BIRZEIT UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL
AND MECHTRONICS ENGINEERING

ENME 321

Measurements Laboratory

Laboratory Manual

2019

LAB MANUAL CONTENT

Lab Safety Instructions and Rules
Mechanical and Mechatronics Engineering department

General Behavior

- Never work in the laboratory alone, always have another qualified person in the area do not use any equipment unless you are trained and approved as a user by your instructor or staff. Ask questions if you are unsure of how to operate something.
- Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.
- Don't eat, drink, or smoke, in the laboratory
- Please don’t yell, scream, or make any sudden loud noises that could startle others who are concentrating on their work.
- When you are done with your experiment or project, all components must be dismantled and returned to proper locations.
- When operating high noise machines put on ear protection, those are available in the lab and will be given by the instructor.
- Shoes must completely cover the foot. No sandals are allowed.
- Dress properly during all laboratory activities. Long hair, dangling jewelry, and loose or baggy clothing are a hazard in the laboratory. Long hair must be tied back and dangling jewelry and loose or baggy clothing must be secured.
- Keep aisles clear and maintain unobstructed access to all exits, fire extinguishers, electrical panels, and eyewashes.

First Aid & fire

- First aid equipment is available in the lab, ask your instructor about the nearest kit.
- Fire extinguisher are available in the lab, ask your instructor about the nearest one to your lab.

Poisons

- Certain liquids used in our apparatus, for example refrigerants, manometer fluids, and mercury, are poisonous or can give off poisonous vapors.
- Avoid contact with such liquids, clean up any that is spilled and perform operations such as the filling of manometer in well ventilated conditions.

Electricity

- Do not handle electrical equipment while wearing damp clothing (particularly wet shoes) or while skin surfaces are damp.
- Never bend or kink the power cord on an instrument, as this can crack the insulation, thereby introducing the danger of electrical shocks or burns.
- Know where the stop button, main switch or other device for stopping the apparatus is located

Machines and moving parts

- In order to avoid the possibility of injuries, it is important that the students be aware of their surroundings and pay attention to all instructions.
- Deal with caution with rotating machines, fans pumps compressors, motors etc. don't touch any of the rotating parts; shafts, or blades.
- Read and understand operation instructions before turning on the machines, do not turn machine till you instructed by the instructor or the technician.

High pressure cylinders

- Deal with caution with high pressure cylinders and systems.
- Turn such cylinders off after finishing the experiment.
- Close LPG cylinders safely after completing your experiment.

Hot surfaces and burns

- Do not touch hot surfaces; hot plates boilers, heating elements machines etc.

High flow streams

- When using compressed air, use only approved nozzles and never direct the air towards any person.
- Exercise care when working with or near hydraulically- or pneumatically-driven equipment.

PREPARATION OF LABORATORY REPORTS

I. ***FORMAL REPORT***

The report should be typewritten including graphs and figures by a computer. Use double spacing with 12 fonts. Spell checks your report. The following sections are to be included in this order:

1. ***TITLE PAGE***

- Course and section Number
- Number and title of the experiment
- Student's name
- Names of group members
- Date the experiment was performed
- Date the report is submitted.

2. ***ABSTRACT***

This is a stand-alone summary of the report. It should include objective, what was done, results and conclusions. It should be clear, informative, concise and short. It should not make any references to the body of the report or to the appendices. An abstract should not exceed one page.

3. ***OBJECTIVE***

The objective of the experiment should be stated on a separate heading OBJECTIVE. State the objective clearly, and make it relevant to the carried experiment

4. ***THEORY***

In this section state and explain any equations or theoretical principles and assumptions that were used in the experiment and the analysis. Define all parameters used. To find this information refer to textbooks, notes etc. Write equations using equation writer in the word processor.

5. ***EXPERIMENTAL***

Give a detailed description of how you accomplished the experiment. This should include equipment used in the experiment as well as how it was used. The description should have sufficient detail so that another experimenter could duplicate your efforts. Name all measured quantities and how they are measured. Use sketches, diagrams, or photos to describe the experimental set-up. Label the main components.

6. *CALCULATIONS*

Demonstrate how you performed the calculation made in the experiment. Include a detailed sample calculation including used formulas and constants. Show the generic calculations to support all your work. Provide any computer or calculator program listings, along with sample input and output.

7. *RESULTS*

Summarize your results in an introductory sentence. Relate your results to your objective. Present the results in the easiest way for your reader to understand and how the experiment's hand out requires: Graphs, tables, figures, etc. Spreadsheets are often a good approach. See section on preparation of graphs. All tables and figures must be referenced in the text; use a numbering system for identification of each one and each should have a distinguishable title.

8. *DISCUSSION OF RESULTS*

Explain the results of the experiment; comment on the shapes of the curves; compare results with expected results; give probable reasons for discrepancies from the theory; answer any questions outlined in the instructions and solve any problems that may have been presented. Tell why things happened, not only that they did happen. Comparisons should include numerical values and corresponding error percentages where relevant. Do not present calculations and formulas in this section. Your calculations should be detailed in the Appendices under SAMPLE CALCULATIONS. Formulas should be discussed in the THEORY section.

9. *CONCLUSIONS*

State your discoveries, judgments and opinions from the results of this experiment. Summarize your primary results in comparison with theory in two or three sentences. These should answer the objective of the

experiment. Make recommendation for further study. Suggest ways to improve the experiment.
Consider that in the real world. Information like that in the RESULTS and CONCLUSIONS will be all that upper management will want to receive.

10. APPENDICES

10.1 DATA TABLES

Data tables are for the convenience of the extremely interested reader. These tables may contain any additional comparisons or calculations that you have prepared and were not included in the RESULTS section which may contain only summaries of your work. Data Tables are the place to show everything that you did.

10.2 RAW DATA SHEETS

Data sheets must be completed in ink and signed by the instructor at the completion of the laboratory period.

In the case of an error, line through the mistake, initial the mistake, and continue. Record the name of the recorder and the group members on the raw data sheets.

11. REFERENCES

List any book or publication that you have referenced in your report. Provide titles, authors, publisher, date of publication, page number, Website addresses etc.
Book reference: Author last name, Author first name. Book's title. Publisher and city of publication, year of publication.
Journal reference: Author last name, Author first name. Paper title, Name of journal, volume, pages, year.
Internet reference: Site location (http://www.   ) and retrieved date.

II. PREPARATION OF GRAPHS

COORDINATE AXES
Draw the axes of coordinates on the cross- sectioned part of the sheet, far enough in from the margin to leave room for inserting the scales and their identifications between the edges of the cross- sectioning and the axes.

SCALES

Start all linear scales at (0, 0) unless such a procedure would obscure the presentation of data. Of course, this is not possible when using log scales. The units on the major divisions of log scales should be powers of 10. Choose scales of 1, 2, 4, or 5 units per centimeter, or any decimal multiples, such as 0.1, .002 and 400. Proper choice of scales is important.
Guiding principles are:

1. Utilize a good portion of the graph sheet area; do not squeeze curves into one corner.
2. Do not unduly extend the scales. Have the scales readable to the precision of the instruments from which data was taken. Further extension of the scales only scatters the data points, emphasizing the experimental error.
3. Keep in mind the purpose of the graph. Avoid using scales that hide the real meaning or fail to show the intended relationships.
4. Letter in the scale numerals along the axes, putting the abscissa scale beneath the horizontal axis at appropriate intervals. Set all numerals on either axis in a vertical position as viewed from the bottom page.
5. Put major and minor ticks in the axis, use as much as needed to make graph clear and understandable.

SCALE LEGEND

Place legend beneath the abscissa scale so as to be read from the bottom of the page. Place name of the ordinate legend to the left of the ordinate scale so as to be read from the right hand of the page. If more than one ordinate scale is used, place each ordinate legend immediately adjacent to the corresponding scale. Use descriptive titles followed by dimensional units, e.g., Temperature (ºC).

DATA POINTS

Indicate data points by small circles or appropriate geometric symbols, except in the case of correction curves for instruments where the plotted points are not emphasized.

CURVES

With EXCEL Software, draw smooth curves whose positions are governed by the plotted points. The curves should not necessarily pass through every point; you may use trend curves from the EXCEL. Only in the case of perfectly smooth data will all the points lie on the curve. Draw curves with ink or with computer printer and software such as EXCEL.

On the graphs show both the experimental data point and the trend curves or data fitting curves.

When more than one curve is drawn on the same set axes, carefully identify each curve, preferable with a legend lettered immediately adjacent to the curve, or number the curves and provide a table of titles. Data points for the different curves should use different geometric symbols.

INDEPENDENT VERSUS DEPENDENT VARIABLES

Plot the independent variable horizontally along bottom of the graph. Plot the dependent variable vertically. The dependent variable is usually mentioned first, e.g., "PRESSURE VERSUS TEMPERATURE" where pressure is the ordinate. Label axis as normally they appear in literature or books, does not exchange the axis.

III. PEPARATION OF TABLES

Give a number and a title for each table, place them above the table. Give names including units for all columns or rows in the table. Use table forms with white background.

IV. TECHNICAL REPORT

In the technical report include only the following items:

Title page
Abstract
Objectives
Calculations
Results
Discussion of results

EXPERIMENT No. (1)

DIMENSIONAL MEASUREMENTS

OBJECTIVE:

The objective of this experiment is to familiarize the student with some basic dimensional measuring devices, such as, micrometer, vernier caliper and height gauge. And to use the measured dimensions to calculate some physical values such as volume and mass.

INTRODUCTION:

In this experiment each student will perform the measurements on a different size of steel cylinder. The inside and outside diameters, the depth and the length of the cylinder will be measured using both the micrometer and the vernier caliper. In addition, the length of the cylinder will be measured using the height gauge.

The Caliper, Figure (1.1), has an accuracy of 0.02mm.When you want to measure, the metric scale should be considered, then you should follow the zero dash of the lowest scale and take the measure , if the zero dash doesn't match with any of the upper scale dashes, you should use the lower scale and see which dash will match an upper scale dash then you will count the number of dashes in the lower scale and multiply them by 0.02mm and then this value will add it to the upper scale measure to calculate the full measure.

The Micrometer, Figure (1.1), has an accuracy of 0.01mm, every dash in the linear scale represents 0.5mm but on the rotation scale represents 0.01mm, when you measure you should add the linear scale value to the rotational scale value. The rotational scale starts from zero to 50 so one rotation represent 0.5mm which is the micrometer linear movement on the linear scale through one rotation.

Whole gauges, Figure (1.1), are instruments used to measure internal holes by opening exactly as the whole diameter and then you fix them on that diameter, then you pick them out and measure it by a caliper and a micrometer.

The height gauge, Figure (1.2), is an instrument used to measure the length of specimens. It should be switch on and then you should calibrate it in which the moving part should attach to the surface and then to push on zero. This operation will give a reference to your measurement so you will be able to put the cylinder on the reference surface and then to move the slider on the top of the cylinder, after that the digital display will show you the measure of the cylinder's length.

Figure (1.1) Vernier Caliper, Micrometer and Hole gauges

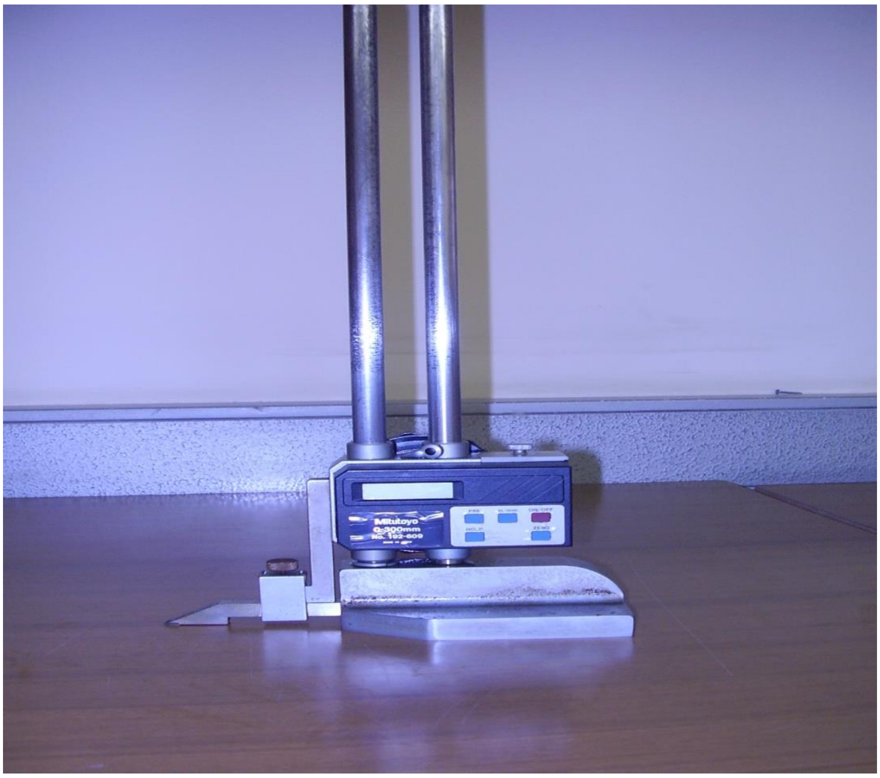


Figure (1.2) Height Gauge

EXPERIMENTAL PROCEDURE:

1. Choose a cylinder.
2. Record the cylinder's number.
3. Measure and record the outside diameter of the cylinder using the micrometer and the caliper.
4. Using a hole gage, measure and record the inside diameter of the cylinder utilizing the micrometer and the caliper.
5. Measure and record the depth of the cylinder using the caliper and the depth micrometer.
6. Measure and record the length of the cylinder using the micrometer, the caliper and the height gauge.

CALCULATIONS:

1. Using the measurements from the caliper, find the mass of water that can be filled in the cylinder.
2. Using the measurements from the micrometer, find the weight of this cylinder.
3. Calculate the mass of your cylinder by using your value of the weight, and find the volume of your cylinder.
4. Calculate the density of the cylinder's material and compare it with the standard value.

QUESTIONS:

1. Comment on the measurements of the depth of the cylinder.
2. Supply the proper views with full dimensions that are needed to machine this cylinder.
3. What are the types of errors in your experiment, and how do they happen.

<u>Data Sheet</u>

Cylinder No. ———

Dimension (mm)	**Micrometer**	**Caliper**	**Height gauge**
Inside diameter			—
Outside diameter			—
Depth			—
Length			

EXPERIMENT No. (2)

TENSILE AND BRINELL HARDNESS TESTS

OBJECTIVE:

- To use a tensile test to find the Young's Modulus of a mild steel specimen.
- To show the force against elongation characteristics of the same material but in different conditions – as drawn and heat treated to remove internal stresses normalized.
- To measure and compare Brinell Hardness for different material.

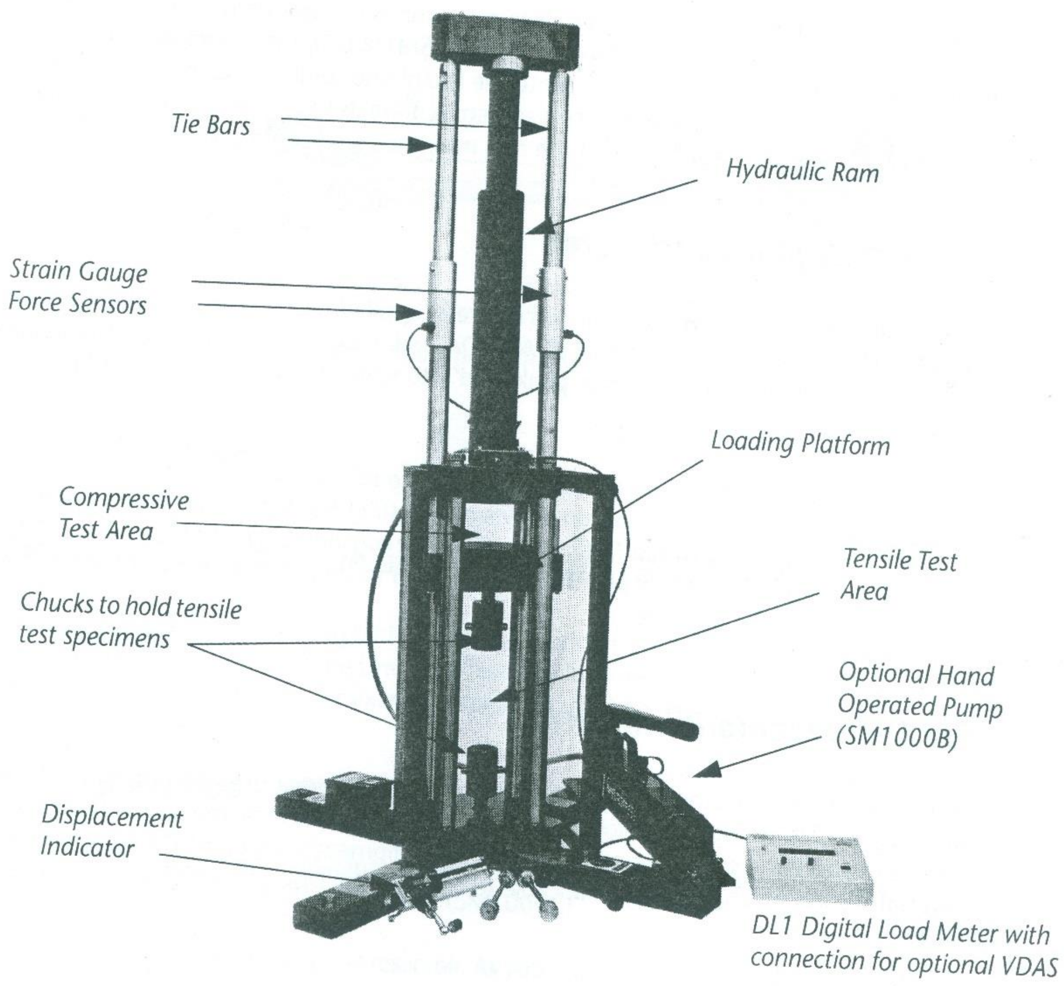


Figure (2.1) Universal Testing Machine

INTRODUCTION:

Part I: Tensile Tests

In 1678, Hooke showed that, up to a certain limit, a piece of material will extend in proportion to the load that produces the extension.

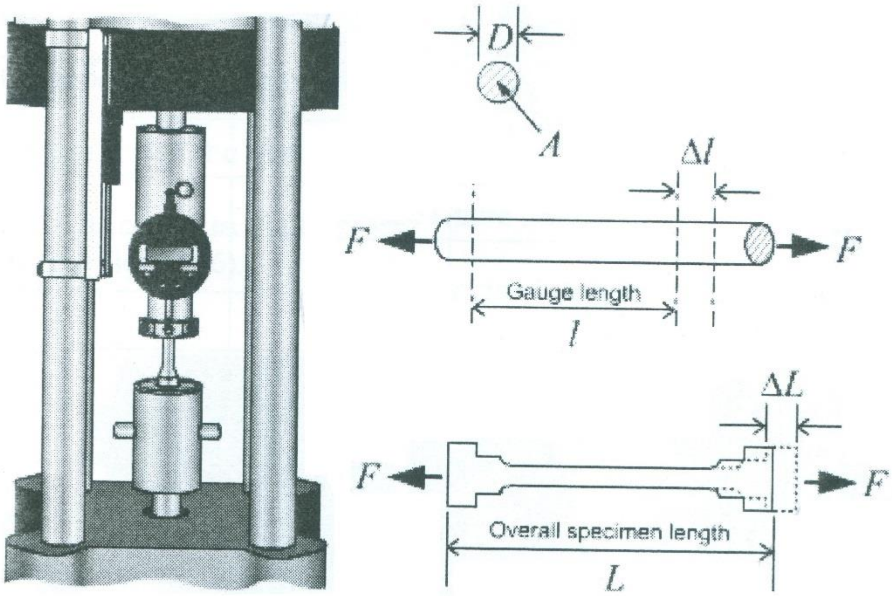
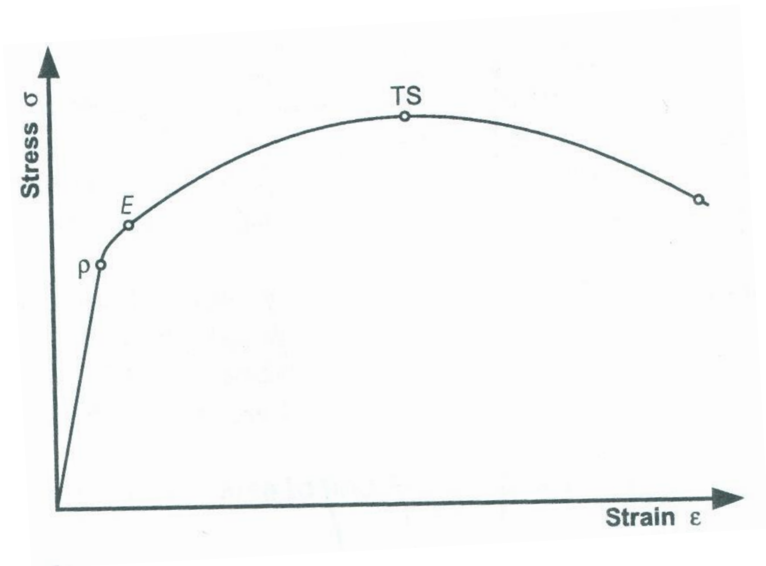


Figure (2.2) setup for the tensile testing

To find the nominal or engineering stress (σ), you must divide the load (F), by the original cross-sectional area of the specimen (A). To find the strain (ε), you must divide the extension values by the original length (L) of the specimen. Figure (2.3) and (2.4) show typical stress and strain graphs. They are linear up to a certain point.

Figure (2.3) Typical Stress/Strain chart for low and medium carbon steel



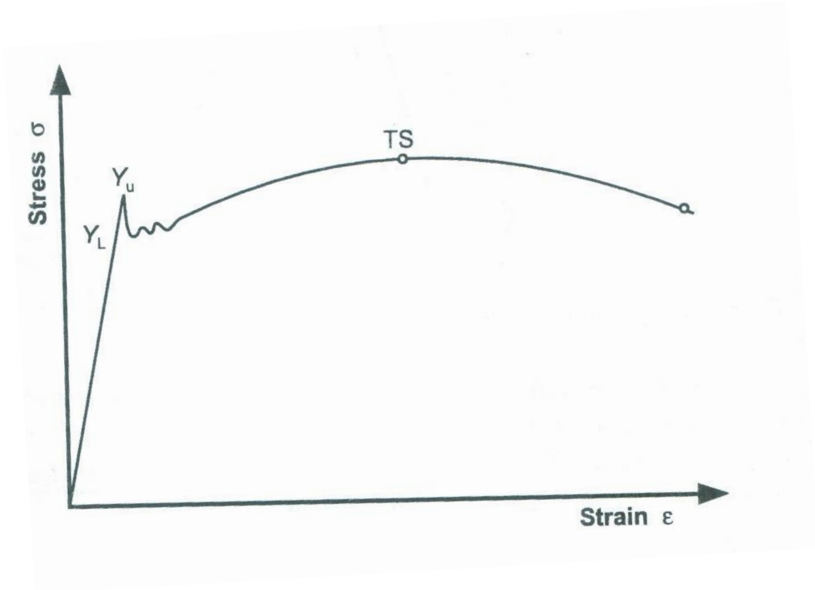


Figure (2.4) Typical Stress/Strain chart for alloy steels and non-ferrous metals

In figure (2.3), the point ρ is the **limit of proportionality**. The point E is the **elastic limit**. The elastic limit is often close to the limit of proportionality and is the highest stress at which no permanent strain remains after unloading.

Once of the most important mechanical constants for the linear elastic material is the constant that relates elastic stress and strain. This is **Young's Modulus of Elasticity, E**. it is the slope of the stress/strain diagram.

$$E = \frac{Stress}{Strain} = \frac{\sigma}{\varepsilon}$$

Straining a metal beyond the elastic limit causes it to yield. Above the yield point the metal is in its plastic range. The transition from elastic to plastic behavior takes one of two forms, shown in figures (2.3) and (2.4). Low and medium carbon steels give the shape of the curve in figure (2.3). It has an upper yield point and a lower yield point. It has a large increase in extension (strain) for an almost constant load (stress) in the plastic region. Engineers use the lower yield point as a limit in their designs. Figure (2.4) shows the shape of the curve found in alloy steels and non-ferrous metals.

Many materials, especially light alloys and certain heat-treated steels, do not have a clear yield point so engineers use a proof stress or percentage stress. This is the stress at which a non-proportional elongation equal to a specified percentage of the original gauge length occurs. Figure (2.5) shows this.

An increasing stress causes continued straining and this causes work hardening or strain hardening of the metal. The specimen has a work hardening limit. It reaches this when the slope of the stress/strain curve becomes zero, as at TS in figure (2.4). This point is the Tensile Strength, or Ultimate TS, and is sometimes used in design in conjunction with a safety factor.

Up to the point TS, the gauge length has reduced in cross-section almost uniformly, but at about the tensile strength, waisting or necking happens. Extension concentrations at this one point and even a reducing load causes continued straining. So, the stress and strain curve falls off until fracture occurs.

