteristics of the surface deviations).Rsk : is a measurement of skewness and will indicate whether the surface consists of mainly peaks, valleys or an equal combination of both. It is the measure of the symmetry of the profile about the mean line. A surface with predominant peaks will be considered as 'positive skew' and a surface with predominant valleys will be considered as 'negative skew'

RSm (it's a spacing parameter– which's a measure of the horizontal characteristics of the surface deviations) Rsm : is the mean spacing between profile peaks as they pass through the mean line (spacing is the distance between points that cross the mean line within a sample length in an upward direction).

*note - almost all parameters are defined over 1 sample length, however in practice more than 1 sample length is assessed (usually 5) and the mean calculated. This provides a better statistical estimate of the parameter's measured value

<u>*PROCEDURE:</u>

1- <u>Tactile assessment :</u> Which's a comparison of the surface roughness with a standard surface (Rubert gauges). The comparison is done by touching the surface with your fingernail & then comparing it with the gauges to establish the roughness value of the sample. Now, each gauge is specified for a certain process, i.e each gauge has a different color indicating a different process used in manufacturing the tested surface as milling, grinding, turning.. etc. *Using rubert gauges, the estimated value of Ra = ………….. micrometer.

2- The tracer method : Which uses a stylus that's dragged across the surface. This method is the most common for obtaining quantitative results.

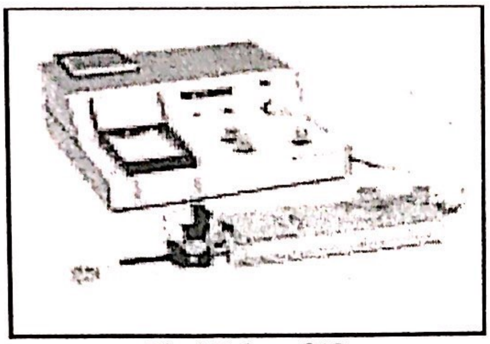


Fig.4 Talysurf 10

****Taylor-Hobson (Talysurf 10) Profilometer**

This equipment measures surface profiles by scanning a mechanical stylus across the sample. The profilometer can be used to measure etch depths, deposited film thickness and surface roughness. A modern typical surface measuring instrument will consist of a stylus with a small tip (diamond) a gauge or transducer, a traverse datum and a processor. The surface is measured by moving the stylus across the surface. As the stylus moves up and down along the surface, the transducer converts this movement into a signal which is then exported to a processor which converts this into a number and usually a visual profile. (The stylus must be moved in a straight line to give accurate readings)

*Below is a description of this process :

a- To record the profile of the specimen, switch on the instrument & adjust the coarse & fine adjustment found on the amplifier recorder to the mid position.

-The magnifications for both the vertical & horizontal are set to 1000 & 20 respectively.

- The specimen is placed in the V-block.
- Slowly bring the stylus on to the specimen until it touches the specimen. To make sure that there's a touching bring the stylus down more until the pen in the Graph Recorder comes to the mid position.
- For trial, take a trace by pressing the switch knob down.
- Now, run for a few centimeters & stop to adjust the vertical until the trace covers the graph paper.
- If you want the profile to be spread apart, switch the function knob to Vv same.

b- To find the roughness average, use the Ra meter.

- Hold the specimen on the V-block.
- Adjust the coarse & fine adjustment knobs to the mid position.
- Set the function knob Vv to the 0.8 mm cut-off length & Vv to 1000 magnification.
- Once again, slowly bring the stylus on to the specimen & check that it touches the specimen as previously.

-Press the start lever & take the reading from the Ra meter.To make use of the full range of the scale, choose the appropriate Vv & take another reading..

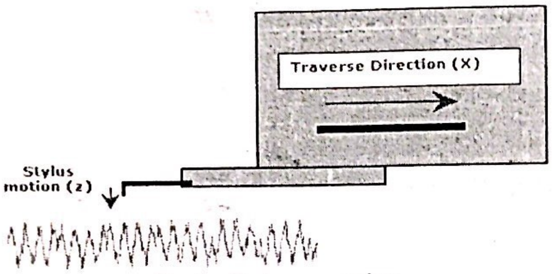


Fig.6 : Stylus operation

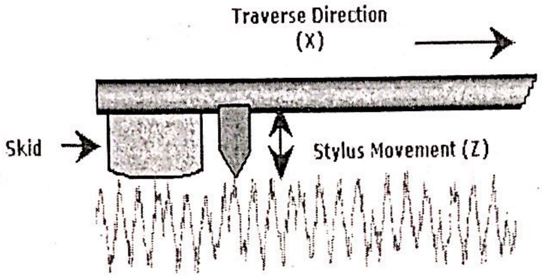


Fig.7 : Stylus and skid operation

***RESULTS:**

Turning 1

	Ra1	Ra2	Ra3	average
Rubert gauge				
Talysurf (direct)				
Talysurf (calculated)				

Turning 2

	Ra1	Ra2	Ra3	average
Rubert gauge				
Talysurf (direct)				
Talysurf (calculated)				

Milling :

	Ra1	Ra2	Ra3	average
Rubert gauge				
Talysurf (direct)				
Talysurf (calculated)				

Grinding:

	Ra1	Ra2	Ra3	average
Rubert gauge				
Talysurf (direct)				
Talysurf (calculated)				

***DISCUSSIONS:**

1- What are the advantages & disadvantages of using Rubert gauges & the stylus.
2- Why do we need the profile of the component & is it a true picture of the surface?
3- What does 1 division on Ra scale represent when Vv= 50000 magnification.
4- How do we achieve the vertical & horizontal magnifications?
5- Why is the horizontal magnification limited to only a small value in comparison with the vertical one?
6- What do you think is more accurate in finding the Ra value, $(\sum A / L)$ or $(\sum H / N)$?
7- What does Ra represent graphically?

***REFERENCES:**

Engineering Metrology by R K Jain.

University Of Jordan
Faculty of Engineering and Technology
Mechanical Engineering Department

Measurement Lab.

Experiment 1

Auto collimator

Auto collimator

Introduction

An autocollimator is an optical instrument that is used to measure small angles with very high sensitivity. As such, the autocollimator has a wide variety of applications including precision alignment, detection of angular movement, verification of angle standards, and angular monitoring over long periods.

Objectives:

- To measure straightness of a beam with the use of Auto-Collimator.
- To identify the principle of Auto-Collimator device.
- To be able to draw conclusions about straightness error using graphical methods and least square method.

Apparatus:

1) auto collimator
2) straight edge with 100mm marked intervals.

Theory:

Increasing demand for product reliability and efficiency has placed a corresponding emphasis on the geometric integrity of components and their assembly. In engineering applications, one often comes across the problems of measurement, of-geometrical parameters such as alignment, straightness, squareness, flatness, etc.

At many places it is required that the surfaces must be perfectly straight, e.g., in a lathe it is desired that tool must move in a straight path to generate perfect cylinder and it is possible .only when the controlling guideways are themselves straight. Also straight line or plane is the basis of most methods of measurements. The quality of straightness in precision engineering is represented by straight edge.

The fundamental principle about straightness measurement is given by Bryan. According to Bryan principle, a straightness measuring system should be in line with the functional point at which straightness is to be measured. If this is not possible, either the slideways that transfer the measurement must be free or angular motion or angular motion data must be used to calculate the consequences of the offset.

Definition of straightness of a line in two planes.

A line is said to be straight over a given length, if the variation of the distance of its points from two planes perpendicular to each other and parallel to the general direction of the line remains within the specified tolerance limits; the reference planes being so chosen that their intersection is parallel to the straight line joining two points suitably located on the line to be tested and the two points being close to the ends of the lengths to .be measured.

The tolerance on the straightness of a line is defined as the maximum deviation in relation to the reference straight line joining the two extremities of the line to be checked (Fig. 1).

