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Metrology & Measurement

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Contents

Preface

Nowadays, trade is leading to a greater awareness worldwide of the role that dimensional and mechanical measurement plays in underpinning activities in all areas of science and technology. It provides a fundamental basis not only for the physical sciences and engineering, but also for chemistry, the biological sciences and related areas such as the environment, medicine, agriculture and food. Laboratory programmes have been modernized, sophisticated electronic instrumentation has been incorporated into the programme and newer techniques have been developed. Keeping these views in mind, this book is written which deals with not only the techniques of dimensional measurement but also the physical aspects of measurement techniques.

In today's world of high-technology products, the most important requirements of dimensional and other accuracy controls are becoming very stringent as a very important aspect in achieving quality and reliability in the service of any product in dimensional control. Unless the manufactured parts are accurately measured, assurance of quality cannot be given. In this context, the first part of the book deals with the basic principles of dimensional measuring instruments and precision measurement techniques. This part of the book starts with discussing the basic concepts in metrology and measurement standards in the first two introductory chapters. Then, linear, angular, machine tool and geometrical shape metrology along with interferometry techniques and various types of comparators are explained thoroughly in the subsequent chapters. Concepts of limits, fits and tolerances and measurement of surface finish are illustrated in detail. Chapters 11 and 12 discuss the metrology of standard machine parts like screw threads and gears respectively. Miscellaneous measurement and recent advancements in the field of metrology are discussed in the last two chapters of the first part of the book.

The second part of this book begins with the explanation of measurement systems and transducers. The methods of measuring mechanical quantities, viz., force, torque, vibration, pressure, temperature, strain and flow measurement are discussed subsequently, covering both the basic and derived quantities. Effort has been made to present the subject in SI units. Some of the recent developments such as use of laser techniques in measurement have also been included.

The Online Learning Center of the book can be accessed at http://www.mhhe.com/bewoor.mm and contains the following material:

For Instructors

- Solution Manual
- PowerPoint lecture slides
- Full-resolution figures and photos from the text
- Model syllabi

For Students

- Interactive quiz
- Objective-type questions

Our objective is to provide an integrated presentation of dimensional and mechanical measurement. This book has been developed in recognition not only with the interdisciplinary nature of engineering practice, but also with the trend in engineering curriculum. The authors have consistently crafted a text such that it gives the reader a methodical and well-thought-out presentation that covers fundamental issues common to almost all areas of dimensional and mechanical measurement. Information on particular instruments and concepts has been combined to improve the logical flow of the manuscript. The coverage is such that the book will be useful both for post-graduate, graduate, polytechnic engineering ITI students and other graduation-level examinations (like AMIE), and competitive examinations and entrance examinations like GATE. We believe that the concise presentation, flexible approach readily tailored to individual instructional needs and the carefully structured topics of the book allow the faculty a wide scope in choosing the coverage plan for students and will prove to be a good resource material for teachers. It would also be equally helpful to professionals and practicing engineers in the field of design, manufacturing and measurement.

We wish to acknowledge our special thanks to measurement instrument manufacturers', viz., M/s Mahr Gmbh for permitting us to use the figures from their product catalogue in the present text. We owe our gratitude to many of our colleagues and the management of Vishwakarma Institute of Information Technology, Pune; Sinhgad College of Engineering, Pune; and D Y Patil College of Engineering, Akurdi. We extend our sincere thanks to all experts for giving introductory comments in the chapters, something which we feel will motivate the reader to study the topic. We also wish to thank the following reviewers who took out time to review the book. Their names are given below.

Ajay G Chandak	Jankibai Trust "Shamgiri', Deopur Dhule, Maharashtra
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We are very much grateful to our family members for their patience, encouragement and understanding. Thanks are also due to many individuals in Tata McGraw-Hill Education Private Limited who have contributed their talents and efforts in bringing out this book.

Suggestions and feedback to improve the text will be highly appreciated. Please feel free to write to us at anandbewoor@rediffmail.com and kulkarnivinay@rediffmail.com.

Anand K Bewoor

Vinay A Kulkarni

List of Important Symbols

H : Combination slip gauge set
ΔL : Change in conductor length
V : Excitation voltage
L : Length (m)
L : Fixed distance between two roller centers of Sine-Bar
n : Number of half wavelengths
N_f : Nominal fraction of the surface
R : Resistance of a conductor
ρ : Resistivity
β : Experimentally determined constant for a given thermistor material,(generally in order of 4000)
Δa : Average Absolute Slope
λa : Average Wavelength
Δq : RMS Average Slope
λq : RMS Average Wavelength
θ : Angular postposition
ϕ : Pressure angle
K : Kelvin
°R : Rankine
C : Constant
D : Depth of the thread
D_b : Constant pitch value
E : Effective diameter
F : Force
f_b : Lead error
f_n : Natural frequency
f_p : Accumulated pitch error
f_{pb} : Normal pitch error
f_{pt} : Single pitch error
Fr : Run-out error of gear teeth
GF : Gauge factor
H : Chordal addendum on gear at which magnitude of 'W' is to be measured respectively