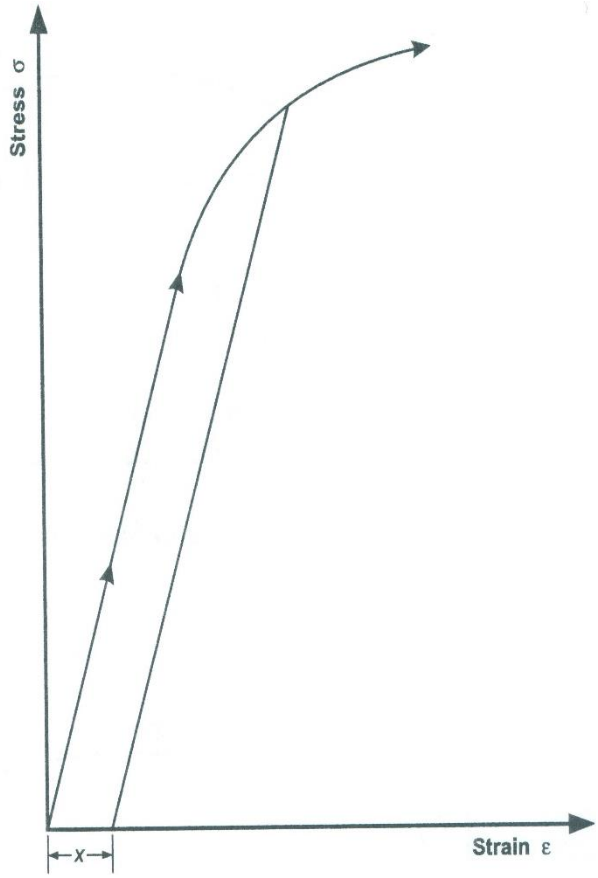


Figure (2.5) Definition of proof stress

Note that this theory only considers engineering values of stress and strain. In practice, the true stress and strain values vary, because the specimen's dimension change during the test.

Ductility

Ductility is an important property that you can find from tensile tests. It is the ability of a material to withstand plastic deformation without fracturing. It can be measured in two ways:

a) Percentage elongation of the gauge length at fracture, shown by :

$$\%\,Elongation = \frac{L_2 - L}{L} \times 100\%$$

b) Percentage reduction in area at fracture, referred to as the neck or minimum section at fracture shown by:

$$\% \, Reduction \, in \, area = \frac{A - A_2}{A} \times 100\%$$

Where L_2 and A_2 are the dimensions at fracture.

Part II: Brinell Hardness Test

Hardness is defined as a material's resistance to abrasion or indentation. It is measured by various methods, the most common are the Vickers, Rockwell and Brinell tests.

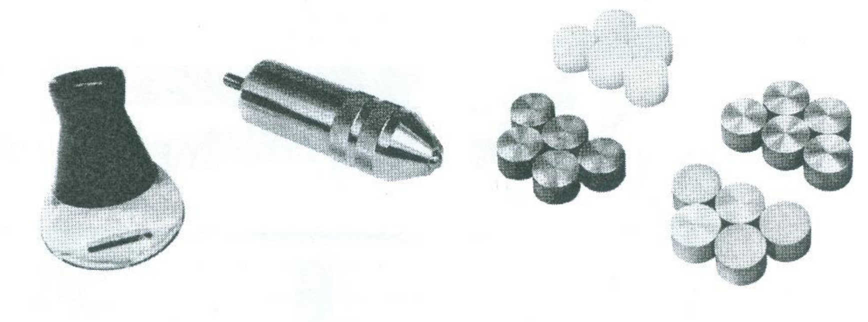


Figure (2.6) Optional Brinell Indenter kit

The Brinell hardness test uses a steel ball as an indenter, which is forced into the material under a given load for at least 10 seconds. Swedish engineer Johan August Brinell created the test in 1900. It was the first widely used and standardized hardness test in engineering.

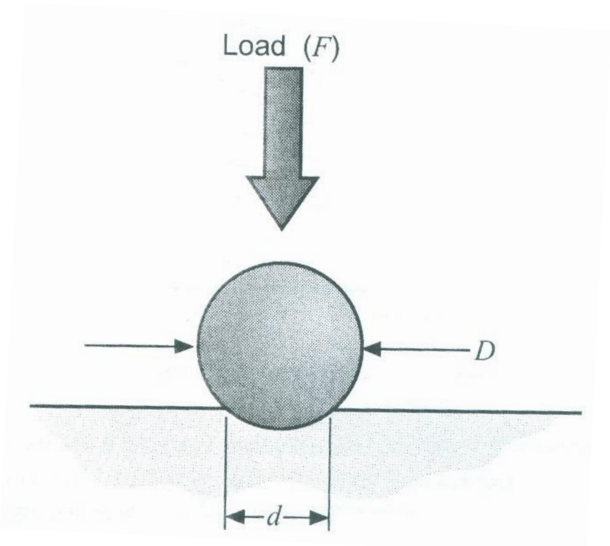


Figure (2.7) Brinell Hardness Test

$$Brinell, HB = \frac{Load\ (F)}{Surface\ area\ of\ indentation} = \frac{2F}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

Where force is in kgf = 9.81 N

Brinell's test has several limitations.

a. You can't test very hard material, because the Indenter will break. The nominal maximum specimen hardness is 450 HB for a steel indenter ball.
b. You can't test plated or surface hardened materials.
c. For accurate results you must use the correct force for the material, as it depends on the ratio of the indenter diameter (D) and the indentation diameter (d). For accurate results, the indent must be between 0.25 x D and 0.5 x D.

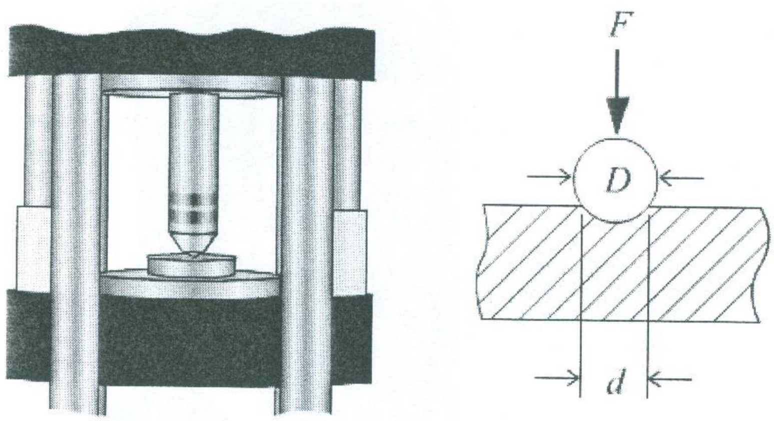


Figure (2.8) setup of the Brinell Hardness Testing

From the d : D ratio, you can find the right force to test your material with your given value of indenter ball diameter. Engineers use the F/D^2 relationship for materials as a guide to find the recommended force (F) for their tests. Many engineering guides and international Standards contain the F/D^2 relationship for materials, to help with Brinell tests.

$$\frac{F}{D^2} = C = material\ constant$$

Examples are:

F/D^2 for steels = 30 and for copper alloys = 10

Given that the ball in the TecQuipment Brinell Test Indenter is 10 mm diameter, then D^2 = 100 mm^2. This gives a maximum force for steel of 3000 kgf (or 29 kN), and 1000 kgf (or 9.8 kN) for copper alloys.

EXPERIMENTAL PROCEDURE:

Part I: TENSILE TEST:

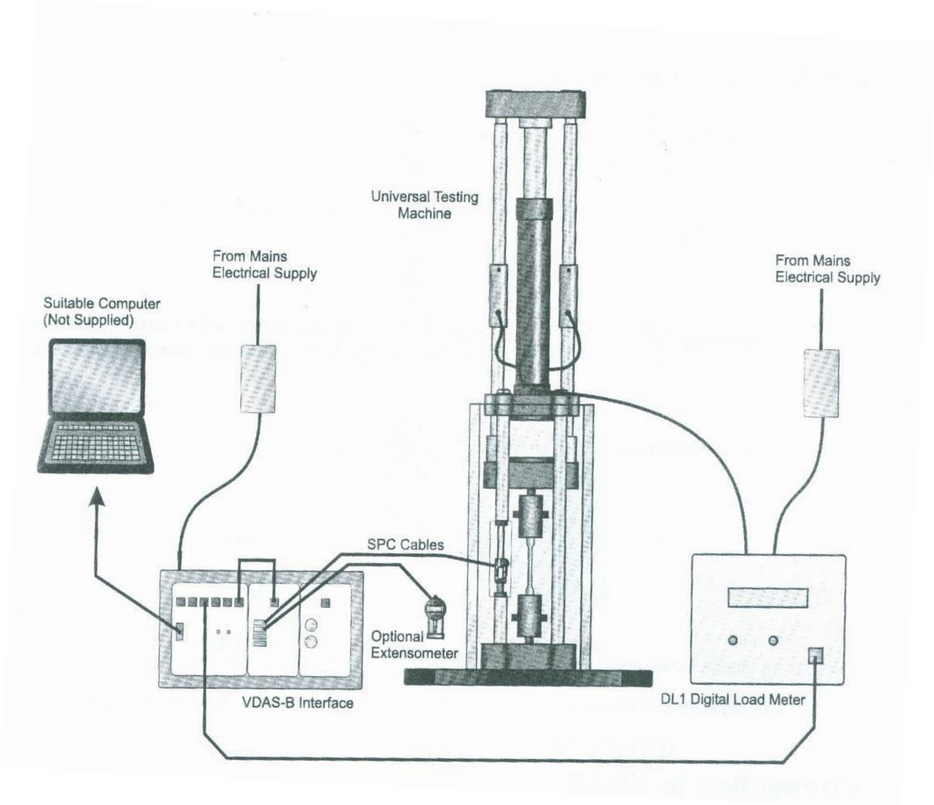


Figure (2.9) connection of the Universal Testing Machine

1. Connect up and switch on the DL1 Digital Load Meter, and allow it to warm up the strain gauges in the force sensors at least 10 minutes before you do any experiments. This allows the strain gauges to reach a stable temperature and give their best performance.
2. Use your pump to fully raise the ram.
3. Find the two sets of chucks that hold the tensile test specimens. They each have three parts – an inner part in two matching halves (collets) and one outer part. Fit the outer of the chucks to both the top and bottom ball joints in the tensile test area. Use the small bar to stop the ball joint turning while you tighten the chuck, figure (2.10).

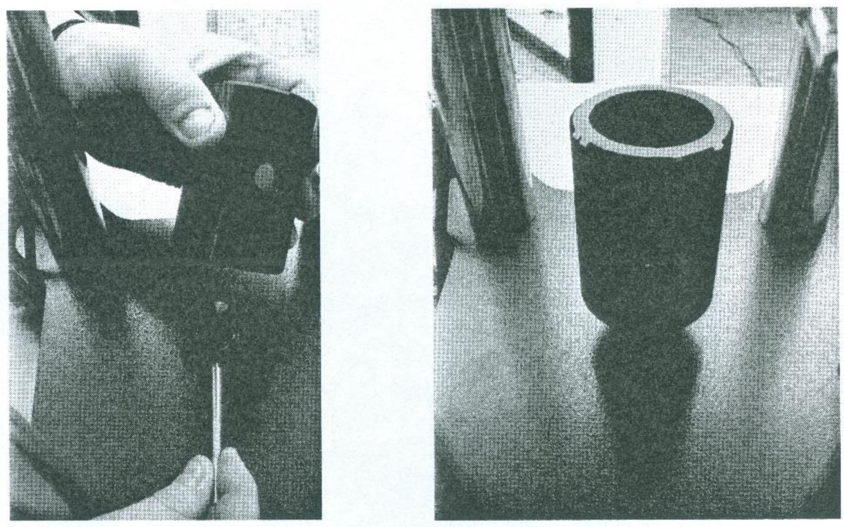


Figure (2.10) Fit the outer of the chucks to both the top and bottom ball joints in the tensile test area

4. Fit the collets to one end of the specimen, figure (2.11).
5. Fit the specimen in its collets to the bottom outer chuck and fit one of the large pins to secure the whole assembly, figure (2.11).
6. Fit the collets to the top of the specimen, and slowly lower the ram. As the ram lowers, align the top collets into the top outer chuck and fit the other pin. It may help to slightly wobble the assembly to align it correctly.

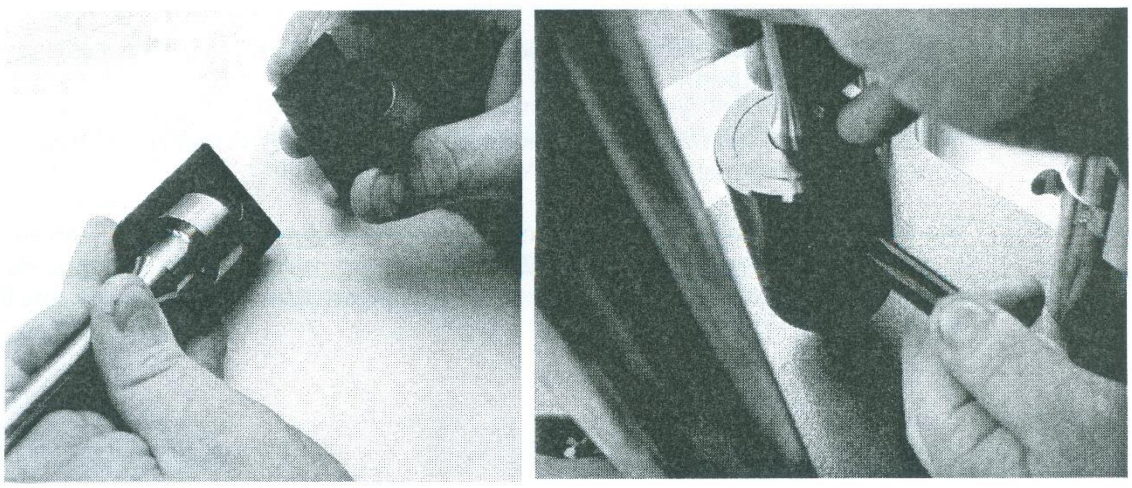


Figure (2.11) Fit the collets to the top of the specimen and fit the other pin

Note: make sure the specimen is not under any tension. It should be free to move by a small amount, figure (2.12)

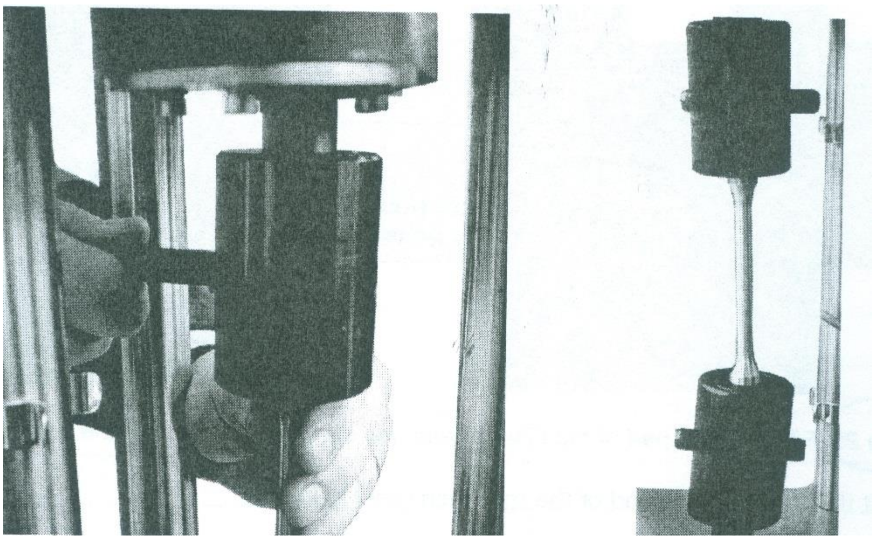


Figure (2.12) fit the top collet and make sure the specimen is not under tension

7. See figure (2.13). If not already fitted, fit the Digital Displacement Indicator to the front left column.

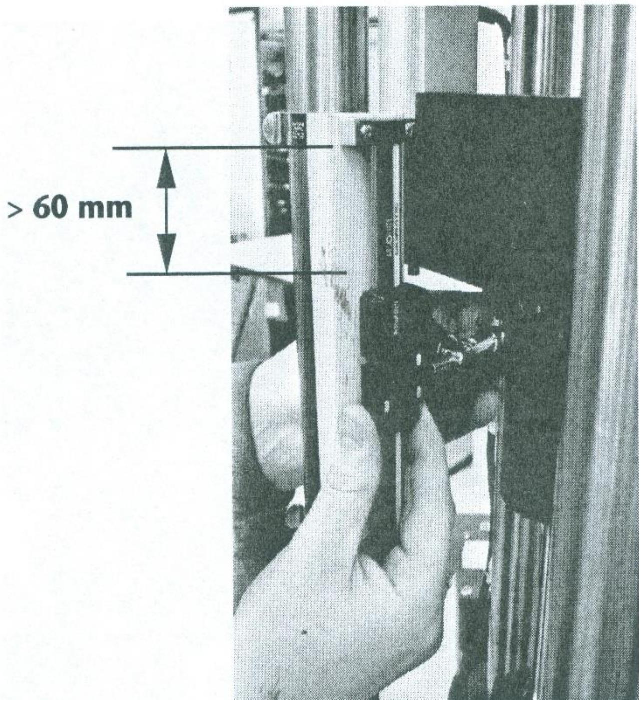


Figure (2.13) fit the digital displacement indicator and carefully adjust for > 60 mm of upward movement

Caution: be careful when you fit or remove the Digital Displacement Indenter – grip it with the metal clips or the support bracket. If you pull or push hard on its display or slide, you may damage them.

8. Slide the whole assembly up the column until the magnet clamps underneath the loading platform. Hold the display carefully and adjust the assembly to give at least 60 mm of upward movement.
9. On the digital Load Meter, press the button to zero the display. If you need to record the maximum force, press the peak hold button.
10. Use your pump to raise the ram slowly to remove the looseness in the specimen. While you do this, watch the Load Meter display and stop when the meter just begins to register a force. Re-zero the load meter, zero the Digital Displacement Indicator.
11. Fit the guard around the teat area.
12. In step of 0.5 kN, increase the ram force slowly – never decrease the force, as your results will become wrong. At each step, record the load, and the readings from the Digital Displacement Indicator.
13. Continue increasing the ram force until you note that the specimen has started to yield (above its elastic limit) – the specimen still stretches, but the force only changes by a small amount.
14. Continue to stretch the specimen, but you will find it is more sensible to take results at set values of displacement instead of force (for example 0.5 mm). As you do this, study the specimen and look for the necking effect of the specimen before it fails.
15. Continue until the specimen fails. Be prepared for a loud noise when the specimen fails. Keep in your mind, that never try to create a ram force greater than 100 kN
16. If you have selected to record the peak load value, note the peak load.

Part II: Brinell Hardness Test:

1. Connect up and switch on the DL1 Digital Load Meter, and allow it to warm up the strain gauges in the force sensors.
2. Use your pump to lower the ram.
3. Fit the Brinell Indenter to the upper part of the compression test area, figure (2.14)

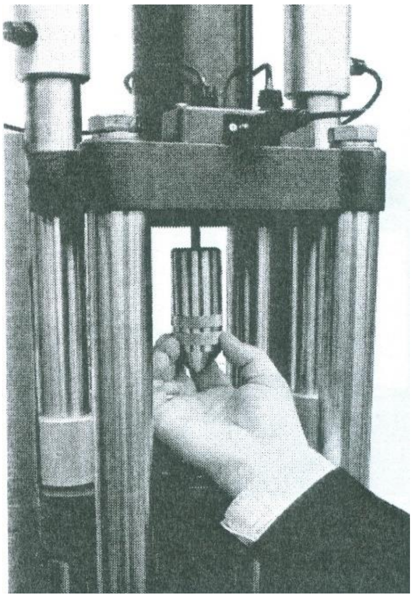


Figure (2.14) fit the Indenter

4. Put your test specimen centrally on the bottom of the compression test area (top of the load platform). If necessary, level hold the loading platform.
5. Fit the guard.
6. Set the Digital Load Meter to zero and set the peak load function.
7. Use your pump to raise the ram to apply a suitable force to your material. Apply the force for approximately 15 seconds.
8. Lower ram and remove the guard.
9. Use the magnifying glass and its measurement scale to find the diameter of the indentation. Take at least two measurements, at right angles to each other and find the average.
10. Put your specimen back onto the loading platform and repeat the experiment at least twice more (but move the specimen around to give indentations on different places across the specimen). Find the average size for your indentations.
11. Repeat the test for different specimen materials.

CALCULATIONS:

Stress (σ)

This is the force applied (F) to a material over a known area (A). It's found by the equation:

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

Compressive stress is where the material is compressed. It has a negative value.
Tensile stress is where the material is stretched. It has a positive value.

Strain (ε)

This is the change in length (distortion caused by stress) of a material over its original length. It is found by the equation:

$$\varepsilon = \frac{\Delta l}{l}$$

Compressive strain is where the material has compressed. It has a negative value.
Tensile strain is where the material has stretched. It has a positive value.

Young's Modulus (E)

This is a ratio of the stress divided by the strain on a material. An English physicist – Thomas Young discovered it. It is a measure of the stiffness of a material (a stiffer material has a higher value of Young's Modulus). It is found by the equation:

$$E = \frac{\sigma}{\varepsilon}$$

DATA VALUES:

Initial cross-sectional area of specimen = mm^2
Initial length of specimen = mm
Steel C = 30, copper C = 10, Aluminum C = 5
Brinell Test Indenter diameter = D =10 mm

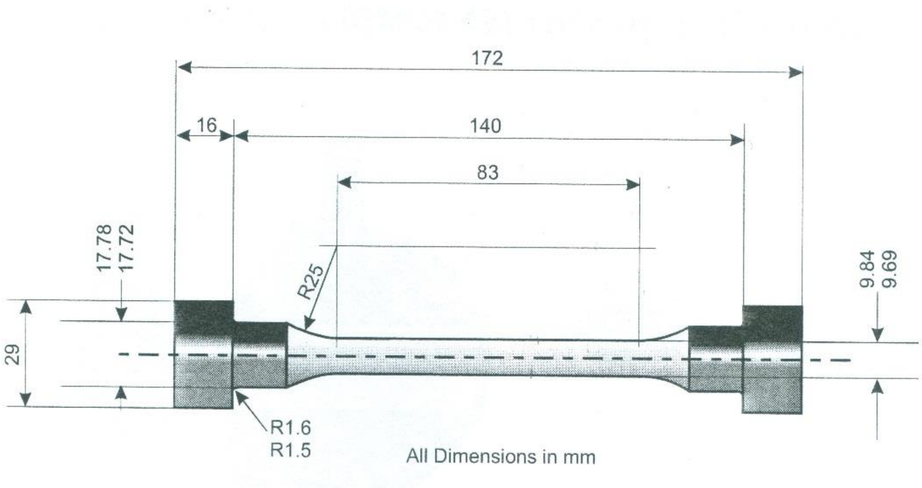


Figure (2.15) recommendation dimensions for a specimen

RESULTS:

Part I: Tensile Test

a. Calculate the stress and strain for each run.
b. Calculate the final cross-sectional area of the specimen after the fracture, and find the percentage reduction in area.
c. Calculate the final length of the specimen after the fracture, and find the percentage elongation.
d. Plot the force against the displacement from the digital meter.
e. Plot the stress against the strain.
f. Calculate the Young's Modulus.
g. Find the tensile strength (TS) and the fracture force and stress.
h. Compare your results with the standard values.
i. What are the types of errors in your experiment, and how do they happen.

Part II: Brinell Hardness Test

a. Calculate the hardness for the different given material.
b. Compare your results with the standard values.
c. What are the types of errors in your experiment, and how do they happen

Data Sheet

A. Tensile Test:

Run #	Force [kN]	Digital Displacement Meter [mm]	Run #	Force [kN]	Digital Displacement Meter [mm]	Run #	Force [kN]	Digital Displacement Meter [mm]
1			35			69		
2			36			70		
3			37			71		
4			38			72		
5			39			73		
6			40			74		
7			41			75		
8			42			76		
9			43			77		
10			44			78		
11			45			79		
12			46			80		
13			47			81		
14			48			82		
15			49			83		
16			50			84		
17			51			85		
18			52			86		
19			53			87		
20			54			88		
21			55			89		
22			56			90		
23			57			91		
24			58			92		
25			59			93		
26			60			94		
27			61			95		
28			62			96		
29			63			97		
30			64			98		
31			65			99		
32			66			100		
33			67			101		
34			68			102		

Peak Force Value = --------------------------- kN

B. Brinell Hardness Test:

Material	Run #	Maximum force [kN]	Dent Diameter [mm]
Steel	1		
	2		
Copper	1		
	2		
Aluminum	1		
	2		

EXPERIMENT No. (3)

TORSION TEST

OBJECTIVE:

- To find the shear modulus for the specimen material and compare it with given values.
- To familiarize students with the equipment and its sensitivity in the specimen's elastic region.

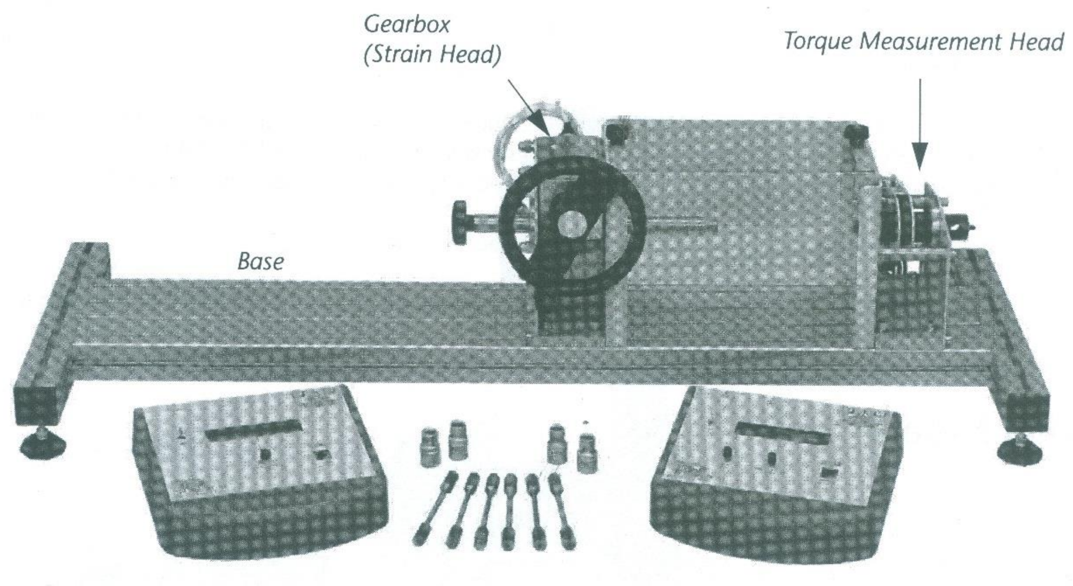


Figure (3.1) Torsion Testing Machine

INTRODUCTION:

Engineers need to know how different materials behave when stressed. They will then know how to use the right materials and material sizes for load-bearing structures and parts in their designs.