Fig. 1: Profile of surface with respect to reference straight line.

It is the usual practice to state the range of measurement, i.e. the length to be checked; and the position of the tolerance in relation to the reference straight line. In most cases, the parts very close to the ends, which most often have local errors of no great importance, may be neglected.

Auto-collimators are sensitive and inherently very accurate optical instruments for the measurement of small angular deviations of a light reflecting flat surface. The auto- collimator has its own target which is projected by collimated light beams on a remotely placed surface and the reflected target image is observed in the ocular of the instrument.

The auto-collimator is stationed at the end of the bed with a rigid support base. The movement of the reflector along the bed will cause the reflected image of the target to deflect according to the angular error of the bed.

The autocollimator is a flat mirror mounted in a short tube made to fit a Newtonian telescope focuser, and set accurately perpendicular to the tube's axis. Centered in it is a small peephole or pupil that you look through.

Principles of operation

Tests for straightness can be carried out by using spirit level or auto-collimator. The straightness of any surface could be determined by either of these instruments by measuring the relative angular positions of number of adjacent sections of the surface to be tested.

So first a straight line is drawn on the surface whose straightness is to be tested.

Then it is divided into, a number of sections, the length of each section being equal to the length of spirit level base or the plane reflector's base in case of auto-collimator. Generally the bases of the spirit level block or reflector are fitted with two feet so that only feet have line contact with the surface and whole of the surface of base does not touch the surface to be tested. This ensures that angular deviation obtained is between the specified two points. In this case length of each section must be equal to distance between the centre lines of two feet. The spirit level can be used only for the measurement of straightness of horizontal surfaces while auto-collimator method can be used on surfaces in any plane.

In case of spirit level, the block is moved along the line on the surface to be tested in steps equal to the pitch distance between the centre lines of the feet and the angular variations of the direction of block are measured by the sensitive level on it.

Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.

In case of measurement by auto-collimator, the instrument is placed at a distance of 0.5 to 0.75 meter from the surface to be tested on any rigid support which is independent of the surface to be tested.

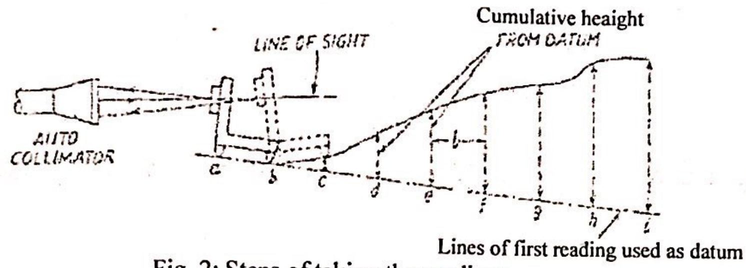


Fig. 2: Steps of taking the readings.

The parallel beam from the instrument is projected along the length of the surface to be tested.

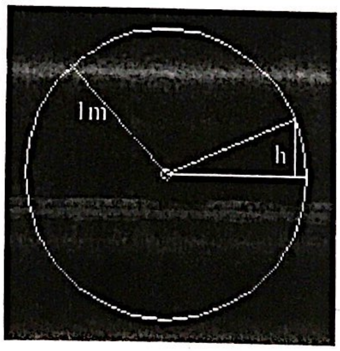
A block fixed on two feet and fitted with a plane vertical reflector is placed on the surface and the reflector face is facing the instrument.

The reflector and the instrument are set such that the image of the cross wires of the collimator appears nearer the centre of the field and for the complete movement of reflector along the surface straight line, the image of cross-wires will appear in the field of eyepiece, the reflector is then moved to the other end of the surface in steps equal to the centre distance between the feet and the tilt of the reflector is noted down in second from the eyepiece.

The autocollimator projects a beam of collimated light. An external reflector reflects all or part of the beam back into the instrument where the beam is focused and detected by a photodetector. The autocollimator measures the deviation between the emitted beam and the reflected beam. Because the autocollimator uses light to measure angles, it never comes into contact with the test surface.

Visual autocollimators rely on the operator's eye to act as the photodetector. Micro-Radian visual autocollimators project a pinhole image. The operator views the reflected pinhole images through an eyepiece. Because the human eye acts as the photodetector, resolution will vary among operators. Typically, people can resolve from 3 to 5 arc-seconds. Because the human eye is able to discern mutiple images simultaneously, visual autocollimators are suitable for measuring multiple surfaces simultaneously. This makes them ideal alignment instruments in applications like aligning laser rod ends or checking parallelism among optics. Visual autocollimators can also be equipped with an eyepiece reticle for aid in lining up test optics to a master reference.

To calculate Tilt of 1 sec of Arc of the Reflector:



$Tan\theta = h / radius$
$\theta = 1$ sec of arc
$h = \tan 1$ sec x Radius
$h = 4.848 \times 10^{-6}$ meter
h = 5 micrometer / meter approximately
h = 0.5 micrometer / 10^{-3} mm

PROCEDURE

1. Clean the surface plate or table.

2. Position the auto-collimator in line with the reflector. Switch on the lamp in the autocollimator, the alignment between the auto-collimator and reflector should be checked at both extremes of the operational distance to make certain that the target graticule is contained within the eyepiece field.

3. Fix a guide strip to control the horizontal displacement of the reflector and minimise the movement of the target graticule.

4. Mark off the positions along the surface plate equal to the pitch positions on the reflector base (in this case 100 mm). Column 1 should indicate this position.

5. At the initial position takes the reading and tabulates (column 2)
6. Move the carriage (reflector) to the next position and again tabulate the reading.

7. This method is to continue until the final outward position is recorded.

To improve on the accuracy and ensure no errors have been introduced, readings should also be taken on the inward run. If this exercise is followed then the average of the two readings is to be shown in column 2.

8. The remainder of the table should be filled by adopting the following procedure:
   - Column 3 This is the variations of the tilt occurring between the position at which the reading is taken and the original position.
   - Column 4 The angular position in column 3 is converted into a linear measure (1 second = 0.5 micro m). Insert a zero at the top of the column to represent the datum.
   - Column 5 This is the cumulative algebraic sum of the displacements. Calculate the mean displacement this is the amount by which the displacement must be adjusted to relate them to the zero datum.
   - Plot the values of column 5 versus column 1.

Observed Data:

Table (1): Variation of rise/fall angle along surface.

1	2	3	4	5
Position of reflector	Auto-coll. Reading	Difference From 1st Reading	Rise (-) or Fall (+) per 100 mm	Cumulative Rise or fall
mm	seconds	seconds	µm	µm
0			0	0
0 – 100				
100 – 200				
200 – 300				
300 – 400				
400 – 500				
500 – 600				
600 – 700				
700 – 800				
800 – 900				
900 – 1000				

Discussion and review Question:

»Explain the principle of the Auto-collimator.

» Are the existence of burrs or dust on the surface plate affect your result.

» Auto collimator works on the principle light reflection, it concerned with the idea that flat surface will reflect light at ------------ angle.

» The main scale is divided into --------- divisions each reads ------- min.

» The accuracy of the device is ----------

» The alignment between the auto-collimator and reflector should be checked at both extremes of the operational distance to -------------

» Determine the maximum straightness error with respect to

a) A line joining end points

b) The least square line.

» Discuss and compare your results.

- Which method is more accurate , why?

Straightness

Increasing demand for product reliability and efficiency has placed a corresponding emphasis on the geometric integrity of components and their assembly. In engineering applications, one often comes across the problems of measurement, of-geometrical parameters such as alignment, straightness, squareness, flatness, etc.

At many places it is required that the surfaces must be perfectly straight, *e.g.,* in a lathe it is desired that tool must move in a straight path to generate perfect cylinder and it is possible .only when the controlling guideways are themselves straight. Also straight line or plane is the basis of most methods of measurements. The quality of straightness in precision engineering is represented by straight edge.