K	: Stiffness
L_o	: Actual Profile Length/Profile Length Ratio
m	: Mass of the body
m	: module = (Pitch circle diameter)! (No. of teeth) = $2R/z$
P	: Pitch of the thread
p	: Constant pitch value
Pc	: Peak count
r	: Radius at the top and bottom of the threads
R	: Resistance at the measured temperature, t
Ro	: Resistance at the reference temperature, t_o
R_1, R_2, R_3, R_4	: Resistance
R_a	: Average roughness value
R_{ku}	: Measure of the sharpness of the surface profile
R_{max}	: Maximum height of unevenness/maximum peak to valley height within a sample length
Rp	: Maximum peak height
Rq	: Root mean square roughness
R_{sk}	: Measurement of skewness
R_v	: Maximum valley height
Rz(ISO)	: Sum of the height of the highest peak plus the lowest valley depth within a sampling length
Rz(JIS)	: The ISO I O-point height parameter in ISO
S	: Number of tooth space contained within space 'W'
Sk	: Skewness
Sm	: Mean spacing
T	: Dimension under the wires
T_0	: Reference temperature generally taken as 298 K (25°C)
Vo	: Output voltage
W	: Chordal tooth thickness
x	: Displacement
z	: Number of teeth on gear
σ	: Standard deviation
μ	: Micron
$\delta\theta$	: Small angle (increment/change)
$\alpha\beta\theta$	: Angles

List of Important Abbreviations

AA : Arithmetic average
ADC : Analog-to-Digital Converter
AF : Audio Frequency
AFD : Amplitude Distribution Function
AM : Amplitude Modulation
BIPM : International Bureau of Weights and Measures
BIS : Bureau of Indian Standards
BS : British Standards
CIM : Computer Integrated Manufacturing
CIPM : International Committee for Weights and Measures
CMM : Coordinate Measuring Machines
CNC : Computer Numerical Controls
DAC : Digital-to-Analog Converter
DAQs : Data Acquisition Devices
DIP : Dual In-line Package
DNL : Differential Non-Linearity
DPM : Standard Digital Panel Meter
EWL : Effective Working Length
FD : Fundamental Deviations
FM : Frequency Modulation
HSC : High Spot Count
I/O : Input/Output
IC : Integrated Circuit
ID : Internal Diameter
INL : Integral Non-Linearity
IPTS : International Practical Temperature Scale
IR : Infrared
ISO : International Organization for Standards
LC : Least Count
LCD : Liquid Crystal Display
LVDT : Linear Variable Differential Transformer
MEMS : Microelectromechanical Systems
NBS : National Bureau of Standards
NTC : Negative Temperature Coefficient Thermistors
OD : Outer Diameter
Op-amp : Operational Amplifier
PSI : Pounds Per Square Inch
PTC : Positive Temperature Coefficient Thermistors
QS : Quality System
RMS : Root Mean Square
RSM : Remote Sensing Module
RTDs : Resistance Temperature Devices
SAR : Successive-Approximations Register
SI : International System of Units
SINAD : Signal-to-Noise Distortion Ratios
SIP : Single In-line Package
SNR : Signal-to-Noise Ratios
SPC : Statistical Process Control
UUT : Unit Under Test

VISUAL WALKTHROUGH

2 Measurement Standards

"Precision is religion and measurement standards make it happen!"
Arun Kudale, MD, Kudale Calibration Laboratory (P) Ltd., Pune

WHAT ARE MEASUREMENT STANDARDS?

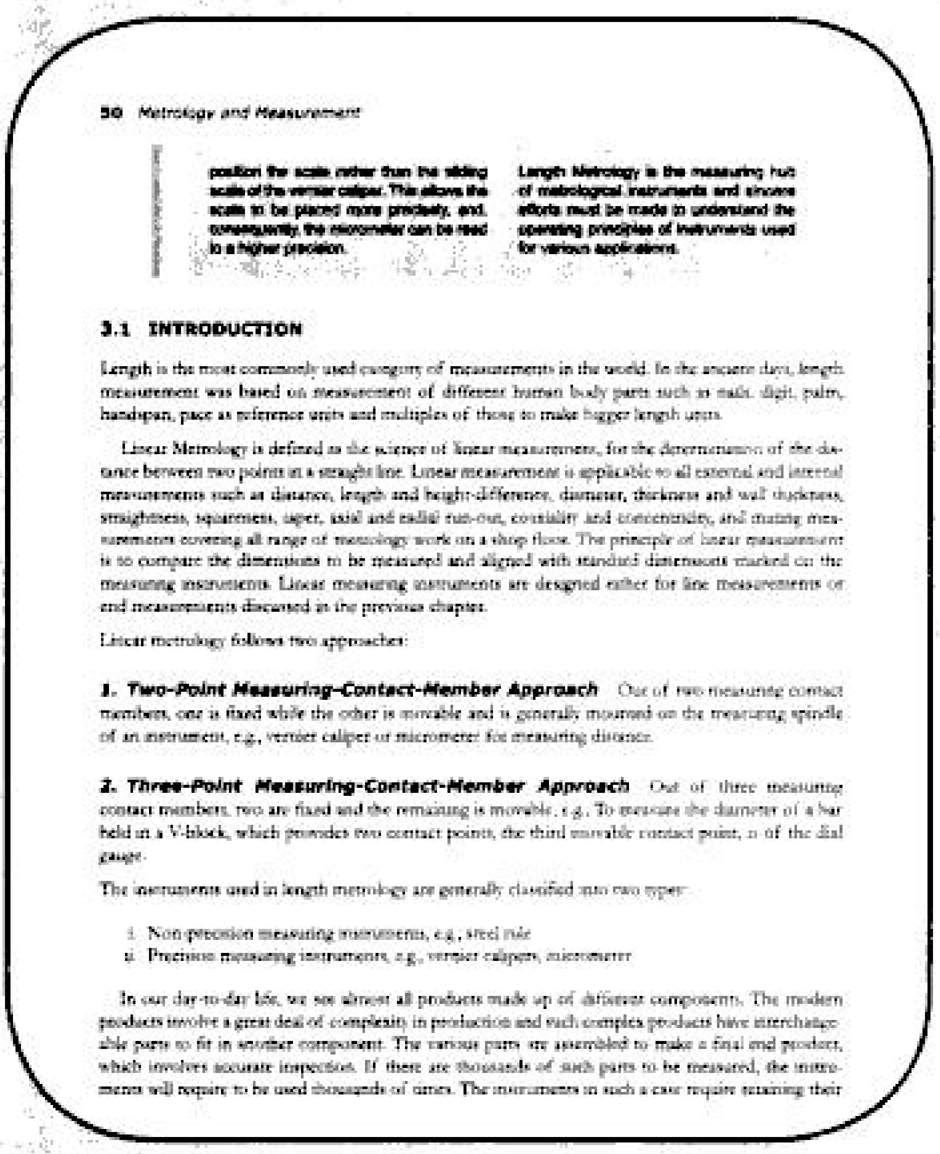
Line and End standards are referred as 'measurement standards' in industries, which are used as references for calibration purpose. In the modern metrological era, digital instruments such as a periodically calibrated digital height gauge are commonly used. In India, light wave standards (wavelength) are used for laboratory purposes only and are not commercially used. Owing to its cost LASER is restricted in use for alignment testing and assessment of movement of subassemblies only.