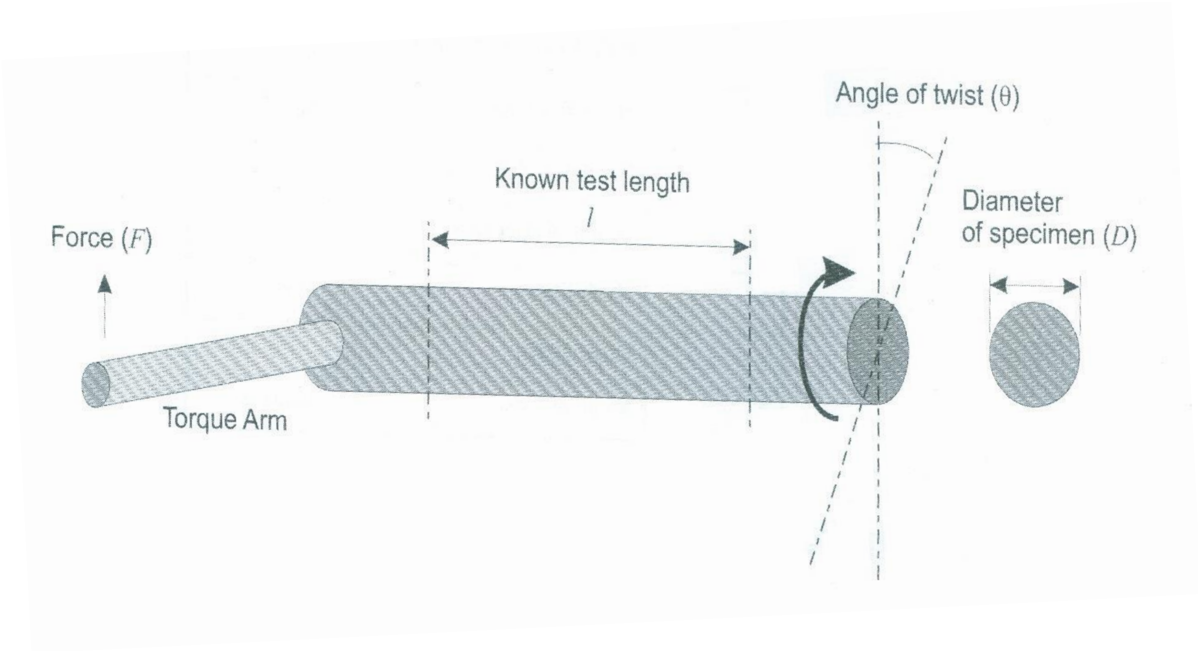


Figure (3.2) Torque (Twisting Force)

Modulus of Rigidity or Shear Modulus (G)

The Shear Modulus or Modulus of Rigidity is a measure of the rigidity for the material when in shear – when it is twisting. It is a ratio of the shear stress and the shear strain of the material:

$$G = \frac{Shear\ Stress}{Shear\ Strain} = \frac{F/A}{\Delta x/h} = \frac{\tau}{\gamma}$$

This formula only works when the material is stressed in its elastic region.

Polar Moment of Inertia (J)

This is an equation that shows the ability of a circular cross-section beam or specimen to resist torsion (twisting). A higher polar moment of inertia shows that the beam or specimen can resist a higher torsion or twisting force. The diameter of the beam determines polar moment of inertia. A larger diameter gives a larger polar moment of inertia.

$$J = \frac{\pi D^4}{32}$$

Where D is the diameter of the specimen in [m].

The general equation for the torque in a circular cross-section beam or specimen is:

$$\frac{T}{J} = \frac{G\theta}{l}$$

Where T: Torque, N.m
J: Polar Moment of Inertia, m^4
G: Shear Modulus, N/m^2
l: Test length, m
θ: Angle of twist, Radians

Torque (T)

The twisting force (Torque) at the end of a specimen is the moment of force on the torque arm:

$$T = F \times Torque\ Arm\ Length\ (m)$$

Shear Stress (τ)

The theoretical shear stress for a solid circular bas is:

$$\tau = \frac{TD}{2J}$$

Shear Strain (γ)

The theoretical shear strain for the solid circular bar is:

$$\gamma = \frac{\tau}{G} = \frac{r\theta}{l}$$

A rearrangement of the Shear Modulus therefore gives:

$$G = \frac{TD/2J}{r\theta/l}$$

Where G: Shear Modulus, N/m^2
T: Torque, N.m
J: Polar Moment of Inertia, m^4
r: Radius of specimen, m
l: Test length, m
θ: angle of twist, Radians

Elasticity and Plasticity (Elastic and Plastic Deformation)

A material is perfectly elastic if it can be compressed or stretched (deformed) by any amount, and then return to its original shape when the stress is removed.

Its atoms have not moved, but the bonds between them have stretched, then returned to their original position.

A material is plastic if it can be compressed or stretched (deformed) by a small amount, and then not return to its original shape when the stress is removed. Its atoms have actually moved and will not return.

Most materials have both elastic and plastic properties. When stressed by a small amount, they behave like an elastic material, up to their elastic limit or yield point. When stressed by a large amount (that takes them past their elastic limit), they behave like a plastic material. Rubber and flexible materials usually have more elasticity than more brittle materials like metal or ceramics.

Nominal and True Stress

The maximum shear stress (τ_{max}) in torsion occurs at the surface of the material in torsion, and we know that the material diameter determines the maximum stress.

However, as a specimen is stressed, its diameter actually becomes smaller, so its stress level is actually higher than predicted and is a nominal stress. This effect is hardly noticeable when the specimen is in its elastic region, but increase as the specimen moves through its plastic region. However, it is acceptable to assume a nominal stress during normal tests.

Upper and Lower Yield Point – Normalized Low Carbon Steel

Normally, materials have a yield point, at the limit of their elastic region. Normalized mild steel (low carbon content) has an upper and lower yield strength.

Figure (3.3) shows this. The specimen yields at point A and the stress immediately falls to a lower value, point B. The stress and strain curve then follows a similar shape to other materials.

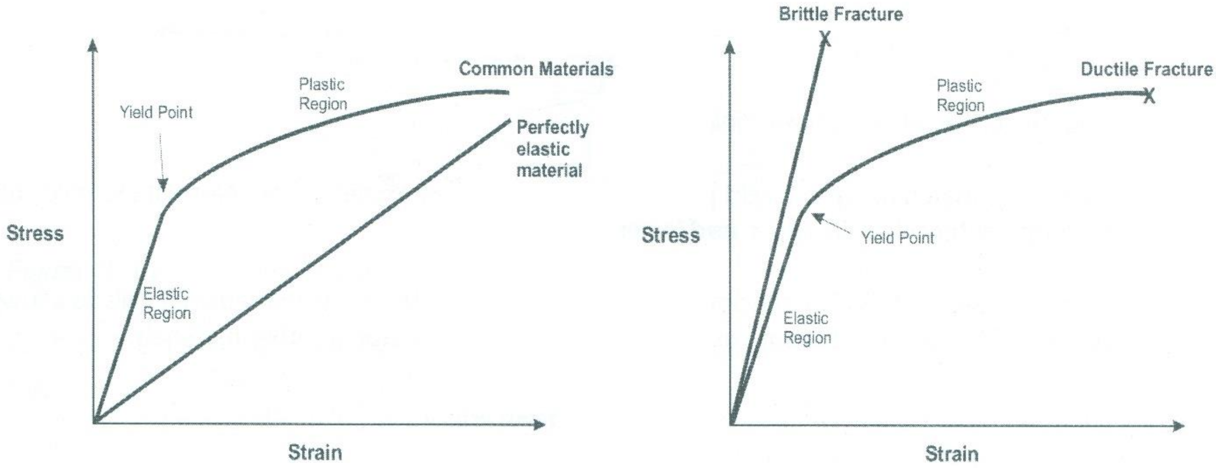


Figure (3.3) Stress/Strain curves

EXPERIMENTAL PROCEDURE:

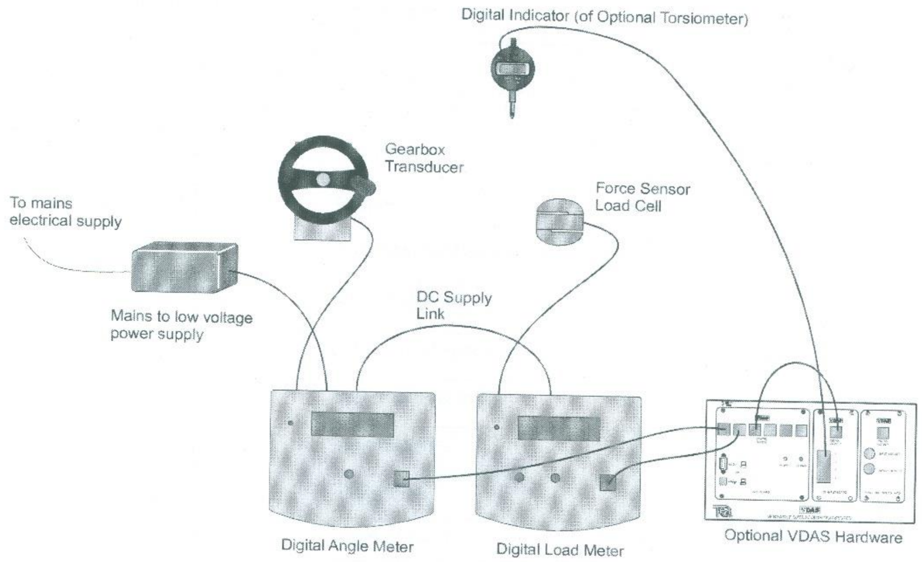


Figure (3.4) connecting the Torsion Testing Machine

1. Accurately measure and record the dimensions of your specimen.
2. Check the distance across the flats at the ends of your specimen, then choose the correct sockets to fit your specimen (12 mm or 3/16 inch whit worth).
3. Fit the sockets to the torque head and the gearbox output, as shown in figure (3.5)

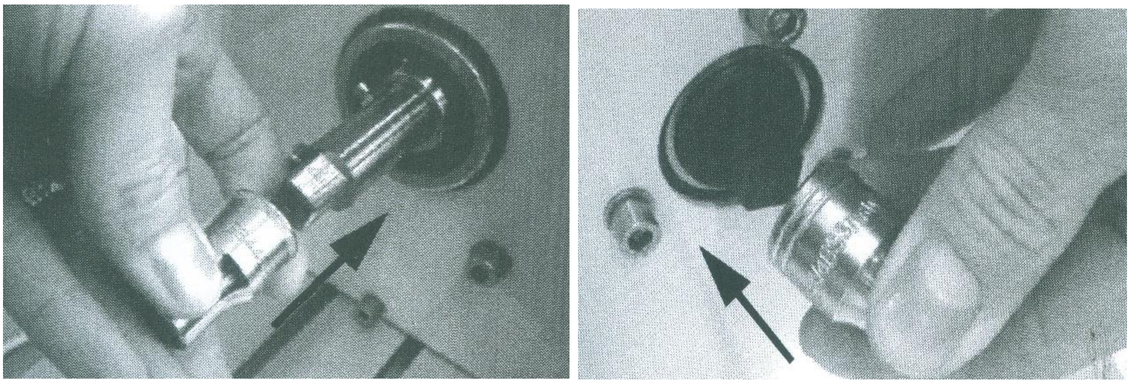


Figure (3.5) Fit the sockets to the torque head and the gearbox output

4. Fit the specimen to the sockets. Slide the gearbox output shaft along so that the specimen's ends fit fully into each socket.

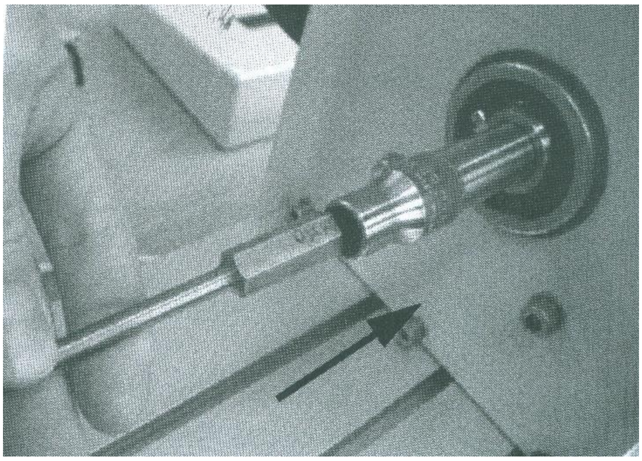


Figure (3.6) Fit the specimen

5. Switch on the both digital meter, and press their "press to zero" buttons.
6. Fit the clear guard around the specimen.
7. To remove any mechanical error (or backlash), slowly turn the gearbox hand wheel until the load display starts to show a small value of torque, then use the "press to zero" buttons to set all displays to zero.
8. If you are to use the Torsiometer, carefully press its button that sets its display to zero.
9. Press the peak hold button of the load meter so that it records the maximum torque in the test.
10. For the first part of the test the specimen will be stressed in its elastic region, so you must increase the angle of twist in small steps of 1 degree. For best results, turn the hand wheel at a constant rate in one direction only. If you turn it backwards by even a small amount, your results for the test will be wrong.

11. At each angle, record the angle and the torque value.
12. After approximately 10 degrees, the specimen has passed its upper yield point. You can now increase the angle size between measurements to larger increments.
13. You may now continue to increase the angle until the specimen breaks.
14. Repeat the test for different materials.

DATA VALUES:

0.001 inch/mm of displacement = 0.001 radian
Test length of the specimen = l = 50 mm
Nominal specimen diameter = D = 6 mm

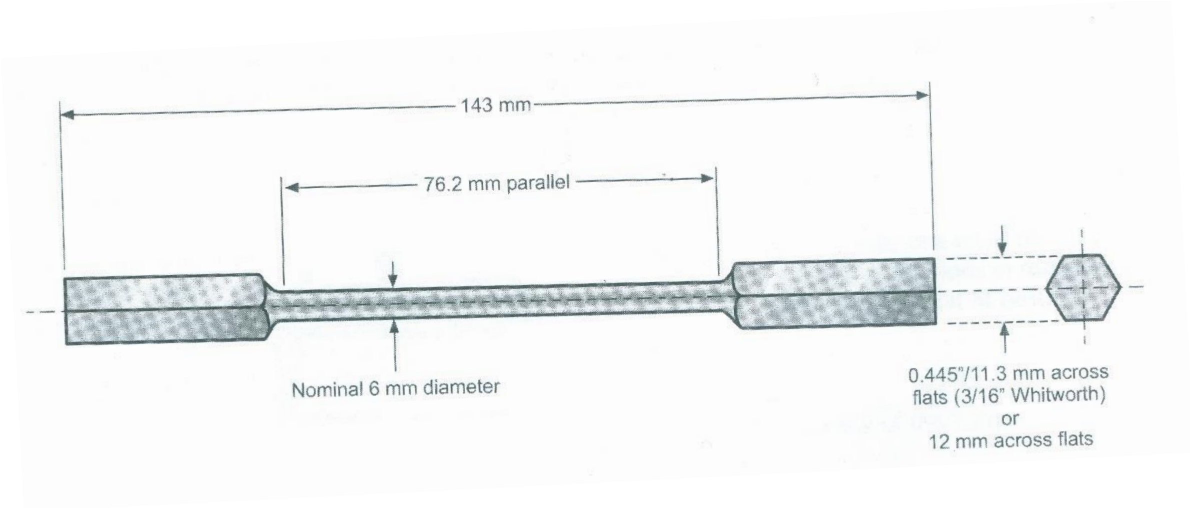


Figure (3.7) Recommendation dimensions of a specimen

RESULTS:

a. Plot the torque against the angle twist in degrees.
b. Mark on your chart the yield point.
c. Calculate the polar moment of inertia for your specimen.
d. Calculate the shear stress at the yield point.
e. Compare your results for the different materials.
f. What are the types of errors in your experiment, and how do they happen.

Data Sheet

Run #	Angle [Degree]	Torque [N.m]	Run #	Angle [Degree]	Torque [N.m]	Run #	Angle [Degree]	Torque [N.m]
1			38			75		
2			39			76		
3			40			77		
4			41			78		
5			42			79		
6			43			80		
7			44			81		
8			45			82		
9			46			83		
10			47			84		
11			48			85		
12			49			86		
13			50			87		
14			51			88		
15			52			89		
16			53			90		
17			54			91		
18			55			92		
19			56			93		
20			57			94		
21			58			95		
22			59			96		
23			60			97		
24			61			98		
25			62			99		
26			63			100		
27			64			101		
28			65			102		
29			66			103		
30			67			104		
31			68			105		
32			69			106		
33			70			107		
34			71			108		
35			72			109		
36			73			110		
37			74					

Peak Torque Value = ________________________ N.m

EXPERIMENT No. (4)

HYDRAULIC PRESSURE AND FORCE

OBJECTIVE:

To verify the relation between hydraulic pressure and force using a cylinder and a load spring, and to know some of the hydraulic systems applications that used in the engineering fields.

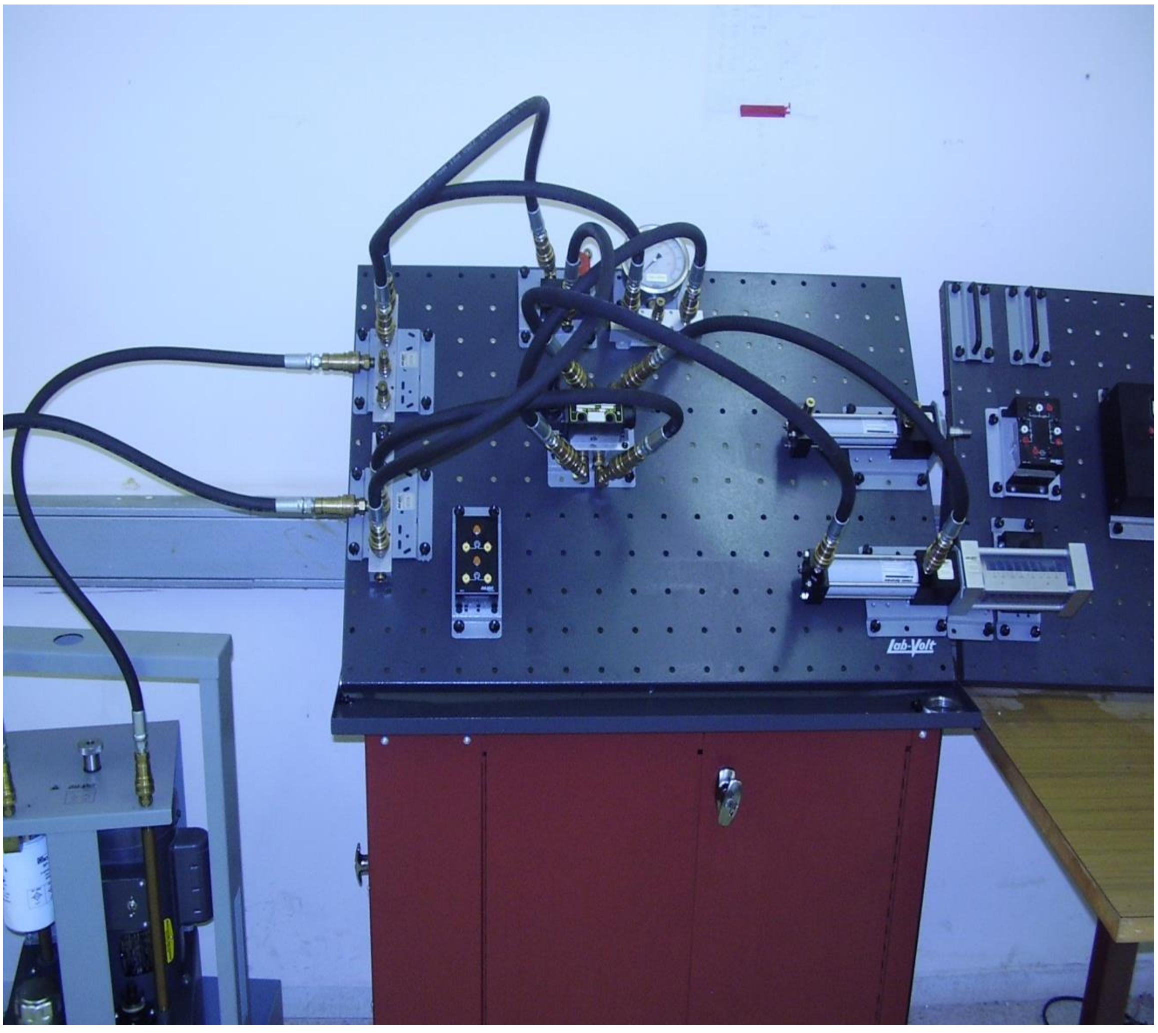


Figure (4.1) Hydraulic Circuit

INTRODUCTION:

Pascal's Law

Pascal's Law states that pressure applied on a confined fluid is transmitted undiminished in all directions, and acts with equal force on equal areas, and at right angles to them.

Pressure and Force

For, hydraulic pistons the generated pressure is equal to the force applied to the piston divided by the area of the piston. In equation form:

S.I. units:

$$\text{Pressure (kPa)} = \frac{\text{Force (N)}}{\text{Area } (m^2)}$$

English units:

$$\text{Pressure (psi)} = \frac{\text{Force } (\text{lb}_f)}{\text{Area } (in^2)}$$

Hydraulic pressure versus cylinder force

In a hydraulic circuit, Figure (4.1), the force that pushes the oil, attempting to make it flow, comes from a mechanical pump. When the oil pushed on by the pump is confined within a restricted area, as in the body of a cylinder, there is a pressure buildup, and this pressure can be used to do useful work.

Pressure is not created by the pump but by resistance to the oil flow. The amount of pressure created in a circuit will only be as high as required to counteract the least resistance to flow in the circuit. Resistance to flow mainly comes from three sources: resistance to motion of the load attached to the cylinder, frictional resistance of the cylinder seals, and frictional resistance of the inner wall of the hoses.

In Figure (4.2), the oil from the pump is confined in the cap **end** of the cylinder. As a result, pressure develops in the cap end of the cylinder. This pressure is exerted evenly over the entire surface of the cap end of the cylinder. It acts on the piston, resulting in a mechanical force to **push** the load.

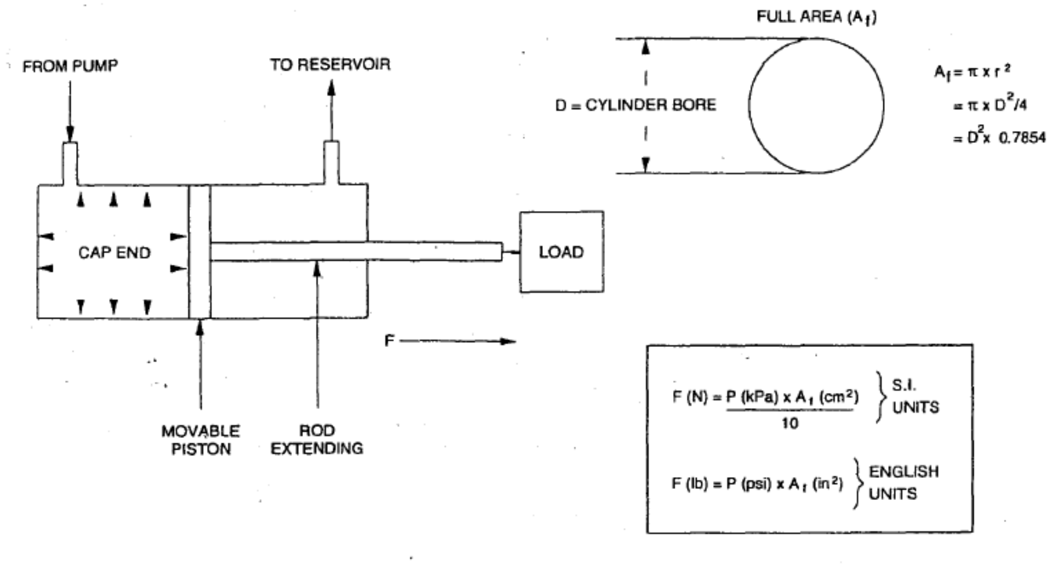


Figure (4.2) Cylinder pushing a load.

To find the amount of force generated by the piston during its extension, we can rewrite the formula P = F/A as **F = P x A.** Therefore, the generated force is equal to the pressure in the cap end of the cylinder times the piston area being acted upon.
This area is called full area, or “face’’ area.

In Figure (4.3), the oil from the pump is confined in the **rod end** of the cylinder. As a result, pressure develops in the rod end of the cylinder. This pressure is exerted evenly over the entire surface of the rod end of the cylinder. It acts on the piston, resulting in a mechanical force to **pull** the load.