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- Test for Straightness by using Spirit Level and Auto-collimator

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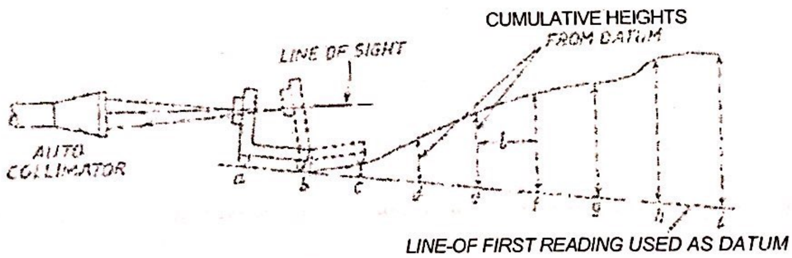

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$$1 \text{ sec. of arc} = 0.000006 \text{ mm/mm}$$

Therefore, 1 sec. of arc will correspond to a rise or fall of 0.000006 * L mm, where "L" is the distance between centers of feet in mm.

The condition for initial and subsequent readings is shown in Fig. 2 in which the rise and fall of the surface is shown too much exaggerated.

With the reflector set at *a-b* (1^{st} reading), the micrometer reading is noted and this line is treated as datum line. Successive readings at *b-c, c-d, d-e* etc. are taken till the length of the surface to be tested has been stepped along. In other to eliminate any error in previous set of readings, the second set of readings could be taken by stepping the reflector in the reverse direction and mean of two taken. This mean reading represents the angular position of the reflector in seconds relative to the optical axis of autocollimator. The data is then fitted as in table (1).

Column 1 gives the position of plane reflector at various places at intervals of 'L' *e.g. a-b, b-c, c-d* ... etc.

Column 2 gives the mean reading of auto-collimator or spirit level in seconds.

In column 3, difference of each reading from the first is given in order to treat first reading as datum.

These differences are then converted into the corresponding linear rise or fall in column 4.

Column 5, gives the cumulative rise or fall, *i.e.*, the heights of the support feet *of* the reflector above the datum line drawn through their first position. It should be noted that the values in column 4 indicate the inclinations only and are not errors from the true datum. For this the values are added cumulatively with due regard for sign. Thus it leaves a final displacement equal to *L* at the end of the ran which of course does not represent the magnitude of error of the surface, but is merely the deviation from a straight line produced from the plane of the first reading. In column 5 each figure represents a point, therefore, an additional zero is put at the top representing the height of point *a*.

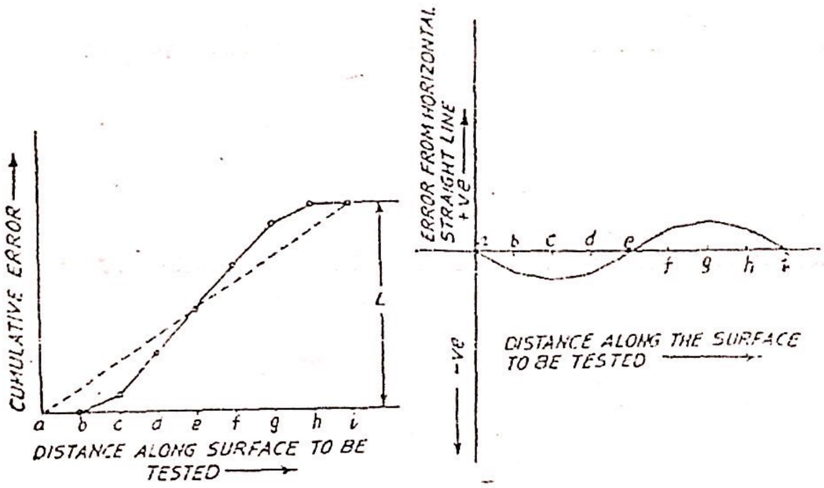


Fig. 3: The results plotted on graph.

The errors of any surface may be required relative to any mean plane. If it be assumed that mean plane is _one joining the end points_ then whole of graph must be swung round until the end point is on the axis (Fig. 3).

This is achieved by subtracting the length L proportionately from the readings in column 5. Thus if n readings be taken, then column 6 gives the adjustments -L/n;-2L/n... etc., to bring both ends to zero.

Column 7 gives the difference of columns 5 and 6 and represents errors in the surface from a straight line joining the end points. This is as if a straight edge were laid along the surface profile to be tested and touching the end points of the surface when they are in a horizontal plane and the various readings in column 7 indicate the rise and fall relative to this straight edge.

Position	Mean Reading of Auto-Collimator or spirit level (sec)	Difference from first leading (sec)	Rise or fall in interval length 'l' (mm)	Cumulative rise or fall (mm)	Adjustment to bring both ends to zero (mm)	Errors from straight line (mm)
1	2	3	4	5	6	7
a				0	0	0
$a-b$	θ_1	0	0	0	$-L/n$	$-L/n$
$b-c$	θ_2	$\theta_2-\theta_1$	$(\theta_2-\theta_1)l$	$(\theta_2-\theta_1)l$	$-2L/n$	$(\theta_2-\theta_1)l-2L/n$
$c-d$	θ_3	$\theta_3-\theta_1$	$(\theta_3-\theta_1)l$	$(\theta_2-\theta_1)l + (\theta_3-q_1)l$	$-3L/n$	$(\theta_2-\theta_1)l+(\theta_3-\theta_1)l-3L/n$
...	...	...	...	...	...	...
...	...	...	...	...	...	...
...	...	...	...	...	...	...
$h-i$	θ_n	$\theta_n-\theta_1$	$(\theta_n-\theta_1)l$	$\Sigma(\theta_n-\theta_1)l = L$	$-L$	0

Table (1): The data in tabular format.

Conversior Factor = (0.5) micro per one second

Table (1) :

Position	Angle Reading (Sec)	Difference from first Reading (min)	Rise/Fall in interval length "l" (micro m)	Cumulative Rise/Fall wrt line ab (micro m)
0				0
100.00	497.000	0.000	0.000	0.000
200.00	483.000	-14.000	-7.000	-7.000
300.00	400.000	-97.000	-48.500	-55.500
400.00	337.000	-160.000	-80.000	-135.500
500.00	***250.000***	***-247.000***	-123.500	***-259.000***
1500.00	1967.00	-518.00	-259.00	-457.00
X prime =	250.00			Y prime =

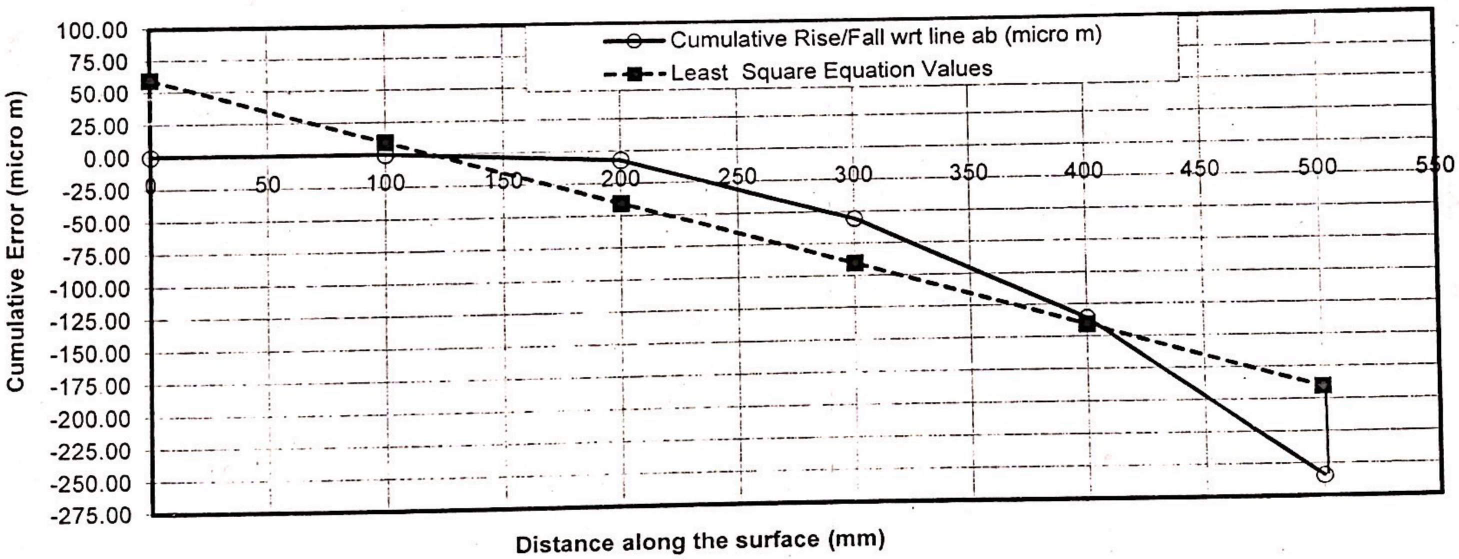
Table (2) :

