



ATME College of Engineering

13th KM mile stone, Mysuru-Kanakapura Rd, Mysuru-028

Department of Mechanical Engineering



MECHANICAL MEASUREMENTS AND METROLOGY LAB

(BME404L)

MANUAL-CUM-DIARY

IV SEMESTER

2025-26

Name of the Student: _____

University Seat No.: _____

Semester: _____ *Batch No.:* _____

DEPARTMENT OF MECHANICAL ENGINEERING
ATME COLLEGE ENGINEERING
13th K.M Mile stone, Mysuru-Kanakapura Road, Mysuru



LABORATORY CERTIFICATE

This is to certify that Mr. /Miss.....

Bearing USN:.....has satisfactorily completed the course of experiments in practical **Mechanical Measurement and Metrology Lab (BME404L)** prescribed by the Visvesvaraya Technological University for the IV semester B.E. course during the year 20.... - 20.....

Course Internal Evaluation (CIE)	Maximum Marks	Sessional Marks Awarded
LCR Marks (Average)	30	
Lab Internal Assessment	20	
TOTAL	50	

Signature of staff

Signature of H.O.D

ATME COLLEGE OF ENGINEERING

VISION

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torch bearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence.

DEPARTMENT OF MECHANICAL ENGINEERING

VISION

To impart excellent technical education in Mechanical Engineering to develop technically competent, morally upright and socially responsible Mechanical Engineering professionals.

MISSION:

- To provide an ambience which impart excellent technical education in Mechanical Engineering.
- To enable the students to acquire skill development, knowledge of Research and recent trends in Mechanical Engineering which will help them in lifelong learning.
- To engage students in co-curricular and extra-curricular activities to impart social & ethical values and imbibe leadership quality.

PROGRAM EDUCATIONAL OBJECTIVES (PEO'S)

After successful completion of program, the graduates will be

PEO 1: Able to have successful professional career in the allied areas and be proficient to perceive higher education.

PEO 2: Attain the ability to understand the need, technical ability to analyze, design and manufacture the product.

PEO 3: Work effectively, ethically and socially responsible in allied fields of mechanical engineering.

PEO 4: Work in a team to meet personal and organizational objectives and to contribute to the development of the society in large.

PROGRAM OUTCOMES (PO'S)

The Mechanical engineering program students will attain:

PO1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems

PO2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences

PO3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations

PO4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions

PO5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations

PO6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice

PO7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development

PO8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice

PO9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings

PO10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions

PO11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments

PO12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

PROGRAM SPECIFIC OUTCOMES (PSO'S)

After successful completion of program, the graduates will be

1. Ability to apply and interpret the acquired mechanical engineering knowledge for advancement in Industrial, Societal, and Environmental arenas.
2. Ability to meet the needs of Industries in the field of design, manufacturing and testing using mechanical engineering software.

MECHANICAL MEASUREMENTS AND METROLOGY LAB
B.E, IV Semester, Mechanical Engineering
[As per Choice Based Credit System (CBCS) 22 Scheme]

Course Code	BME404L	CIE Marks	50
Teaching hours/ week (L:T:P:S)	0:0:2:0	SEE Marks	50
Credits	01	Exam Hours	03
Examination nature (SEE)		Practical	
Course Objectives:			
<ol style="list-style-type: none"> 1. To illustrate the theoretical concepts taught in Mechanical Measurements & Metrology through experiments. 2. To illustrate the use of various measuring tools measuring techniques. 3. To understand calibration techniques of various measuring devices. 			
PART – A: MECHANICAL MEASUREMENTS			
<ol style="list-style-type: none"> 1. Calibration of Pressure Gauge 2. Calibration of Thermocouple 3. Calibration of LVDT 4. Calibration of Load cell 5. Determination of modulus of elasticity of a mild steel specimen using strain gauges. 			
PART B: METROLOGY			
<ol style="list-style-type: none"> 1. Measurement using Optical Projector / Toolmaker Microscope. 2. Measurement of angle using Sine Center / Sine bar / bevel protractor 3. Measurement of alignment using Autocollimator / Roller set 			
Demonstration Experiments [For CIE only]			
<ol style="list-style-type: none"> 1 Measurement of cutting tool forces using <ol style="list-style-type: none"> a) Lathe tool Dynamometer OR b) Drill tool Dynamometer. 2 Measurement of Screw threads Parameters using two wire or Three-wire methods. 3 Measurement of Surface roughness, using Tally Surf/Mechanical Comparator. 4 Measurement of gear tooth profile using gear tooth Vernier /Gear tooth micrometer. 5 Calibration of Micrometer using slip gauges. 6. Measurement using Optical Flats. 			
Course outcomes: At the end of the course the students will be able to:			
<ol style="list-style-type: none"> 1. To calibrate pressure gauge, thermocouple, LVDT, load cell, micrometer. 2. To measure angle using Sine Center/ Sine Bar/ Bevel Protractor, alignment using Autocollimator/ Roller set. 3. To demonstrate measurements using Optical Projector/Tool maker microscope, Optical flats. 4. To measure cutting tool forces using Lathe/Drill tool dynamometer. 5. To measure Screw thread parameters using 2-Wire or 3-Wire method, gear tooth profile using gear tooth vernier/Gear tooth micrometer. 6. To measure surface roughness using Tally Surf/ Mechanical Comparator. 			

Examination Scheme:

ONE question from part -A: 30 Marks

ONE question from part -B: 50 Marks

Viva -Voice: 20 Marks

100

Total= 100 Marks

INDEX

Sl. No.	List of Experiments	Date of Submission	Marks Obtained	Initials of Staff
PART-A: MECHANICAL MEASUREMENTS				
01				
02				
03				
04				
05				
PART-B: METROLOGY				
01				
02a				
02b				
02c				
03				
Average				
Test Marks				
Total Marks				

CLO & CO's: MECHANICAL MEASUREMENTS AND METROLOGY LAB

PART - A	
EXPERIMENT-1:	DURATION:2 Hours
Objective: To evaluate the calibration of pressure gauge.	
Generic Skills / Outcomes:	
Students will be able to state pressure and its types with unit and describe pressure measuring methods	
EXPERIMENT-2:	DURATION:2 Hours
Objective: To introduce the basic operating principles of thermocouples and thermistors and to calibrate these devices.	
Generic Skills / Outcomes:	
Students will be able to state temperature measurement and its types with unit and describe temperature measuring methods	
EXPERIMENT-3:	DURATION:2 Hours
Objective: To measure displacement using LVDT with the aid of micrometer	
Generic Skills / Outcomes:	
Students will be able to understand principle of operation, the principles of step up and step down transformer and concept of inductance.	
EXPERIMENT-4:	DURATION:2 Hours
Objective: To measure the weights using Gauge Load Cell	
Generic Skills / Outcomes:	
Students will be able to state working of load cell and its functioning with unit and describe load measuring methods	
EXPERIMENT-5:	DURATION:2 Hours
Objective: To evaluate the Young's Modulus of steel specimen	
Generic Skills / Outcomes:	
Students will be able to learn the concept of young's modulus and strain and describe the use of gauge measuring methods and Bridgestone networks	
PART - B	
EXPERIMENT-1:	DURATION:2 Hours
Objective: Study of Tool Maker's Microscope	
Generic Skills / Outcomes:	
Students will be able to appreciate the importance of precision measurement, know how precise measurements can be taken with this instrument, explain the field of application/working of this instrument and understand the principle of working of tool room microscope.	
EXPERIMENT-2a, 2b and 2c:	DURATION:2 Hours
Objective: Measurement of angle using Sine Center / Sine bar / bevel protractor.	
Outcomes:	
Students will be able to measure angles using sine bar, understand the methods of measuring the deflection using dial gauge, state protractors and its types with unit, describe angle measuring methods	
EXPERIMENT-3:	DURATION:2 Hours
Objective: To measure the straightness and flatness given specimen using two axis Auto Collimator.	
Generic Skills / Outcomes:	

Students will be able to state principles of collimation and describe flatness measuring methods

EXPERIMENT-1: Demonstration Experiments

Objective: Measurement of cutting tool forces using t used to measure the cutting forces coming on the tool tip.

Generic Skills / Outcomes:

Students will be able to state principles of force measurement and describe principle of magnetism and induction

EXPERIMENT-2: DURATION:2 Hours

Objective: To measure the major, minor and effective diameter of given specimen by using a Floating Carriage Micrometer.

Outcomes:

Students will be able to state principles of floating carriage and describe principle of thread measurement and parameters of threads

EXPERIMENT-3: DURATION:2 Hours

Objective: To check the dimensions of a given set of specimen using a mechanical comparator.

Generic Skills / Outcomes:

Students will be able to state principles of comparators and describe dial gauges, parts and working of gauges

EXPERIMENT-4: DURATION:2 Hours

Objective: To measure the thickness and depth of the gear using gear tooth vernier

Generic Skills / Outcomes:

Students will be able to state principles of vernier calipers and describe L.C, parts and working of calipers

EXPERIMENT-5: DURATION:2 Hours

Objective: To evaluate the given micrometer using set of slip gauges

Generic Skills / Outcomes:

Students will be able to state principles of micrometer and describe L.C, parts and working of micrometer

EXPERIMENT-6: DURATION:2 Hours

Objective: To evaluate and to be used as a reference against which the flatness of an unknown surface may be compared

Generic Skills / Outcomes:

Students will be able to state principles of optical flats and describe concept of interference and diffraction

CONTENTS

PART-A Mechanical Measurements:

1) <i>Calibration of Pressure Gauge</i>	3
2) <i>Calibration of Thermocouple</i>	6
3) <i>Calibration of LVDT</i>	11
4) <i>Calibration of Load cell</i>	15
5) <i>Determination of modulus of elasticity of a mild steel specimen using strain gauge</i>	19

PART-B Metrology:

1) <i>Measurements using Toolmaker Microscope</i>	25
2) <i>Measurements of angle using Sine Bar/ Sine Centre / Bevel protractor</i>	28
3) <i>Measurements of alignment using Autocollimator</i>	35

Demonstration Experiments (For CIE)

4) <i>Measurements of cutting tool forces using Lathe tool Dynamometer</i>	39
5) <i>Measurements of Screw thread Parameters using two wire method</i>	46
6) <i>Measurements of Surface roughness Using Mechanical Comparator</i>	50
7) <i>Measurements of gear tooth profile using gear tooth vernier</i>	53
8) <i>Calibration of micrometer using slip gauges</i>	57
9) <i>Measurement using Optical Flats</i>	62

Experiment -1

CALIBRATION OF PRESSURE GAUGE

AIM: To calibrate the given pressure gauge.

OBJECTIVE: To evaluate the calibration of pressure gauge

APPARATUS: Pressure gauge, dial type pressure indicator, compressor to develop the pressure, digital pressure indicator.

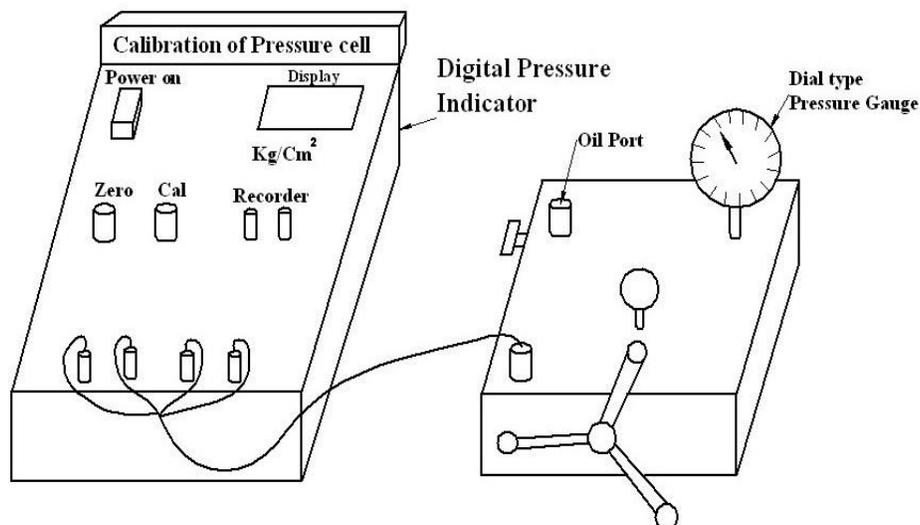
Formulae:

(i) Error = $P_a - P_m$

(ii) % Error = $\frac{(P_a - P_m)}{P_a} \times 100$

THEORY: Pressure is defined as the force per unit area and is measured in Newton per square meter (Pascal) or in terms of an equivalent head of some standard liquid (mm of mercury or meter of water). Electrical transducers are becoming very much popular in the measurement system. For pressure measurement barometer, monometer and bourdon tube pressure gauge are analog and mechanical type. Unbounded resistance element type, bonded strain gauges type, inductive type, piezo electric type is the electromechanical type transducers.

Pressure cell which is calibrating here consists of a circular thin metallic element called diaphragm and it is fixed around its edge. The materials most commonly used for manufacturing of diaphragms are steel, phosphorous bronze, nickel, silver, beryllium and copper. The strain gauges are bonded on the flat diaphragm which deflects when pressure is applied. Strain gauges are bridged in the form of wheat stone bridge. Strain gauges sense the deflection of diaphragm. The pressure to be measured is admitted to one side of the diaphragm. The deflection of diaphragm may be existing related to pressure differential (gauge pressure). Since the atmospheric pressure exists on the other side of the diaphragm.



TABULAR COLUMN:

Sl. No.	Pressure Readings (gm/cm ²)		Error (gm/cm ²)	% Error
	Actual Pressure (P _a)	Measured Pressure (P _m)		

PROCEDURE:

1. Connect the pressure gauge to the digital pressure indicator by inserting the corresponding color codes.
2. Connect the digital pressure indicator to the main power supply and keep it in the ON position.
3. Adjust the digital pressure indicator reading to zero by using ZERO knob.
4. Apply the pressure to the pressure gauge until the empty pan rises to required level.
5. Adjust the digital pressure indicator reading to show the as that of dial type pressure indicator by using CAL knob.
6. Release the pressure fully in the pressure cell.
7. Add the weights on the pan and slowly increase the pressure until the pan rises to the required level.
8. Note down the dial type gauge and pressure indicator readings simultaneously in every step of loads.
9. Calculate the error and % error.