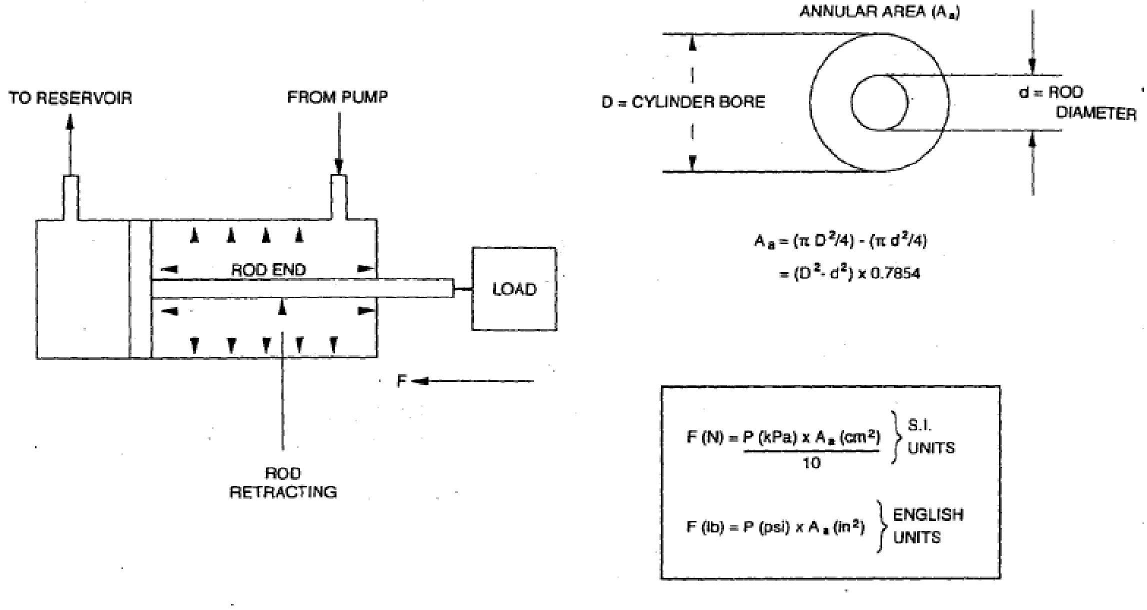


Figure (4.3) Cylinder pulling a load.

This time, however, the generated force is lower because the piston area available for the pressure to act on is reduced by the fact that the cylinder rod covers a portion of the piston. This area is called annular area, or "donut" area. Therefore, the system must generate more pressure to pull than to push the load.

EXPERIMENTAL PROCEDURE:

1. Define the formula for determining the force in a hydraulic system?

2. If the bore diameter, D, of a cylinder piston equals 3.81 cm (1.5in), calculate the full area, A_F, of this piston. Use the formula shown in Figure1. It is given below for your convenience.

$$A_F = D^2 \times (\pi/4)$$

3. Using this area and the formula from step 1, calculate the theoretical force of the cylinder for the pressure levels in the data sheet Table1. Record your calculations in Table 1 under " THEORETICAL"

4. Remove the 3.81-cm (1.5-in) bore cylinder from its adapter by unscrewing its retaining ring. Make sure the cylinder tip (bullet) is removed from the cylinder rod end.
5. As Figure (4.4) (a) shows, screw the cylinder into the Loading Device until the load piston the Loading Device begins to push on the spring and

the cylinder fittings point inside upwards. Do not use a tool to turn the cylinder.

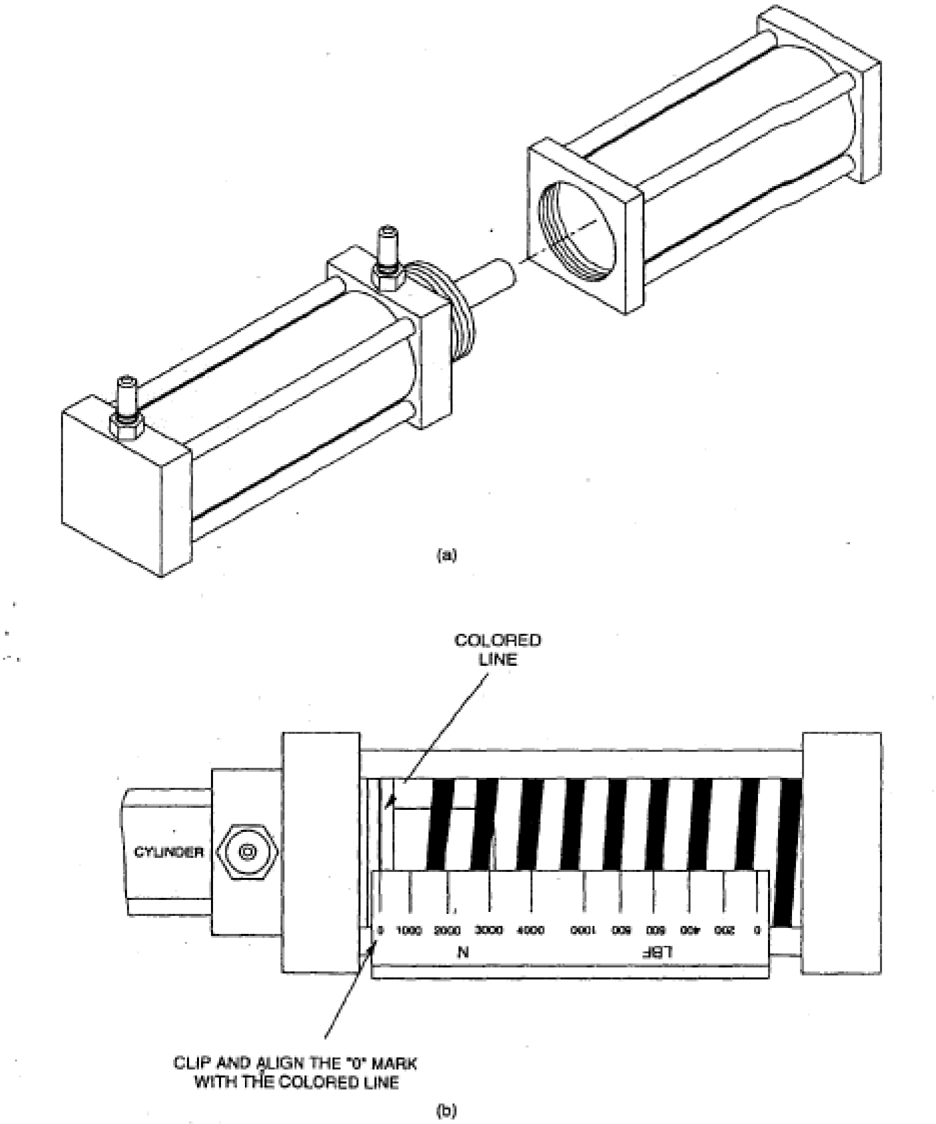


Figure (4.4) Loading device assembly.

6. Clip the NEWTON/LBF-Graduated ruler to the Loading Device, and align the “0 Newton” or “0 lbf” mark with the colored line on the load piston. Figure (4.3) (b) shows ruler installation for measurement of forces in Newton’s (N). The ruler must be installed on the other side of the Loading Device in order to measure forces in pounds (Ib_f).

7. Connect the circuit shown in Figures (4.5) and (4.6).

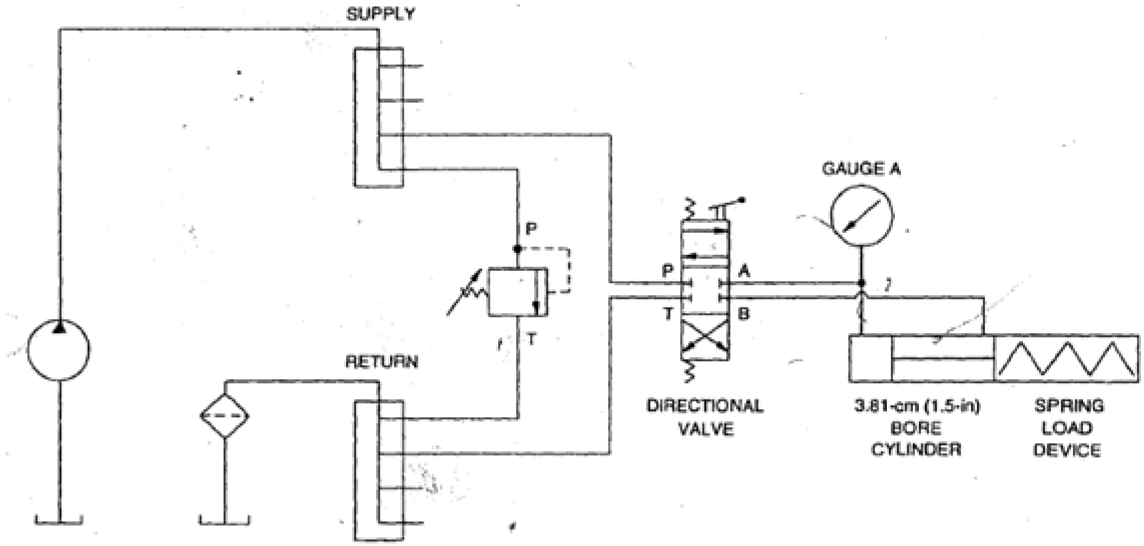


Figure (4.5) Schematic diagram of the circuit for measuring the output force of a cylinder.

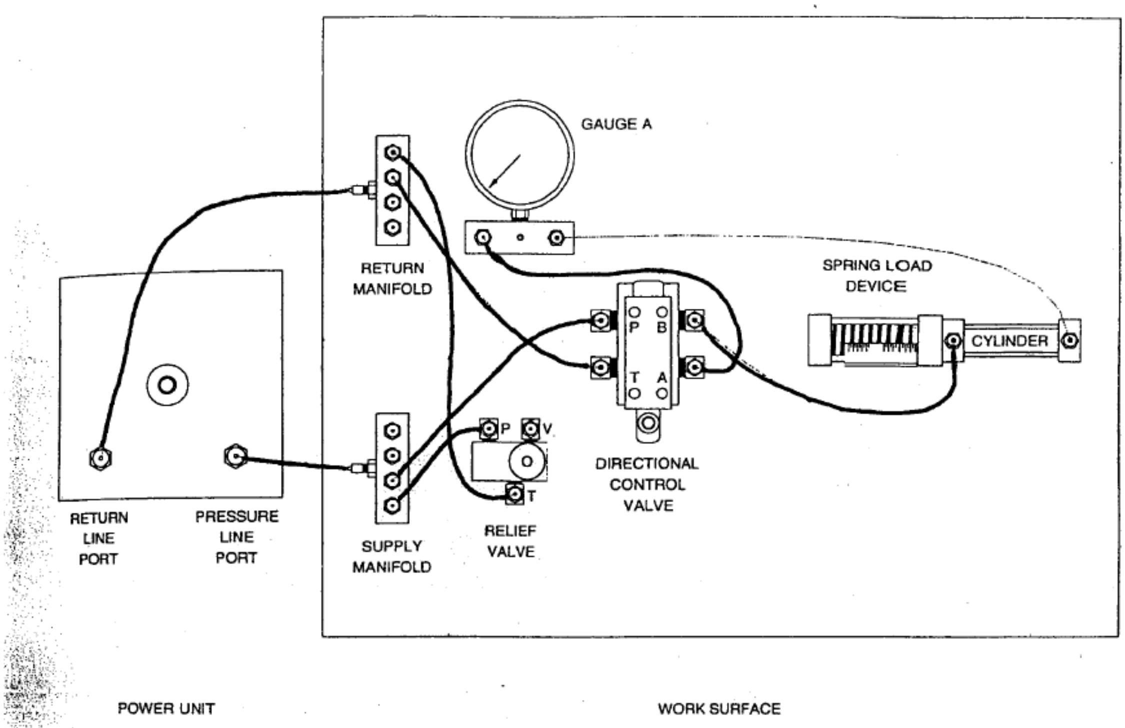


Figure (4.6) connection diagram of the circuit for measuring the output force of a cylinder.

8. Before starting the Power Unit, perform the following start- up procedure:

   a. Make sure the hoses are firmly connected.
   b. Check the level of the oil in the reservoir, Add oil if required.
   c. Put on safety glasses.

d. Make sure the power switch on the Power Unit is set to the OFF position.
e. Plug the Power Unit line cord into an AC outlet.
f. Open the Relief Valve by turning its adjustment knob fully counterclockwise.

9. Turn on the Power Unit.

10. Move the lever of the directional valve toward the valve body to direct the pumped oil toward the cap end of the cylinder. While keeping the valve lever shifted, turn the Relief Valve adjustment knob clockwise until the pressure at gauge A equals 4100 kPa (600 psi). Observe that the applied pressure caused the cylinder to compress the spring in the Loading Device.

11. With the lever of the directional valve still shifted toward the valve body, turn the Relief Valve adjustment knob counterclockwise to decrease the pressure at gauge A at 3500 kPa (500 psi). Note the force reading on the Loading Device, and record this value in Table1 under "ACTUAL"

12. By shifting the directional valve lever and adjusting the knob on the Relief Valve to decrease the pressure at gauge A in steps, measure the force reading for the pressure levels in Table 1. Record your results in Table 1. Use a steel rule to measure the displacement travelled by the piston on the spring and record it on Table 1.

13. Repeat steps 10 and 11 for a pressure value of 2500 kPa 5 times and record the result to calculate the error.

14. When you have finished, move the directional valve lever outward from the valve body to retract the rod. Then turn off the power Unit. Open the Relief valve completely (turn knob fully counterclockwise).

RESULTS:

1. Compare the actual forces you obtained in the experiment with the theoretical forces in Table 1. Are these values within 10% of each other?

2. Plot the relationship between the force and pressure, and compare actual results to theoretical ones.

3. Calculate the spring stiffness and plot the Force versus the spring Displacement (x).

4. What are the types of errors in your experiment, and how do they happen.

Data Sheet

Cylinder force, pressure and displacement.

Pressure Applied on Full Piston Area	Theoretical Cylinder Force	Actual Cylinder Force	Displacement
3500 kPa			
3200 kPa			
2900 kPa			
2600 kPa			
2300 kPa			
2000 kPa			
Errors			
2500 kPa			
2500 kPa			
2500 kPa			
2500 kPa			
2500 kPa			

EXPERIMENT No. (5)

PRESSURE MEASUREMENTS

OBJECTIVE:

The purpose of this experiment is to familiarize the student with some techniques and devices that are used in pressure measurements.

INTRODUCTION:

Bourdon Tube Gauge

Bourdon tube pressure gauges are used for the measurement of relative pressures from 0.6 ... 7,000 bar. They are classified as mechanical pressure measuring instruments, and thus operate without any electrical power.

Figure (5.1): Bourdon Tube Gauge

Bourdon tubes are radially formed tubes with an oval cross-section. The pressure of the measuring medium acts on the inside of the tube and produces a motion in the non-clamped end of the tube. This motion is the measure of the pressure and is indicated via the movement.

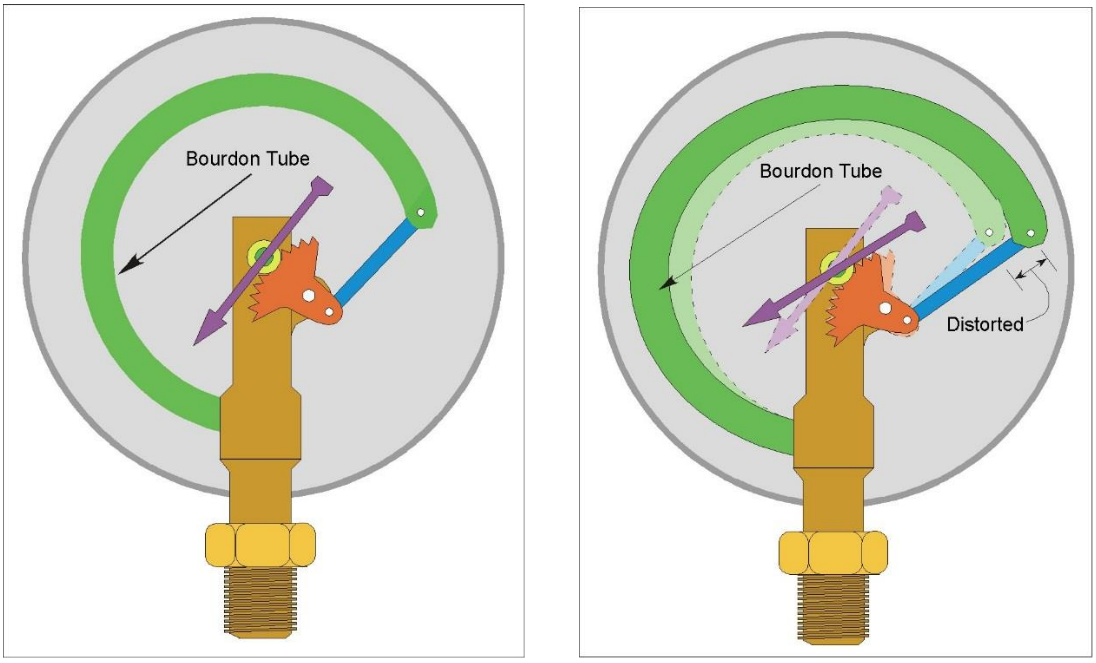


Figure (5.2) Operation principle of the Bourdon tube pressure gauge

The C-shaped Bourdon tubes, formed into an angle of approx. 250°, can be used for pressures up to 60 bar. For higher pressures, Bourdon tubes with several superimposed windings of the same angular diameter (helical tubes) or with a spiral coil in the one plane (spiral tubes) are used.

Pitot - static tube

A Pitot tube is a pressure measurement instrument used to measure fluid flow velocity. It was invented by the French engineer Henri Pitot in the early 18th century and was modified to its modern form in the mid-19th century by French scientist Henry Darcy. It is widely used to determine the airspeed of an aircraft, water speed of a boat, and to measure liquid, air and gas flow velocities in industrial applications. The Pitot tube is used to measure the local flow velocity at a given point in the flow stream and not the average flow velocity in the pipe or conduit.

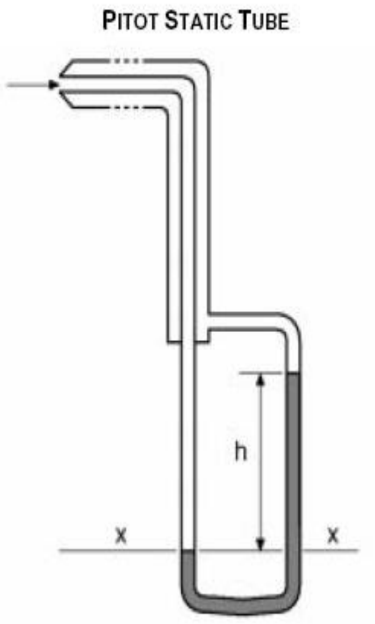


Figure (5.3) Pitot-static tube

EXPERIMENTAL PROCEDURE:

Part I: Calibration of a Bourdon Tube Gauge

Figure (5.4) Bourdon Gauge

The set-up is shown in Figure (5.4).

1. Fill the gauge by water to its top, and then insert the cylindrical piston (which is equal to 1 kg) into the vertical cylinder.
2. Rotate the piston gently.
3. Read and record the Bourdon Tube gauge, in kN/m^2
4. Record the weight of piston (kgf).
5. Add weights in increments of 0.5 kgf (four increments in total).
6. Read and record the Bourdon Tube gauge, in kN/m^2
7. Record the total load on piston. (Total load = weight of piston + weight added).
8. Repeat procedure 5-7 in increments of 1.0 kgf (three increments in total).
9. Unload the piston by removing the weights.

<u>Part II</u>: Pitot-static tube

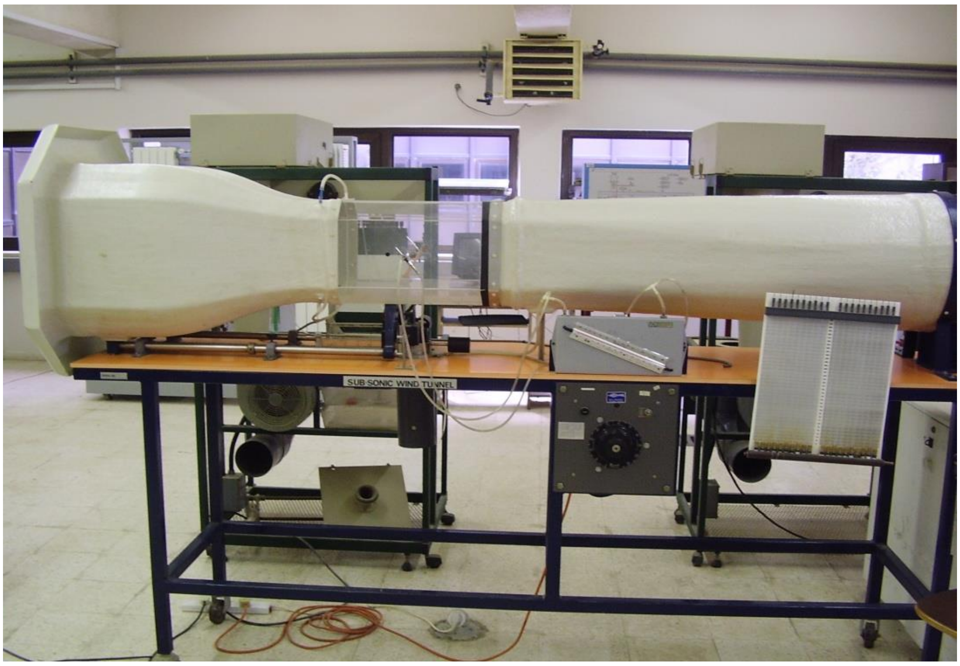


Figure (5.5) Pitot - static tube fitted on Wind Tunnel

1. Connect the Pitot-static tube to the inclined manometer and to the digital micro manometer. Figure (5.5).
2. Switch the wind tunnel fan on.
3. Start at low speed :
    a) Read and record the inclined manometer, ΔP, in mm of water.
    b) For the digital micromanometer, press the button that gives you reading of velocity, V, in m/s. Record the velocity reading.
4. Increase the speed of the fan a little.
5. Repeat step number 3 above.
6. Repeat steps 4 and 5 until you have 10 readings.
7. For error calculations, Repeat one ΔP 5 times.
8. Shut the system off.
9. Record the unit gravity force, γ_o, of the fluid in the inclined manometer.

CALCULATIONS:

1. Calculate the true pressure exerted by the piston on the fluid inside the cylinder.

$$P_{true} = \frac{\text{Total weight}}{\text{Area}} = \frac{\text{kgf} \times 9.81}{\text{Area}}$$

Area = 333 mm^2

2. Calculate % error.

$$\%\,\text{error} = \frac{\text{Bourdon Tube Pressure} - \text{True Pressure}}{\text{True Pressure}} \times 100\%$$

3. Calculate the air velocity in the air tunnel from the reading of the inclined manometer.

$$V = \sqrt{2g\,\Delta P\left(\frac{\gamma_o}{\gamma} - 1\right)}$$

Where V ≡ air velocity, m/s
g ≡ gravity
ΔP ≡ pressure change in Pascal
γ_o ≡ unit gravity force of manometer fluid, 0.784 N
γ ≡ unit gravity force of air, 1.2 x 10^{-3} N

4. Calculate % error.

$$\%\,\text{error} = \frac{\text{Velocity from inclined manometer} - \text{Digital}}{\text{Digital}}$$

RESULTS:

1. Compare the theoretical and actual values of gauge pressure from the Bourdon Tube.
2. Plot Bourdon Tube pressure gauge vs. True pressure.
3. Plot % error of Bourdon Tube vs. True pressure.
4. Compare the theoretical and actual values of fluid velocity from the Pitot tube.
5. Plot the air velocity measured by inclined manometer vs. the digital reading.
6. Plot % error between inclined manometer and digital reading vs. Digital reading.
7. What are the types of errors in your experiment, and how do they happen.