Xm	Ym	Xm Ym	Xm^2	Least Square Equation Values	Maximum Difference
-250.00	65.28571	-16321.42857	62500	59.71429	59.71429
-150.00	65.28571	-9792.857143	22500	9.714286	9.714286
-50.00	58.28571	-2914.285714	2500	-40.2857	-33.2857
50.00	9.785714	489.2857143	2500	-90.2857	-34.7857
150.00	-70.2143	-10532.14286	22500	-140.286	-4.78571
250.00	***-193.714***	***-48428.57143***	***62500***	***-190.286***	***68.71429***

sum 0.00 -65.29 -87500.00 175000.00

-65.2857 micro m m = -0.5

c= 59.71428571



Conversion Factor = (20/60) micrometer for one second

(A) Line Joining End Points

	Position	Angle Reading (Sec)	Difference from first Reading (Sec)	Rise/Fall in interval length "l" (micro m)	Cumulative Rise/Fall wrt line ab (micro m)	Line Joining End Points Y=mx+c	Difference C6-C5 (micro m)
0	0	0	0.00	0.00	0.00	0.00	0.00
a-b	100.00	507.000	0.00	0.00	0.00	60.36	60.36
b-c	200.00	433.000	74.00	24.67	24.67	120.71	96.05
c-d	***300.00***	***350.800***	***156.20***	***52.07***	***76.73***	***181.07***	***104.34***
d-e	400.00	287.000	220.00	73.33	150.07	241.43	91.36
e-f	500.00	200.000	307.00	102.33	252.40	301.78	49.38
f-g	600.00	177.780	329.22	109.74	362.14	362.14	0.00

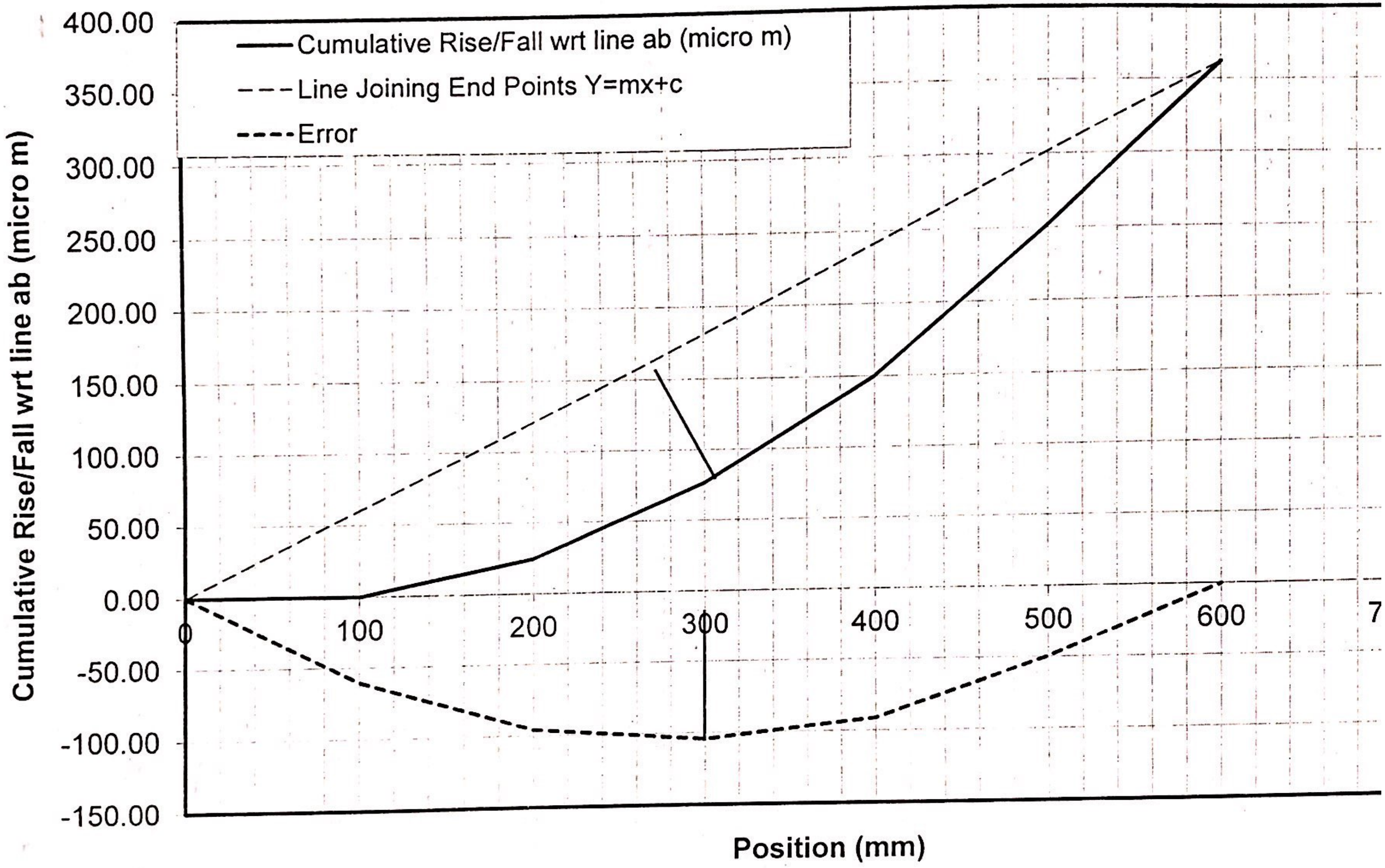
m = 362.14/600
0.603566667

(B) Method of Adjustment

	Position	Angle Reading (Sec)	Difference from first Reading (Sec)	Rise/Fall in interval length "l" (micro m)	Cumulative Rise/Fall wrt line ab (micro m)	Adjustment	Error
0	0	0			0.00	0.00	0.00
a-b	100.00	507.000	0.00	0.00	0.00	-60.36	-60.36
b-c	200.00	433.000	74.00	24.67	24.67	-120.71	-96.05
c-d	***300.00***	***350.800***	**156.20**	**52.07**	**76.73**	**-181.07**	**-104.34**
d-e	400.00	287.000	220.00	73.33	150.07	-241.43	-91.36
e-f	500.00	200.000	307.00	102.33	252.40	-301.78	-49.38
f-g	600.00	177.780	329.22	109.74	362.14	-362.14	0.00

(C) Method of Adjustment Same As (B) but with sign

	Position	Angle Reading (Sec)	Difference from first Reading (Sec)	Rise/Fall in interval length "l" (micro m)	Cumulative Rise/Fall wrt line ab (micro m)	Adjustment	Error
0	0	0			0.00	0.00	0.00
a-b	100.00	507.000	0.00	0.00	0.00	-60.36	60.36
b-c	200.00	433.000	-74.00	-24.67	-24.67	-120.71	96.05
c-d	***300.00***	***350.800***	***-156.20***	***-52.07***	***-76.73***	***-181.07***	***104.34***
d-e	400.00	287.000	-220.00	-73.33	-150.07	-241.43	91.36
e-f	500.00	200.000	-307.00	-102.33	-252.40	-301.78	49.38
f-g	600.00	177.780	-329.22	-109.74	-362.14	-362.14	0.00



Cumulative Rise/Fall wrt line ab (micro m)
Line Joining End Points Y=mx+c
Error
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
-50.00
-100.00
-150.00
0
100
200
300
400
500
600
7
Cumulative Rise/Fall wrt line ab (micro m)
Position (mm)

STRAIN GAUGES

Objectives

Upon completion of this study and the evaluation of experimental measurements, the student will be able to:

- Describe how strain gauge devices are used for measurements,
- Describe the type of circuitry used in connecting strain gauge transducers,
- Describe how a strain gauge should be physically attached to objects.