RESULT: The given pressure is calibrated and the readings obtained are recorded and tabulated in the tabular column.

GRAPHS: (i) Error v/s Actual reading
(ii) % Error v/s Actual reading

CALCULATION:

Outcome:

Students will be able to

- State pressure and its types with unit.
- Describe pressure measuring methods

Viva Questions

1. What is static and dynamic pressure meant?
2. What is the role of diaphragm
3. What are the other instruments to measure pressure
4. What is the difference between absolute pressure and dynamic pressure

Experiment -2

CALIBRATION OF THERMOCOUPLE

AIM: To calibrate the given thermocouple using resistance temperature detector.

OBJECTIVE: To introduce the basic operating principles of thermocouples and thermistors and to calibrate these devices.

APPARATUS: Thermocouple, resistance temperature detector (RTD), digital temperature indicator, water bath, heat coil.

Formulae:

- (i) $\text{Error} = T_a - T_m$
- (ii) $\% \text{ Error} = \frac{(T_a - T_m)}{T_a} \times 100$

THEORY:

(i) **Thermocouple:** The common electrical method of temperature measurement is by using thermocouple. When two dissimilar metal wires are joined at both ends, forms two junctions. One which senses the desired unknown temperature is called the hot or measuring junction and the other junction maintained at a known fixed temperature is called cold or reference junction (usually maintained at temperature of ice). By knowing the temperature of one junction, the temperature of other junction may be easily calculated by using the thermo elastic properties of material.

The thermo elastic effects of the material are

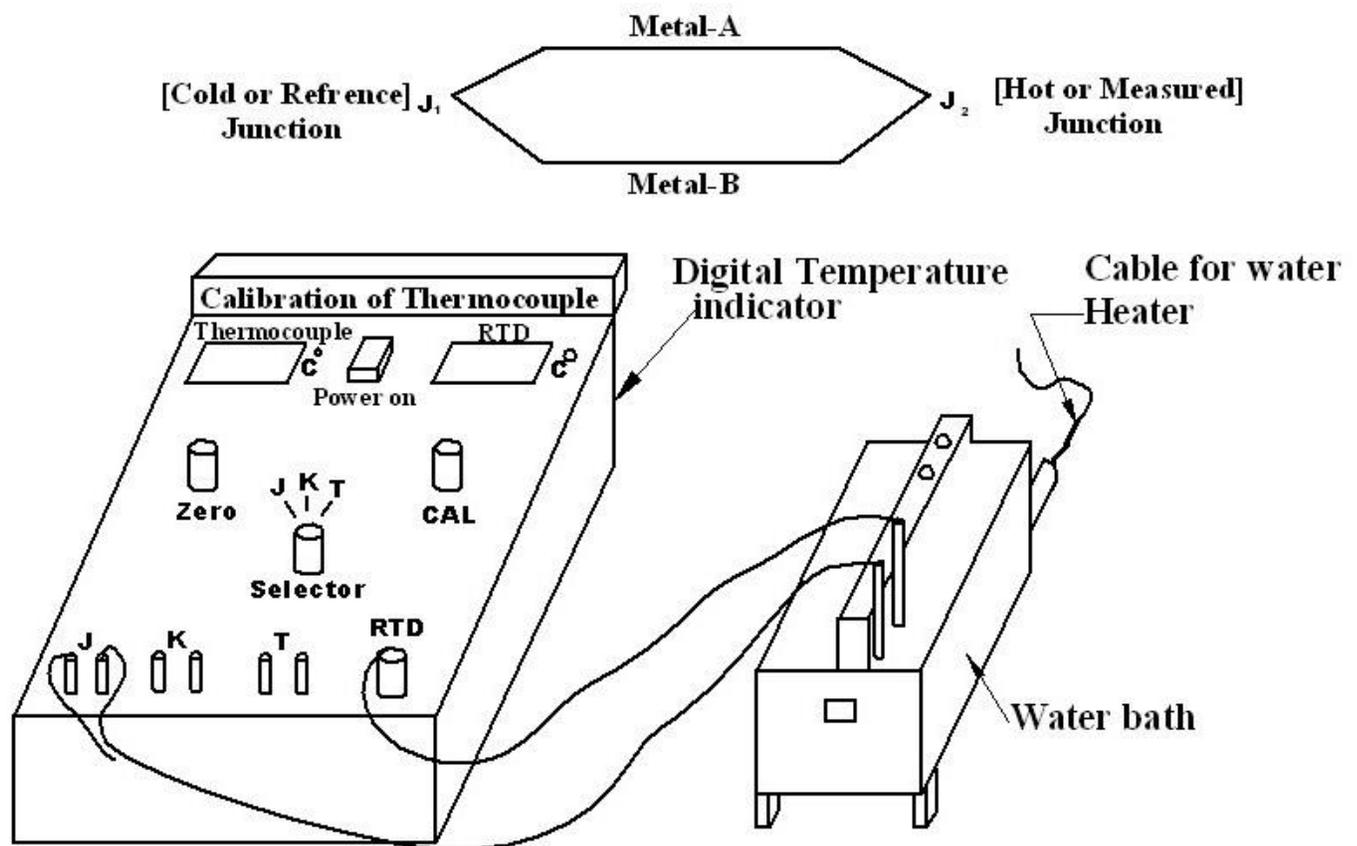
- 1) **Seebeck effect:** When two dissimilar metals are joined together, an electromotive force will exist between the two junctions which is primary function of junction temperature. This phenomenon is called see beck effect.
- 2) **Peltier effect:** If two metals are connected to an external circuit in such a way that a current is drawn, the emf may be altered slightly owing to a phenomenon is called peltier effect.
- 3) **Thomson effect:** Further, if a temperature gradient exists along either of both of the metals. The junction emf may undergo an additional slight alteration. This is called Thomson effect.

Hence there are three emf's present in a thermoelectric circuit.

- (i) The see beck emf caused by the junction of dissimilar metals.
- (ii) The peltier emf caused by the current flow in the circuit.
- (iii) The Thomson emf, resulting from a temperature gradient in the metals.

The thermocouple material must be homogeneous. Some of the materials are listed below.

Sl. no	Metal	Type	Temperature Range
1	Iron – Constantan [40% Ni , 60% Cu]	J	-200 to + 850° C
2	Chromel [90% Cr , 10% Ni] - Alumel [94% Ni , 2% Al, + Si & Mn]	K	-200 to + 1100° C
3	Copper - Constantan	T	-250 to + 400° C
4	Chromel - Constantan	E	-200 to + 850° C
5	Platinum - Rhodium	S	0 to + 1400° C
6	Rhodium - Iridium	R	0 to + 2100° C



- (ii) **Resistance Temperature Detector (RTD):** One of the accurate methods of temperature measurement is the electrical resistance thermometer. It consists of some type of resistance element, which is exposed to the temperature to be measured. Since the resistance of an element depends on the temperature, the temperature is indicated through a measurement of the change in resistance of the element. Usually platinum, nickel and copper are the most commonly used materials. Although other materials like tungsten, silver, iron can also be used.

TABULAR COLUMN:

Sl. No.	Temperature Readings (°C)		Error (°C)	% Error
	Actual Temperature (T_a)	Measured Temperature (T_m)		

PROCEDURE:

- 1) Turn the type selector to the desired position according to the given type of thermocouple.
- 2) Connect the RTD probe and given thermocouple probe to the digital temperature indicator.
- 3) Place the thermocouple hot junction to the end and the RTD probe into a beaker containing water at room temperature.
- 4) Connect the power supply mains to the digital temperature indicator and record the room temperature from RTD indicator.
- 5) Adjust the thermocouple reading until the display shows the room temperature by using Min or Zero setting knob.
- 6) Connect the power supply to the heating coil and heat the water in a beaker to certain higher temperature (say 80°-100°C) and switch off the heating coil.
- 7) Adjust the thermocouple reading until the display shows the RTD reading by using Max or Calibration knob.
- 8) Record the readings of RTD [actual reading] and thermocouple [measured reading] on the indicator simultaneously at regular intervals. (say for every 5°C decrease / increase in temperature)
- 9) Calculate the error and % error.
- 10) Plot the graph of error v/s actual reading and % error v/s actual reading.

RESULT: The given thermocouple is calibrated and the readings obtained are recorded and tabulated in the tabular column.

GRAPHS: (i) Error v/s Actual reading
(ii) % Error v/s Actual reading

CALCULATION:

Outcome:

Students will be able to

- State temperature measurement and its types with unit.
- Describe temperature measuring methods

Viva Questions

1. What is Thermocouple?
2. Distinguish between Thermocouple and Thermometer?
3. What are the advantages of Thermocouple?
4. What is Thermister?

Experiment -3

CALIBRATION OF LVDT

AIM: To calibrate the given LVDT using micrometer.

OBJECTIVE: To Measure Displacement using LVDT with the aid of micrometer

APPARATUS: Linear variable differential transformer (LVDT), Micrometer and digital displacement meter.

Formulae:

(i) Error = $R_a - R_m$

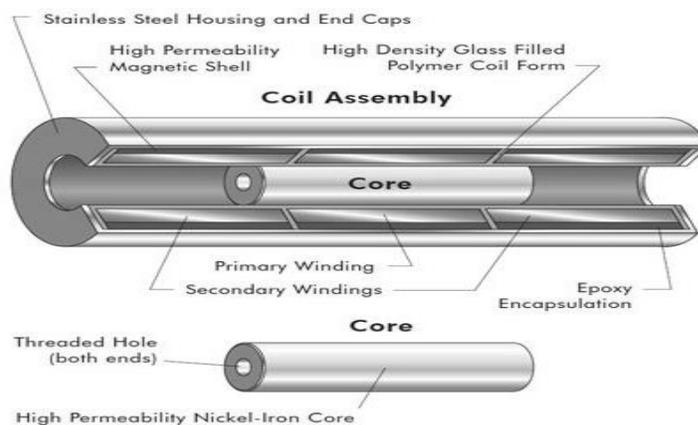
(ii) % Error = $\frac{(R_a - R_m)}{R_a} \times 100$

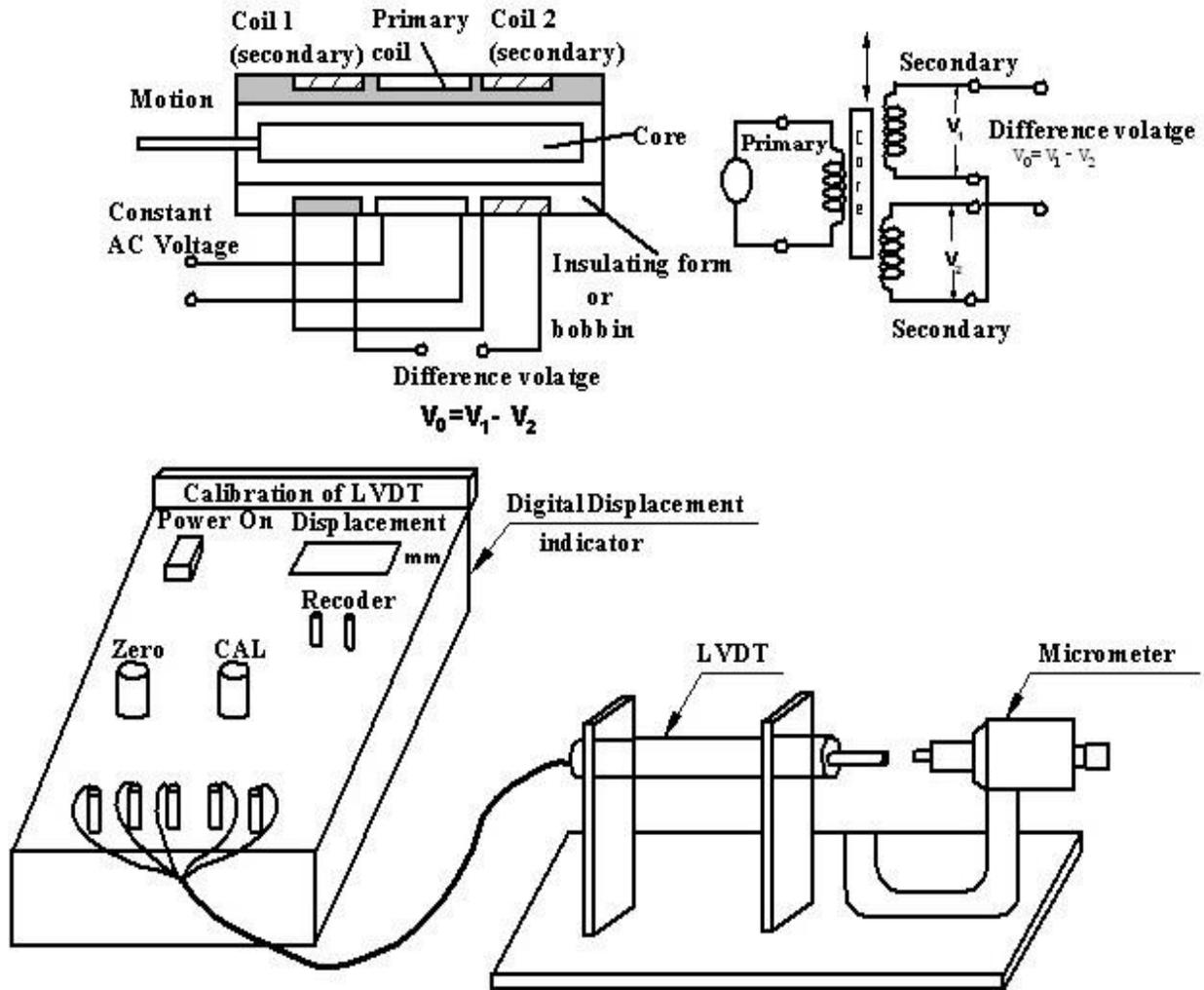
THEORY: In linear variable differential transformer, the linear movements can be transferred into induction variations. It consists of a primary A.C coil on each side of which are mounted two secondary coils wired in a series opposition. Along the axis of three coils, an iron core is mounted on a non-magnetic rod. The output will occur only when the emf's induced in the two secondary coils are unequal. The movement of iron core causes the induced emf's in the secondary coils to vary and because of their series opposition connection, their combined output will be the difference of induced emf's. Thus, the output voltage of the device is an indication of the displacement of the core.