Data Sheet

Part I

Run	Weight added to Piston kgf	Gauge Reading KN/m^2
1	0	
2	0.5	
3	1	
4	1.5	
5	2	
6	3	
7	4	
8	5	

Part II

Run	Inclined Manometer mm H_2O	Digital MicroManometer m/s
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

For error calculations

Run	Inclined Manometer mm H_2O	Digital MicroManometer m/s
1		
2		
3		
4		

<u>Part III:</u> **Pressure Sensor Measurement**

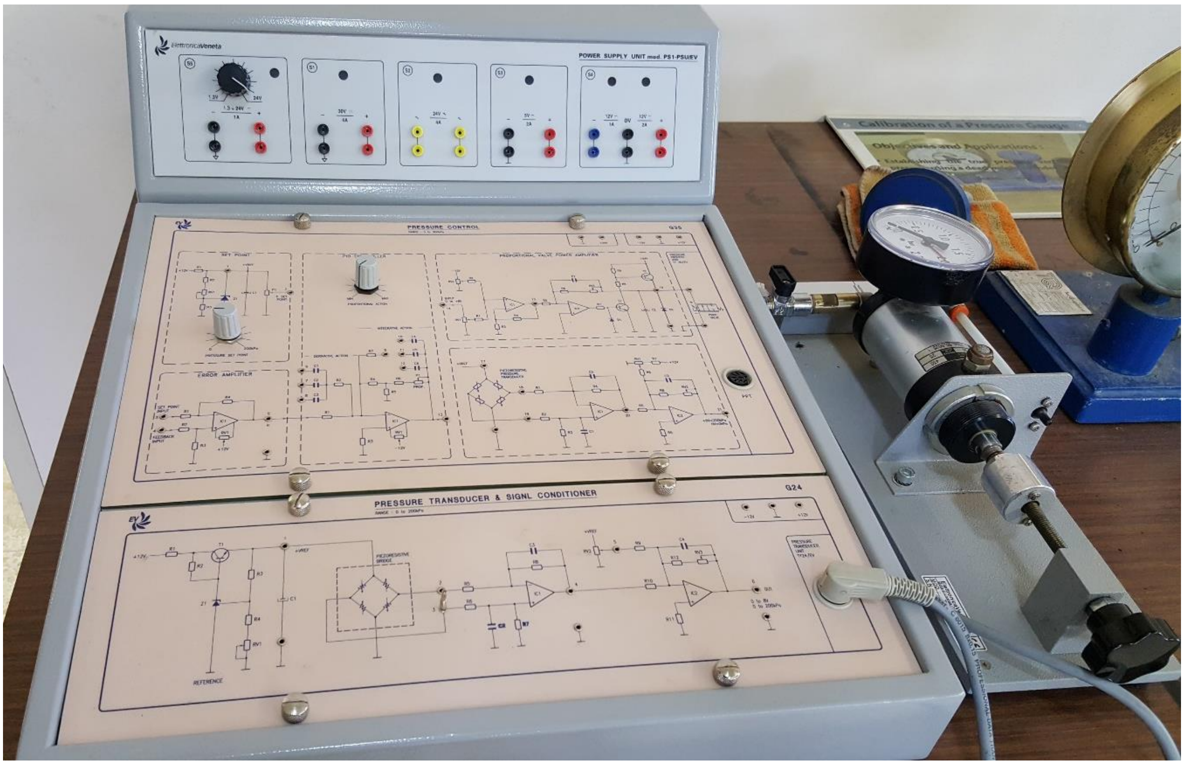


Figure (5.6) Pressure Sensor Measurement Set-up

Objectives of the Experiment:

Upon conducting this experiment, students should be able to :

1. Know different methods for pressure measurements.
2. Know main differences between pressure measurement.
3. Be able to conduct pressure transduction properly.

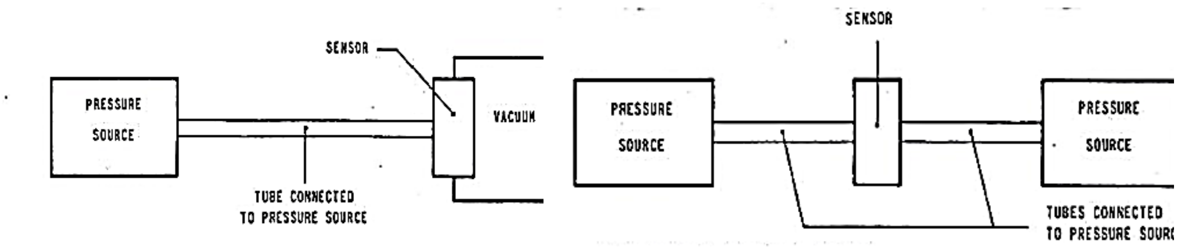
Brief Introduction of Pressure Measurement

Pressures in liquids and gases may be measured electrically using an infinite variety of pressure sensors. Pressure sensors however are categorized:

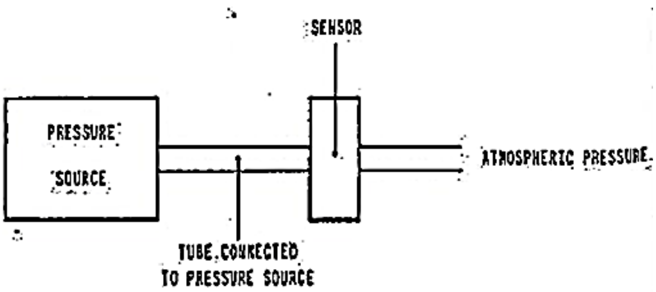
i) Absolute pressure transducer which is a device containing reference vacuum for the measurement of absolute pressure of the ambient or of the pressure source connected to it by a tube.

ii) Differential pressure transducer which is a device for the measurement of differential pressure between two pressure sources connected to it by a tube.

iii) Gage pressure transducer which is a differential pressure transducer in which the pressure source consists of the local atmospheric pressure, while the other source is connected to it by a tube.



a) Absolute Pressure Transducer *b) Differential Pressure Transducer*



c) Gage Pressure Transducer

Figure (5.7) Categories of Pressure Transducers and Connections to Pressure Sources

There are also other terminologies that are utilized for pressure sensor such Barometric sensor, Altimetric sensor and Vacuum sensor. Independently of their classification within these groups, pressure transducers consist basically two main parts: the first part converts a pressure P (t) into a movement; the second part converts this movement X (t) into an electric signal V (t).

Table (5.1) below shows the principal characteristics of different types of pressure transducers. Note that the operating range may vary significantly for transducers of the same type; this clearly affects their cost.

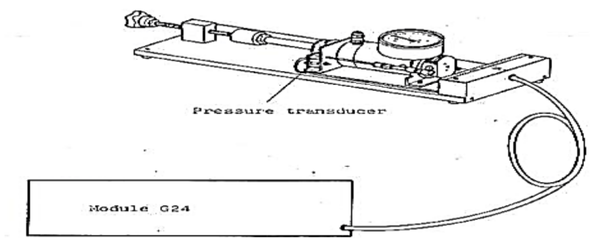
Table (5.1) Characteristics of Different Types of Pressure Transducers

Characteristics / Transducer	Accuracy	Cost	Electronic Interface	Principal Advantages	Principal Disadvantages	Use
LVDT	Fair	Average	Complex	-	Expensive if a high level of accuracy is required	Low-precision apparatus
Potentiometric	Fair	Low	Simple	Low Cost	Low accuracy and reliability	-
Strain-Gage	Excellent	High	Simple	High Precision	Very Expensive	Precision industrial uses: nuclear and oceanography
Monolithic Capacitive	In theory: Excellent	Relatively High	Complex	Excellent Stability and Low Temperature Dependence	Distance between the two electrodes is critical	Industrial
Monolithic Piezoresistive	Good	Relatively High	Simple	Temperature Stability and Excellent Linearity	-	Industrial
Monolithic Semiconductor	Good	Low	Complex if heat-compensating	Small Size	Highly sensitive to Temperature	Industrial
Piezoelectric	Excellent	High	Charge Amplifier	High Precision	Very Expensive	Precision measurement: Sound Measurement

Parts and Components of Pressure Sensor Measuring Experiment

- **Pressure Transducer**

Pressure sensor is based on the phenomenon of piezoresistivity. That is the ability of a certain number of materials to change their resistance when it is subjected to a deformation.

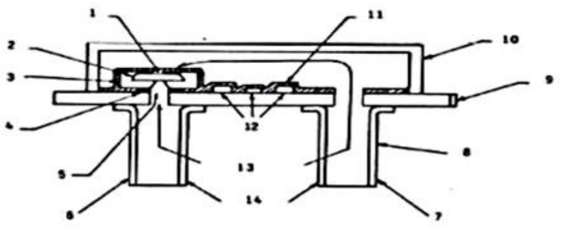


The advantages of such a sensor are its size (about one tenth of other monolithic transducers), excellent electrical characteristics and the intrinsically low cost of the sensitive element. On the other hand, it is considered to have a high sensitivity shift with temperature, and the fact that the fluid being tested comes into contact with the sensitive element. These limitations are often circumvented by fitting laser-trimmed resistors for close null and sensitivity tolerances. In order to reduce sensitivity shift with temperature, some sensors are fitted with thermistors (temperature- compensated).

- **Sample Pressure Generation Device**

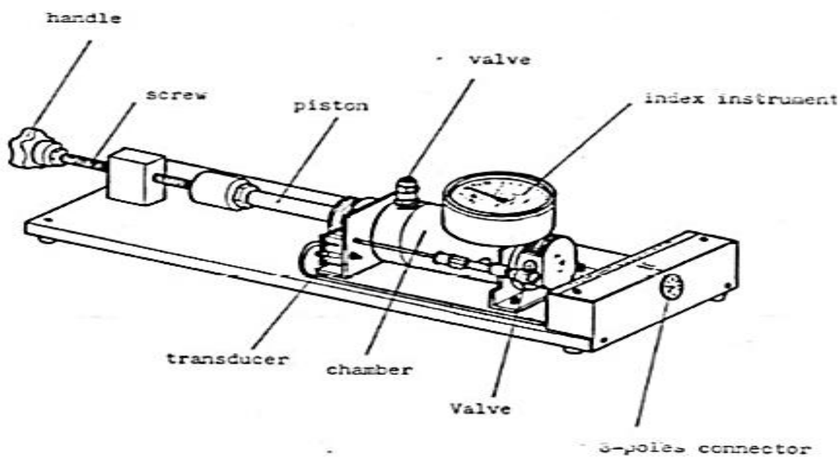
In order to study the characteristics of the pressure transducer and the signal conditioner, a sample pressure must be made available. For this purpose a device, called Pressure Transducer Unit Ty24, has been manufactured, which is able to generate pressures from 0 to 2 bar.

1- Diffusion Sensor Element.
2- Sensor Cavity.
3- SI Crystal.
4- Stress Relief Mount.
5- Alternate inlet (Closed for Absolute, open for Gage or Differential).
6- Single Port (Backward Gage).
7- Single Port (Absolute or Gage).
8- Cd-Plated Brass.
9- Ceramic Substrate.
10- Ceramic Cover.
11- Conformal Parylene Coating.
12- Circuit Components.
13- Pressure.
14- Dual Port (Differential).



- **Pressure Generator**

It consists of a piston, controlled by a handle by means of a screw, which can be inserted into a chamber. By varying the position of the piston, you vary the pressure inside the chamber.



A differential type transducer is fitted beside the chamber, and this has an input connected to the pressure of the chamber and the other part is left free (so at ambient pressure); in this way we obtain the relative pressure (gauge).

Over the chamber there are an exhaust valve and an index instrument, which operates as reference for the pressure inside the same chamber. Besides, the availability of an exhaust valve gives the possibility to obtain a zero value of pressure (atmospheric pressure) for each position of the piston. The connection to the module is obtained by the 8 poles connector fitted on the side of unit TY24.

Exercise-1: Measuring output voltage that corresponds to applied pressure

Setting Up Signal Conditioner:

The purpose of this exercise is to adjust signal conditioner so that a pressure of 0 atm corresponds to an output voltage of 0 V and a pressure of 2 bar corresponds to an output voltage of 8 V.

Tracing The "Output Voltage/Pressure" Curve Of The Transducer/Conditioner:

The purpose of the exercise is to plot the curve which represents the relationship between the pressure applied to the transducer and the output voltage of the signal conditioner. Also, it is required to find the best fit straight line which perfectly represents the relationship between the pressure applied to the transducer and the output voltage of the signal conditioner. Additionally, it is desired to calculate the linearity of the sensor/transducer.

Procedure:

1. After setting up the signal conditioner, connect the digital voltmeter to the output marked OUT.

2. Starting from 0, vary the pressure of the sample generator in steps of 0.1 bar.

3. The data gathered in this way should be listed in Table (5.2).

4. For the curve representing the data in Table (5.2), find the best fit line connecting the majority of data points.

5. Plot two parallel and equidistant lines with respect to the best fit straight line so that they can include all the data points. Calculate the linearity of the system.

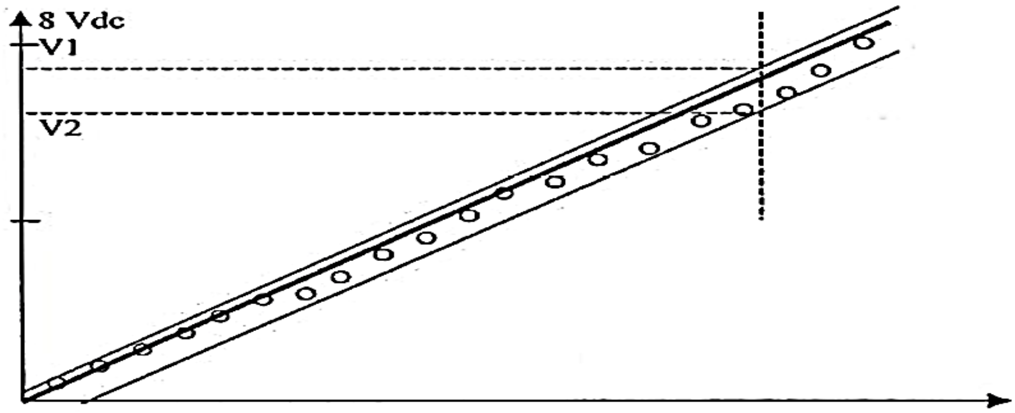


Figure (5.8) Linearity

6. Linearity value referred to the full scale value: :$\pm\frac{1}{2}\frac{V_1 - V_2}{F.S.O}$

, Where F.S.O. is the full scale output (8 volt in this case)

Table (5.2) Output Voltage Corresponding to Pressure Changing

P (bar)	V_{out} (Volt)
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1	
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	
1.7	
1.8	
1.9	
2	

Excercies-2 Studying the Effect of Transducer's Temperature on the Measurement Process

In this part of the experiment, it is required to analyze the effect of the temperature on the measuring process to observe the variation in measurement as the temperature of the transducer varies.

Procedure:

1. Heat the transducer using an incandescent lamp for 3 minutes and measure the new characteristics by starting from 0, vary the pressure of the sample generator in steps of 0.1 bar .

2. Compare your results with the results obtained in the previous exercise.

Table (5.3) Output Voltage Corresponding to Pressure Changing While Changing Temperature Value

P (bar)	**V_{out} (Volt)**
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1	
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	
1.7	
1.8	
1.9	
2	

EXPERIEMENT No. (6)

TEMPERATURE MEASUREMENTS

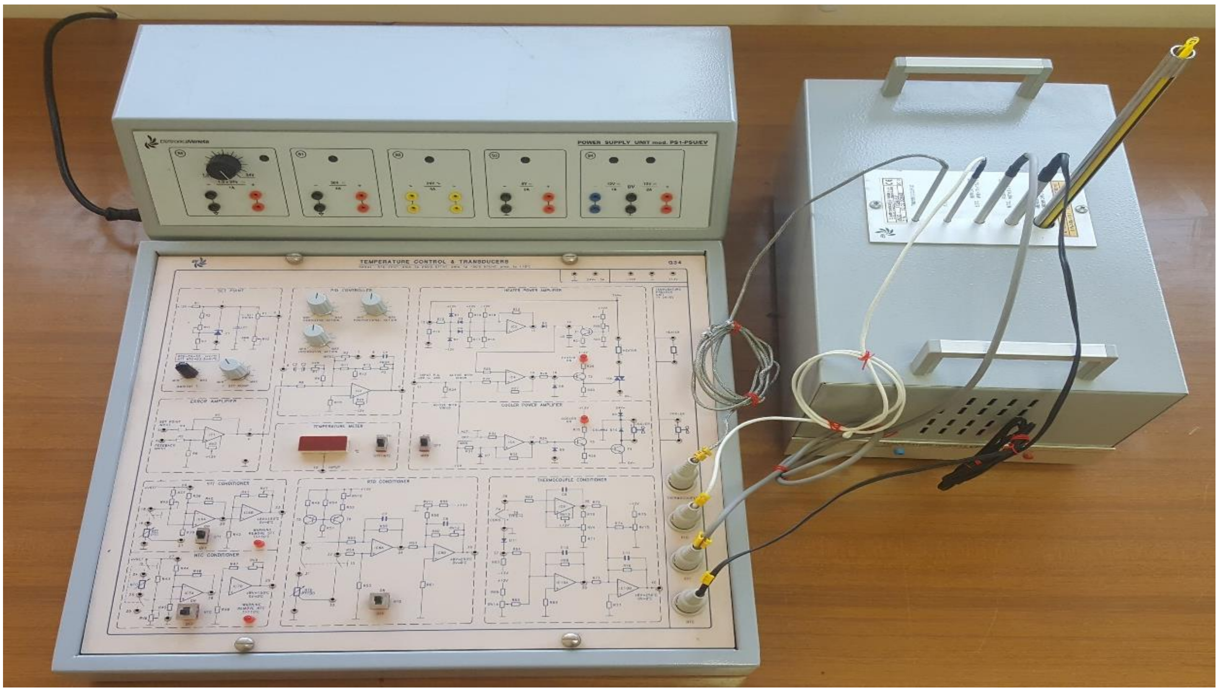


Figure (6.1) Temperature Measurement Set-up

Objectives of this Experiment:

Upon conducting this experiment, the students should be able to:

1. Know different temperature sensors (thermocouple, RTD, NTC …etc.)
2. Know main operation differences between these temperature sensors.
3. Be able to identify characteristics of each temperature sensor.
4. Know important requirements needed to conduct temperature measurement.

When energy is provided to a physical system in any form, the state of the system inevitably changes and the temperature in this case is considered one of the important indicators that represents the state of the system. In the International System, *kelvin* (K) is considered the standard unit for the temperature where the absolute zero corresponds to 0 K. Two other temperature scales are normally used: the Celsius or centigrade scale (°C) and the Fahrenheit scale (°F). The relationship between these temperature scales is shown in Table (6.1).

Table (6.1) Relationship between Celsius, Fahrenheit and kelvin

°***K***	°C	°F
0	-273.1	-460
273.1	0	32
373.1	100	212
1273	1000	1832

Conversion from Centigrade to Fahrenheit is based on the following equation:

$$°\mathrm{F} = \frac{9}{5} \, . \, °\mathrm{C} + 32$$

Centigrade scale however is used in this manual which is perhaps the most practical of the three, as 0 °C corresponds to the temperature of melting ice and 100 °C correspond to the boiling-point of water at sea-level. In industrial and domestic applications, temperature is measured by numerous different types of transducers of varying complexity and accuracy.

The most commonly used are semiconductor transducers, thermo-resistances and thermocouples, as these transducers offer a high degree of accuracy together with simple construction and ease of use. These types of transducers can also be very small, and are therefore easy to insert directly into the process.

Transducers Types Used To Measure Temperature:

i) Semiconductor Temperature Transducers

Semiconductor temperature transducers are based on the degree of sensitivity of the semiconductor materials to the temperature. The temperature coefficient of a semiconductor temperature transducer is much higher than that of a thermo-resistance, and it is much cheaper to produce. Its main disadvantages lie in a limited temperature range and lower linearity.

Devices of this type may have one or two terminals, and are classified as follows:

Semiconductor resistive block.

Junction between two semiconductors doped P and N (diodes).

Integrated circuit.

This type of devices is considered the most simple in structural terms, and may have a positive or negative temperature coefficient of approximately 0.7%/ ℃ and linearity of +_0.5% within a temperature range of –65 ℃ to +200 ℃.

The law by which resistance varies with temperature is, in approximate terms, as follows:

$$R_T = R_0 (1 + \alpha T)$$

The transducer and the signal conditioner are generally connected by two wires. As the temperature to which these wires are subjected varies, the overall resistance of the transducer and wires also varies. However, the measurement error caused by the wires is, in most cases, negligible. In rare cases, three-or four-wire devices are used as in the classic connection with two constant-current generators (see Figure (6.2)).

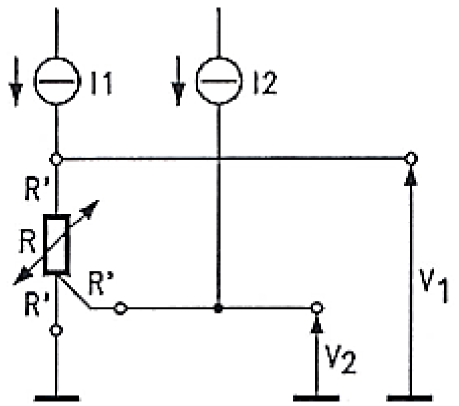


Figure (6.2) Transducer connection

The wires which carry the transducer output are always made using the same material and are always of the same length, and their resistance R' is therefore identical. As a result, using a differential amplifier, it is possible to obtain a voltage which varies only with the resistance R. The nominal resistance at a temperature of 25 ℃ is between 10Ω and 10KΩ, with a tolerance of between 1% and 20%; in physical terms, their form in that of a ¼ Watt resistance or a signal diode.

As the characteristics are specified for null power dissipation (i.e. without any appreciable current circulating in the device), care must be taken to prevent overheating caused by the measurement current. For this reason, the transducer is not generally powered with currents in excess of 10 mA.

The transducer examined in this experiment is the Philips KTY83-110, whose main characteristics are as follows:

- Nominal resistance: 1000Ω (25 ^{o}C, 1 mA)
- Temperature range: -55 ^{o}C / +175 ^{o}C
- Maximum tolerance: 1%
- Temperature coefficient: +0.75%/ ^{o}C (P.T.C.)

ii) **NTC Thermistors**

Thermistors are considered resistance variation transducers constructed with materials of high temperature coefficient, and with very cheap manufacturing processes. Moreover, these types of temperature sensors are categorized as semiconductor RTDs (Resistance Temperature Detectors) and can determine negative (NTC) or positive (PTC) temperature coefficients; according to their composition.

The resistance of NTC thermistors depends on the absolute temperature which is given by:

$$R(T) = R_0 \cdot \exp\left(\frac{b}{T}\right)$$

PTC thermistors have a constant thermal coefficient in a limited temperature range, showing a fairly good sensitivity. In addition to that, PTC thermistors have a positive temperature coefficient and their characteristic increases as temperature rises. On the other hand, NTC thermistors have a negative temperature coefficient and their resistance/temperature characteristic decreases as temperature rises.

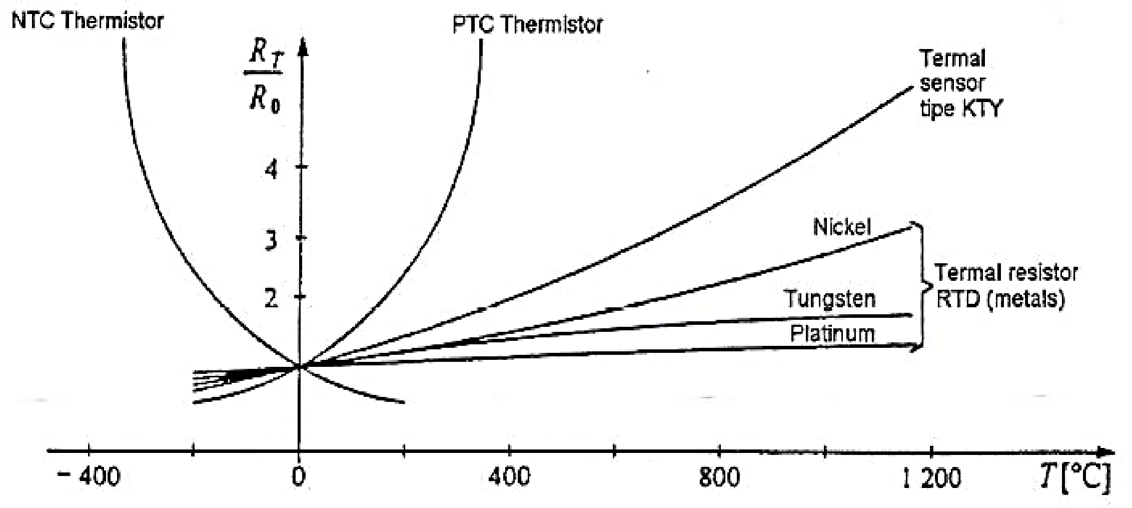


Figure (6.3) Comparison between different types of thermistors

NTC thermistors can use various circuits to reduce their nonlinearity that it undergoes (e.g.: a resistor bridged with the sensor and another one series connected with it); or using a microprocessor which leads to digital linearization with interpolation of the calibration curve. Resistance and temperature of an NTC thermistor will vary according to the following formula:

$$R_T = A \, . \, e^{\frac{B}{T}}$$

Where:

- R_T is the resistance of the material at the generic temperature T.
- *A* and *B* are constants depending on the material with 200K < *B* < 5500K
- *T* is the generic temperature expressed in Kelvin degrees.

The main relation between resistance of the thermistor R_T and temperature *T* is given by:

$$R_T = R_{Ta} \, . \, e^{B.\frac{Ta-T}{Ta.T}}$$

Where:

- Ta is the reference temperature Ta = 293K (Ta =20 ℃).
- R_{Ta} is the resistance of the thermistor at the temperature Ta.
- B is a constant depending on the material 200K < B < 5500K.

The transducer examined with the module G34/EV shows the following characteristics:

- R_{Ta}= 12.09 kΩ.
- B = 3435K ± 1%.

The characteristic of NTC thermistors however can be linearized through a bridged resistance calculated with the following formula:

$$R_L = R_{Tmed} \cdot \frac{B - 2 \cdot T_{med}}{B + 2 \cdot T_{med}}$$

Where:

- R_L is the value of the bridged resistance for linearization.
- R_{Tmed} is the resistance of NTC thermistor corresponding to the mean temperature T_{med}.
- B is the dimensional constant of the thermistor.

Considering a range of temperature between 0 ℃ and 80 ℃, set the linearization resistance of the thermistor examined in the module G34/EV, according to the following table:

T_{min} = 20 ℃	R_{Tmin} = 12.09 kΩ
T_{med} = 40 ℃	R_{Tmed} = 5827 Ω
T_{min} = 80 ℃	R_{Tmax} = 1668 Ω

Applying the formula $R_L = R_{Tmed} \cdot \frac{B - 2 \cdot T_{med}}{B + 2 \cdot T_{med}}$ will lead to:

$$R_L = R_{Tmed} \cdot \frac{B- 2 \cdot T_{med}}{B + 2 \cdot T_{med}} = 5827 \text{ X } \frac{3435-2 \text{ X } 40}{3435 + 2 \text{ X } 40} = 5560\ \Omega$$

The bridged resistance used for linearization, being equivalent to the same resistance, RL shows a slight nonlinearity; reducing the range of use will also progressively reduce this nonlinearity.

iii) **Thermoresistances**

Thermoresistances measure temperature by detecting variations in the resistance of an electrical conductor. The law by which resistance varies with temperature is, in approximate terms, as follows:

$$R_T = R_o(1 + \alpha T)$$

where the temperature coefficient α is the average value over the measurement range.