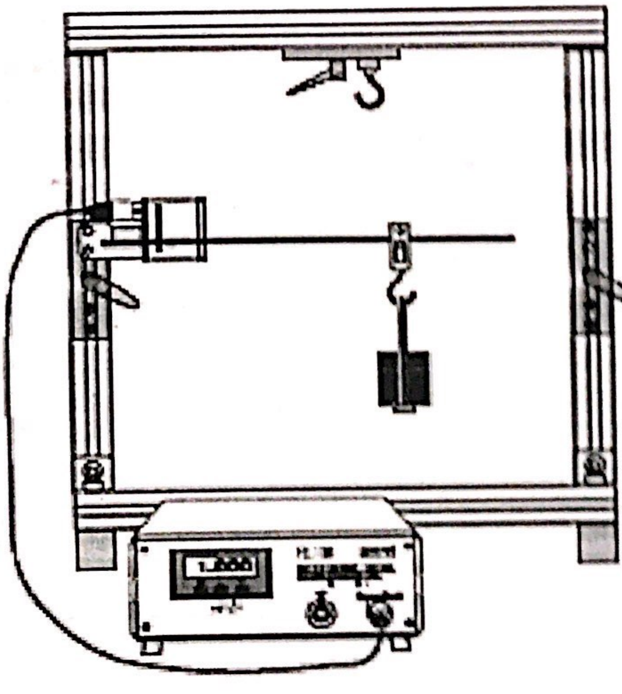
Introduction

Strain gauges permit simple and reliable determination of stress and strain distribution at real components under load. The strain-gauge technique is thus an indispensable part of experimental stress analysis. Widespread use is also made of strain gauges in sensor construction (scales, dynamometers and pressure gauges, torque meters).

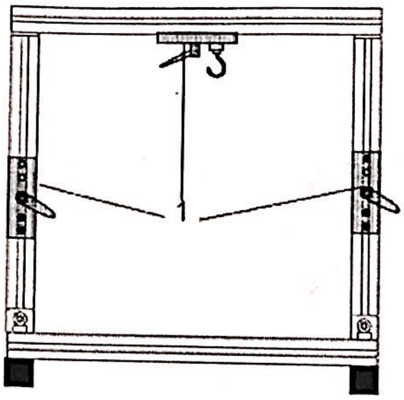
All **test objects** are provided with a full-bridge circuit and are ready wired. A Perspex cover protects the element whilst giving a clear view.
The test objects are inserted in a frame and loaded with weights.

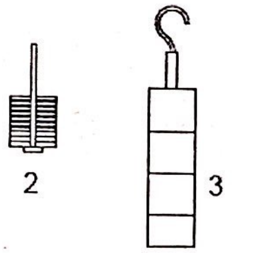
The **measuring amplifier** has a large bright digital LED display, which is still easy to read from a distance. The unit is thus also eminently suited to demonstration experiments.

2 Unit description



2.1 Loading frame

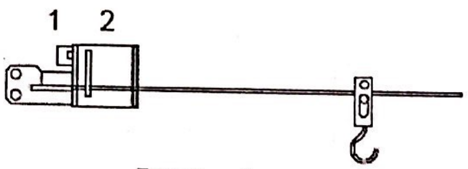




The loading frame is made of light-alloy sections and serves to accommodate the different test objects. Various holders (1) are attached to the frame for this purpose. Clamping levers enable these holders to be quickly and easily moved in the grooves of the frame and fixed in position.
The training system is provided with two different sets of weights for loading the test objects.

- Small set of weights (2) ------1 - 6 N, graduations 0.5 N for bending experiments

2.2 Test objects



Bending beam

2.2.1 Bending beam

The test object used for **bending experiments** is a clamped steel cantilever beam (4).
- Length L: 385 mm
- Cross section Area:
  h=4.75 mm
  b=19.75 mm
- Modulus of elasticity E: 210000 N/mm2

The strain-gauge element (2) (full-bridge circuit) is attached in the vicinity of the clamping point. Electrical connection is by way of a small PCB and a 5-pin socket (1) with bayonet lock. The strain-gauge configuration can be seen from the adjacent diagram. The element is protected by a Perspex housing. An adjustable slider (3) with hook permits loading with a single force at defined lever arm.

2.3 Measuring amplifier

The measuring amplifier with digital 4-position LED display (1) gives a direct indication of the bridge unbalance in mV/V. The connected strain-gauge bridge can be balanced by way of a ten-turn potentiometer (2).

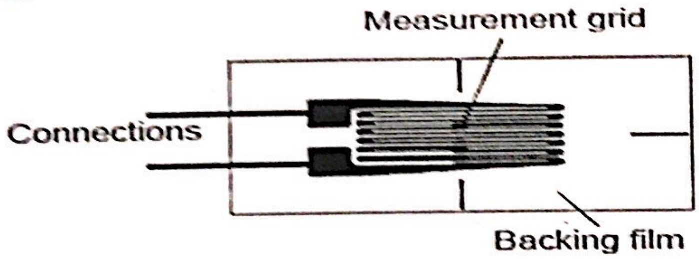
- Range: ± 2.000 mV/V
- Resolution: 1 µV/V.
- Balancing range: ± 1.0 mV/V.
- Nominal strain-gauge resistance: 350 Ω
- Strain-gauge feed voltage :10V
- Power supply: 230V / 50Hz

The unit is envisaged for the connection of strain gauge full bridges. The test objects are connected by way of the cable (4) supplied to the 7-pin input socket (3) on the front.

3 Experiments

3.1 Principle of strain-gauge technique

When dimensioning components, the loads to be expected are generally calculated in advance within the scope of design work and the components then dimensioned accordingly. It is often of interest to compare the loads subsequently encountered in operation to the design forecasts. Precise knowledge of the actual load is also of great importance for establishing the cause of unexpected component failure. The mechanical stress is a measure of the load and a factor governing failure. This stress cannot generally be measured directly. As however the material strain is directly related to the material stress, the component load can be determined by way of strain measurement. An important branch of experimental stress analysis is based on the principle of strain measurement.