In general, there are four levels of standards used as references all over the world, viz., primary, secondary, tertiary and working standards. Primary standard is the one that is kept in Paris and secondary is the one kept with NPL India; tertiary standard is the standard, which we use in our industries as a reference for calibration purpose. Working standards are used on the shop floor. Hence it could be said that there is an unbroken chain for tracing the standards. Every country has a custodian who looks after secondary standards. The National Physical Laboratory (NPL) holds the secondary standard for India. My company holds tertiary standards and is accredited by the National Accreditation board for Testing and Calibration Laboratories. The type of standards being calibrated will govern the use of primary/secondary standards as a reference, e.g., slip gauges are calibrated once in three years. Determination and confirmation of length and calibration must be made under specified conditions. The National Accreditation board for Testing and Calibration Laboratories specifies that a calibration laboratory should be adequately free from vibrations generated by the central air-conditioning plant vehicular traffic and other sources. In other words, there should be vibration-free operational conditions, the illumination should be 450 lux to 700 lux on the working table with a glass index of 19 for lab work, a generally dust-free atmosphere, temperature should be controlled between 20 ± 1°C and humidity should be controlled between 50 ± 10%. To avoid any such adverse effect on instruments, a calibration laboratory is required to be set underground.

In our opinion, quality should be built up at the design stage, which is an important

Introductory Quotation

Each chapter begins with an introductory quotation (by an eminent personality in the respective field) that is not only motivating but also gives the importance of the subject matter of the chapter.



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position the scale rather than the sliding scale of the vernier caliper. This allows the scale to be placed more precisely, and, consequently, the micrometer can be read to a higher precision.

Length Metrology is the measuring hub of metrological instruments and sincere efforts must be made to understand the operating principles of instruments used for various applications.

3.1 INTRODUCTION

Length is the most commonly used category of measurements in the world. In the ancient days, length measurement was based on measurement of different human body parts such as nails, digit, palm, handspan, pace as reference units and multiples of those to make bigger length units.

Linear Metrology is defined as the science of linear measurement, for the determination of the distance between two points in a straight line. Linear measurement is applicable to all external and internal measurements such as distance, length and height-difference, diameter, thickness and wall thickness, straightness, squareness, taper, axial and radial run-out, coaxiality and concentricity, and mating measurements covering all range of metrology work on a shop floor. The principle of linear measurement is to compare the dimensions to be measured and aligned with standard dimensions marked on the measuring instruments. Linear measuring instruments are designed either for line measurements or end measurements discussed in the previous chapter.

Linear metrology follows two approaches:

1. Two-Point Measuring-Contact-Member Approach Out of two measuring contact members, one is fixed while the other is movable and is generally mounted on the measuring spindle of an instrument, e.g., vernier caliper or micrometer for measuring distance.

2. Three-Point Measuring-Contact-Member Approach Out of three measuring contact members, two are fixed and the remaining is movable, e.g., To measure the diameter of a bar held in a V-block, which provides two contact points, the third movable contact point, is of the dial gauge.

The instruments used in length metrology are generally classified into two types:

i. Non-precision measuring instruments, e.g., steel rule
ii. Precision measuring instruments, e.g., vernier calipers, micrometer

In our day-to-day life, we see almost all products made up of different components. The modern products involve a great deal of complexity in production and such complex products have interchangeable parts to fit in another component. The various parts are assembled to make a final end product, which involves accurate inspection. If there are thousands of such parts to be measured, the instruments will require to be used thousands of times. The instruments in such a case require retaining their

Introduction

Each chapter begins with an introduction that gives a brief summary of the background and contents of the chapter.