Since the secondary coils are connected in series opposition, a null position exists at which the net output voltage essentially zero. The output voltage V_0 undergoes a 180° phase shift from one side of the null position to the other.

In practical differential transformers, there is always a capacitive effect between the primary and secondary coils are in equal opposition. This is normally less than 1% of the maximum voltage. LVDT provides comparatively high output and is also insensitive to temperature.

Setup: The displacement sensor used here has primary and secondary coils wound and covered by an aluminum body. Five core cables are connected to the primary coil. [Input supply] and the secondary coil [output of the sensor]. An iron core is placed so as to move inside the coil, which will be supported by the springs for an easy to and fro movement. This sensor has been mounted on an aluminum bracket. Micrometer is fixed with the help of bracket in line with the core for linear measurement of the core movement. Since it is operating in the linear range, hence it is called as linear variable differential transformer.





TABULAR COLUMN:

Sl. No.	Displacement Readings (mm)		Error (mm)	% Error
	Actual Displacement (R_a)	Measured Displacement (R_m)		

PROCEDURE:

- (1) Connect the LVDT to the digital displacement indicator by inserting the corresponding color codes.
- (2) Connect the digital displacement indicator to the main power supply and keep it in the ON position for 15 minutes for initial warming up of the instrument.
- (3) Rotate the micrometer thimble to the clock wise direction to bring the LVDT core to null position and set **00.00** reading in the display of the indicator by using ZERO knob.
- (4) Now move the core to any one position from the null position by rotating the screw gauge knob to clockwise or anticlockwise direction until it reads + or – 10 mm in the micrometer and set the display of the indicator to show ± 10.00 by using CAL knob.
- (5) Move the core to the initial position (null position). Now the given LVDT is calibrated and ready to take the readings.
- (6) Move the core to one side of the null position in the steps of 1mm or 1.5mm or 2mm etc by rotating the thimble of micrometer and record the micrometer and digital displacement indicator reading simultaneously.
- (7) Repeat the experiment by moving the core to the other side of the null position.
- (8) Calculate the error if any and % error.

RESULT: The given LVDT is calibrated and the readings obtained are recorded and tabulated in the tabular column.

GRAPHS: (i) Error v/s Actual reading
 (ii) % Error v/s Actual reading

CALCULATION:

Outcome:

Students will be able to

- Its principle of operation
- The principles of step up and step-down transformers
- Concept of inductance

Viva Questions

1. How does a linear variable differential transformer work?
2. What is the moving part of a linear variable differential transformer?
3. What is the linear displacement?
4. How does a position sensor works?

Experiment -4

CALIBRATION OF LOAD CELL

AIM: To calibrate the given load cell using weights.

OBJECTIVE: To measure the weights using Gauge Load Cell

APPARATUS: Load cell, standard weights and digital load indicator.

Formulae:

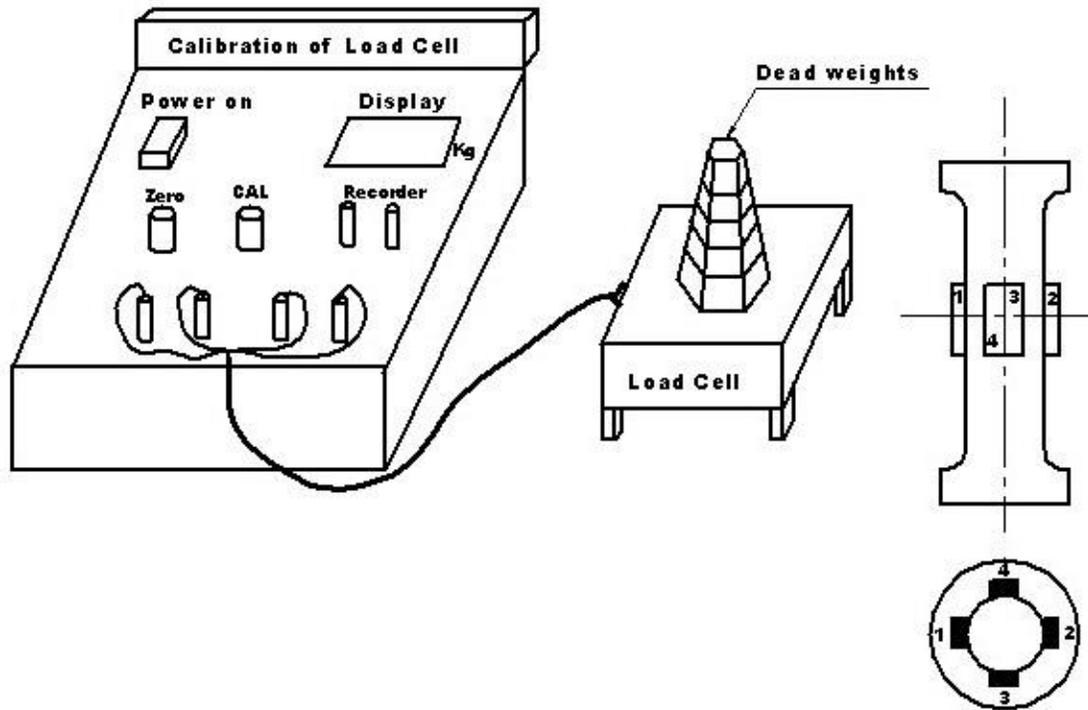
(i) Error = $W_a - W_m$

(ii) % Error = $\frac{(W_a - W_m)}{W_a} \times 100$

THEORY: For weighing the load / force using spring deflection is a widely accepted one. But the deflection of spring reading mechanically is very tedious and time consuming. One of the most effective and accurate method is using strain gauge based load cells using the principle of deflection of high tensile strength material when load is applied on it and converting it into electrical signal using strain gauges will give accurate way of measuring the load.

Strain gauges are bonded on the columns of corrosion resistance super tough alloy of high tensile strength steel that deforms very minutely under load. This deformation is converted into electrical signal through strain gauges bonded on the column and connected to form a wheat stone bridge. This electrical output is proportional to the load acting on the columns. This output of the load cell calibrated with reference to some standard i.e., Standard weights.

Load cell sensor used here is a stainless steel material fitted on bottom frame, stainless steel pipe has been bonded with strain gauges to form a wheat stone bridge and an output is taken out through four pin connector this sensor can be used as tensile or compressive load cell. Here it is used as compressive top of the sensor is fixed with metal frame with stainless steel cover upon which the dead weights can be loaded.



TABULAR COLUMN:

Sl. No.	Weight Readings (kgs)		Error (kgs)	% Error
	Actual Weight (W_a)	Measured Weight (W_m)		

PROCEDURE:

1. Connect the load cell to the digital load indicator.
2. Connect the indicator to the power mains.
3. Switch on the power supply and set zero value on the display of the indicator without load on the load cell using zero setting knob.
4. Keep the known maximum weight on the load cell and set the value on the display of the indicator until it shows the known maximum value using calibration knob.
5. Select the standard weight to the maximum of 8 – 10 kgs.

6. Keep the known weights on the platform of the load cell in the increasing / decreasing order.
7. Record the readings on the indicator [measured reading] to the corresponding weights [actual reading].
8. Calculate the error and % error.
9. Plot the graph of error v/s actual reading and % error v/s actual reading.

RESULT: The given load cell is calibrated and the obtained readings are recorded and tabulated in the tabular column.

GRAPHS: (i) Error v/s Actual reading
(ii) % Error v/s Actual reading

CALCULATION:

Outcome:

Students will be able to

- State working of load cell and its functioning with unit.
- Describe load measuring methods

Viva Questions

1. What is a load cell used for?
2. How does a strain gauge sensor work?
3. What does a strain gauge measure?
4. What is the force transducer?

Experiment -5

DETERMINATION OF MODULUS OF ELASTICITY OF A MILD STEEL SPECIMEN USING STRAIN GAUGES

AIM: To determine the modulus of elasticity of a mild steel specimen using strain gauges.

OBJECTIVE: To evaluate the young's modulus of steel specimen

APPARATUS: A cantilever beam with concentrated end load arrangement, strain gauges and strain indicator.

- Formulae:**
- (i) Measured Strain $\epsilon_m = \epsilon \times 10^{-6} / 4$ for Full bridge
 - (ii) Measured Strain $\epsilon_m = \epsilon \times 10^{-6} / 2$ for Half bridge
 - (iii) Measured Strain $\epsilon_m = \epsilon \times 10^{-6}$ for Quarter bridge
 - (iv) $\sigma = 6WL / bh^2$
 - (v) $E = \sigma / \epsilon_m$

THEORY: A body subjected to external forces is in a state of both under stress and strain. Stress cannot be directly measured but its effect i.e., the change of shape of the body can be measured. If there is a relationship between stress and strain, the stress occurring in a body can be computed if sufficient strain information is available. The constant relating the stress and strain in elastic material under the direct stresses is called the modulus of elasticity. i.e., $E = \sigma / \epsilon$

The principle of electrical strain gauge was given by Lord Kelvin, when he observed that a stress applied to a metal wire, besides changing its length and diameter, also changes its electrical resistance. Metallic electrical resistance strain gauges are made in the two basic forms bonded wire and bonded foil. Wire gauges are sandwiched between two sheets of thin paper and foil gauges are sandwiched between two thin sheets of epoxy.

The strain gauge is connected to the material in which it is required to measure the strain, with a thin coat of adhesive and most common adhesive used is Eastman duco cement etc. as the test specimens extends or contracts under stress in the direction of windings. The length and cross sectional area of the conductor after resulting in a corresponding increase or decrease in electrical resistance.

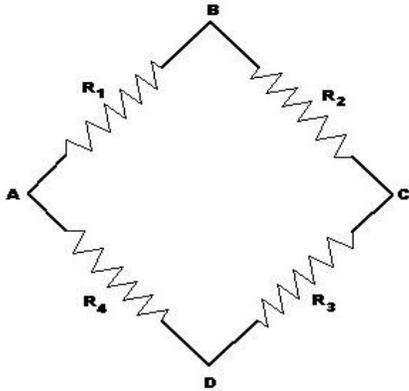
Gauge Factor: A dimension less relationship between the change in gauge resistance and change in length is called gauge factor of the strain gauge and is expressed mathematically as

$$\text{Gauge Factor} = \frac{\Delta R/R}{\Delta L/L}$$

In this relationship, R and L represent the initial resistance and initial length of the strain gauge filament respectively. While ΔR and ΔL represents the change in resistance and length occurs as the gauge is strained along with the surface to which it is bonded. Thus the gauge factor of the strain gauge is a measure of the amount of resistance change for a given strain. Higher the gauge factor, greater will be electrical output for indication or recording purposes. The gauge factor is supplied by the manufacturer.

The usual method of measuring the change of resistance in a gauge element is means of wheat stones bridge circuit. It consists of a galvanometer, four resistors and a battery. Resistance

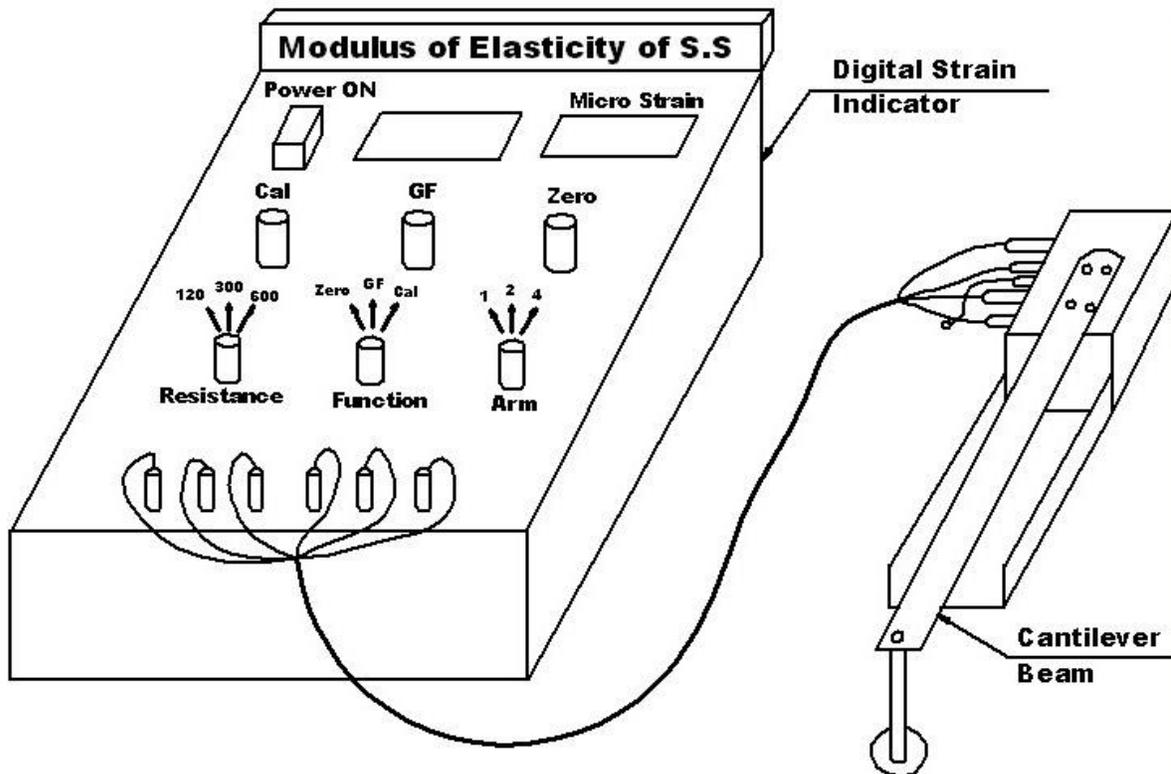
R_1 is the strain gauge used for strain measurement which is mounted on the test specimen. The three resistors R_2 , R_3 & R_4 are internal to the device. Let us assume that the resistance has been adjusted so that the bridge is balanced.



i.e, Voltage end=0
 Thus for initial balance,
 $R_1 R_3 = R_2 R_4$
 (or)
 $R_1 = \frac{R_2 R_4}{R_3}$

If the structural member to whom the strain gauge is bonded is to be loaded and strained, there would be a resultant change in the resistance R_1 . According to the relationship,

$$\Delta R = \frac{R_1 \times \delta g \times \Delta L}{L}$$



The imbalance will be indicated by the movement of galvanometer needle from zero point. The galvanometer deflection itself might be taken as a measure of strain. If the galvanometer were calibrated in units of micro mm per mm of strain. The strain indicator is calibrated for gauges of given factor. Thus it provides accurate readings only when gauges having the same gauge factor

are used. Most instruments incorporate a variable resistor which allows the strain indicator to be matched to gauges having somewhat different gauge factor. If no such adjustment exists in the instrument, then

$$\text{True strain} = \frac{\text{Indicated strain} \times \text{Instrument gauge factor}}{\text{Strain gauge factor}}$$

The most common bridge arrangements are one arm, two arms and four arms mode.