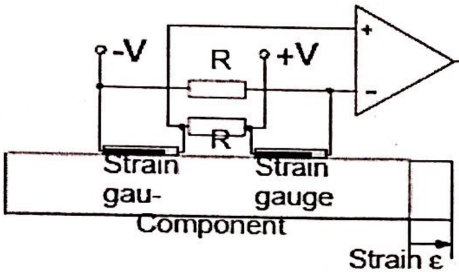
Foil-type strain gauge (greatly enlarged)

...se of the strain-gauge technique enables strain to be measured at the surface of the ...ent. As the maximum stress is generally found at the surface, this does not represent a ... With metallic strain gauges, the type most frequently employed, use is made of the ...e electrical resistance of the mechanically strained thin metal strip or metal wire. The change in resistance is the combination of tapering of the cross-sectional area and a change in the resistivity. Strain produces an increase in resistance. To achieve the greatest possible wire resistance with small dimensions, it is configured as a grid. The ratio of change in resistance to strain is designated **k**

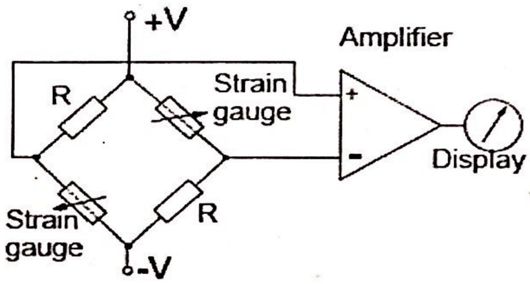
$$k = \frac{\Delta R / R0}{\varepsilon}$$

ε : strain
R_0 : resistance at zero point (no force) Ω
ΔR : change in resistance after applying force Ω

Strain gauges with a large k-factor are more sensitive than those with a small one. The constantan strain gauges used have a **k-factor of 2.05.** In order to be able to assess the extremely small change in resistance, one or more strain gauges are combined to form a Wheatstone bridge, which is supplied with a regulated DC voltage (±V).



Configuration of half bridge on component



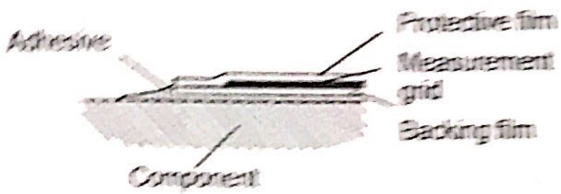
Halve-bridge circuit

The bridge may be fully (full bridge) or only partially (half and quarter bridge) configured with active strain gauges. The resistors R required to complete the bridge are called complementary resistors. The output voltage of the bridge reacts very sensitively to changes in resistance in the bridge branches. The voltage differences occurring are then amplified in differential amplifiers and displayed.

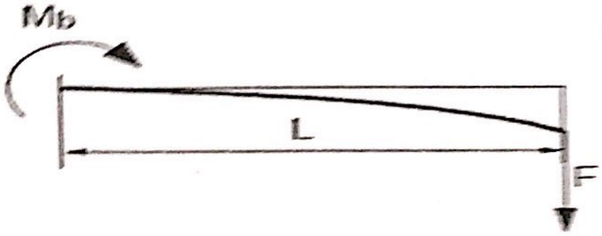
The design of a strain gauge is shown in the adjacent illustration. The wave-form metal strips are mounted on a backing material, e.g. a thin elastic polyimide film and covered with a protective film. Today's metal strips are usually produced by etching from a thin metal foil (foil-type strain gauges). Thin connecting wires are often welded directly to the strain gauge.

The strain gauge is bonded to the component with a special adhesive, which must provide loss-free transmission of the component strain to the strain gauge.

Design of strain gauge



3.3 Bending experiment



3.3.1 Fundamentals

The stress at the surface of the bending beam can be calculated from the bending moment **Mb** and the section modulus **Wy**

$$\sigma = \frac{Mb}{Wy}$$

Bending moment calculated for cantilever beam

$$M_b = -F \cdot L$$

where **F** is the load and **L** the distance between the point at which the load is introduced and the measurement point. The section modulus for the rectangular cross section of width **b** and height **h** is

$$W_y = \frac{bh^2}{6}$$

For **experimental determination** of the bending stresses, the bending beam is provided with two strain gauges each on the compression and tension sides. The strain gauges of each side are arranged diagonally in the bridge circuit. This leads to summation of all changes in resistance and a high level of sensitivity. The output signal **U_A** of the measuring bridge is referenced to the feed voltage **U_E**. The sensitivity k of the strain gauge enables the strain ε to be calculated for the full bridge as follows

$$\varepsilon = \frac{1}{k} \cdot \frac{U_A}{U_E}$$

According to **Hooke's law** the stress being sought is obtained with the modulus of elasticity **E** (Modulus of elasticity for steel: 210000 N/mm2)

$$\sigma = \varepsilon \cdot E$$

3.3.2 Performance of experiment

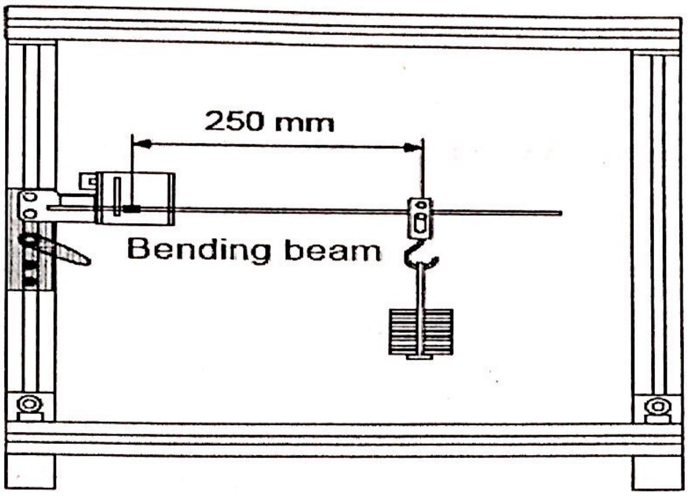
- Fit **bending beam** in frame as shown using holder with two pins.

- Connect up and switch on measuring instrument.

- Set slider to distance of 250 mm.

- Use offset adjuster to balance display.
- Load beam with small set of weights.

Increase load in steps and note down reading.



Bending experiment, lever arm 250 mm							
Load in N	0	1 (holder only)	2	3	4.5	5.5	6
Reading in $mV/V.10^{-3}$							

Discussion :

1. Plot the measurement results in a graph.

2. Calculate stress and strain .
3. Name two types of strain gauge.

Example :

The stress is now to be determined for a load of 6.5 N where the reading was -0.227.10^{-3} . The following results for the strain

$$\varepsilon = \frac{1}{k} \cdot \frac{U_A}{U_E}$$

$$= \frac{1}{2.05} \cdot (-0.227 \cdot 10^{-3})$$

$$= -0.0001107.$$

The modulus of elasticity for steel of 210000 N/mm2 gives the following stress

$\sigma = \varepsilon \cdot E = -0.0001107 \cdot 210000 = -23.25$ N/mm^2.

The measured stress is to be compared to the theoretical result in the following.
The section modulus for the rectangular cross section is $W_y = 74.26$ mm^3.

The calculation produces the following stress

$$\sigma = \frac{Mb}{Wy}$$

$$= -6.5 \cdot 250/74.26 = -21.88 \text{N/mm}^2 .$$

ENGINE TESTING TECHNIQUES

This introduction gives general information on engine testing with brief description of apparatus and formulae involved in determining parameters.

The testing of high-speed engines usually falls into one of the following categories:

1. Pure analytical research into the special phenomena or characteristics f engines. Engine tests are conducted on both single-cylinder and multi-cylinder types under selected operating conditions. Performance is determined by instrumentation and is usually assessed by graphical interpretation.
2. Research and development testing of new engine from the drawing board stage to prove the design and develop it until ultimately suitable for production.
3. Routine proof and acceptance tests (including quality) to ensure that production engines are satisfactory.

PERFORMANCE VARIABLES

- **BRAKE POWER [kW]**

This is the measured output of the engine. This power from the engine drive shaft is measured by a *Dynamometer* (also known as *Brake*). The engine is connected to a brake or dynamometer, which can be loaded in such a way that the torque exerted by the engine can be measured. The dynamometer may be of the absorption or the transmission type. The absorption type is more usual and can be classified as:

A) Friction type, [These are used for smaller powered, lower-speed engines],
B) Hydraulic type,
C) Electrical type, or,
D) Air-Fan type.