Sections and Sub-sections

Each chapter has been neatly divided into sections and sub-sections so that the subject matter is studied in a logical progression of ideas and concepts.

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11.4 MEASUREMENT OF SCREW THREADS

1. Geometrical Parameter

a. Major Diameter — Bench Micrometer

b. Minor Diameter — Bench Micrometer

c. Thread angle and profile — Optical Profile Projector, Pin Measurement

2. Functional Parameters

a. Effective Diameter — Screw Threads Micrometer, Two-or Three-wire methods, Floating Carriage Micrometer

b. Pitch — Screw Pitch Gauge, Pitch Error Testing Machine

Measurement of screw threads can be done by inspection and checking of various components of threads. The nut and other elements during mass production are checked by plug gauges or ring gauges.

11.4.1 Measurement of Major Diameter

A bench micrometer serves for measuring the major diameter of parallel plug screw gauges. It consists of a cast-iron frame on which are mounted a micrometer head with an enlarged thimble opposite a fiducial indicator; the assembly makes a calliper by which measurements are reproducible within ±0.001 mm (±0.00005 in). The micrometer is used as a comparator. Thus, the bench micrometer reading R_B is taken on a standard cylindrical plug of known diameter B of about the same size as the major diameter to be measured. A reading R_G is then taken across the crests of the gauge. Its major diameter D is given by $D = B + R_B - R_G$

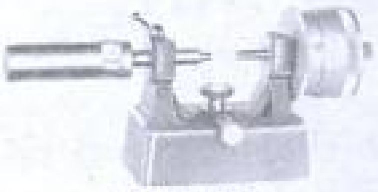


Fig. 11.9 *Bench micrometer*

Readings should be taken along and round the gauge to explore the variations in major diameter. Finally, the reading R_s on the standard should be checked to confirm that the original setting has not changed. It is recommended that the measurement should be repeated at three positions along the thread to determine the amount of taper which may be present.

11.4.2 Measurement of Minor Diameter

For checking the minor diameter, the anvil end and spindle end have to reach roots on opposite sides, but it doesn't happen. Therefore, the wedge-shaped pieces are held between the anvil face root of the thread and spindle face root of the thread. One reading is taken over a dummy minor diameter

Illustrative Examples

Example 1 *Design a plug gauge for checking the hole of 70H_8. Use $i = 0.45\sqrt[3]{D} + 0.001D$, $IT_8 = 25i$, Diameter step = 50 to 80 mm*

Solution: Internal dimension = 70H_8, $d_1 = 50$, $d_2 = 80$

$$D = \sqrt{d_1 \times d_2} = \sqrt{50 \times 80} = 63.245 \text{ mm}$$

$$i = 0.45\sqrt[3]{63.245} + 0.001D = 1.8561 \text{ micron}$$

Tolerance for $IT_8 = 25i = 25 \cdot 1.8561 = 46.4036$ microns

Hole dimensions

GO limit of hole = 70.00 mm

NO GO limit of hole = 70.00 + 0.04640 = 70.04640 mm

GO plug gauge design

Workmanship allowance = 10 % hole tolerance = 10/100 × 0.4640 = 0.004640 mm

Hole tolerance is less than 87.5 micron. It is necessary to provide wear allowance on a GO plug gauge.

Lower limit of GO = 70.000 mm

Upper limit of GO = 70.0000 + 0.004640 = 70.00464 mm

Sizes of GO = 70 [illegible]

NO GO plug gauge

Workmanship allowance = 0.004640

NO GO Sizes = 70 [illegible] = 70 [illegible]

Example 2 *Design and make a drawing of general purpose 'GO' and 'NO-GO' plug gauge for inspecting a hole of 22 D8. Data with usual notations:*

i. i (microns) = $i = 0.45\sqrt[3]{D} + 0.001D$

ii. Fundamental deviations for hole D = $16^{0.44}$.

iii. Value for IT8 = 25i

Example 3 *Design a 'Workshop' type GO and NO-GO Gauge suitable for 25 H_7. Data with usual notations:*