Thermoresistances are also known as Resistance Temperature Detectors (R.T.D.), and have the following electrical symbol:

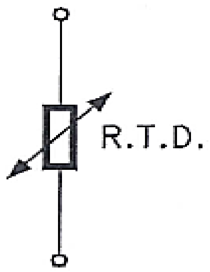


Figure (6.4) Resistance Temperature Detector

This type of transducer has the following main characteristics:

- Long-term invariability of characteristics
- Reproducibility of characteristics
- Good resistance variation with temperature

Two types of thermoresistance are generally accepted as standard: the nickel thermoresistance and the platinum thermoresistance.

The nickel thermoresistance has a temperature coefficient $\alpha = 6.17*10^{-3}$ C^{-1}, and can be used at temperatures between -60 and +150°C. The platinum thermoresistance has a temperature coefficient $\alpha = 3.85*10^{-3}$ C^{-1}, and can be used at temperatures between -220 and +750°C. The characteristic curves are shown in Figure (6.5).

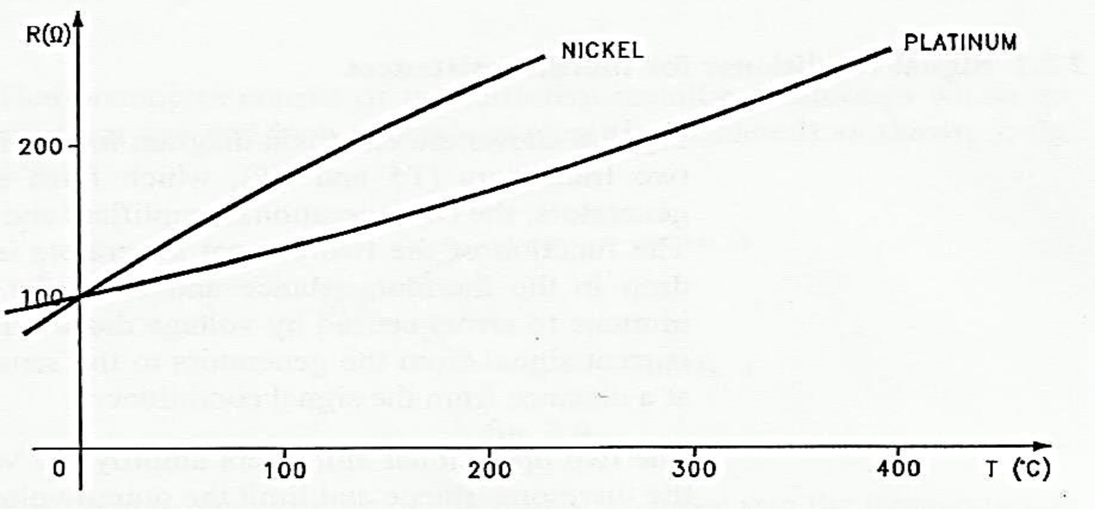


Figure (6.5) Characteristic Curves of Thermoresistance And Platinum Thermoresistance.

The most commonly used thermoresistances have a resistance of 100 Ω at 0°C and a tolerance of ±0.1°C.These normally consist of a wire (platinum or nickel) which is wound on an insulating cylindrical or flat support. The support is in a material which withstands high temperatures (ceramic, glass, etc.)

This structure results in a fairly high thermal constant. In other words, thermoresistances are relatively slow to follow the variations in the process temperatures.

The thermoresistance and the signal conditioner are normally connected by two wires. In order to reduce the influence of these wires on the measurement as the ambient temperature varies, the three- or four-wire connection in used together with a special electronic circuit, as in the semiconductor temperature transducer.

The overheating generated by the measurement current causes an error whose entity depends on the transmission of heat between the sensitive element, the protective sheath, and the ambient. For this reason, the measurement current is not normally in excess of 10 mA. These experiments use a Pt-100 3-wire platinum thermoresistance, which has a temperature range of 0 to 250°C, excellent linearity, and a low tolerance.

iv) **Thermocouples**

Thermocouples consist of two different metallic conductors which are joined at one end by a galvanic contact (i.e. soldered) as shown in Figure (6.6).

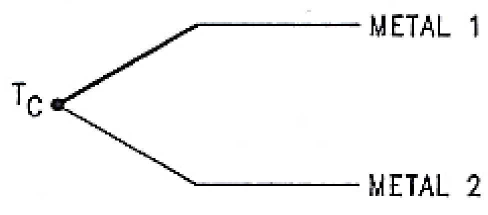


Figure (6.6) Thermocouple

The thermocouple (or hot junction) is introduced into the temperature to be measured (e.g. inside an oven) and the conductors are brought to the point of measurement (cold junction), which is at a different temperature as seen in Figure (6.7). This circuit generates a thermoelectric e.m.f. (electromotive force) which varies according to the difference between TC and TF (Seebeck effect).

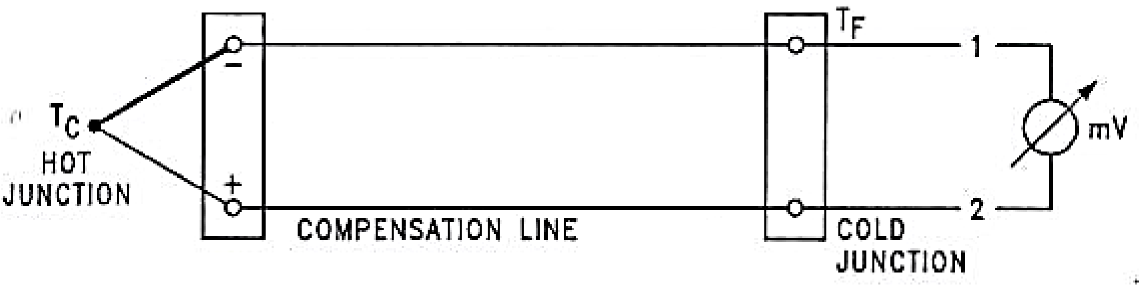


Figure (6.7) Seebeck effect

By measuring this electromotive force, and as the temperature TF is a known quantity, it is possible to calculate the value of TC. Since it is necessary to know the value of TF in order to calculate TC, it is necessary to extend the wires of the thermocouple with compensating wires to a point at which the temperature is constant and known.

The most important of the thermocouples available in the market are as follows:

- Fe-Constantan (type J)
- Ni-NiCr (type K)

• Cu-Constantan (type T)

Figure (6.8) shows the e.m.f./temperature curves for these types of thermocouples.

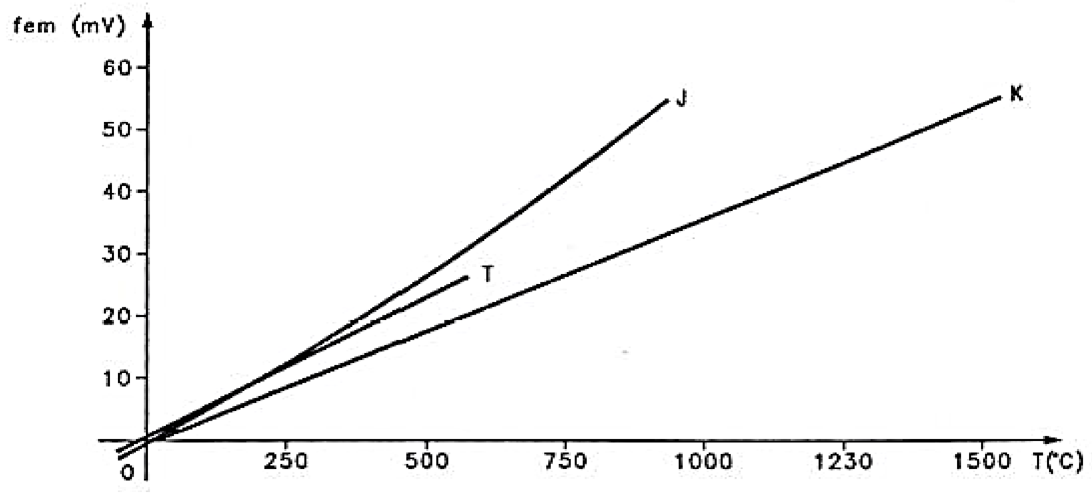


Figure (6.8) EMF vs Temperature

The e.m.f. of the Fe-Constantan thermocouple is much greater than that of the other types; its linearity is good, and it is inexpensive. One disadvantage is that the maximum temperature is limited by the iron element (700 – 800°C). The e.m.f. of the Ni-NiCr thermocouple is less than that of the Fe-Constantan type, but its operating temperature is significantly higher (in excess of 1500oC). Its linearity is good, especially in the high temperature range, although it is slightly more expensive to produce than the Fe-Constantan thermocouple. The main disadvantage of the Ni-NiCr thermocouple is that it is vulnerable to reducing gases, and therefore requires protection.

The temperature range of the Cu-Constantan thermocouple is lower than that of the Fe-Constantan type (500 – 600°C), but its linearity is better while it is not more expensive. This type of thermocouple is used mainly for low temperatures. The compensation wires must have the same thermoelectric characteristics as the thermocouple up to 150 – 200°C, and they must be inexpensive.

The thermocouple examined in this case is of the Fe-Constantan type (type J), and has the following main characteristics (see data sheet for further details):

• Transduction constant: 53 V/°C

• Error: ±2.2°C in the 0 – 270°C range

±0.75% in the 270 – 760ºC range

• Protected against atmospheric agents by metallic sheath

Temperature Process

1. **Heating a body**

The physical process of heating a body is described below. The body is assumed to be a heat conductor with a mass *m* and a specific heat *c*. If a quantity of heat *Q* is applied to such a body, its temperature increases by δT, which is given by the following equation:

$$\delta T = \frac{Q}{m \cdot c}$$

The quantity of heat *Q*, in the International System, is expressed in Joules, and may be calculated by multiplying the value of the power supplied to the heating element (which is assumed to be constant, and is expressed in Watts) by the time (in seconds) for which this power is applied. In approximate terms, therefore, the heating process is an integrating process which, in the time domain, will have a response with a delay of τ. The process may take place in a crucible, a tank containing chemical reagents, an oven etc.

In the TY34/EV temperature unit, the process takes place on an aluminum plate. This makes it possible to achieve high temperatures (up to 250ºC) with a relatively low heating power (100W max), and to bring the process to operating temperature extremely quickly.

The temperature unit also features the thermal actuators: a two-element electrical resistance (2 x 50W/24VAC) and a fan (170 m^3/hr/24VDC/4.5W). The fan makes it possible to cool the aluminum plate very rapidly, so that a series of experiments can be carried out without delays between one and the next.

The aluminum plate features wells for the three different types of industrial temperature transducer supplied with the temperature unit (PTC, thermoresistance and thermocouple). The unit also includes a mercury thermometer, which is used to provide the reference temperature. The thermometer, too, is inserted into a special well in the aluminum plate. The temperature unit is illustrated in Figure 12.9. The temperature unit can operate with the following temperature range:

Tamb → 250ºC

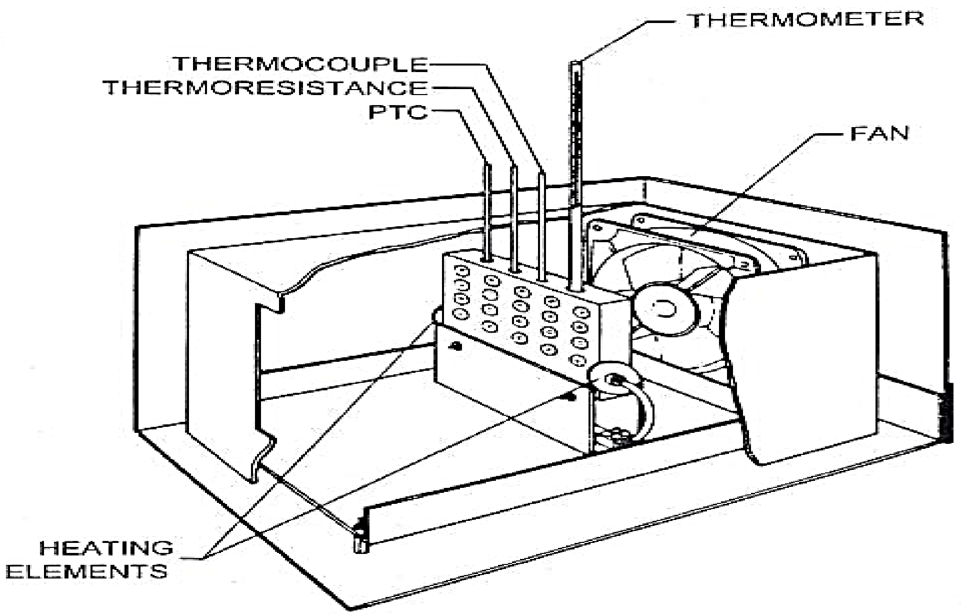


Figure (6.9) Heating element

Exercise-1: Plotting the characteristic curve of the silicon transducer

It is required to plot the characteristic curve of the silicon transducer (with the relative signal conditioner) on a graph.

Procedure:

1. Connect the silicon transducer to the corresponding signal conditioner.

2. Connect the output of the SET-POINT block terminal 2 to the input of the HEATER AMPLIFIER (block terminal 11).

3. Connect the HEATER output of the POWER AMPLIFIER to the heating elements of the oven.

4. Connect the COOLER output of the HEATER AMPLIFIER to the fan on the TY34/EV unit.

5. Set up the connection of the power supply for alternating voltage (24+24V AC) to the POWER AMPLIFIER block.

6. Connect the multi-meter to the output of the signal conditioner.

7. Power the circuit and check that the voltage supplied to the power supply is 24+ 24V AC.
8. Starting from ambient temperature, adjust the Set-Point knob in order to increase the temperature of the oven in 10ºC steps. Measure the output voltage of the signal conditioner as soon as the temperature is stabilized. The reference temperature is given by a precision mercury thermometer (Centigrade scale).

    Note: Be careful to avoid exceeding the maximum temperature that the transducer can withstand (175 ºC). For safety, do not exceed (100ºC to 110ºC). Write your results in table (6.1).
9. Make a table listing the values measured and use these measurements to plot a graph with the temperature on the x-axis and the output voltage of the transducer on the y-axis.

Table (6.1): temperature vs. output voltage (STT)

T (ºC)-Heating	**V_{out} (V)**	**T (ºC) - Cooling**	**V_{out} (V)**

Exercise-2: Determining the Characteristics of NTC Thermistor

It is required to determine the characteristic curve of the NTC thermistor with the respective signal conditioner, and transferring it into a Cartesian coordinate system.

Procedure:

1. Replace the signal conditioner for STT with the signal conditioner for NTC thermistors.

2. Starting from ambient temperature, adjust the Set-Point knob in order to increase the temperature of the oven in 10ºC steps. Measure the output voltage of the signal conditioner as soon as the temperature is stabilized. The reference temperature is given by a precision mercury thermometer (Centigrade scale).

   <u>Note:</u> Be careful to avoid exceeding the maximum temperature that the transducer can withstand (175 ºC). For safety, do not exceed (100ºC to 110ºC). Write your results in table (6.2).

3. Arrange a Voltage vs. Temperature table (use Table (6.2) and plot the characteristic curve on a chart.

Table (6.2): temperature vs. output voltage (NTC)

T (°C) Heating	**V_{out} (V)**	**T (°C) Cooling**	**V_{out} (V)**

Exercise-3: Plotting Characteristics of thermoresistance Temperature Sensor

The purpose of this exercise is to plot the characteristic curve of a thermoresistance (with the relative signal conditioner).

Procedure:

1. Replace the signal conditioner for the NTC thermistor with the signal conditioner for the thermoresistance.

2. Starting from ambient temperature, adjust the Set-Point knob in order to increase the temperature of the oven in 10ºC steps. Measure the output voltage of the signal conditioner as soon as the temperature is

stabilized. The reference temperature is given by a precision mercury thermometer (Centigrade scale).

Note: Be careful to avoid exceeding the maximum temperature that the transducer can withstand (175 ºC). For safety, do not exceed (100ºC to 110ºC). Write your results in table (6.3).

The reference temperature is given by a precision mercury thermometer (Centigrade scale)

3. Arrange a Voltage vs. Temperature table use table (6.3) and plot the characteristic curve on a chart.

Table (6.3): temperature vs. output voltage (RTD)

T (ºC) Heating	**V_{out} (V)**	**T (ºC) Cooling**	**V_{out} (V)**

Exercise-4: Plotting the Characteristics of the Thermocouple temperature sensor

The purpose of this experiment is to plot the characteristic curve of a J-type thermocouple (with the relative signal conditioner)

Procedure:

1. Replace the signal conditioner for the thermoresistance with the signal conditioner for the thermocouple.

2. Starting from ambient temperature, adjust the Set-Point knob in order to increase the temperature of the oven in 10ºC steps. Measure the output voltage of the signal conditioner as soon as the temperature is stabilized. The reference temperature is given by a precision mercury thermometer (Centigrade scale).

   Note: Be careful to avoid exceeding the maximum temperature that the transducer can withstand (175 ºC). For safety, do not exceed (100ºC to 110ºC). Write your results in table (6.4).

3. Arrange a Voltage vs. Temperature table (use Table (6.4)) and plot the characteristic curve on a chart.

Table (6.4): temperature vs. output voltage (thermocouple)

T (°C) Heating	**V_{out} (V)**	**T (°C) Cooling**	**V_{out} (V)**

EXPERIMENT No. (7)

VISCOSITY MEASUREMENT

OBJECTIVE:

The objective of this experiment is to familiarize the students with some devices and techniques that are used to measure the kinematic viscosity.

INTRODUCTION:

The device is called Saybolt viscometer, Figure (7.1).
Time is measured for 60 ml of fluid to flow through a short capillary tube under a falling head, Figure (7.2).

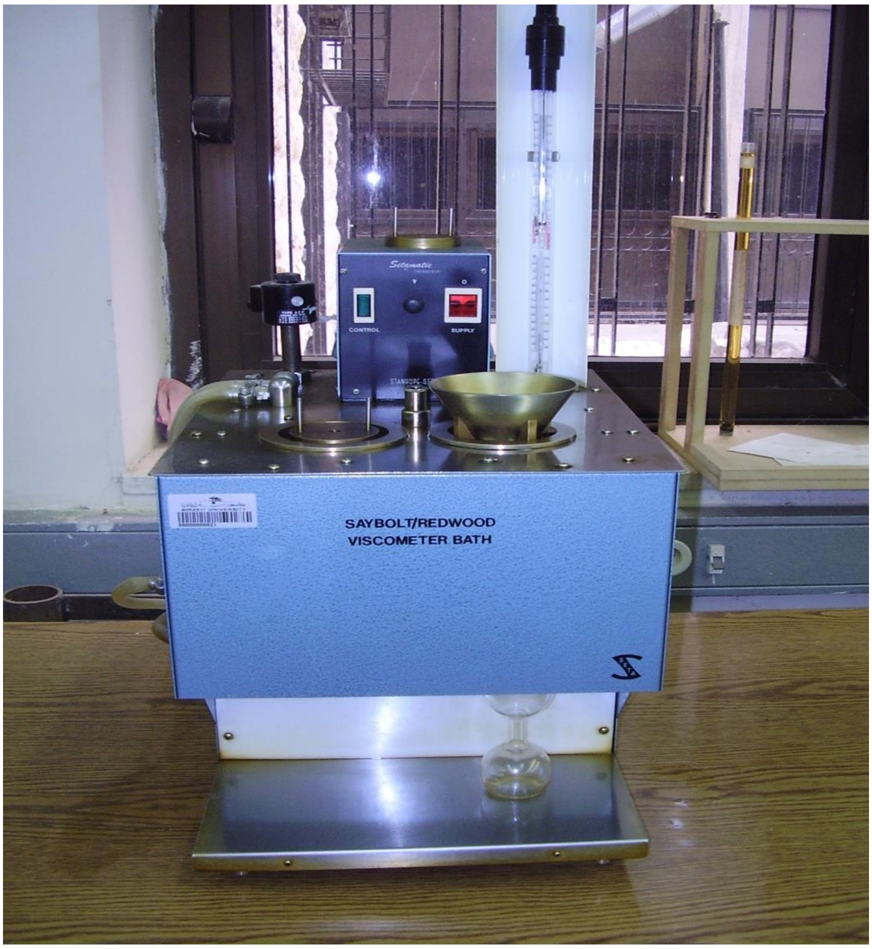


Figure (7.1) Saybolt Viscometer

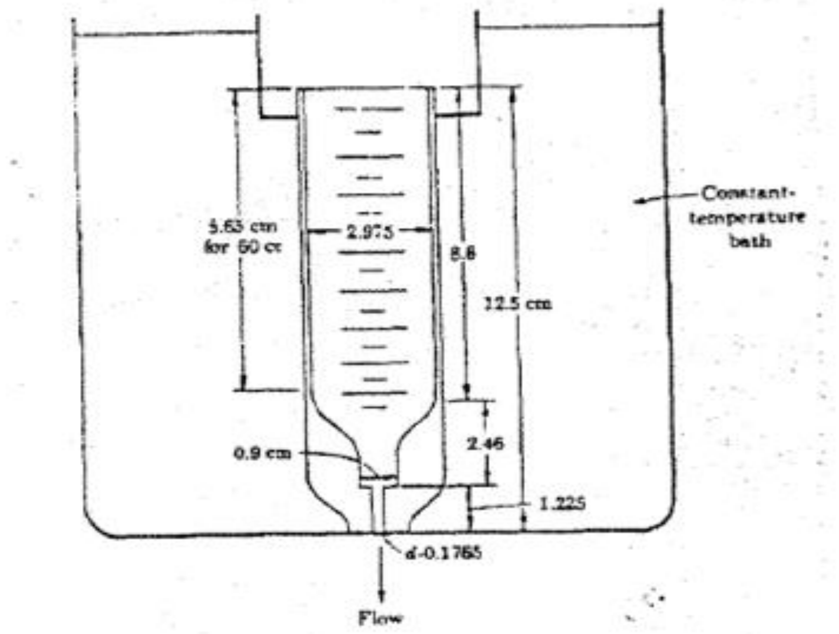


Figure (7.2) Schematic of the Saybolt Viscometer

EXPERIMENTAL PROCEDURE:

1. Select the desired temperature (about 30 ^{o}C) from the thermostat and the fixed thermometer. Actual bath temperature is given by the thermometer.
2. Switch power on, the neon lamp will glow.
3. When the desired temperature is reached, the light will disappear.
4. Pour the Oil in the Saybolt cup and put the 60 ml flask below it.
5. Insert the thermocouple into fluid.
6. Wait until the desired oil temperature is reached.
7. Record the temperature.
8. Put the 60 ml flask under the outlet.
9. Open the outlet by removing the cock (be careful) and start the stop-watch.
10. Stop the stop-watch at the instant the fluid reaches the marked line on the flask. (60 ml of fluid).
11. Record the time it took to fill the 60 ml of fluid.
12. Repeat this procedure at the same oil temperature.
13. Increase the water temperature, using the thermostat, by 5^{o}C increments and repeat steps 3 to 12.
14. For error calculations, repeat last oil temperature 5 times.

CALCULATIONS:

1. Calculate the average flow time for each temperature setting.
2. Find the kinematic viscosity from the following relation:

$$\nu = C_1 t + \frac{C_2}{t} \quad ------(1)$$

Where ν is the Kinematic viscosity in Centistoke
t average time in seconds
C_1 = 0.222 cst/sec
C_2 = - 182.528 cst.sec *[Note, stoke=cm^2/sec, cst=mm^2/sec]*

3. Find the kinematic viscosity from the attached chart.

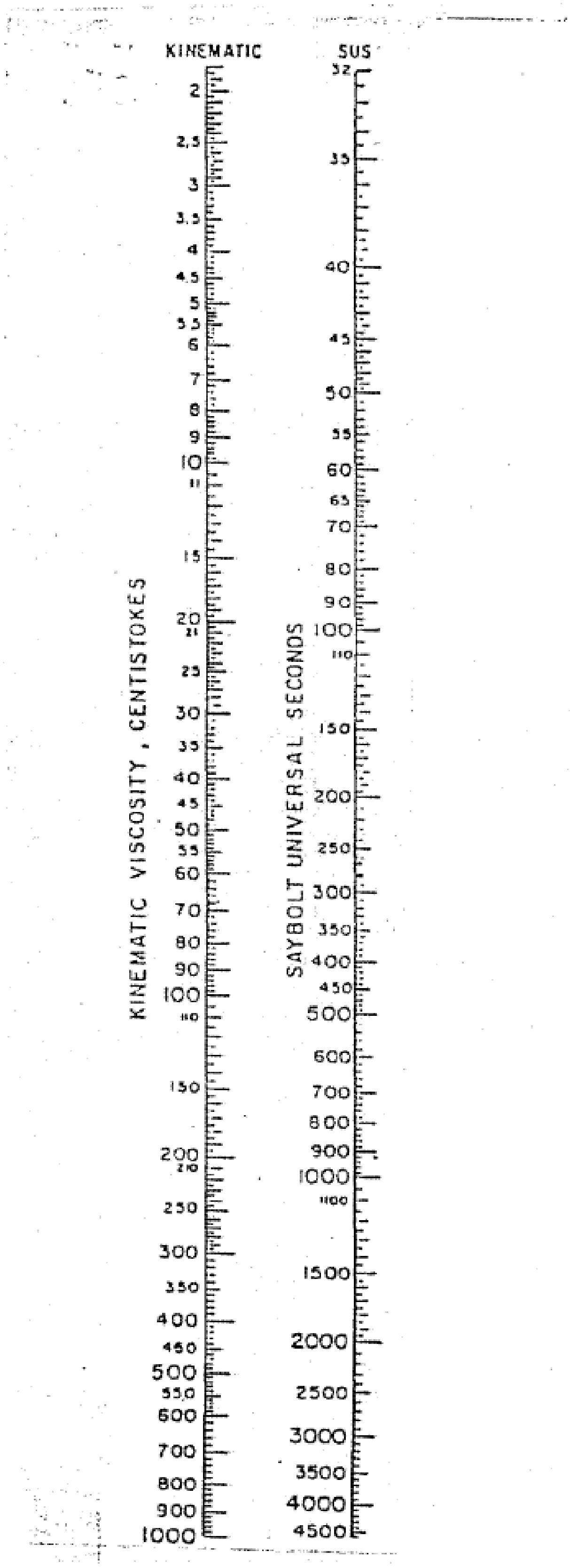
RESULTS:

- Plot the kinematic viscosity found from equation versus that found from chart. Include ideal relationship.