The most common of all of them is the absorption type in which the all the energy output of the engine is absorbed and converted to heat. This conversion can be achieved by an electric generator and resistance bank or by straightforward transmitted to a load, and registered by torque reaction only, with negligible loss. Following is the description of the simplest absorption types i.e. the friction dynamometer.

Electric Swinging Field Dynamometer

In this type, an electric generator converts the mechanical energy to electrical energy. Early brakes used this principle to give direct measurement of electrical power, but heat losses in the generator windings made the accuracy of the results questionable. However, torque reaction can be measured by freely mounting the motor casing to allow angular movement, restraining such movement by the application of force provided by spring balance and torque arm. This made the torque measurement very accurate. With separately controlled dynamometer field, the degree of power absorption can be varied. The machine can also be used as motor to drive the engine, with ignition (or fuel) switch off, enabling friction losses to be measured (motoring test).

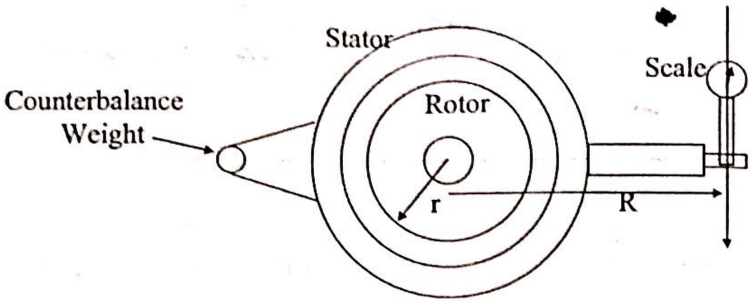


Figure (1) : Schematic Diagram on the Electric Swing Type Dynamometer.

As shown in the figure, a rotor driven by the engine under test is electrically, hydraulically or magnetically coupled to the stator.

For every revolution of the shaft, the rotor periphery moves though a distance = $2 * \pi * r$ against a coupling force "F".
Hence, work done per revolution is = $2 * \pi * r * F$
Now, the external moment or torque is = $P * R$ (p = scale reading, R = scale arm)
This moment balances the turning moment of the coupling force = $F * r$
When the system is balanced, $F * r = P * R$
OR, we can re-write the work done per revolution equation as follows:

Work Done per revolution = $2 * \pi * P * R$
Work done per second = $2 * \pi * R * P * (N/60)$ (where N = rpm)
OR, we can write $P*R$ = torque "T"

[redacted]

- **SPECIFIC FUEL CONSUMPTION (kg/kW-hr)**

This factor represents a useful index of the fuel consumed per unit power produced (either brake of indicated). To measure the amount of fuel fed to the engine, a simple method is to measure the volume flow in a timed interval and to convert the volume o mass after measuring the specific gravity of the fuel.

Fuel Calculations :

Fuel consumption measured in liter per hour but quoted in kilograms per hour,

[redacted]

where: sp. gr. for petrol = 0.741 (kg/L)
sp. gr. for diesel = 0.84 (kg/L)

From the definition of the specific fuel consumption, we can write:

$[illegible] = \frac{[illegible]}{\text{brake power (bp)}}$ (kg/kW.h)

- ## Volumetric Efficiency

This parameter (sometimes called Breathing Efficiency) determines or compares the actual volume of air taken into the engine with the ideal volume. It is invaluable in testing the suitability of the inlet duct design. The volumes compared should both be calculated for environmental conditions, but it is simpler to compare masses of air. The amount of air-fuel mixture taken into the cylinder on the intake stroke is a measure of the engine's volumetric efficiency. If the mixture were drawn into the cylinder very slowly, a full measure could get in. But the mixture must pass very rapidly through a series of restricting openings and bends in the carburetor and intake manifold. In addition, the mixture is heated (from engine heat); it therefore expands. The two conditions; rapid movement and heating, reduce the amount of mixture that can get into the cylinder. A full charge of air-mixture cannot enter, because the time is too short and the air because the air becomes heated.

Volumetric efficiency is the ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions.

$$\eta_V = \frac{\text{Mass of air induced}}{\text{Mass of free air occupying volume equal to swept volume of engine}} \times 100\%$$

$$\eta_{vol} = \frac{\dot{m}_a}{\rho_a \frac{N}{n} V_d} \times 100\%$$

where;

$$\dot{m}_a = \rho_a . V_a . A . Cd$$

$$V_a = \sqrt{2 \Delta h g \frac{\rho_w}{\rho_a}}$$

$$\rho_a = \frac{P}{R.T}$$

Cd = coefficient of discharge ; = 0.625
d = orifice diameter ; 48 mm
P = atmospheric pressure (bar)
T = room temperature (K)
R = gas constant
V_d = Swept volume (m^3)
Va = Air velocity (m/s)
ρ_w = water density (Kg/m^3)
ρ_a = air density (Kg/m^3)
h = manometer height (m)
Swept volume for Petrol engine = 598 cm^3
Swept volume for Diesel engine = 1500 cm3

APPARATUS

Here, a description of the apparatus is presented to serve for all the experiments assigned under this laboratory.

✓ GENERAL ARRANGEMENT

This unit is a completely self - contained test bed incorporating a swinging field DC dynamometer. The dynamometer, which is capable of absorbing 22 kW (30 hp), is supplied in standard form for absorbing power only. Service includes oil/water heat exchanger for the main cooling system and a water/oil heat exchanger for the oil cooling system.

✓ BASE PLATE

The main base plate is welded up from substantial channel sections to form a rectangular frame of great rigidity and stability. Bolting down is not necessary as the engines are flexibly mounted in the frame. Instrumentation is mounted where possible on a separate overhead frame that is free standing and structurally isolated from the main chassis. This avoids harmful vibration that could cause damage to instruments and errors of observation.

The base plate carries the following items:

- **(a)** The engine and dynamometer.
- **(b)** The water / water heat exchanger and header tank.
- **(c)** The water /oil heat exchanger.
- **(d)** Engine starting and battery charging panel.

✓ ENGINE

The bed is supplied with a 4-cylinder, 4-stroke, water-cooled diesel engine of 1500 cm^3 swept volume.

✓ CONTROL UNIT

The field control unit is enclosed in a steel cabinet located on a platform in the overhead frame. The unit is for use with 220/240 V single-phase 50/60 HZ supplies.

The AC input from the mains is transformed and rectified for the field circuit of the dynamometer. Voltage control is by variable transformers. Overload protection is essential in a test bed. A circuit of accessible at the rear provides this.

The instruments incorporated in the control unit are as follows:

A. Armature voltmeter.
B. Armature ammeter
C. Field voltage control. This control knob regulates the field strength when absorbing power.
D. Turn clockwise to increase field strength.
E. Tachometer. This is the read-out of the electronic tachometer described later.

✓ DYNAMOMETER

The dynamometer is a 400 V (nominal) DC machine, compound wound and separately excited carried on Turin mountings, and used for absorbing power only. The maximum permissible speed is 3000 rev/min. but the belt reduction drive permits the engine speed to reach 5000 rev/min. The belt drive obviates the need for a flexible coupling to accommodate shaft misalignment; it has negligible friction and hysteresis losses.

The dynamometer casing is restrained by a combination of spring balance and masses. The spring balance is anchored to the overhead frame and the torque of the dynamometer. A constant torque of 80 Newton meters may be maintained from 1500 rev/min. to 3000 rev/min. Two stops restrict the movement of the dynamometer, but when in use the torque arm should "float" between the stops. On the dynamometer casing is a "load control" switch for adjusting the field strength in conjunction with the "field voltage" control on the power unit. With the switch in the "half "position the field control will handle all loads up to 2000 rev/min. (engine speed) and in the " full " position all loads above 2000 rev/min. N. B The field control should be turned to zero before operating the switch.

✓ FUEL SYSTEM

The fuel tank is mounted at the top of the overhead frame and has capacity for 30 liters (7 Imp . gal). Fuel measurements by simple gravity pipette type gauge, with two bulbs calibrated for 50 cm^3 and 100 cm^3 respectively The system may be easily be drained for safety when not in use.