1. i (in microns) = $i = 0.45\sqrt[3]{D} + 0.001D$

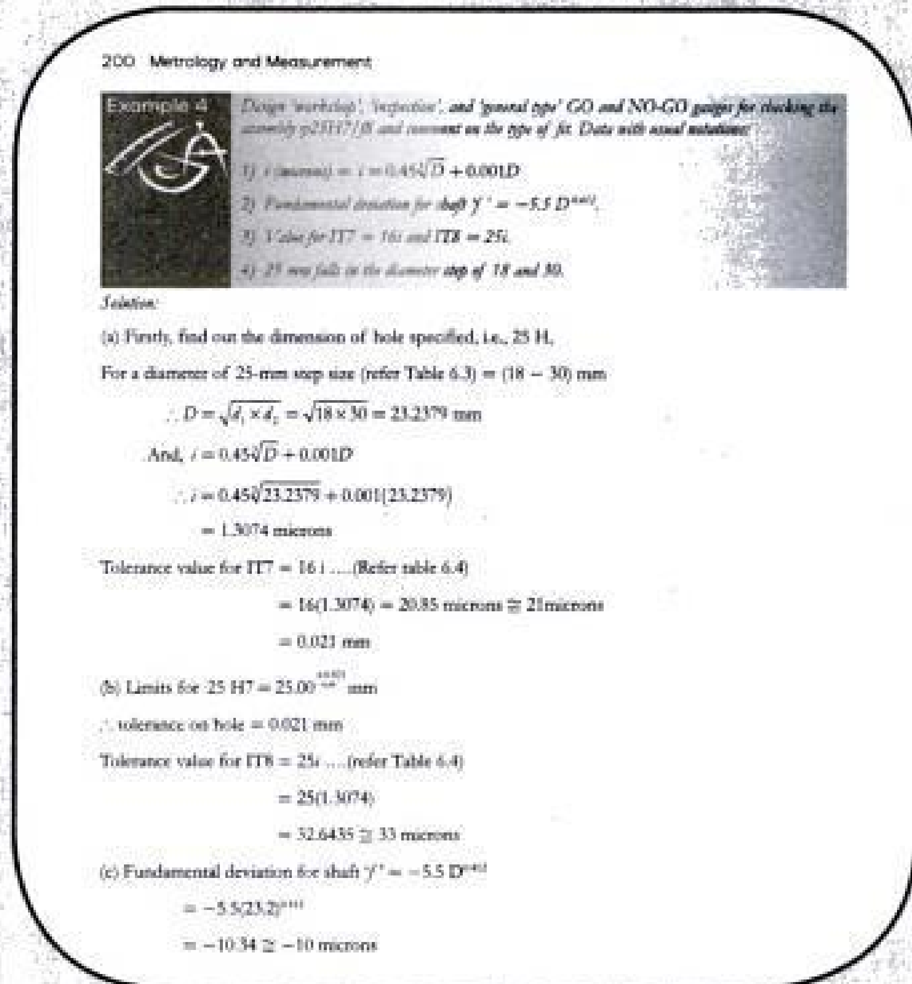
2. The value for IT7 = 16i.

Solution:

(a) Firstly, find out the dimension of hole specified, i.e., 25 H7.

Illustrative Examples

Illustrative Examples are provided in sufficient number in each chapter and at appropriate locations, to aid in understanding of the text material.



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Example 4 *Design 'workshop', 'inspection', and 'general type' GO and NO-GO gauges for checking the assembly φ25H7/f8 and comment on the type of fit. Data with usual notations:*

1) i (microns) = $i = 0.45\sqrt[3]{D} + 0.001D$

2) Fundamental deviation for shaft 'f' = $-5.5\,D^{0.41}$.

3) Value for IT7 = 16i and IT8 = 25i.

4) 25 mm falls in the diameter step of 18 and 30.

Solution:

(a) Firstly, find out the dimension of hole specified, i.e., 25 H,

For a diameter of 25-mm step size (refer Table 6.3) = (18 − 30) mm

$\therefore D = \sqrt{d_1 \times d_2} = \sqrt{18 \times 30} = 23.2379$ mm

And, $i = 0.45\sqrt[3]{D} + 0.001D$

$\therefore i = 0.45\sqrt[3]{23.2379} + 0.001(23.2379)$

= 1.3074 microns

Tolerance value for IT7 = 16 i ….(Refer table 6.4)

= 16(1.3074) = 20.85 microns ≅ 21microns

= 0.021 mm

(b) Limits for 25 H7 = $25.00^{+0.021}_{-0.0}$ mm

∴ tolerance on hole = 0.021 mm

Tolerance value for IT8 = 25i ….(refer Table 6.4)

= 25(1.3074)