One arm mode [one fourth or quarter bridge]: This bridge arrangement consists of a single cavity gauge in position and three resistors are internal to the device. The temperature compensation is possible only if a self-temperature compensating strain gauge is used.

Two arms mode [one half or half bridge]: In this mode, two resistors are internal to the device and the remaining two are strain gauges. One arm of this bridge is commonly labeled as active arm and the other as compensating arm. The bridge is temperature compensated.

Four arm mode [Full bridge]: In this bridge arrangement, four active gauges are placed in the bridge with one gauge in each of the four arms. If the gauges are placed on a beam for bending for the elastic constant by bending test experiment, the signal from each of the four gauges will add and the bridge arrangement is temperature compensated.

Consider a plate subjected to axial tensile force. The gauges R_1 & R_3 measures the uniaxial strain while the gauges R_2 & R_4 serves the purpose of the temperature compensation. Only in this particular arrangement of mounting of gauges, the influence of bending and temperature are compensated. Since the gauges is said to be working as half bridge.

Let

W= Load applied on the beam in N

b= Width of beam in mm

h= Thickness of beam in mm

A= Cross sectional area in mm^2 [A= bh]

ϵ = Strain indicator reading in micro strain

i= no of active gauges

M_b = Bending moment in N-mm [$M_b = WI$]

I= Moment of inertia in mm^4 [$I=bh^3/12$]

$C=h/2$

Therefore, Bending Equation is $\frac{M_b}{I} = \frac{\sigma}{C}$

Bending Stress, $\sigma = \frac{M_b}{I} \times C$

$$\sigma = WI \times \frac{h}{2} \times \frac{12}{bh^3}$$

$$\boxed{\sigma = \frac{6 WI}{bh^2}} \quad \text{N/mm}^2$$

Therefore, Measured strain, $\epsilon_m = \frac{\epsilon \times 10^{-6}}{i}$

Modulus of Elasticity, $E = \frac{\text{Stress } (\sigma)}{\text{Strain } (\epsilon_m)}$

$$\boxed{E = \frac{6 WI}{bh^2 \times \epsilon_m}} \quad \text{N/mm}^2$$

OBSERVATIONS: (i) Distance between gauge center to the point of application of load, $l=250\text{mm}$

- (ii) Width of beam, $b= 41$ mm
- (iii) Thickness of beam, $h= 2.85$ mm

TABULAR COLUMN:

Sl. no	Load Applied (W)		Strain Indicator Reading ϵ -micro strain	Measured Strain $\epsilon_m = \epsilon \times 10^{-6}$	Bending Stress $\sigma = 6Wl/bh^2$ N/mm ²	Modulus of Elasticity $E = \sigma / \epsilon_m$ N/mm ²
	kg	N				

PROCEDURE:

- 1) Switch on the instrument and leave 15 minutes to warm up.
- 2) Connect the respective colored wires of sensors to terminals in the indicator panel.
- 3) Keep the arms selector switch on 4 or 2 or 1 depending on the selected bridge.
- 4) Keep the function switch to gauge factor and adjust the G.F pot to read 500 in display.
- 5) Select the function switch to cal and adjust the cal pot to read 1000.
- 6) Keep the function switch to read and adjust the display to read zero.
- 7) Apply the load of 100 grams and note down the readings on the display.
- 8) Apply the load of 100 grams step by step and note down the corresponding strain readings on the display.
- 9) Calculate the young's modulus and compare it with the theoretical value.
- 10) Plot the graph of stress v/s measured strain and find out the young's modulus by slope of the graph.

RESULT: The modulus of elasticity of a given mild steel specimen has been found out and the corresponding readings are recorded and tabulated in the tabular column.

GRAPHS: (i) Measured strain v/s stress for all the three types of bridges.

CALCULATION:

Outcome:

Students will be able to

- Learn the concept of young's modulus and strain.
- Describe use of gauge measuring methods and Bridgestone networks

Viva Questions

1. What is a strain gauge?
2. What is the gauge factor?
3. What is a bridge network?
4. What is moment of inertia?

PART B-Metrology

Experiment -1

Measurements using Toolmaker Microscope

AIM: To determine the major diameter, minor diameter, depth, pitch and angle of given thread.

OBJECTIVE: Study of tool maker's microscope

APPARATUS: Tool maker's microscope, screw thread.

THEORY: Tool maker's microscope is versatile instrument based on the optical means. It consists of a heavy hollow base accommodating the illuminating unit underneath. Work table is mounted on the base of the instrument on cross slides and is equipped with accurate micrometer screws to move it in two mutually perpendicular directions in the horizontal plane. i.e., in longitudinal and lateral direction.

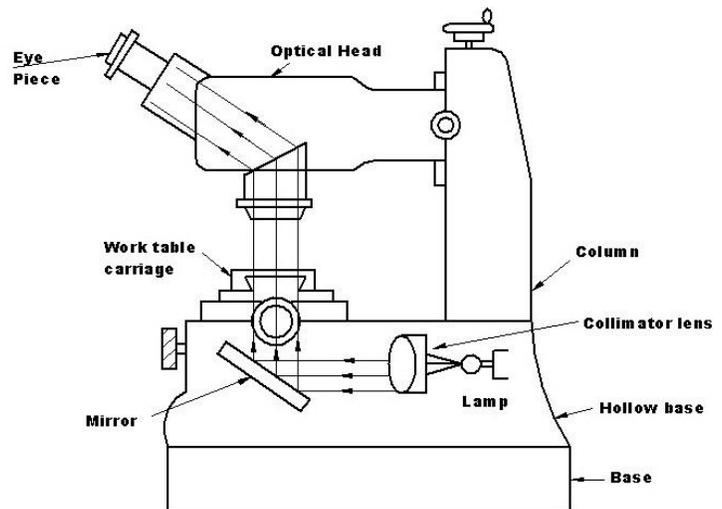
The optical head is mounted on vertical column and can be moved up or down and focused over the work. Clamping screw is provided to clamp the optical head at any desired position. Work piece is mounted on a glass plate placed on the table. A light source is provided horizontal beam of light which is reflected from a mirror by 90° upwards towards the table. The beam of light passes through transparent glass plate on which work piece to be checked are placed.

A shadow image of the outline of the contour of the work piece passes through the objective of the optical head and is projected by a system of three prisms to a ground glass screen observations are made through the eye piece of the optical head.

Measurements are made by means of cross lines engraved on ground glass screen. The screen can be rotated through 360° and the angle of rotation can be viewed through auxiliary eye piece provided on the optical head.

Tool makers microscope is designed for measurements on parts of complex forms such as

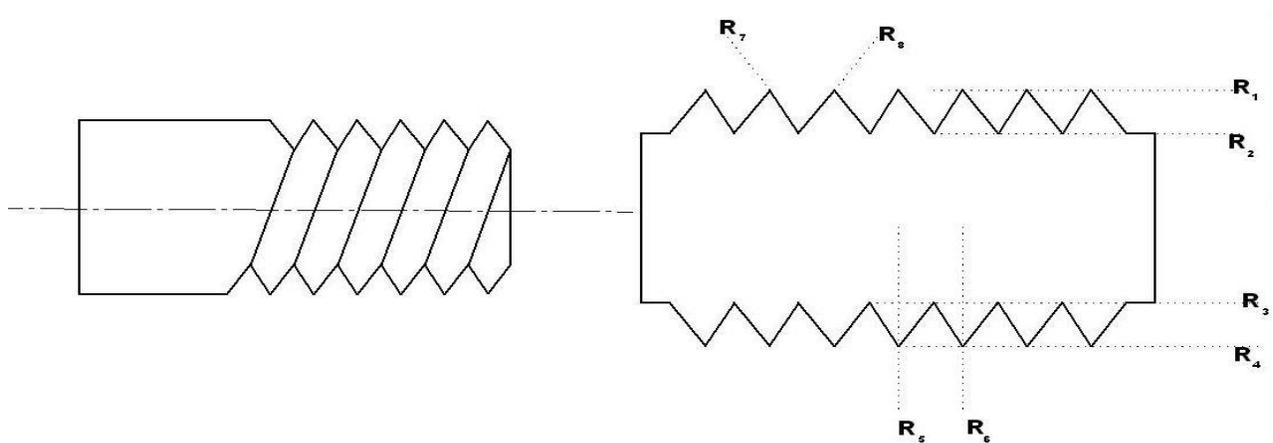
- (i) Linear measurements. Eg: Length, width, diameter etc
- (ii) Measurement of pitch of the screw.
- (iii) Measurement of thread angle.
- (iv) Compare the thread forms with the standard profiles.
- (v) Measurement of Pitch diameter.
- (vi) For measurement of centre to centre distance of holes in any plane.
- (vii) Measuring of coordinates of the outline of a complex template gauge. etc





OBSERVATIONS AND CALCULATIONS:

- (i) Least count of X-Y direction micrometers =
- (ii) Least count of Circular scale =
- (iii) Reading R_1 =
- (iv) Reading R_2 =
- (v) Reading R_3 =
- (vi) Reading R_4 =
- (vii) Reading R_5 =
- (viii) Reading R_6 =
- (ix) Reading R_7 =
- (x) Reading R_8 =
- (xi) Major diameter = $(R_1 \sim R_4)$ =
- (xii) Minor diameter = $(R_2 \sim R_3)$ =
- (xiii) Depth of thread = $(R_1 \sim R_2)$ or $(R_3 \sim R_4)$ =
- (xiv) Pitch of thread = $(R_5 \sim R_6)$ =
- (xv) Angle of thread = $(R_7 \sim R_8)$ =



PROCEDURE:

- 1) Keep the given object (screw thread) on the specimen table.
- 2) Switch on the mains and lights of the microscope.
- 3) Adjust the X-Y direction lines in the eye piece by using micrometers to measure major, minor diameter, pitch and depth of the thread.
- 4) Determine the angle of thread using circular scale.
- 5) Tabulate the results.

RESULT: The unknown parameters of the given thread are measured and tabulated in the tabular column.

Thread Parameter	Measured Values
Major diameter	
Minor diameter	
Pitch	
Angle	
Depth	

Outcome:

Students will be able to

- appreciate the importance of precision measurement
- know how precise measurements can be taken with this instrument,
- explain the field of application/working of this instrument
- understand the principle of working of tool room microscope

Viva Questions

1. What are the applications of Tool maker's microscope?
2. Differentiate Precision and Accuracy?
3. What are the uses of micrometers in Tool maker's microscope?
4. What is the significance of cross-wire arrangement in Tool maker's microscope?

Experiment -2(a)

Measurement of angle using Sine bar

AIM: To determine the angle of taper for a given work piece by using sine bar.

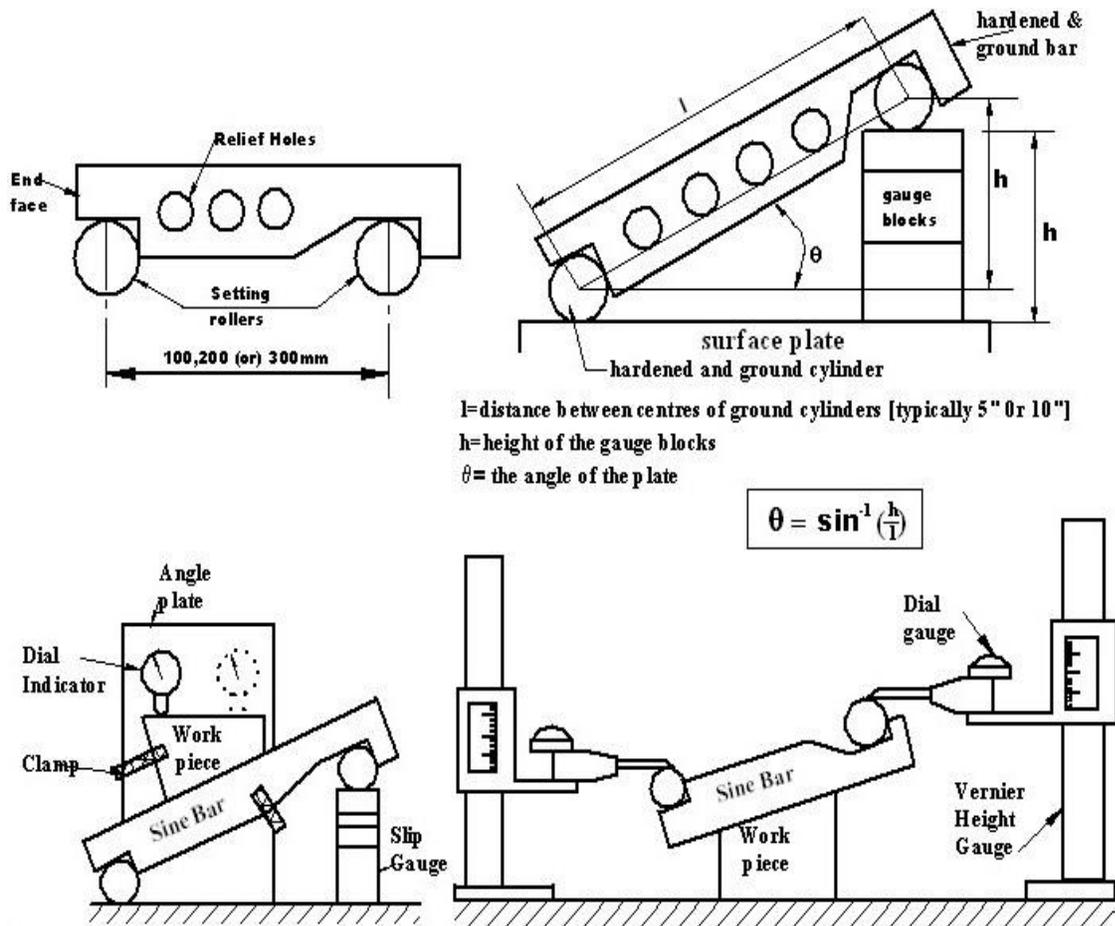
OBJECTIVE: To measure the angle of the given wedge using Sine bar

APPARATUS: Sine bar, slip gauges, surface table and work piece.