✓ COOLANT FLOW METER

A drowned orifice plate is inserted in the water circuit between the engine and the header tank. The pressure differential across the orifice is indicated by a mercury manometer (U-tube), calibrated in mm mounted on the instrument chassis of the test bed. Connections to the manometer are by rubber or plastic tubing.The rate of flow is given by the formula $Q = K\sqrt{h}$ where the value of k, the meter constant is given on the manometer panel.

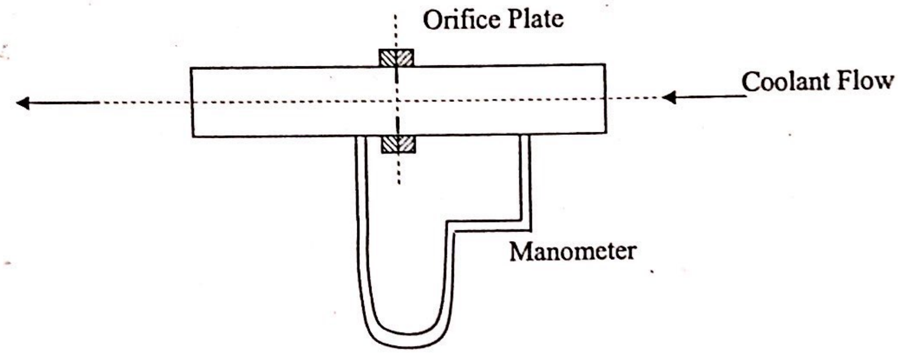


Figure (2) : Orifice Meter Setup.

✓ INLET AIR ORIFICE FLOW METER

For general purpose engine testing the inlet air for combustion may be measured by a simple orifice-type flow meter. The pressure differential across the orifice ' h' is displayed on a mercury manometer (U-tube). The flow rate is given by the equation $Q = K \sqrt{h}$ where k is the meter constant indicated on the manometer panel. This relationship is true for steady conditions but due to the pulsating nature of the airflow to a reciprocating engine, root mean square errors will occur. Also, when an engine is operated over a wide speed range, a large pressure drop may develop at the orifice resulting in breathing and cerebration difficulties. (This is a consequence of the relationship between Q and h).

The correct choice of orifice size and meter capacity, and the provision of resilience may minimize these problems in the system. The orifice air meter uses a cylindrical reservoir or damping chamber to minimize the effect of pulsation's and produce a steadier flow through the orifice inserted in one of its end walls. The other end wall of the chamber consists of a resilient synthetic rubber diaphragm secured at its edges between rings of marine plywood sealed to the cylinder.

Movement of this diaphragm compensates for fluctuations in flow to the engine. The air outlet to the engine is via a branch from the underside of the curved surface. The capacity of the reservoir is matched to the requirements of the engine whose supply it meters. It cannot therefore be used indiscriminately on engines of all types. The air supplied with a sensitive inclined manometer calibrated in mm of water gauge, which measures the depression inside the chamber, near to the orifice. This effectively the pressure differential across the orifice if the engine is naturally aspirated.

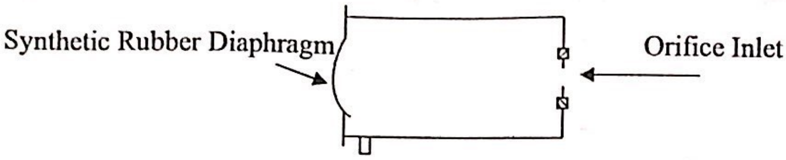


Figure (3) : Inlet Air Orifice Flow Meter.

POWER & TORQUE

OBJECTIVE

To measure the general performance of the engine at fixed load setting.

PURPOSE

Simple test to measure or calculate the variation of brake power, torque, fuel consumption, specific fuel consumption and efficiencies engine speed, while maintaining a constant load. Further, the engine torque and power will be compared with the electrical system for the purpose of calibration.

PROCEDURE

1. Start engine.
2. Introduce brake load and open the throttle to its widest setting.
3. Increase the brake load to reduce the speed to the lowest possible value consistent with stability of operation.
4. Where possible adjust ignition timing and mixture strength controls (if appropriate) to optimum settings.
5. Observe the readings listed below :

(a) Engine speed.
(b) Brake loads (Newton).
(c) Fuel consumption timing (sec)
(d) Manometer reading $\Delta p =$ mm
(e) Dynamometer Voltage and Current

6. Increase the speed is even steps by reducing the load and record observations after each step. Taking cares to ensure that steady conditions have been reached.
7. Repeat the test procedure for a medium and a low setting of the throttle to observe the displacement of the peak power and peak torque values.
8. Stop the engine.

CALCULATIONS

1. To determine the torque use: **T (N-m) = F (N) . r (m)** with r (arm radius) = 0.4 m
2. To determine the brake power use: **BP = 2π (T.N / 60000)** (kW)
3. To calculate the rate of fuel consumption use:

$$M_f = (\text{Volume/Time}) * \text{Specific Gravity of the Fuel}$$

$$M_f = (V/t)*\gamma \quad (\text{Kg/Sec})$$

Where the specific gravity of the fuel = 0.741 Kg/Liter for petrol and = 0.84 Kg/L for diesel fuels.

4. To dtermine the specific fuel consumption use:

BSFC = (Fuel Consumption in Kg/h)/(Brake Power (kW)

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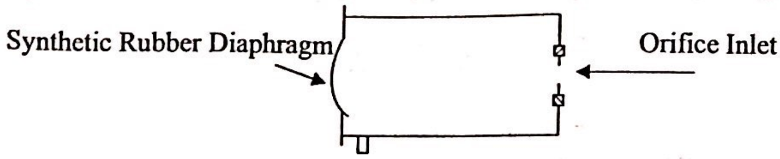

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$$M_f = (V/t)*\gamma \quad (\text{Kg/Sec})$$

Where the specific gravity of the fuel = 0.741 Kg/Liter for petrol and = 0.84 Kg/L for diesel fuels.

4. To dtermine the specific fuel consumption use:

BSFC = (Fuel Consumption in Kg/h)/(Brake Power (kW)

5. To determine the brake thermal efficiency use:

Brake Thermal Efficiency = (Brake Power *100%)/(Fuel Equivalent of Power)

where;

Fuel equivalent of power = mass flow rate of fuel * Calorific Value

CV_f = 42000 kJ/Kg for petrol and 39000 kJ/Kg for diesel.

6. To determine the combustion air flow rate use:

$$M_a \text{ (Kg/Sec)} = \rho_a \text{ (Kg/m}^3\text{)} * V_a \text{ (m/sec)} * A \text{ (m)} * C_d$$

Where; ρ_a = density of air at 20 C. = 1.2 Kg/m^3

ρ_w = density of water

A = Cross-Sectional area of the orifice

V_a = Velocity of the air = $\sqrt{2*\Delta h*g*(\rho_w / \rho_a)}$

Table (1) : Data Recording and result presentation

Engine Speed (rps)	Brake Load (N)	Manometer Reading ΔP mm of Water	Time needed for fuel consumption (Kg/s)	Armature Current (A)	Armature Voltage (V)
10					
20					
30					
40					
50					
60					

RESULTS AND DISCUSSION

After making necessary calculations for the Brake Power, Brakle Torque, Mass flow rate of fuel, Mass flow rate of air, Brake Thermal Efficiency and volumetric efficiency, plot the following:

1) All the above parameters (on Y-Axis) versus Engine Speed (on X-axis).
2) Compare the relative position of maximum power and maximum torque. Also compare the positions of maxinum brake thermal efficiency and minimum fuel consumption.
3) The brake power (mechanical) versus brake power (electrical).
4) Make calibration for the engine brake power as you have studied in Engineering Measurement course.