= 32.6435 ≅ 33 microns

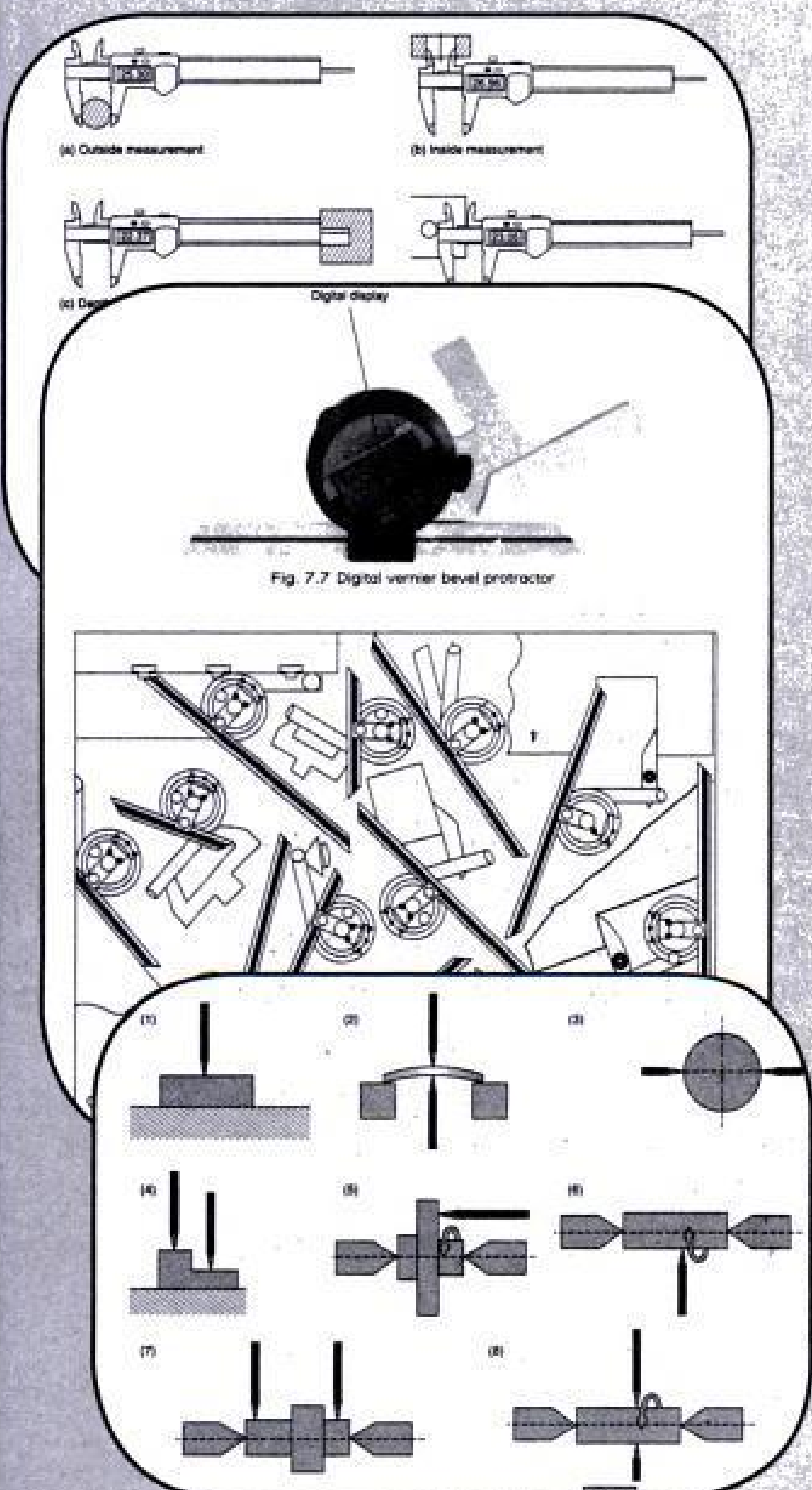
(c) Fundamental deviation for shaft 'f' = $-5.5\,D^{0.41}$