- Plot the kinematic viscosity found from equation versus temperature.

- What are the types of errors in your experiment, and how do they happen.

Kinematic Viscosity Chart



Data Sheet

Run	Water Temperature ºC	Oil Temperature ºC	Time sec
1	30		
2	30		
3	35		
4	35		
5	40		
6	40		
7	45		
8	45		

For error calculations

Run	Water Temperature ºC	Oil Temperature ºC	Time sec
1	45		
2	45		
3	45		

EXPERIMENT No. (8)

Ultrasonic and Proximity Measurement

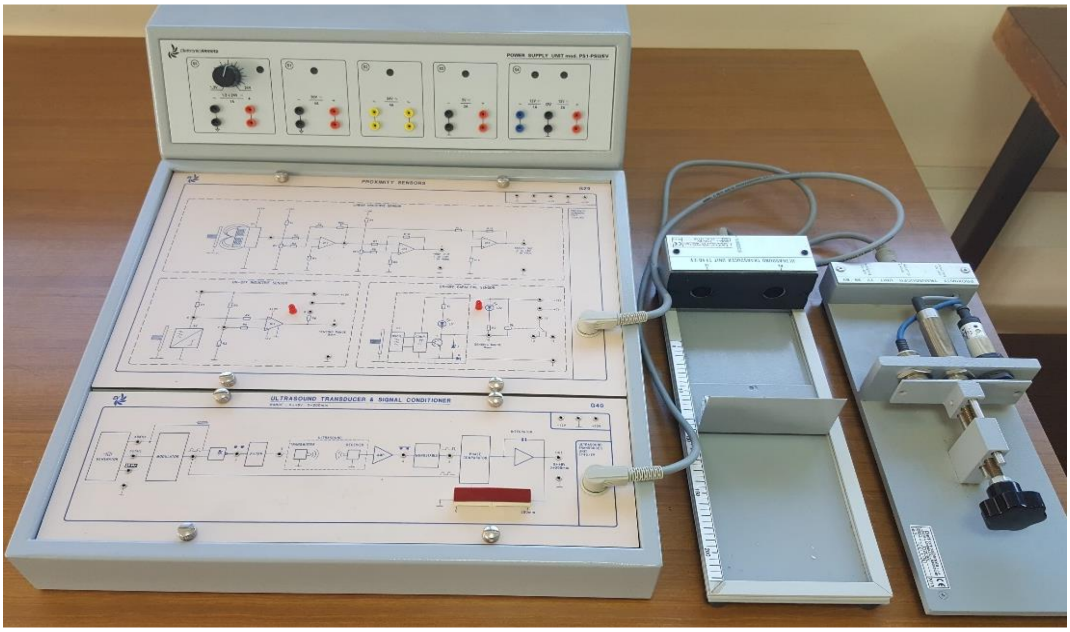


Figure (8.1) Distance Measurements Set-up Using Ultrasonic and Proximity Sensors

Objectives of this Experiment:

Upon conducting this experiment, the students should be able to:

1. Know different distance measurement methods.
2. Be able to analyze distance sensor output.
3. Know main important characteristics of proximity and ultrasonic sensors as well as their operation of wok.

Section A: Ultrasonic Sensor

Ultrasonic sensors enable to carry out distance measurements by assessing the time spent by a sound pulse to cover the path between two sound transducers of transmission and reception. The speed of sound however must be known which is approximately equal to 340 m/s for air in the normal conditions.

Transmitter and receiver are placed side by side and oriented in the same direction; the sound detected is the echo reflected by any obstacle met along the path.

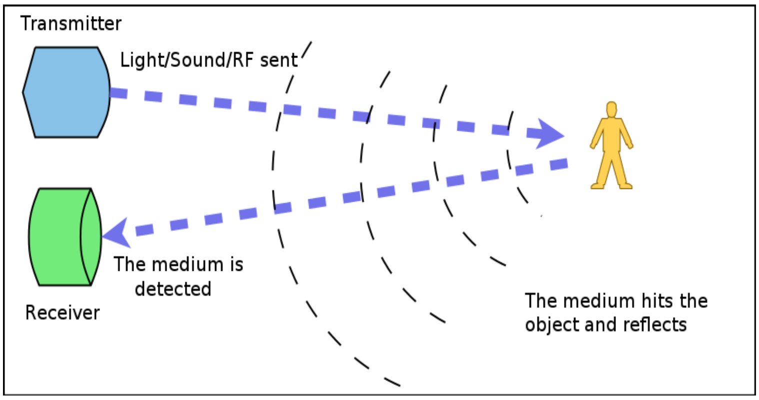


Figure (8.2) Main Components for Ultrasonic Sensor

An ultrasound measuring system is able to detect the surface of most solid and liquid objects, for variable material sensitivity that depends on the type of reflecting material, size of the target and environmental conditions. Measuring accuracy however depends mainly on the precision of knowledge for the speed sound in those particular operating conditions since the time measurement (up to some thousandth of second) does not show any particular problem of accuracy with the current circuit technology.

The same transducer is often used for the production of ultrasound pulses and for the echo detection with the alternation of its operating mode. Consequently, the system can be more compact and alignment within the transmitter and therefore the receiver can be eliminated.

Modulating the carrier with properly coded pulses, usually at a frequency of some tens of Hz, will enable to send ultrasounds. The pulses with a certain frequency are reflected by the target and consequently they are picked up and decoded by the receiving circuit.

The distance from the obstacle is determined on the ground of the time spent; that is of the delay between the transmitted pulse and the pulse received after reflection; if necessary, the variations of temperature and of other environmental conditions must be compensated. As time can be measured with the utmost accuracy and the speed of sound versus the environmental conditions is known, distance could be the result of the following formula:

$$D = \frac{1}{2} T_v C_s$$

Where D is the distance in mm, Tv is the time of flight, that is the time spent from the emission of ultrasound pulse to the reception of echo, expressed in milliseconds, and Cs the speed of sound, expressed in meters per second. Obviously, when the distance of an object is known, the speed of sound in that particular condition can be determined and thus the tabulation of Cs and the need of further sensors for monitoring the environmental conditions can be avoided.

The measurement interval when the sensor can be used depends on several factors such as the emission power of the sound wave, the sensitivity of the receiving circuit, properties of reflection, roughness, shape, inclination of the reflecting surface, influence of environmental condition and the position of the target with respect to the axis of emission. The values indicated in the characteristics of these sensors normally refer to a metallic target of prefixed size, perpendicular and aligned to the axis of ultrasound emission, to a temperature of 25^{o}C and to a relative humidity of 60% in standstill air.

The external unit module for TY40/EV includes two sensors (transmitter and receiver) arranged side by side and oriented in the same direction, as well as a metallic barrier running on slides that can be positioned at a minimum distance of 40 mm (position “0 mm”) up to a distance of 260 mm (position “220 mm”) from the sensors.

The applications using this type of piezoelectric sensors and transducers enable to cover maximum distances not longer than a some meters; consequently they enable to realize ultrasound radars for detecting objects in the range of some meters (detector of parking obstacles for automotive applications, or burglar systems for detecting the passage of people).

Generally, ultrasonic sensors produce output waves of frequencies that exceed 20000 Hz. Moreover, ultrasonic sensors can detect signals of the same type where their range of application is very wide, especially in the measurement and detection of objects.

Ultrasonic sensors are manufactured with the technology of piezoelectric ceramics whose characteristics are very high level that can ensure:

1. Very compact and light sensors.
2. High sensitivity and production of sound pressures.
3. Low power consumption.
4. High reliability.
5. Joint use of the vibrations of ceramic transducer and of radial base.
6. Water-tightness and high resistance to hard environmental conditions; consequently the have the high possibility for outdoor installation since they are enclosed with wholly sealed vessels.
7. Transmitters with coupling of piezoelectric vibrations output by particular acoustic adapters (horns) to obtain perfect coupling with the air where ultrasound waves are diffused.
8. High frequency and consequently low wavelength and high directionality for high-accuracy measurements of distance.

Sensitivity

The highest sensitivity for both the sensors of transmission and reception can be attained at an operating frequency of 40 kHz.

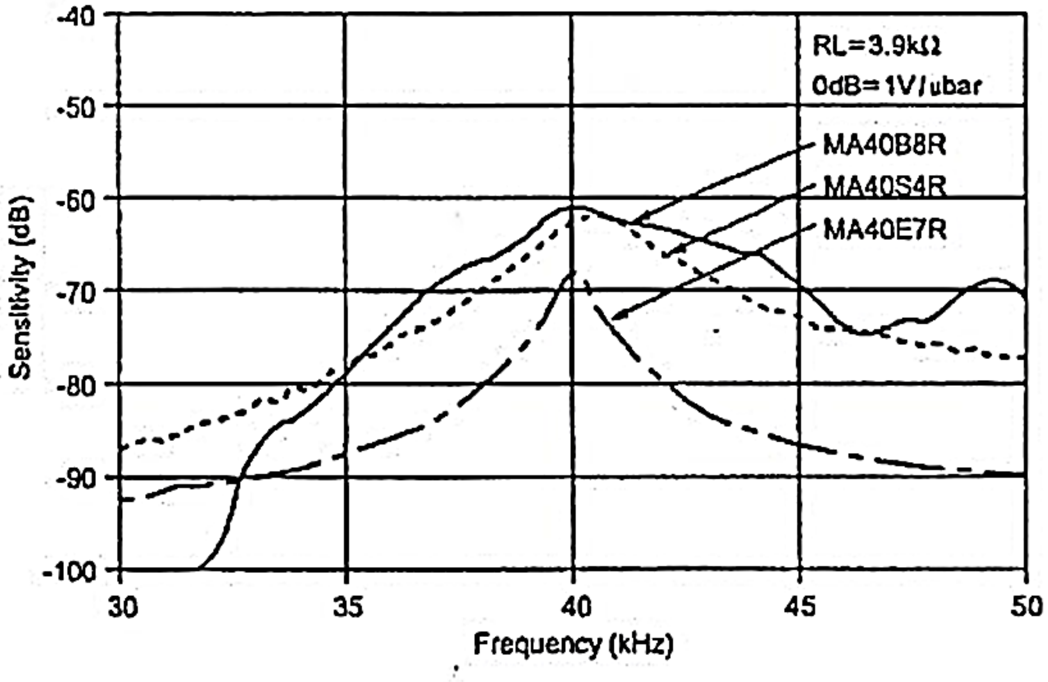


Figure (8.3) Sensitivity vs. Frequency of the receiving sensor

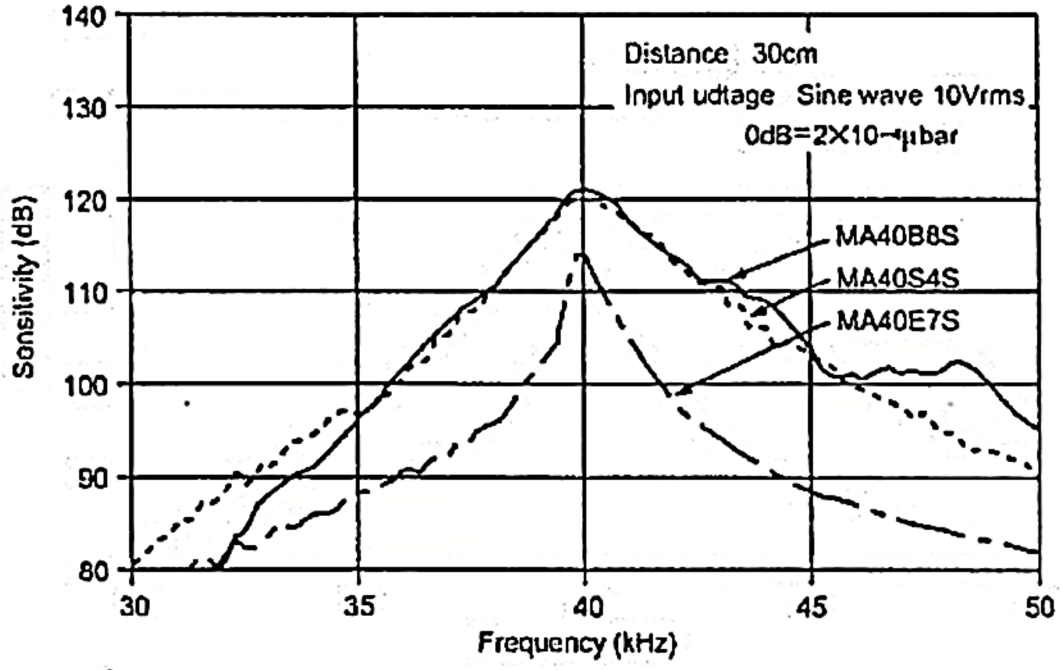


Figure (8.4) Pressure Levels vs. Frequency of Transmitting sensor

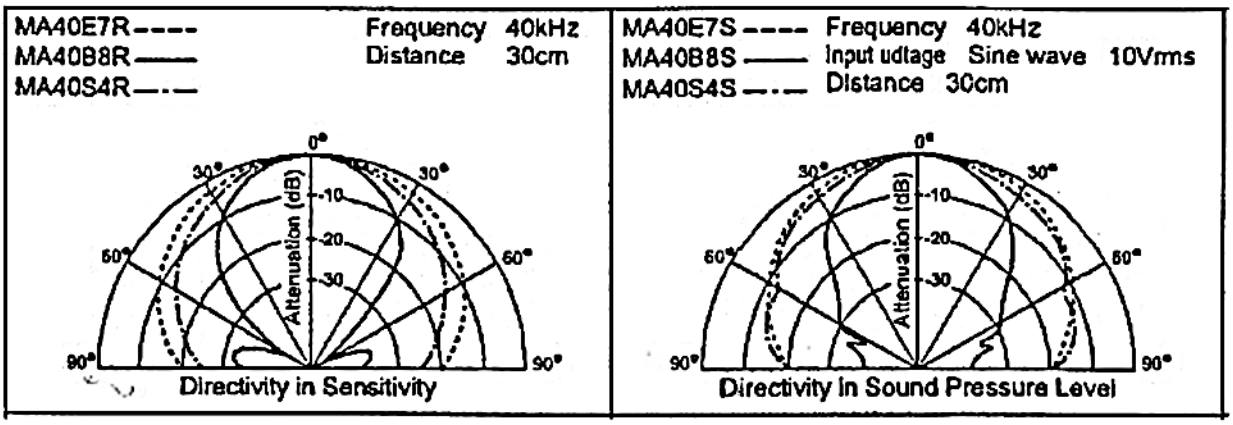


Figure (8.5) Directionality of Receiving and transmitting sensors

Parts and Components of Ultrasonic Sensor Experiment

G40/EV ultrasonic model which is used to study the photoelectric sensors.

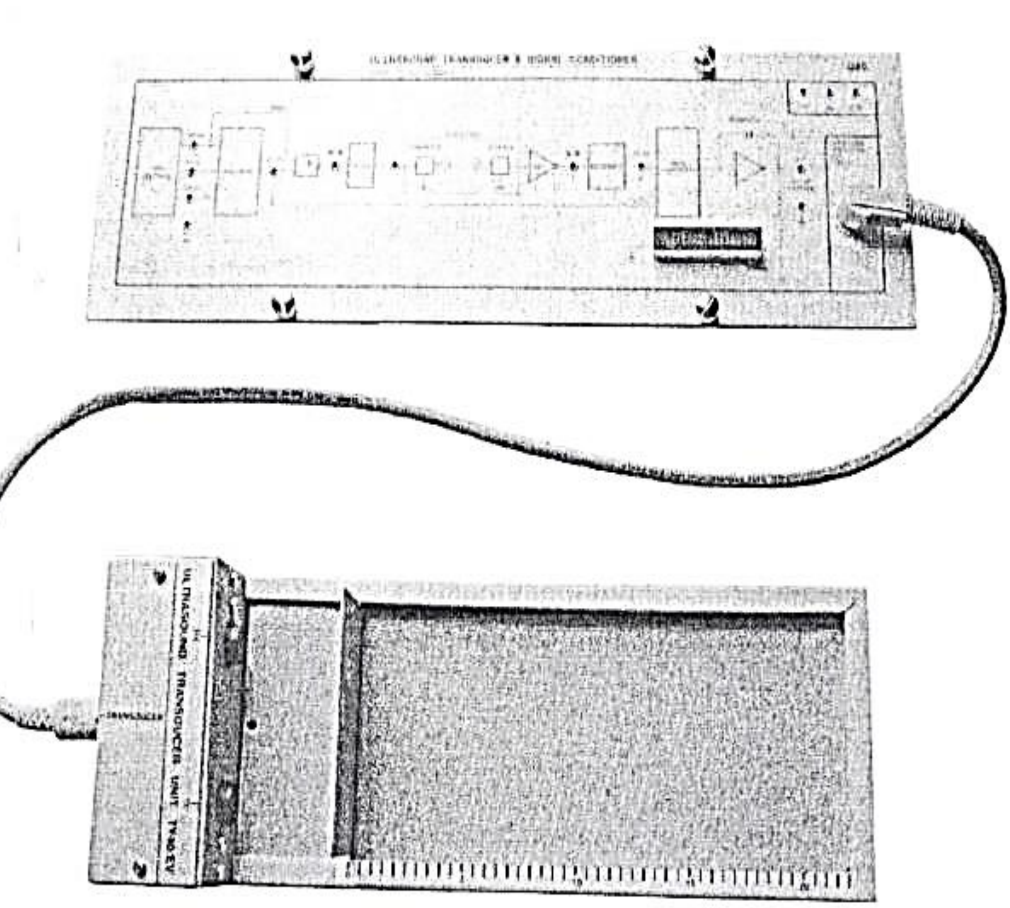


Figure (8.5) G40/EV Ultrasonic Module.

The schematic diagram shown in Figure 8.5 shows the main parts of the G40/EV module which includes the following sections:

i) A particulate section for signal Generator, Modulator, Filter and Transmitter.

ii) A particulate section for reception (Receiver) with amplification and conditioning.

iii) A particulate section for comparison between the signals transmitted and received (Phase Comparator).

iv) A particulate section for the integration of the resulting signal (Integrator) and displaying the distance of the barrier (acting as an obstacle) from the transmitting and receiving sensors.

v) External unit module TY40/EV with installation of two sensors of transmission and reception and system with movable metallic barrier that can be positioned continuously between a minimum distance (0 mm) and a maximum distance of 220 mm from the transducers.

Multi-meter.

Dual-trace oscilloscope.

The module is inserted in the module holder module BOX/EV and is powered via the jacks ±12 V and earth (power supply unit module PS1-PSU/EV.

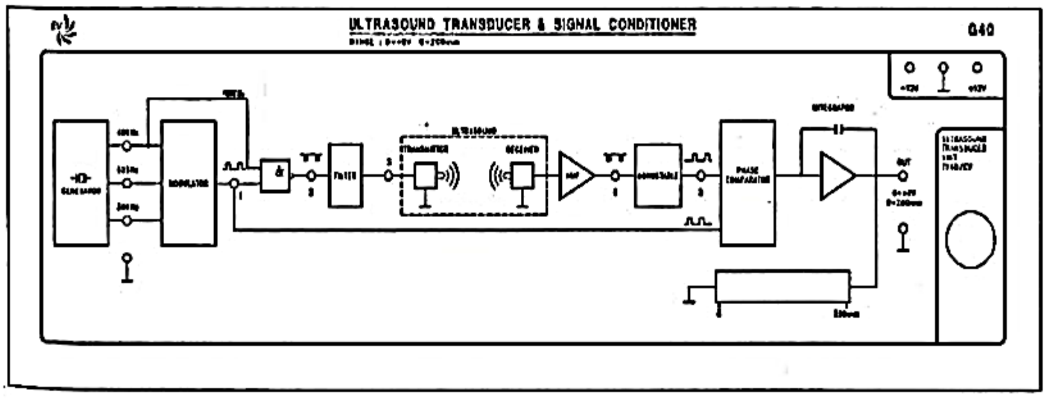


Figure (8.6) Schematic Diagram of the Module G40/EV

Exercise-1 Finding Output Voltage That Corresponding to Distance Variation

Plotting the "Distance vs. Voltage" line of the module G40/EV

This part is concerned with plotting the relationship between the distances of the barrier from the ultrasound sensors of the transmission/reception to the voltage available at the output OUT of the module G40/EV. Moreover, it is required to study the effects of the hysteresis of the sensor and calculate the value of linearity of the sensor-conditioner system.

Procedure:

1. Connect the digital voltmeter between the output OUT and the earth.
2. Change the distance of the barrier on the external unit, starting with the distance 0 mm, by steps of 10 mm, and detect the corresponding output voltage measured by the digital voltmeter, until the value of 200 mm. Wait some seconds so that a final stable value can be obtained before detecting the output voltage value on pin OUT because the integration of output signal will take 2 to 5 seconds.
3. Fill in Table 8.1 with the resulting data.
4. Change the distance of the barrier on the external unit, starting with the distance of 200 mm, by steps of 10 mm, until the value goes back to 0 mm. Wait some seconds so that a final stable value can be obtained before detecting the output voltage value on pin OUT because the integration of output signal will take 2 to 5 seconds.
5. Fill in Table 8.2 with the resulting data.
6. Plot on the same graph Vout (V) vs. D (mm).
7. Check if the two curves coincide. If not, what do we call his phenomena? Explain.

8. For the curve representing the data in Table 8.1, find the best fit line connecting the majority of data points.
9. Plot two parallel and equidistant lines with respect to the best fit straight line so that they can include all the data points. Your result will look something like Figure 8.7

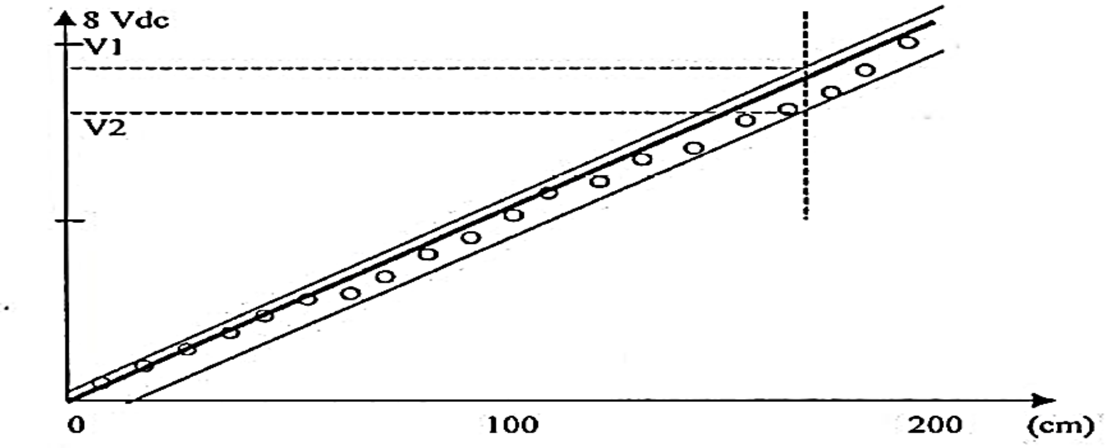


Figure (8.7) Linearity

10. Linearity value referred to the full scale value: :$\pm \frac{1}{2} \frac{V_1 - V_2}{F.S.O}$ Where F.S.O. is the full scale output.(8 volt in this case)

Table (8.1): Distance of barrier vs. V_{out}

Distance of Barrier (mm)	V_{Out} **(V DC), Pin OUT**
0	
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
110	
120	
130	
140	
150	
160	
170	
180	
190	
200	

Table (8.2): Distance of barrier vs. V_{out}

Distance of Barrier (mm)	**V_{Out} (V DC), Pin OUT**
200	
190	
180	
170	
160	
150	
140	
130	
120	
110	
100	
90	
80	
70	
60	
50	
40	
30	
20	
10	
0	

Section B: Proximity Sensor

Proximity sensor is considered a very common sensor that is used to measure the small distances between the object and the sensor. There are however different types of proximity sensor which they depend on the internal set-up of the sensor. In this lab, only inductive and capacitive proximity sensors are presented, where a detailed description of the inductive and capacitive proximity sensors are revealed as follows:

Inductive Proximity Sensors

The principle operation of the inductive proximity sensors is based on the damping of an electromagnetic field due to the eddy currents induced within conducting materials placed near the sensors. An oscillating circuit generates a high-frequency electromagnetic field which induces eddy currents within the near metallic actuators.