Formulae: (i) $\sin\theta = H/L$

THEORY: Sine bar is used to measure or set the accurate angles. It consists of a bar made up of high carbon high chromium corrosion resistance steel and is hardened, ground and stabilized. Two cylinders of equal diameters are attached at the ends. The axes of these cylinders are mutually parallel to each other and also parallel to and equally spaced from top surface of the sine bar. The distance between the rollers is fixed to high degree of accuracy. When the rollers are brought in contact with a flat surface, the top of the sine bar is parallel to the flat surface.

Sine bar is generally used in conjunction with the slip gauges and surface plate. The principle of sine bar is upon the application of trigonometry. In a right angle triangle, the ratio of lengths of opposite to the hypotenuse sides is referred as sine of the angle θ .



PROCEDURE:

(1) When size of the component is small:

- 1) Place the rectangular tapered specimen on the surface of the sine bar and clamp it using angle plate if necessary.
- 2) Fix the dial gauge of known accuracy on the stand.
- 3) Set the dial gauge to show zero reading at one end (smaller end) of the component and move it to the other end (larger end) and note down the difference in the dial reading.
- 4) Prepare a combination of slip gauges equal to the difference in dial gauge reading and place the combination under the smaller end roller.
- 5) Move the dial gauge starting from smaller end of the rectangular tapered bar to the larger end.
- 6) Note down the dial gauge reading and alter the combination of slip gauges under the smaller end roller until the null deflection is obtained.
- 7) Note down the height of the slip gauge combination under the smaller end roller and calculate the angle of the component.

(2) When size of the component is heavy:

- 1) Place the rectangular tapered specimen on the surface of the surface plate.
- 2) Mount the sine bar over the component upside down.
- 3) Fix the dial test indicator on the anvil of the vernier height gauge.
- 4) Touch the sine bar roller at the smaller end with dial test indicator with pressure and note down the reading.
- 5) Touch the sine bar roller at the larger end with dial test indicator with pressure.
- 6) Prepare and place a combination of slip gauges under the smaller end roller and alter the combination until the dial test indicator to show the initial reading.
- 7) Note down the height of the slip gauge combination under the smaller end roller and calculate the angle of the component.

RESULT: The angle of a given rectangular tapered work piece is _____.

Outcome:

Students will be able to

- Measure angles using sine bar
- Understand the methods of measuring the deflection using dial gauge

Viva Questions

1. What is a sine bar?
2. What are the limitations of Sine bar?
3. What are slip gauges and why do we use them?
4. What is the difference between the sine bar and sine center?
5. What are the modifications of Sine bar?

Experiment -2(b)

Measurement of angle using Sine Center

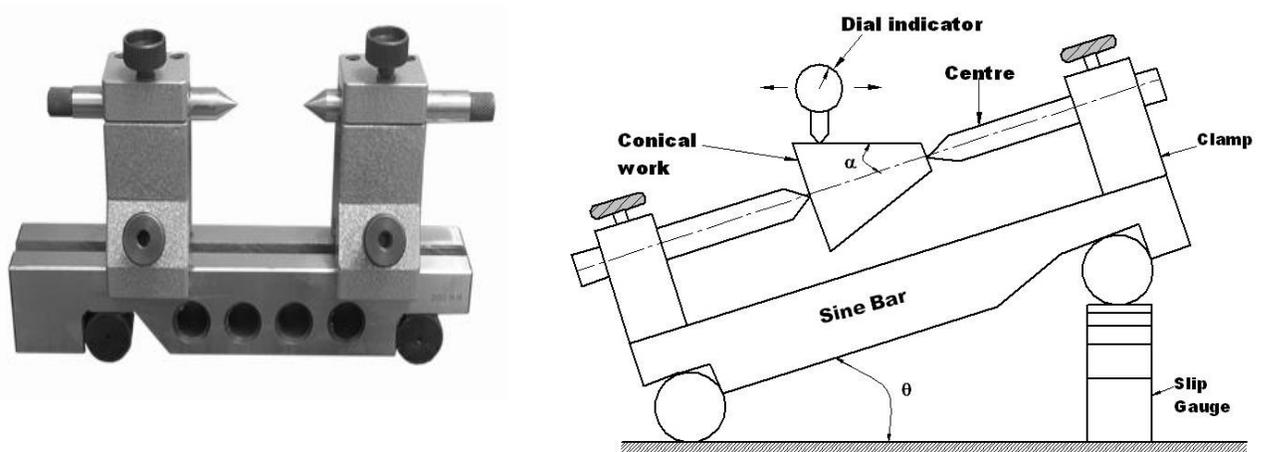
AIM: To determine the angle of taper for a given work piece using sine centre.

OBJECTIVE: To measure the angle of the conical specimens using Sine centre

APPARATUS: Sine centre, dial indicator, slip gauges, surface table and specimen.

Formulae: (i) $\sin\theta = H/L$

THEORY: Sine centre is basically a sine bar with block holding centers which can be adjusted and rigidly clamped in any position. Sine centres are used for inspection of conical objects which can be held between centres. When the sine centre is brought in contact with a flat surface, the top of the sine centre and the axis of the centres are parallel to the flat surface.



PROCEDURE:

- 1) Fix the given conical work piece between the centres of the sine centre.
- 2) Fix the dial gauge of known accuracy on the stand.
- 3) Set the dial gauge to show zero reading at one end of the component and move it to the other end and note down the difference in the dial reading.
- 4) Prepare a combination of slip gauges equal to the difference in dial gauge reading and place the combination under the smaller end roller.
- 5) Pass the dial gauge across the length of the component, if there is any deflection of the dial gauge, then alter the combination of slip gauges under the smaller end roller until the null deflection is obtained.
- 6) Note down the height of the slip gauge combination under the smaller end roller and calculate the angle of the component.

RESULT: The semi cone or taper angle of a given conical work piece is _____.

Outcome:

Students will be able to

- Measure angles using sine centre
- Understand the methods of measuring the deflection using dial gauge

Viva Questions

1. What is a sine centre?
2. What are the limitations of Sine centre?
3. What are slip gauges and why do we use them?
4. What is the difference between the sine bar and sine center?
5. What are the modifications of Sine center?

Experiment -2(C)

Measurement of angle using Bevel Protractor

AIM: To determine the angle of taper for a given work piece by using bevel protractor.

OBJECTIVE: For measuring the angle of the specimen using the universal bevel protractor

APPARATUS: Bevel protractor and specimen.

THEORY: It is simplest instrument for measuring the angle between two faces of a component. It consists of a base plate attached to the main body an adjustable blade which is attached to a circular plate containing vernier scale. The adjustable blade is capable of sliding freely along the groove provided on it and can be clamped at any convenient length. The adjustable blade along with the circular plate containing the vernier scale can rotate freely about the centre of the main scale engraved on the body of the instrument and can be locked in any position with the help of clamping knob. The base plate is made flat so that it can be laid flat upon the work and any type of angle (ie., from 0° – 360°) can be measured. The main scale is graduated in degrees of arc and the vernier scale has 12 divisions on either sides of centre zero.



PROCEDURE:

- 1) Place the specimen on the surface plate.
- 2) Place the fixed arm or blade or beam of bevel protractor parallel to the lower end or base of the specimen.
- 3) Move the adjustable arm to make it parallel to the inclined surface of the specimen.
- 4) Note down the reading on the main scale and vernier scale.
- 5) Repeat the same procedure for different inclined surfaces.

RESULT: The unknown angle of inclined face in a given specimen is measured and is _____.

Outcome:

Students will be able to

- State protractors and its types with unit.
- Describe angle measuring methods

Viva Questions

1. What is the use of angle plates?
2. Name some angle measuring devices?
3. What is the least count of mechanical Bevel Protractor?
4. What are the types of Bevel Protractor?
5. Differentiate between Sine bar and Protractor?

Experiment-3

Measurement of alignment using Autocollimator

AIM: To measure the non-linearity or alignment of a surface by using auto collimator.

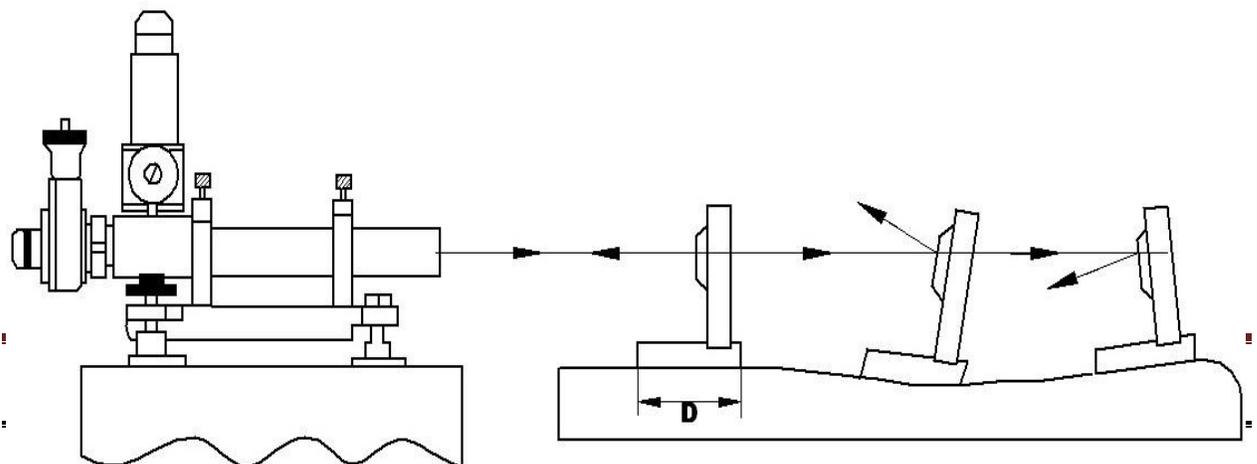
OBJECTIVE: To measure the straightness and Flatness given specimen using two axis Auto Collimator.

APPARATUS: Auto collimator and surface table.

THEORY: Auto collimator is an optical instrument used for the accurate measurement of smaller angular differences, changes or deflection, plane surface inspection etc.

If a light source is placed in the focus of a collimating lens, it is projected as a beam of light. If this beam is made to strike a plane reflector, kept normal to the optical axis, it is reflected back along its own path and is brought to the same focus. If the reflector is tilted through a small angle ' θ ', the parallel beam of deflected twice that of angle and is brought to a focus in the same plane as the light source, but to one side at a distance $x = 2f\theta$. Where f is the focal length of lens and θ is the angle of inclination of reflecting mirror.

In an auto collimator, there are three parts viz. micrometer microscope, lighting unit and collimating lens. A 45° transparent beam splitter reflects the light from the graticule towards the objective (collimating lenses). The image seen after reflection in the external reflector, whose angular variations are being measured, is formed by the light from the objective lens. This light passes through the beam of splitter, and the image is picked up by the microscope. For simultaneous measurements in two planes at right angles a micrometer is fitted to the largest graticule, optically at right angles to that on the eye piece graticule.



TABULAR COLUMN:

No. of points to be checked	Position in mm	Initial reading	Final reading	Difference in micrometer reading	Level x in μ

$$x = \tan \theta * 100 * 1000 \text{ microns}$$

PROCEDURE:

- 1) Place the auto collimator with stand on the surface table which is to be inspected.
- 2) Place the reflector along the axis of auto collimator.
- 3) Adjust the micrometer for least value of the main scale division.
- 4) Adjust the stand so that the auto collimator appears to be pointing straight at the flat reflective surface.
- 5) Observe through an eye piece and try to locate the cross line image for the target graticule.
- 6) Adjust the micrometer for the reference position and note down the reading on the main scale.
- 7) Move the reflector to the next position.
- 8) Observe through an eye piece, if the surface plate flatness is exact, the two horizontal lines gets coincide, if not there will be a gap between positions A and B.
- 9) Coincide the horizontal lines by using micrometer.
- 10) Repeat the above procedure for different positions of plane reflector.
- 11) Calculate the readings and plot the graph of x in microns v/s position to know the straight line of a flat surface plate.

RESULTS: The readings are tabulated in the tabular column and the graph is plotted.

CALCULATION:

Outcome:

Students will be able to

- State principles of collimation.
- Describe flatness measuring methods

Viva Questions

1. Define Straightness.
2. Define the tolerance for Straightness.
3. What is flatness?
4. What is autocollimator?
5. What are the applications of autocollimators?

Demonstration Experiments (For CIE)

Experiment -01

MEASUREMENT OF CUTTING TOOL FORCES USING LATHE TOOL DYNAMOMETER

AIM: To study the forces acting on the cutting tool while turning.

OBJECTIVE: To study the cutting force measuring instrument used to measure the cutting forces coming on the tool tip

APPARATUS: Lathe tool dynamometer, Digital force measuring indicator, Lathe, Specimen, etc.

- Formulae:**
- (i) Resultant force, $R = \sqrt{F_x^2 + F_y^2 + F_z^2}$ Newtons
 - (ii) Cutting velocity, $v = \frac{\pi D n}{1000}$ m/min
 - (iii) Power in cutting, $P = \frac{F_t v}{4500}$ hp = $\frac{F_t v}{4500} \times 0.746$ kW

THEORY: The metal cutting process is a complex physical process involving both plastic and elastic deformation. A force should be applied on the work piece to deform it. Various forces of resistance are applied on the tool because of plastic deformation, friction of chip and machined surface on the tool. The resultant of all forces on the tool from the material being machined is called as the force of resistance to cut. The resultant force R can be resolved into three mutually perpendicular components acting on the tool.