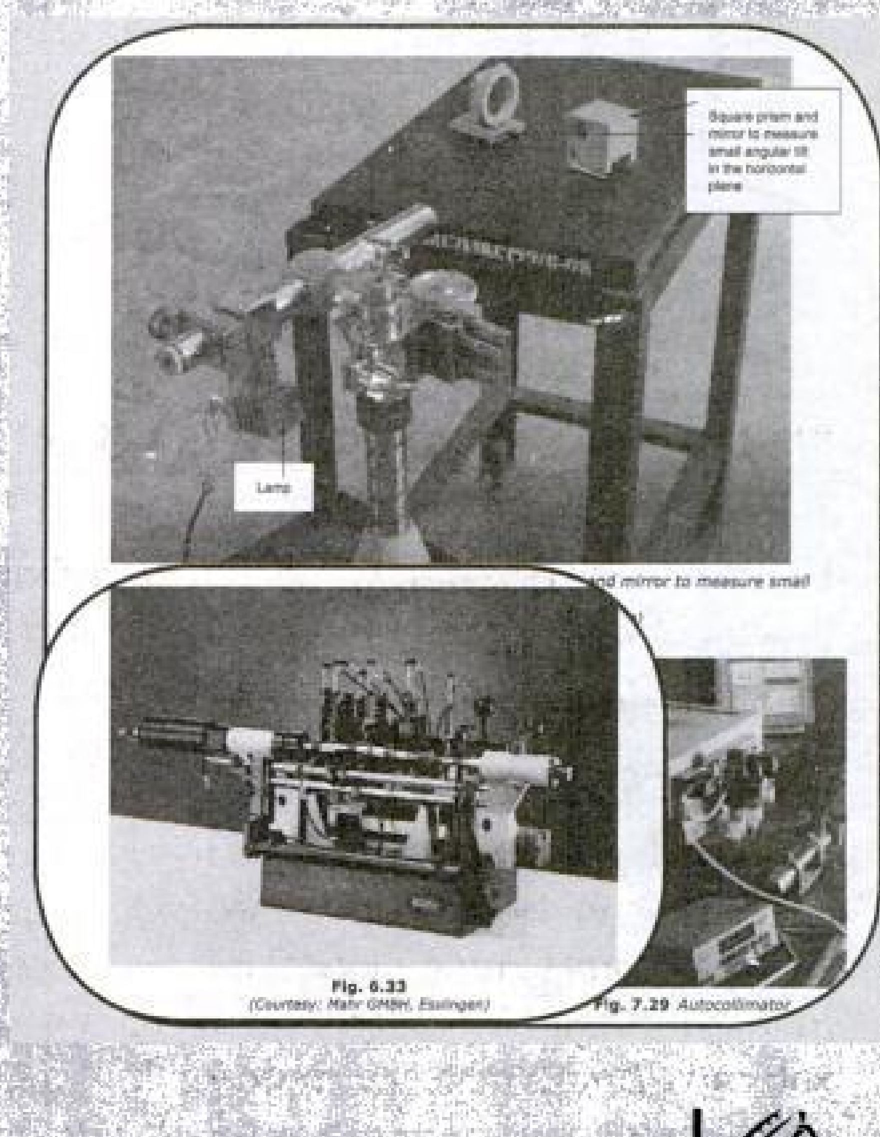
= $-5.5(23.2)^{0.41}$

= −10.34 ≅ −10 microns

Solved Problems with Detailed Explanations

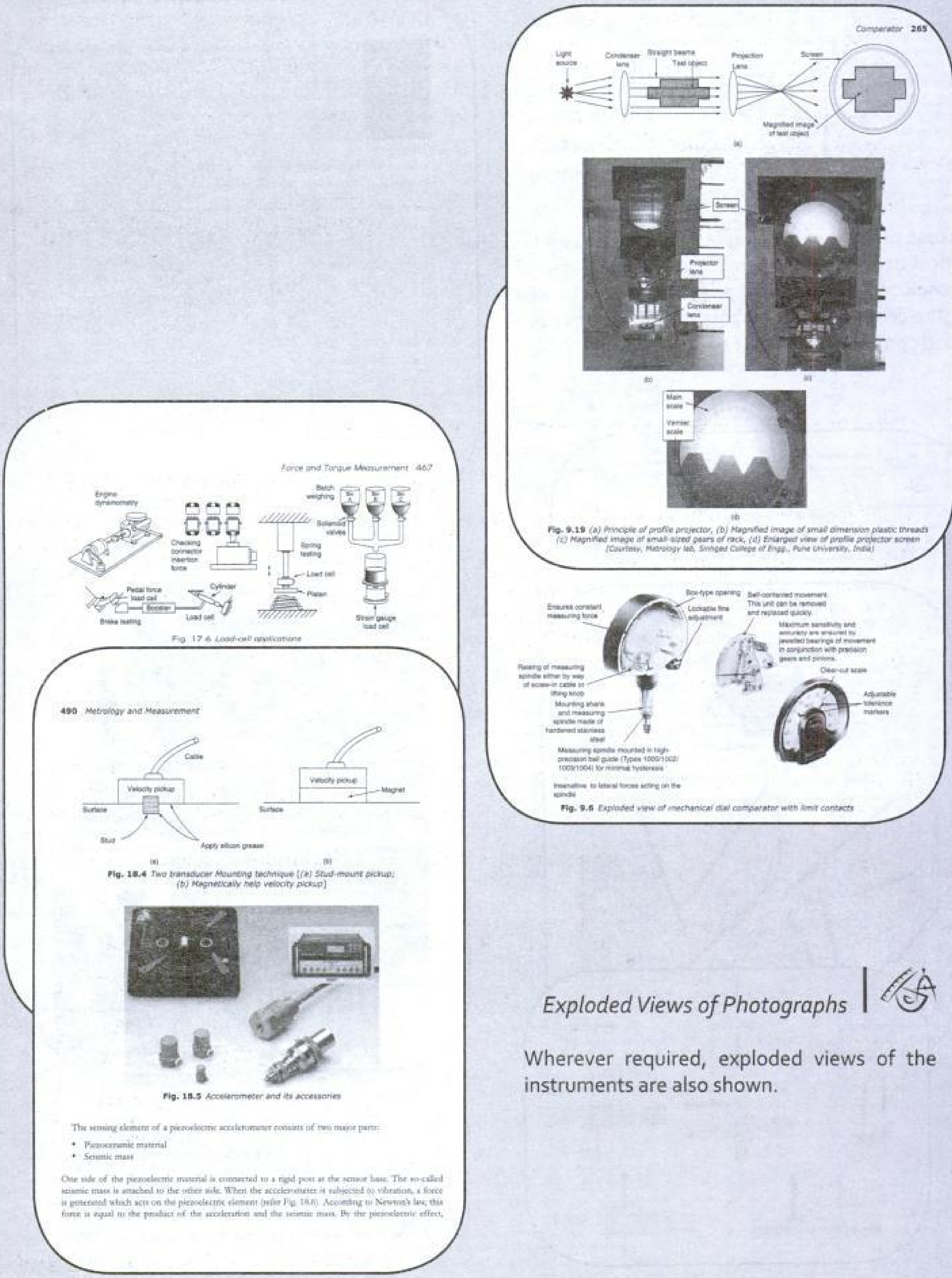
In case of some of the chapters which involve analytical treatment, problems (numerical) related to those concepts are explained stepwise at the end of the chapters which enable the student to have good comprehension of the subject matter.





Photographs

Photographs of instruments and their applications are presented at appropriate locations in the book.



Comparator 265

Fig. 9.19 (a) Principle of profile projector, (b) Magnified image of small dimension plastic threads (c) Magnified image of small-sized gears of rack, (d) Enlarged view of profile projector screen [Courtesy, Metrology lab, Sinhgad College of Engg., Pune University, India]

Fig. 9.6 Exploded view of mechanical dial comparator with limit contacts

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Fig. 17.6 Load-cell applications

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Fig. 18.4 Two transducer Mounting technique [(a) Stud-mount pickup; (b) Magnetically help velocity pickup]

Fig. 18.5 Accelerometer and its accessories

The sensing element of a piezoelectric accelerometer consists of two major parts:

- Piezoceramic material
- Seismic mass

One side of the piezoelectric material is connected to a rigid post at the sensor base. The so-called seismic mass is attached to the other side. When the accelerometer is subjected to vibration, a force is generated which acts on the piezoelectric element (refer Fig. 18.6). According to Newton's law, this force is equal to the product of the acceleration and the seismic mass. By the piezoelectric effect,

Exploded Views of Photographs

Wherever required, exploded views of the instruments are also shown.