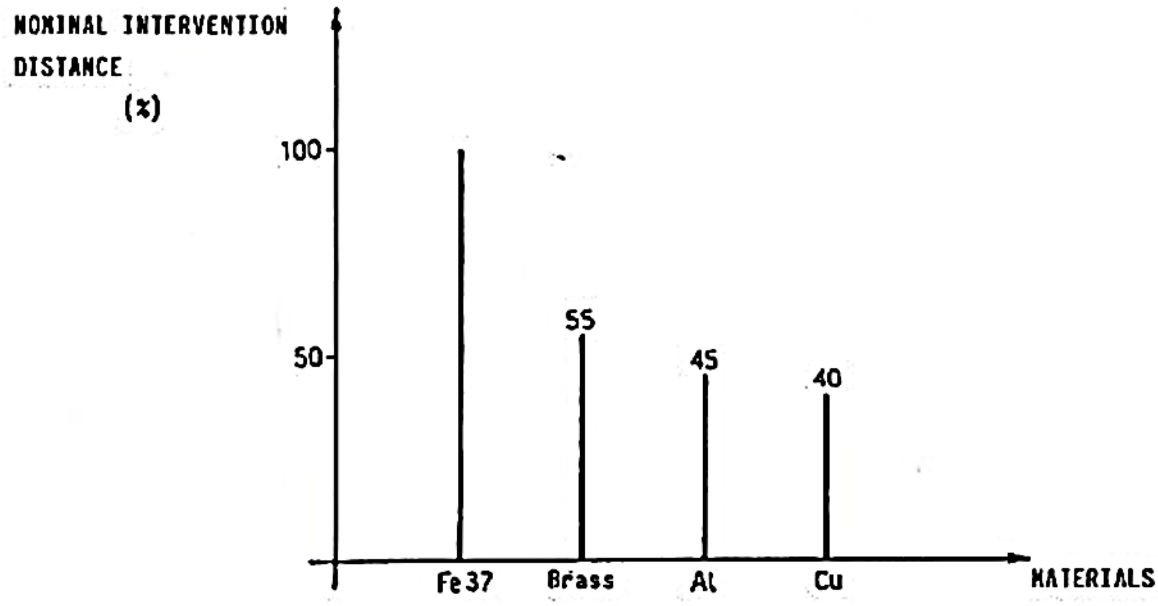


Figure (8.8) Nominal Intervention Distance for some Materials

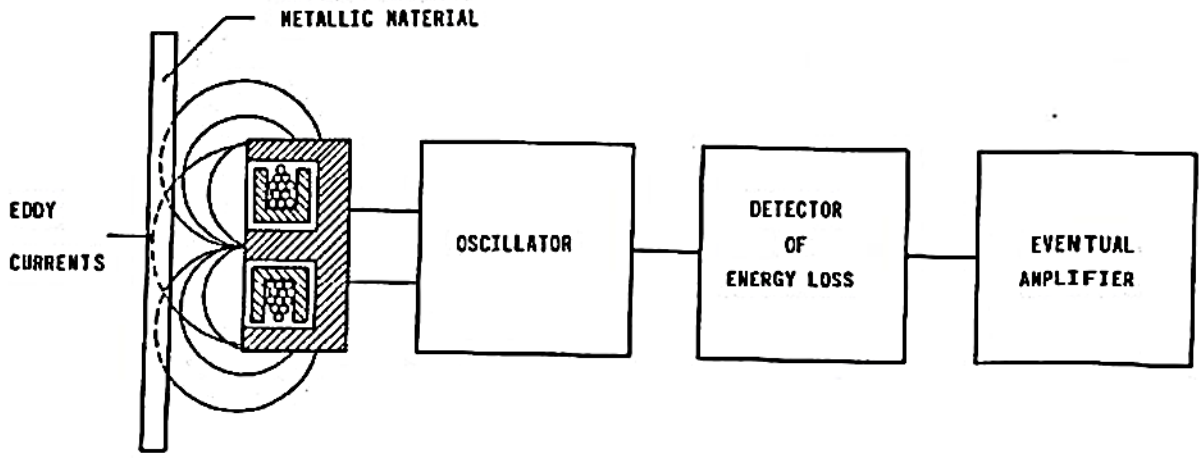


Figure (8.9)

Inductive proximity sensor with linear output

The inductive proximity sensors with linear output can generate a variable output voltage, the voltage variation however is directly proportional (linear) to the distance actuator/sensor, within certain limits. The characteristics can be useful when carrying out very accurate positioning for detecting thicknesses, flexures, and vibrations. More generally, it is used to convert distance into voltage, in electro-conducting materials. Figure (8.10) shows the characteristic curve of this type of sensor.

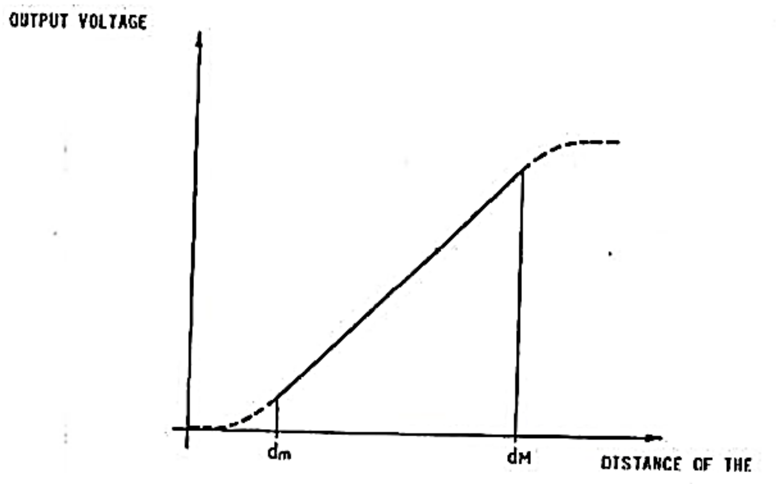


Figure (8.10) Characteristics of Inductive Proximity Sensor

The voltage vs. distance relation is linear only between the two values dm (minimum distance) and dm (maximum distance). The minimum distance dm does not coincide with the null position. However, The output voltage signal of the sensor is normally amplified and shifted so that the signal conditioner can generate a voltage proportional to the distance between the actuator and sensor.

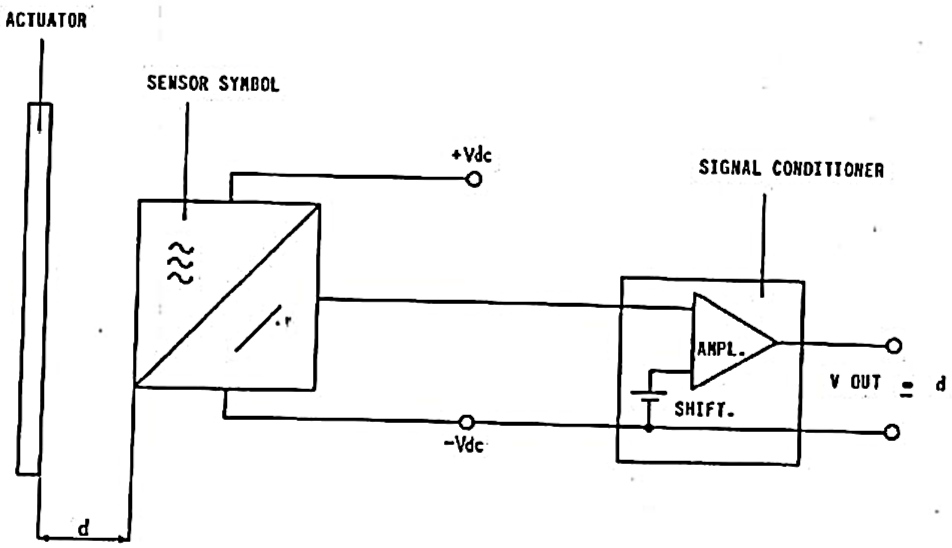


Figure (8.11) Schematic Diagram

Inductive Proximity Sensors with Two-Level Output

The inductive proximity sensors with two-level output deliver two different output current values; according to the position of the metallic actuator. In fact, they can be considered current regulators with two possible output values depending on the distance of the metallic actuator.

The inductive proximity sensors with two-level output however operate at very low electric levels that make them important to be used for installations and systems that operate in an ambient with danger of explosion.

Figure (8.12) shows schematic diagram for the proximity sensor connected with the amplifier (signal conditioner). Generally, the amplifier is physically placed far from the sensor. A sine wave mark however appears at the sensor symbol which indicates the oscillating circuit that generates the magnetic field. On the other hand, there is another mark that indicates the step which is related to the two-level output.

The amplifier mainly consists of a voltage generator connected in series to a resistor. Varying the current, also the voltage drop across the resistor varies, so that the ON-OFF (voltage) signal is generated at the output. This signal indicates whether the distance of the actuator is shorter or longer than the switching distance.

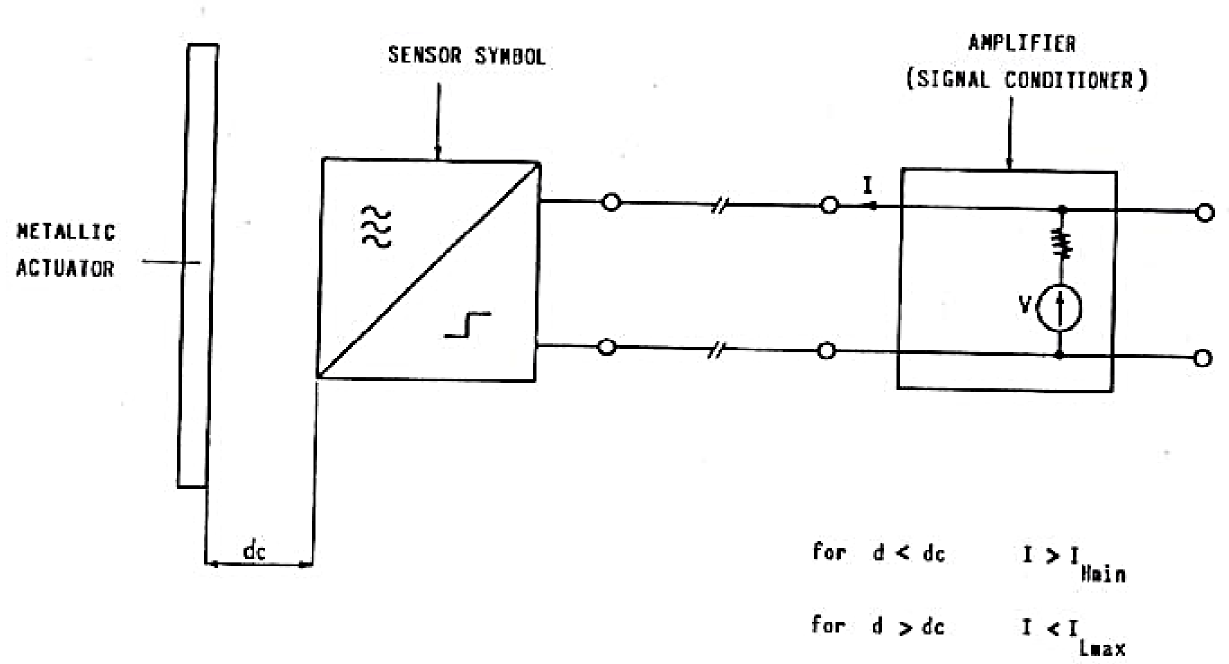


Figure (8.12) Schematic Diagram

Capacitive Proximity Sensor

Capacitive proximity sensor is used to detect metallic and non-metallic objects such as wood, liquids, and plastic materials. The principle operation of the capacitive proximity sensors is based on the variation of stray capacitance generated between the sensor and the object to be detected. At a certain distance of this object from the sensitive surface of the sensor, a circuit starts oscillating; the starting or ending of this oscillation is perceived by a threshold detector which controls an amplifier for driving an external load. Figure (8.13) shows the block diagram of this device.

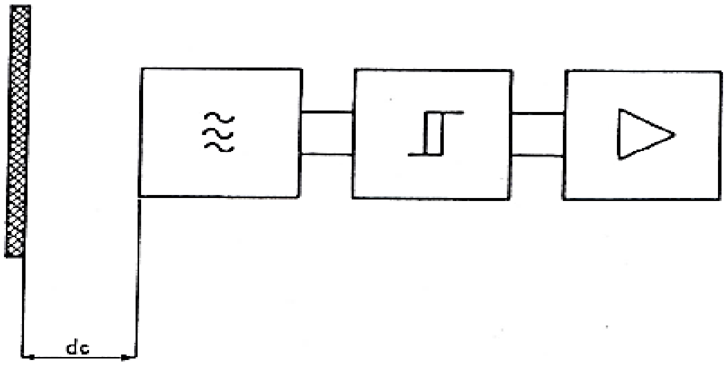


Figure (8.13) Block Diagram

Capacitive Proximity Sensor Classification

The capacitive proximity sensors are classified according to the operating voltage as:

1. Direct-current capacitive proximity sensors where their output types are sorted according to:

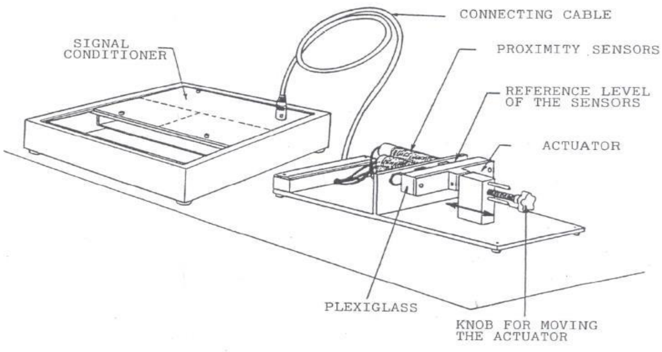
   i) Polarity: NPN and PNP.

   ii) Output function: normally closed, normally open, ambivalent or exchange.

2. Alternating-current capacitive proximity sensors where the output actuator is a SCR with the relevant driving circuit and it can be normally closed or normally open.

Parts and Components of Proximity Sensor Experiment

1. **TY29 Module**



This Model consists of two main parts: the panel which includes the signal conditioners (G29/EV) and the device which generates linear displacement (TY29).

2. **Inductive sensor with linear output, inductive sensor with two-level output and capacitive sensor with DC output.**

Exercise-2: Inductive Proximity Sensor with Linear Output Measurement

i. Distance and Voltage Relationship for the Sensor:

This part of the experiment concerns with the determining the relationship (curve) between the distance range (actuator/sensor) and the output voltage of the sensor (terminal 1).

Procedure:

1. Insert the voltmeter between terminal 1 and the ground.
2. Change the distance of the actuator through the proper knob, starting from a distance of 1 mm, by steps of 0.5 mm, then measure the corresponding actual distance with the gage reading the value of the output voltage on the digital voltmeter.
3. Fill in Table (8.3)

Table (8.3): Distance vs. Output Voltage

L (mm)	V_{out}**(V)**
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	

ii. Distance and Voltage Relationship for the Sensor and Conditioner.

For this part of the experiment, the curve that is corresponding to the distance range (actuator/sensor) and voltage which is measured at the proportional output of the conditioner (terminal 3) is required to be determined.

Procedure:

1. Carry out the same operations of exercise 2.ii changing the scale of the output voltage from mV to V.
2. Fill the data in Table (8.4).
3. Using the resulting data, it is possible to plot the characteristic curve of the sensor and conditioner.
4. For the curve representing the data in Table (8.3), find the best fit line connecting the majority of data points.
5. Plot two parallel and equidistant lines with respect to the best fit straight line so that they can include all the data points. Calculate the linearity of the system.
6. Linearity value referred to the full scale value: :$\pm\frac{1}{2}\frac{V_1 - V_2}{F.S.O}$

   F.S.O. is the full scale output.

Table (8.4): Distance vs. Output Voltage

L (mm)	V_{out}(V)
4	
3.5	
3	
2.5	
2	
1.5	
1	

Exercise-3: Inductive Proximity Sensor with Two-Level output Measurement

i. Measurement of the current with and without the actuator

It is required to check whether the values of the current crossing the sensor (with and without the actuator) correspond to those of the data sheets.

Procedure:

1. Insert the digital voltmeter between terminals 5 and 6, measure the voltage value across R1, with and without the actuator.
2. Knowing that R1 is equal to 2200, calculate the values of the two currents.
3. Insert the digital voltmeter between terminals 5 and 6, measure the voltage value across R1, with Plexiglas plate.

Table (8.5): Distance vs. Output Voltage

L (mm)	V_{5-6}(V) without the Plexiglas plate	V_{5-6}(V) with Plexiglas plate
0 (with the actuator)		
20 (without the actuator)		

Exercise-4: Capacitive Proximity Sensor with two-level output Measurement

1. Insert the digital voltmeter between terminal 10 and the ground, with and without the actuator.

2. Insert the digital voltmeter between terminal 10 and the ground, measure the output voltage value, with and without Plexiglas plate.

Table (8.6): Distance vs. Output Voltage

L (mm)	V_{10}(V) without the Plexiglas plate	V_{10}(V) with Plexiglas plate
0 (with the actuator)		
20 (without the actuator)		

EXPERIMENT No. (9)

NATURAL FREQUENCY MEASUREMENT

OBJECTIVE:

The purpose of this experiment is to familiarize the student with the mechanical vibrating systems and their natural frequencies. The student gets an idea about the mass, stiffness and the vibrating modes of the mechanical structures.

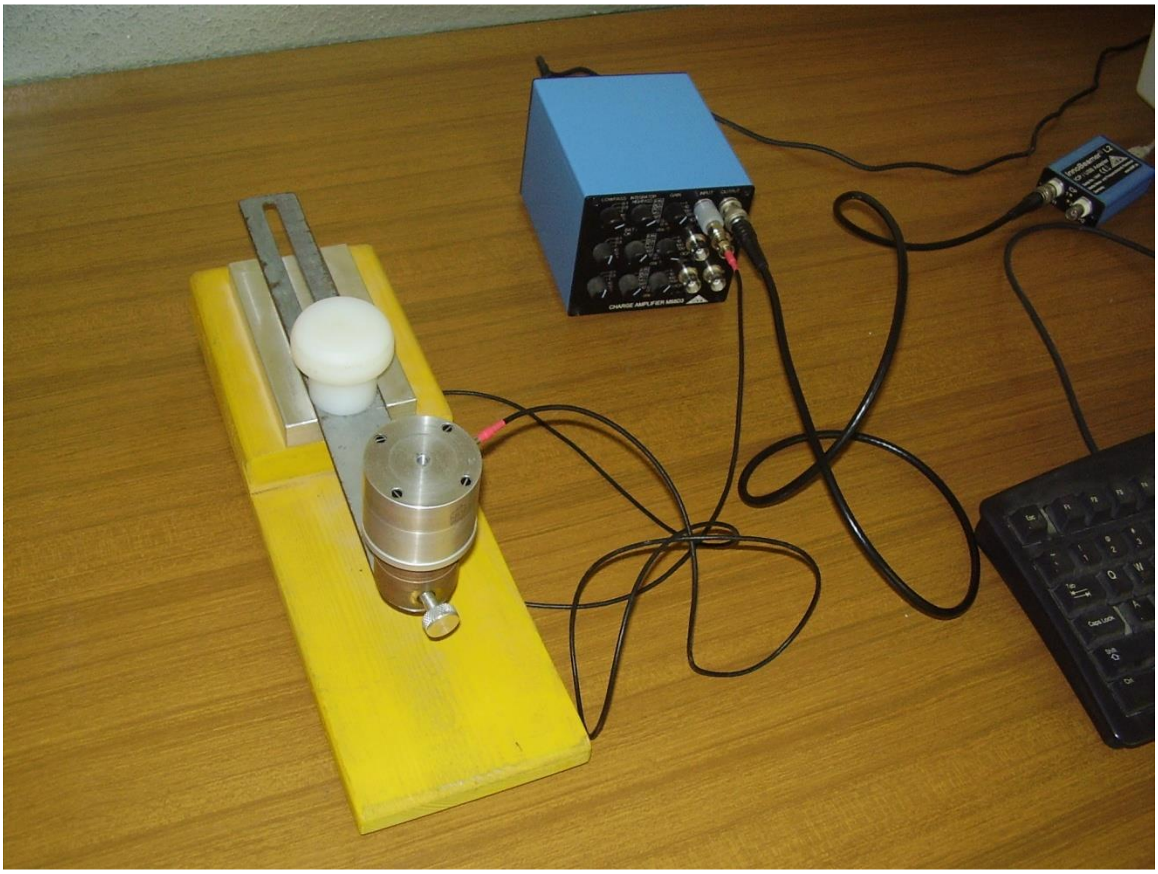


Figure (9.1) Natural Frequency Measurement

EXPERIMENTAL PROCEDURE:

1. Switch the PC on.
2. Switch the "Charge amplifier M68D3" on from the rear switch.
3. Adjust the charge amplifier from the front panel:-
    a) Low pass filter at 0.1kHz
    b) Integrator high pass at 0.1Hz
    c) Gain equals to one.
4. Switch on the InnoMaster Program RT1.3 by going through these icons:-
    a. (Start → Programs → VibroMatrix → InnoMaster RT1.3
    b. Or from the desktop "InnoMaster RT1.3" program.
5. After logging through the program three columns will appear respectively {Sensors, Measuring channels, Instruments} from left to right.
6. Select the sensor type as KB12 from the sensor column and drag it into channel "1" in the measuring channels column.
7. The KB12 sensor will light yellow and channel one also will light yellow as an indication that your system is operating.
8. Select the Innoscope from the instruments column with a double click on it.
9. The scope will display, choose from the trigger part the free run mode.
10. In this point you will transfer to the hardware equipment by Fixing the flexible beam at number 10 (10 cm is the distance between the mass and the edge of the flexible beam).
    - Note that the accelerometer KB12 is placed on the mass.
11. From the scope window there is an icon called (Switch on) located on the right middle of the window, click on it to start measuring the vibrations of the mass.
12. Trigger the mass gently downward and leave it to vibrate freely.
13. Change the (x,y) settings of the oscilloscope to fit the measured signal, from the display settings of the scope there is an Auto scale for both axis (x,y).
14. After that immediately you should turn the trigger part on the scope window to the normal instead of free run. (This option will freeze the signal so you can take your measurements on it).
15. After freezing the signal you should go to the cursor part on the scope and to select Cursor 1 and fix it using the mouse on the peak of a cycle

and cursor 2 on the peak of the next cycle and read the time of each peak in addition you should read the time difference between cursor 1 and 2.

16. Copy the graph of the signal from "Data Transfer" part, click on copy icon located to the left of ''Switch on" icon and then you will paste it as a picture on the paint program for an example.
17. Repeat the steps from 9 to 15 by changing the length of the beam 6 times from no10 to no 25 and register the time as we shown before. (Repeat the last trial 5 times to calculate the error).
18. In the second part you should put some loads on the vibrated mass.
19. Fix the beam on no 10.
20. Repeat steps from 9 to 15 by adding new masses 5 times with an increment of 100 gm every time (repeat the last trial 5 times to calculate the error).

THEORY AND CALCULATIONS:

In the single degree of freedom (DOF) oscillator shown in Figure (2), the governing equation of motion in the case of free vibrations is as follows:

$$M\ddot{x} + C\dot{x} + Kx = 0$$

Where:
M = total mass of the cylinder and accelerometer (350 + 150 = 500 gram).
K = Stiffness of the flexible beam (N/m).
C = Damping coefficient (N.s/m).

If we neglect the damping effect (***C*** close to 0) and solve the equation of motion, the Eigen value of the second order differential equation results:

$$\omega = \sqrt{\frac{K}{M}}$$

Here ω is the natural frequency of the system (rad/s) when it vibrates in free vibrations and neglecting the damping effect in the system.
The measured frequency *f* in (Hz) or (1/s) is:

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

The natural frequency in (rad/s) is:

$$\omega = 2\pi f$$

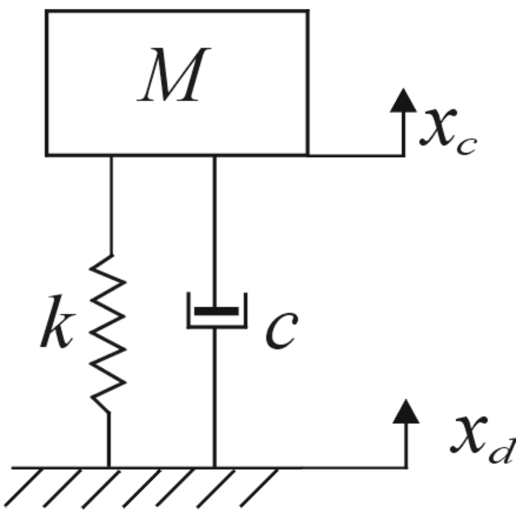


Figure (9.2) Single Degree of Freedom Oscillator

RESULTS:

1- Calculate the natural frequency at each time you change the stiffness of the beam and plot the square of the natural frequency versus the stiffness.
2- Calculate the natural frequency at each time you change the mass and plot the natural frequency versus the mass.
3- Calculate the measurement error for the two parts of the experiment.

QUESTIONS:

1- What is the effect of the mass change on the natural frequency of the system?
2- What is the effect of the stiffness change on the natural frequency of the system?
3- Does changing the material of the flexible beam influence the natural frequency? Explain why?
4- What are the types of errors in your experiment, and how do they happen?

Data sheet

Part 1:- Without load

Run	L(cm)	t_1(ms)	t_2(ms)	Δt(ms)
1	10			
2	12			
3	14			
4	16			
5	18			
6	22			
7	25			
8	25			
9	25			
10	25			
11	25			

Part 2:- With load (Fix the beam at L=10cm)

Run	Load(g)	t_1(ms)	t_2(ms)	Δt(ms)
1	100			
2	200			
3	300			
4	400			
5	500			
6	500			
7	500			
8	500			
9	500			