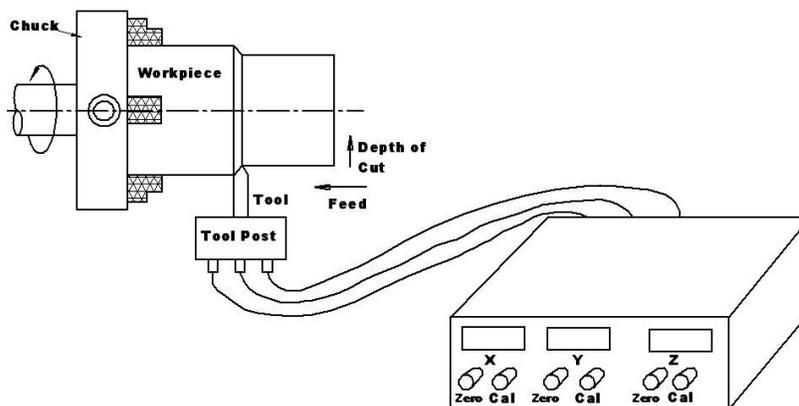
F_t – Tangential component, tangential force is acting tangent to the surface of the cut and coincides with the directing of primary cutting motion.

F_a – Axial component, axial or feed force acting parallel to the work axis in a direction opposing feed motion.

F_r – Radial component, radial force acting in horizontal plane perpendicular to the axis of work.

The resultant, R is given by $R = \sqrt{F_x^2 + F_y^2 + F_z^2}$

Lathe tool dynamometer is an instrument which measures the three components of the resultant force during turning operation.



TABULAR COLUMN:

(a) Varying Speed

(i) Feed = _____ mm/min

(ii) Depth of cut = _____ mm

Sl. no	Speed rpm	Cutting Velocity m/min	Axial feed force (F_a) F_x		Tangential force (F_t) F_y		Radial force (F_r) F_z		Resultant Force R	Power in cutting kW
			kgf	Newtons	kgf	Newtons	kgf	Newtons		
1										
2										
3										

(b) Varying Feed

(i) Speed = _____ rpm

(ii) Depth of cut = _____ mm

Sl. no	Feed mm/min	Cutting Velocity m/min	Axial feed force (F_a) F_x		Tangential force (F_t) F_y		Radial force (F_r) F_z		Resultant Force R	Power in cutting kW
			kgf	Newtons	kgf	Newtons	kgf	Newtons		
1										
2										
3										

(c) Varying Depth of cut

(i) Speed = _____ rpm

(ii) Feed = _____ mm/min

Sl. no	Depth of cut mm	Cutting Velocity m/min	Axial feed force (F_a) F_x		Tangential force (F_t) F_y		Radial force (F_r) F_z		Resultant Force R	Power in cutting kW
			kgf	Newtons	kgf	Newtons	kgf	Newtons		
1										
2										
3										

PROCEDURE:

- 1) Fix the Lathe tool dynamometer to the tool post using a center hole provided on the dynamometer ensure that the object being turned has smooth surface and the tool tip is exactly at center height.
- 2) Connect the leads from the dynamometer to the respective channels on the digital force indicator.
- 3) Switch on the instrument / digital force indicator and change the mode selecting switch to READ mode. Adjust the display to read ZERO for all the three force components F_x , F_y & F_z . This operation has to be conducted when the dynamometer does not have any load applied.
- 4) Change/turn the mode selecting switch to CAL mode and adjust the display to read 500 kgf for all the three force components.
- 5) Fix the work piece in the chuck, start the lathe and do the turning operation.
- 6) Note down the forces F_x , F_y & F_z for different speeds keeping the feed and depth of cut as constant.
- 7) Repeat the above process for different feeds with speed and depth of cut as constant and for different depth of cuts with speed and feed as constant.
- 8) Tabulate all the readings taken and calculate the resultant force and power during cutting.
- 9) Plot the graphs showing the variation of cutting forces with speed, feed and depth of cut.

RESULT: The results obtained are tabulated in tabular column.

GRAPHS: Resultant force v/s Speed
 Resultant force v/s Feed
 Resultant force v/s Depth of cut

CALCULATION:

Outcome:

Students will be able to

- State principles of force measurement.
- Describe principle of magnetism and induction

Viva Questions

1. Define cutting forces.
2. Define the principle of dynamometer.
3. What is induction?
5. What are the applications of dynamometers?

INSERT GRAPH SHEET

INSERT GRAPH SHEET

Experiment -02

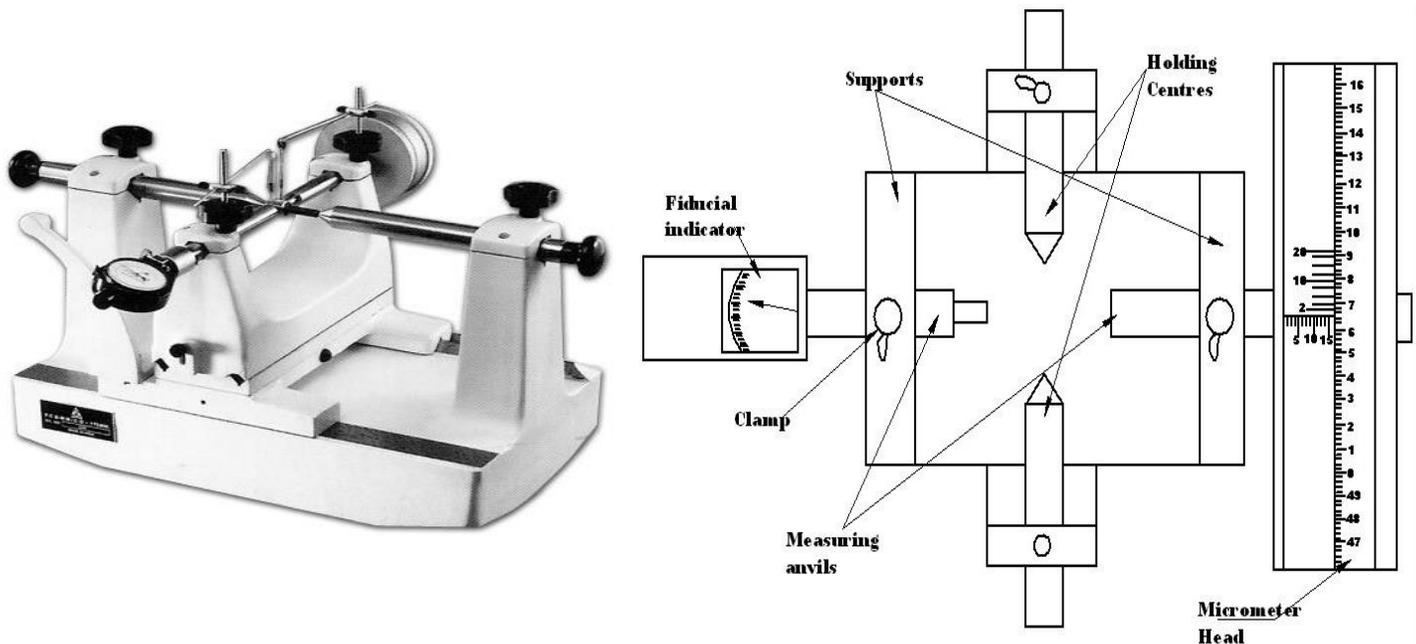
MEASUREMENTS OF SCREW THREAD PARAMETERS USING TWO WIRE OR THREE-WIRE METHODS

AIM: To determine the major, minor and effective diameter of a given screw thread specimen using floating carriage micrometer.

OBJECTIVE: To measure the major, minor and effective diameter of given specimen by using a floating carriage micrometer.

APPARATUS: Floating carriage diameter measuring machine, test specimen, master specimen, wires and thread measuring prisms.

THEORY: The floating carriage diameter measuring machine is precision measuring equipment used to measure major, minor and effective (pitch) diameter of threads gauges and precision thread components. This instrument ensures that the axis of the micrometer is maintained at 90° to the axis of the screw thread specimen under test. It consists of two slides (lower and upper). The lower slide moves parallel to the thread axis. The upper slide also called as measuring slide carries a micrometer head and a fiducial indicator. The measuring slide or carriage floats on three balls in the V-grooves of the lower slide. The thimble of micrometer is graduated for readings of 0.002mm and vernier has a least count of 0.0002mm. The fiducial indicator is a highly sensitive indicator which reduces the errors due to feel of micrometer. The indicator operates at a constant pressure at null position of the pointer. It has a magnification of more than 150 times the movement of the micrometer anvil. This helps in high degree of control and repeatability required for accurate measurements. The micrometer readings are taken with indicator pointer at null position.



PROCEDURE:

1) Measurement of major diameter:

- (1) Fix a standard cylinder of approximately same size as the nominal size of the threads between the centers of the floating carriage diameter measuring machine.
- (2) Note down the reading of micrometer as R_1 when the fiducial indicator is at null position.
- (3) Replace the standard cylinder by the given screw thread specimen and note down the reading of micrometer as R_2 .
- (4) Calculate the major diameter of the screw thread.

2) Measurement of minor diameter:

- (1) Fix a standard cylinder of approximately same size as the nominal size of the threads between the centers of the floating carriage diameter measuring machine.
- (2) Select a best sized prism based on the type of thread and pitch from the given chart.
- (3) Insert the prisms between the measuring anvils and the standard cylinder and note down the reading of micrometer as R_1 when the fiducial indicator is at null position.
- (4) Replace the standard cylinder by the given screw thread specimen and note down the reading of micrometer as R_2 .
- (5) Calculate the minor diameter of the screw thread.

3) Measurement of effective diameter:

- (1) Fix a standard cylinder of approximately same size as the nominal size of the threads between the centers of the floating carriage diameter measuring machine.
- (2) Select a correct sized wires based on the type of thread and pitch.
- (3) Insert the wires between the measuring anvils and the standard cylinder and note down the reading of micrometer as R_1 when the fiducial indicator is at null position.
- (4) Replace the standard cylinder by the given screw thread specimen and note down the reading of micrometer as R_2 .
- (5) Calculate the Pitch value P . It is the difference between the effective pitch and diameter under the thread measuring wire. It can read from the given chart and calculated by the formula $P = 0.86602 p - d$ [for metric thread] where 'p' is the pitch and 'd' is the diameter of the thread measuring wire.
- (6) Calculate the effective diameter of the screw thread.

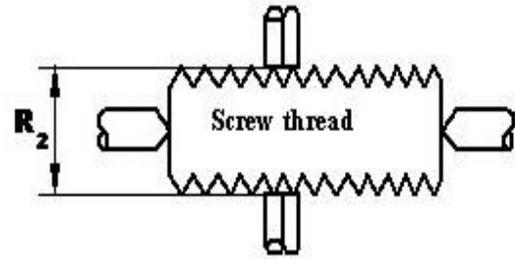
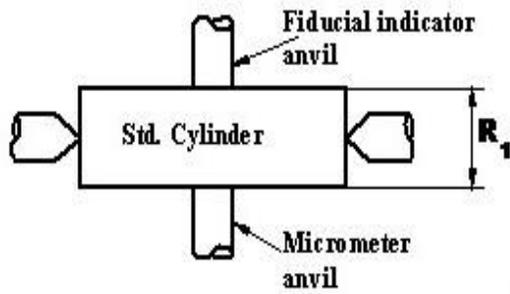
OBSERVATIONS AND CALCULATIONS:

a) Major diameter:

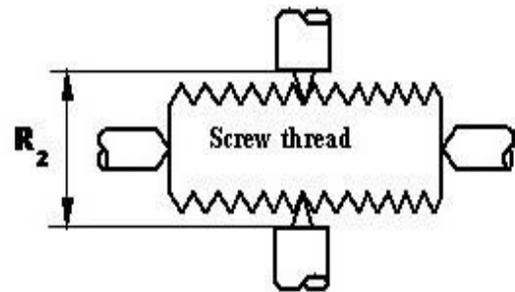
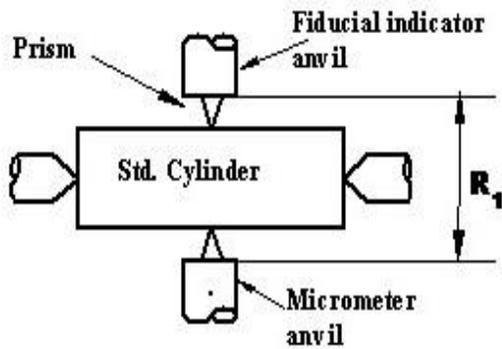
- 1) Diameter of the standard cylinder, $D =$ mm
- 2) Reading on standard cylinder, $R_1 =$ mm
- 3) Reading on threaded specimen, $R_2 =$ mm
- 4) Major diameter of threaded specimen $D_1 = D + (R_1 - R_2) =$ mm

b) Minor diameter:

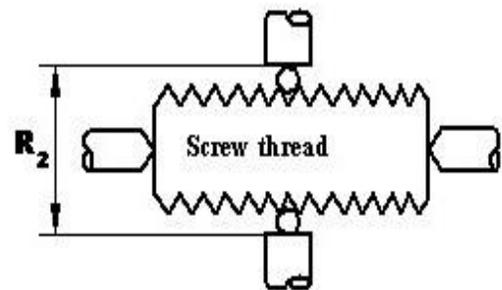
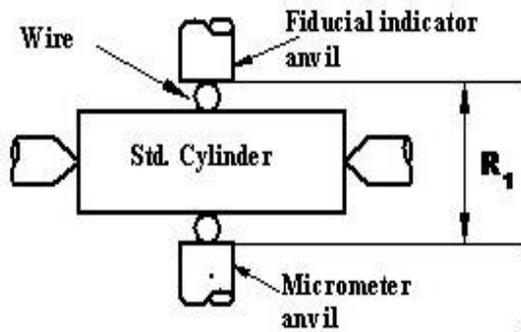
- 1) Diameter of the standard cylinder, $D =$ mm
- 2) Reading on standard cylinder, $R_1 =$ mm
- 3) Reading on threaded specimen, $R_2 =$ mm
- 4) Major diameter of threaded specimen $D_2 = D + (R_1 - R_2) =$ mm



(a) Major Diameter



(b) Minor Diameter



(c) Effective Diameter

c) Effective diameter:

- 1) Diameter of measuring wire, $d =$ mm
- 2) Pitch of the thread, $p =$ mm
- 3) Diameter of the standard cylinder, $D =$ mm
- 4) Reading on standard cylinder, $R_1 =$ mm
- 5) Reading on threaded specimen, $R_2 =$ mm
- 6) Pitch value, $P = 0.86602 p - d =$ mm
- 7) Major diameter of threaded specimen $D_3 = D + [(R_1 - P) - R_2] =$ mm

RESULT: The effective diameter of a given screw threads specimen is _____ mm.

CALCULATION:

Outcome:

Students will be able to

- State principles of floating carriage.
- Describe principle of thread measurement and parameters of threads

Viva Questions

1. What is floating carriage micrometer?
2. What is effective diameter of thread?
3. What is minor diameter of thread?
4. Define pitch.
5. Define Flank Angle?

Experiment -03

MEASUREMENTS OF SURFACE ROUGHNESS MECHANICAL COMPARATOR

AIM: To measure the deviation in values of a given specimens by using mechanical comparator.

OBJECTIVE: To check the dimensions of a given set of specimen using a mechanical comparator.

APPARATUS: Mechanical comparator (Dial indicator), Comparator stand, Slip gauges and specimens.

THEORY: Comparators are used to compare the unknown dimension with one of the reference standard. The purpose of a comparator is to detect and display the small difference between the unknown and standard. The deviations in size are detected as the displacement of sensing device. The comparator should also magnify the small input displacements. The scale used on the comparator should be linear. The various types of comparators are mechanical, optical, mechanical – optical, electrical, electronic and pneumatic, etc. dial gauge is used as a mechanical comparator. It is simple and robust in design. It can be set to be comparing any dimension easily and quickly. The major disadvantage of a mechanical comparator is that the range is small and mechanical parts have large inertia.



PROCEDURE:

- 1) Clean the comparator stand and fix the dial gauge to the stand.
- 2) Place the combination of slip gauges of specified basic size on the comparator stand.
- 3) Adjust the needle of the dial gauge such that it touches the slip gauges with some pressure.
- 4) Set the dial reading to zero.
- 5) Mark the tolerance values on either side of the zero-dial reading.

- 6) Place the given components one after the other under the dial gauge and note down the dial reading.
- 7) Find the mean and standard deviation and draw the control chart.

OBSERVATIONS AND CALCULATIONS:

- 1) Least count of dial gauge = _____ mm
- 2) Specified basic size of the component, b = _____ mm
- 3) Tolerance on the component = _____ mm
- 4) Total number of components, N = _____

TABULAR COLUMN:

Sl. No	Dial gauge reading (Deviation), d	Accepted / Rejected	Size of the component, X = (b + d)	Standard deviation, σ
1				
2				
3				
4				
5				

- 1) Mean, $X = (\Sigma X) / N$ _____
- 2) Standard deviation, $\sigma = \sqrt{(X^2/N-1)}$ _____
- 3) Upper control limit = $X + 3\sigma$ = _____
- 4) Lower control limit = $X - 3\sigma$ = _____

RESULTS: The given components are checked for deviations and are tabulated in the tabular column.

Outcome:

Students will be able to

- State principles of comparators.
- Describe dial gauges, parts and working of gauges

Viva Questions

1. What is comparator?
2. What are the types of comparators?
3. What is the LC for comparators?
4. What is the difference between comparator and measuring instruments?
5. What are the advantages of Comparator?

Experiment - 04

MEASUREMENT OF GEAR TOOTH PROFILE USING GEAR TOOTH VERNIER

AIM: To determine the thickness of gear tooth of a spur gear wheel using vernier.

OBJECTIVE: To measure the thickness and depth of the gear using gear tooth vernier

APPARATUS: Gear tooth vernier and Specimen (spur gear wheel).

Formulae: (i) Least Count = value of 1MSD / no. of divisions on the vernier scale

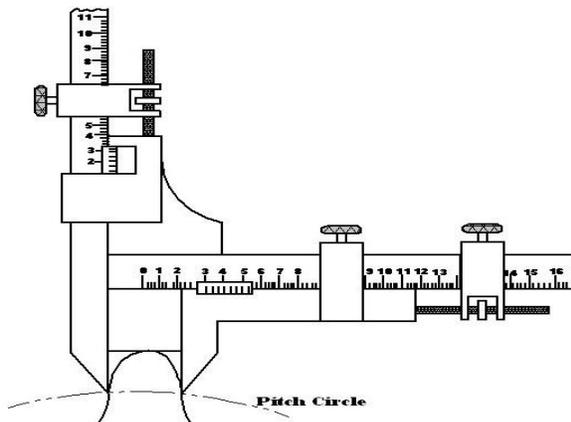
(ii) Total Reading = MSR + (CVD x LC)

THEORY: Since gear tooth thickness is defined as the length of arc, it is not possible to measure it directly. It is generally measured at pitch circle and is therefore the pitch line thickness of the tooth. In most cases, it is sufficient to measure chordal thickness. Ie, the chord joining the intersection of the tooth profile with the pitch circle.

There are various methods of measuring gear tooth thickness.

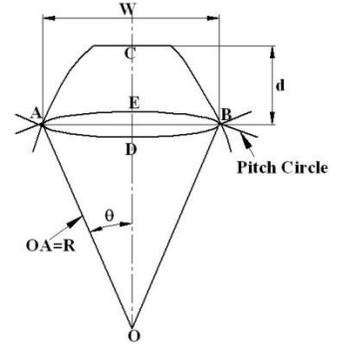
- (i) Chordal thickness method (Measurement of tooth thickness by gear tooth vernier)
- (ii) Constant chord method
- (iii) Base tangent method
- (iv) Measurement over pins or balls

In chordal thickness method, gear tooth vernier caliper can be conveniently used to measure the thickness of gear tooth at pitch line. Since gear tooth thickness varies from tip to base circle of the tooth, the instrument must be capable of measuring the tooth thickness at a specified position on the tooth. The gear tooth has two perpendicular vernier arms with vernier scales on each arm. The vertical vernier scale is used to set the depth (d) along the pitch circle from the top surface of the tooth at which the width (w) of the teeth. The caliper is so set that it slides on the top of tooth of gear under test and the lower ends of the caliper jaws touch the sides of the tooth at the pitch line. The reading on the horizontal vernier scale gives the values of chordal thickness (w) and the reading on the vertical vernier scale gives the value of chordal addendum. These measured values are then compared with the calculated values.



Consider one gear tooth, the theoretical values of w and d can be found out which may be verified by the instrument. As shown in the fig, w is a chord ADB , but the tooth thickness is specified as an arc distance AEB . Also the depth (d) adjusted on the instrument is slightly greater than the addendum CE , width (w) is therefore called chordal thickness and d is called chordal addendum.

$$w = AB = 2AD$$



In a $\Delta^{\text{le}} ADO$,

$$W = 2AD = 2 \times AO \sin \theta$$

$$= 2R \sin \frac{360}{4N}$$

$$w = 2 \times N \times \frac{m}{2} \times \sin \frac{360}{4N}$$

$$W = N \times m \times \sin \frac{90}{N}$$

(R = Pitch circle radius)

$$\text{Module, } m = \frac{\text{Pitch circle diameter}}{\text{Number of teeth}} = \frac{2R}{N}$$

$$\text{Therefore, } R = \frac{N \times m}{2}$$

Also from the figure,

$$d = OC - OD$$

Addendum is the radial distance from the pitch circle to the tip of the tooth. Its value is equal to one module.

But $OC = OE + \text{Addendum}$

$$OC = R + m$$

$$OC = \frac{Nm}{2} + m$$

Also, $OD = R \cos \theta$

$$OD = \frac{Nm}{2} \cos \frac{90}{N}$$

$$\text{Therefore, } d = \frac{Nm}{2} + m - \frac{Nm}{2} \cos \frac{90}{N}$$

$$d = \frac{Nm}{2} \left\{ 1 + \frac{2}{N} - \cos \frac{90}{N} \right\}$$

OBSERVATIONS AND TABULATIONS:

- 1) Least count of the gear tooth vernier caliper, LC = mm
- 2) Number of teeth on the gear, $N =$
- 3) Diameter of the gear blank, $D_o =$ mm
- 4) Diameter of dedendum circle, $D_i =$ mm
- 5) Pitch circle diameter, $D_p =$ mm
- 6) Module of the gear tooth, $m =$ mm

PROCEDURE:

- 1) Note down the least count of gear tooth vernier caliper and number of teeth 'N' on the gear to be tested.
- 2) Using vernier caliper, find the blank diameter and dedendum circle diameter.
- 3) Find the module 'm' of the gear teeth.
- 4) Calculate the depth 'd' of the tooth at which the tooth thickness 'w' has to be measured using the formula.

$$d = \frac{Nm}{2} \left\{ 1 + \frac{2}{N} - \cos \frac{90}{N} \right\}$$
- 5) Set the vertical scale of the gear teeth vernier to the calculated value of 'd'.
- 6) With the help of horizontal scale of the gear tooth vernier measure the tooth thickness 'w'
- 7) Compare the measured tooth thickness 'w' with that of the calculated value of 'w_c' using the formula,

$$w = N \times m \times \sin \frac{90}{N}$$

RESULT: Various parameters of spur gear wheel are measured and observations are recorded.

Sl. No	Depth 'd' mm	Measured thickness 'w _m ' mm	Calculated tooth thickness 'w _c ' mm
Gear-1			
Gear -2			
Gear -3			

CALCULATION:

Outcome:

Students will be able to

- State principles of vernier calipers.
- Describe L.C, parts and working of calipers

Viva Questions

1. What are the applications of Gear tooth vernier caliper?
2. How do we check the profile of a Gear tooth?
3. What are the methods available for measuring gear profile?
4. What is Pitch?
5. Define Module?

Experiment - 05

CALIBRATION OF MICROMETER USING SLIP GAUGES

AIM: To calibrate the given micrometer using set of slip gauges.

OBJECTIVE: To evaluate the given micrometer using set of slip gauges

APPARATUS: Micrometer and set of slip gauges.

Formulae: (i) Least Count = Pitch / no. of divisions on the head scale

(ii) Total Reading = PSR + (HSR x LC)

(iii) Error = $R_a - R_m$

(iv) % Error = $\frac{(R_a - R_m) \times 100}{R_a}$

THEORY: Micrometer is one of the common precision linear measuring instruments. The operation of micrometer depends upon the principle that the distance moved by the nut along the screw is proportional to the number of revolutions made by the nut, therefore by controlling the number of revolutions and fractions of a revolution made by a nut, the distance it moves along the screw can be accurately predicted.

Many types of errors are indicated while manufacturing micrometers. Pitch errors are most common among all errors. Pitch errors are errors in effective diameter of helix measured parallel to the axis of screw thread and are of mainly two types –progressive and periodic errors.

1) Progressive errors:

If the pitch of the thread is uniform but is longer the shorter than its nominal value, such a type of errors is called as progressive errors. Progressive errors progressive in nature and increases as the length of axis increases. These errors occur when,

- i) Tool work velocity ratio is incorrect.
- ii) Change in length due to hardening by error in the pitch of lead screw.
- iii) Due to fault in saddle guide ways.
- iv) Due to casing of an incorrect gear train between work and tool.

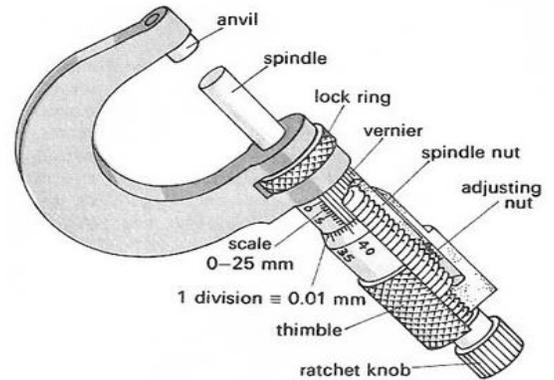
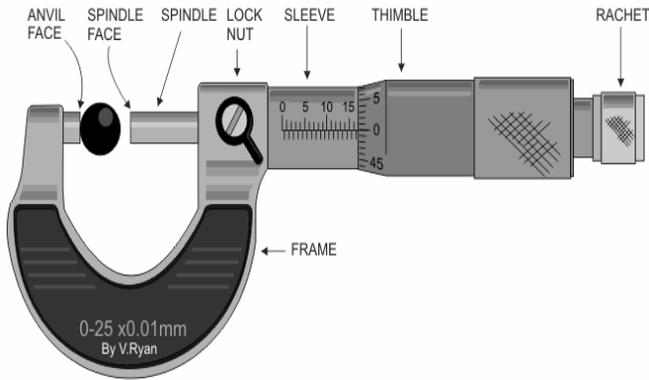
2) Periodic errors:

Periodic errors are those which vary in magnitude along the length of the thread and repeats at regular intervals. The deviation from the true helix occurs an adjacent thread at the same fraction of revolution but the pitch remains constant and such errors will not be detected by measurement along e line parallel to the axis. Errors of this type are most frequently caused by lack of squareness in the thrust bearing of the lead screw used to produce the thread.

Some possible sources of errors which may result the incorrect functioning of the instrument are

- (i) Lack of flatness of the anvils.
- (ii) Lack of parallelism of the anvils.

- (iii) Inaccurate setting of the zero reading.
- (iv) Inaccurate reading followed by the zero position.
- (v) Inaccurate reading shown by the fractional divisions on the thimble.
- (vi) Errors in micrometer screw threads.



TABULAR COLUMN:

(a) Progressive Error

Sl. No.	Readings (mm)		Error (mm)	% Error
	Actual Reading (R_a)	Measured Reading (R_m)		

(b) Periodic Error

Sl. No.	Readings (mm)		Error (mm)	% Error
	Actual Reading (R_a)	Measured Reading (R_m)		

PROCEDURE:

- 1) Clean the anvils and check the micrometer for zero reading.
- 2) Note down the least count of the micrometer.
- 3) For progressive error, take readings of micrometer by placing the slip gauges from 2.5mm to 20mm in steps of 2.5mm.
- 4) For periodic error, take readings of micrometer by placing the slip gauges from 2.1mm to 2.4mm in steps of 0.1mm and from 20mm to 20.4mm in steps of 0.1mm.
- 5) Record the readings of slip gauges [measured reading] to the corresponding micrometer readings [actual reading].
- 6) Calculate the error and % error.
- 7) Plot the graph of error v/s actual reading for both the type of errors.

RESULT: The given micrometer is calibrated and the corresponding readings are recorded and tabulated in the tabular column.

GRAPHS: (i) Progressive Error v/s Actual reading
(ii) Periodic Error v/s Actual reading

CALCULATION:

Outcome:

Students will be able to

- State principles of micrometer.
- Describe L.C, parts and working of micrometer

Viva Questions

1. What are the applications of micrometer?
3. What are the methods available for measuring L.C?
4. What is Pitch?
5. Define Module?

Experiment – 06

MEASUREMENT USING OPTICAL FLATS

AIM: To determine whether the given surface is flat or curved by using optical flat and monochromatic light source.

OBJECTIVE: To evaluate and to be used as a reference against which the flatness of an unknown surface may be compared

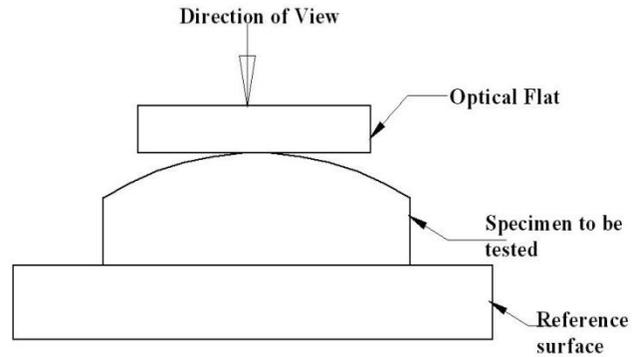
APPARATUS: Monochromatic light source, Optical flat and specimen.

Formulae: (i) Flatness Error = $\frac{n \lambda}{2}$

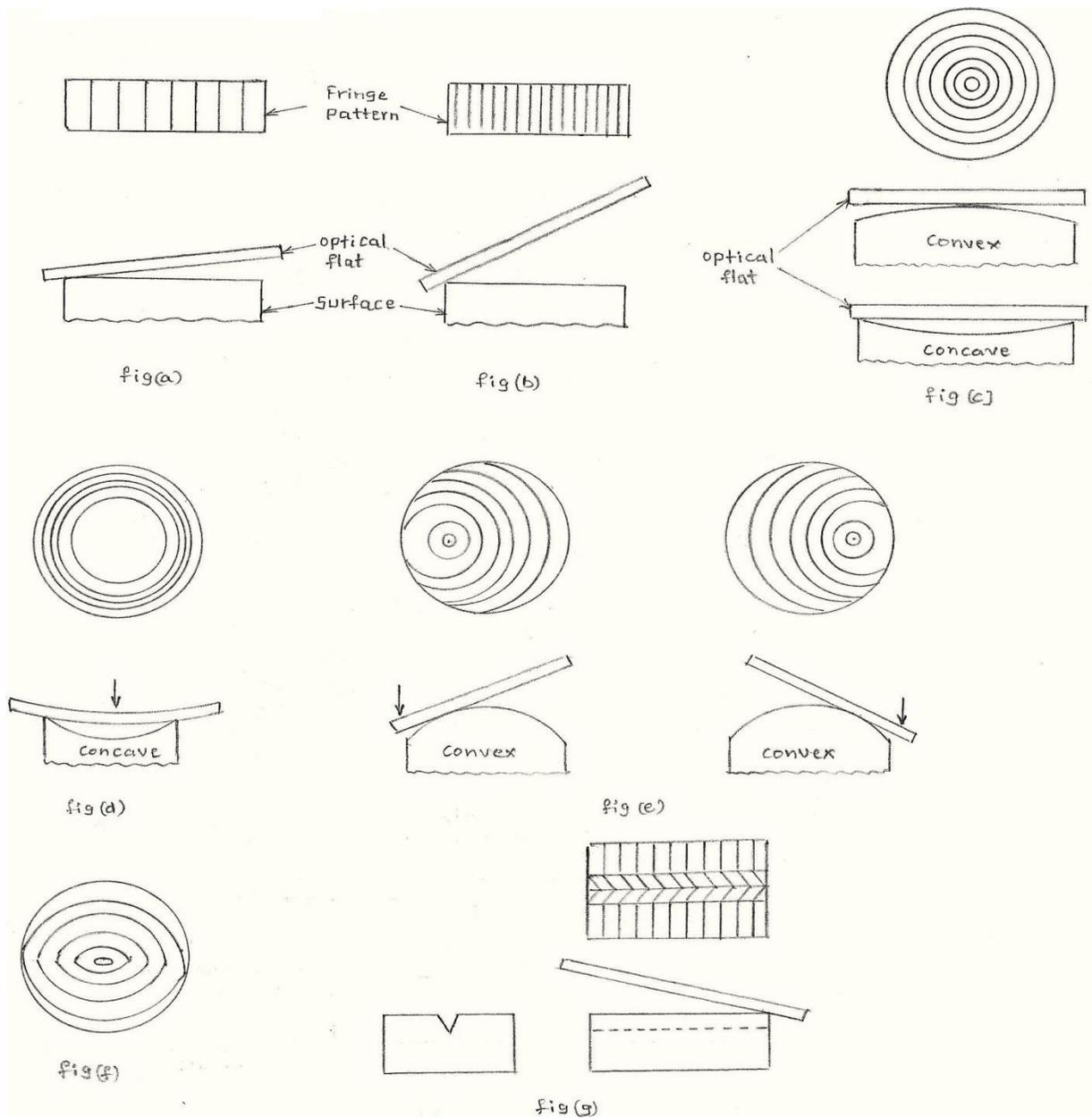
THEORY: A source emitting light of single color or wavelength is called monochromatic (which eliminates all the colors except yellowish color or orange). It is used test the metallic components to inspect the surface quality. An optical flat is circular piece of unstressed glass or quartz usually about 5cm in diameter or more and with the thickness of about 1/6th of the diameter. They are made of transparent materials such as quartz, glass, sapphire etc. The upper and lower surfaces are ground optically flat to get reference planes. An arrow is made on the flat to indicate the finished surface. They provide the most advantageous combination of precision and accuracy of measurement. Optical flats are made in a range of sizes, shapes and materials. Materials range from inexpensive glass to very expensive sapphire. However, high quality optical quartz or borosilicate glasses are most commonly used because of its hardness, low coefficient of thermal expansion, resistance to corrosion and much longer useful life. Sometimes the flats can be coated with thin film of titanium oxide to reduce the light lost by reflection which makes the band more clear. The yellow orange light radiated by helium gas is most satisfactory for use with optical flat. Optical flats are of two types; type A has only one flat surface while type B has two parallel flat surfaces.

Cleanliness is of tremendous importance in optical flat measurements. Even a stray particle of dust might settle on the part before the flat is placed over it can result in inaccurate measurement. Hence it is an advisable to use lint free paper or cloth for cleaning the optical flat and the surfaces of the parts to be checked. Temperature changes are more apparent when using optical time to regain the ambient temperature.

When an optical flat is placed on a surface to be tested and illuminated monochromatic light, interference fringes. Ie. Alternate dark and bright bands are observed. These are produced by the interference of light rays reflected from bottom face of the optical flat and top surface of the test piece through a very thin layer of air entrapped between the two surfaces. If the surfaces under test are perfectly flat there will be patterns alternate light and dark straight, parallel and equally spaced bands on the surface and even after applying light pressure at any edge there will not be change in the fringe pattern. However, if the surface to be tested is not flat, the bands obtained will be curved. If the bands curved around the point or line of contact, the surface is convex and if the bands curve in opposite direction, the surface is concave. If the curvature of bands is more convexity and vice versa.



The patterns at (a) and (b) represent flat surfaces. The difference in spacing of the fringes represents different inclinations of the optical flat to the surface. The inclination of the optical flat is more in case of (b) when compared to (a). The circular concentric fringes with decreasing diameter at (c) represent a spherical surface of either convex or concave nature. To determine whether the surface is convex or concave, light finger pressure may be applied at the centre of the rings. If the fringes move away from the centre as shown in (d), then the surface will be concave. A test for convexity is to press lightly at opposite edges alternately, as shown in fig (e), thereby rocking the optical flat and causing the centre rings to move to and fro. Figure (f) shows a surface which is curved in more in one direction than the other. Finally, the fig (g) indicates the pattern over a vee block.



OBSERVATIONS:

- 1) Type of light source used =
- 2) Wavelength of light source used = mm

Sl. No	No. of fringes observed, n	Flatness Error $\frac{n \lambda}{2}$	Remarks on the type of surface
1			
2			
3			
4			

PROCEDURE:

- 1) Switch on the monochromatic light source and wait till yellowish or orange color light is obtained.
- 2) The specimen with a polished surface is placed on the worktable so that incident rays are reflected.
- 3) The optical flat is placed on the specimen and the position is adjusted to obtain the fringes.
- 4) Count the number of fringes obtained and calculate the flatness error.
- 5) Depending on the fringe pattern, the type of surface can be determined by comparing it with standard chart.

RESULTS: The flatness of a given surface is determined by using optical flat and monochromatic light and observed fringes are shown in fig.

Outcome:

Students will be able to

- State principles of optical flats.
- Describe concept of interference and diffraction

Viva Questions

- 1) What is monochromatic light? And mention its use.
- 2) Define optical flat. It is made of _____ material.
- 3) Write down the fringe patterns for flat, concave and convex surfaces.
- 4) What is the function of coating the optical flat with thin film of titanium oxide?
- 5) What is the wavelength of monochromatic light?

Viva- Voce Questions

Pressure Gauge

- 1) Define pressure and mention the unit.
- 2) Define atmospheric pressure, Vacuum pressure, Gauge pressure.
- 3) List the commonly used materials for manufacturing diaphragms.

Thermocouple

- 1) Define thermocouple and how it is made?
- 2) What is hot and cold junction?
- 3) Mention the effects which play the role in thermocouples.
- 4) Name three emf's present in a thermoelectric circuit.
- 5) Name the materials used to make the following types of thermocouples, J, K, T, E, S & R and mention their temperature ranges also.
- 6) How RTD is made?
- 7) What are the commonly used materials in RTD as a resistance element?
- 8) What is thermopile and thermistor?

LVDT

- 1) How LVDT is made? And what is function of primary and secondary coils?
- 2) Define Null position of a core.
- 3) Name the material used to prepare a core.

Load Cell

- 1) Define load.
- 2) How the load cell is made?
- 3) Define gauge factor or sensitivity of a strain gauge.

Strain Gauge

- 1) Define gauge factor?
- 2) What do you mean by full bridge, half bridge and quarter bridge circuits?
- 3) Define stress, strain and modulus of elasticity with units.
- 4) Name the adhesive used for connecting the strain gauge to the member to be deformed.
- 5) Define bending or flexural stress.
- 6) Write the bending equation and mention the terms with units.
- 7) Why it is necessary to warm up the strain gauges after some period of time while it is rest?

Tool Makers Microscope

- 1) Define major diameter, minor diameter, depth, pitch and angle of a thread.
- 2) Briefly explain the construction of tool maker's microscope.
- 3) Mention the uses of tool maker's microscope.

Sine Bar

- 1) What is the principle of sine bar?
- 2) Mention the uses of sine bar.
- 3) What are the limitations of sine bar?

- 4) What is the purpose of providing relief holes on the sine bar?
- 5) Name the material used to make sine bar.
- 6) What is wringing of slip gauges?
- 7) Name some of the standards for angular measurements.
- 8) How to measure taper angle of a conical work piece using sine bar?
- 9) What do you mean by included angle?

Sine Centre

- 1) What is the principle of sine centre?
- 2) What is the difference between sine bar and sine centre?
- 3) Can we inspect wedge objects using sine centre?
- 4) Do you think that sine centre is a measuring device when we use it alone?
- 5) What type of angle that you will measure using sine centre?

Bevel Protractor

- 1) What is the unit for angle in sexagesimal system?
- 2) Name some of the angular measuring devices.
- 3) What are the types of bevel protractors?
- 4) Briefly explain the construction and working of a vernier bevel protractor.

Autocollimator

- 1) What is the use of autocollimators?
- 2) Define focal length.

Lathe tool Dynamometer

- 1) What is the use of lathe tool dynamometer?
- 2) Name the forces acting on a cutting tool used in tool while performing any operation.
- 3) Write the Mohr's circle diagram and mention the forces in that.
- 4) Define speed, feed, depth of cut, cutting velocity and power in cutting.

Two Wire method

- 1) Define effective diameter of a screw thread.
- 2) What is the function of fiducial indicator?
- 3) Why the instrument is called as floating carriage micrometer?
- 4) Briefly explain the construction and working of floating carriage micrometer.
- 5) Why do you need prisms for measuring minor diameter?
- 6) What are the least count values of a scale on thimble and vernier scale of a micrometer?
- 7) Write down the total reading formula.
- 8) Define pitch value.

Mechanical Comparator

- 1) Give four examples for mechanical comparator.
- 2) What are the types of mechanisms used for magnification in mechanical comparators?
- 3) What type of mechanism is used for magnification in dial indicator?

Gear tooth vernier

- 1) Define various elements of a spur gear.
- 2) Define gear tooth thickness.
- 3) Mention the various methods of measuring the gear tooth thickness.
- 4) Define module.

Micrometer Calibration

- 1) What is wringing of slip gauges?
- 2) What are the types of errors?
- 3) What are the sources of errors in slip gauges?
- 4) Name the material and process used to prepare slip gauges.
- 5) What are precautions necessary to take to prevent the damage of slip gauges?

Optical flat

- 6) What is monochromatic light? And mention its use.
- 7) Define optical flat. It is made of _____ material.
- 8) Write down the fringe patterns for flat, concave and convex surfaces.
- 9) What is the function of coating the optical flat with thin film of titanium oxide?
- 10) What is the wavelength of monochromatic light?