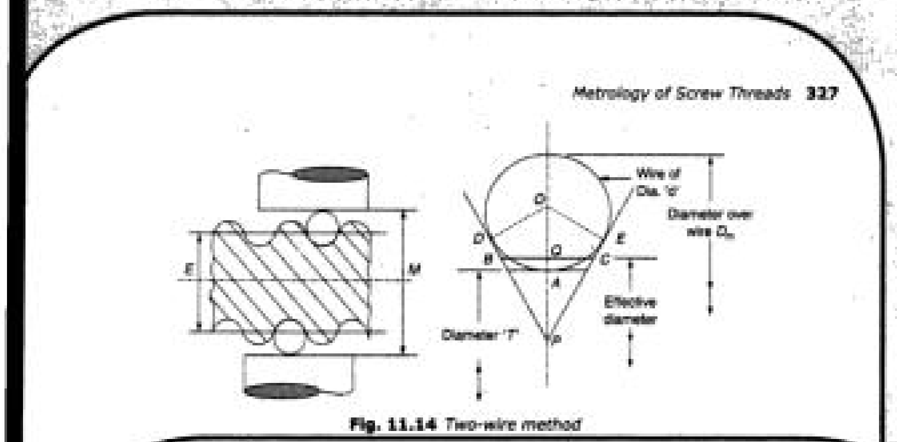
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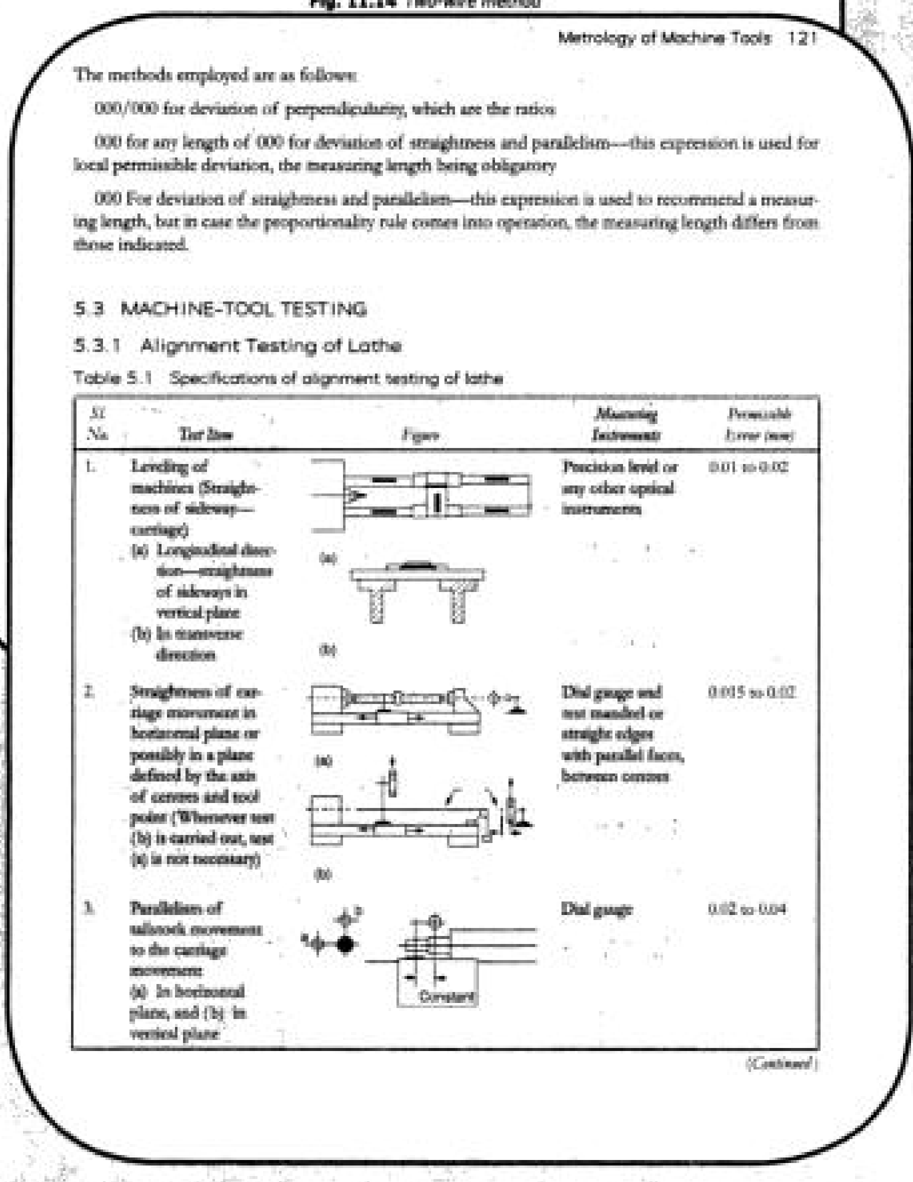
Fig. 11.14 Two-wire method


Metrology of Machine Tools 121

The methods employed are as follows:

000/000 for deviation of perpendicularity, which are the ratios

000 for any length of 000 for deviation of straightness and parallelism—this expression is used for local permissible deviation, the measuring length being obligatory

000 For deviation of straighness and parallelism—this expression is used to recommend a measuring length, but in case the proportionality rule comes into operation, the measuring length differs from those indicated.

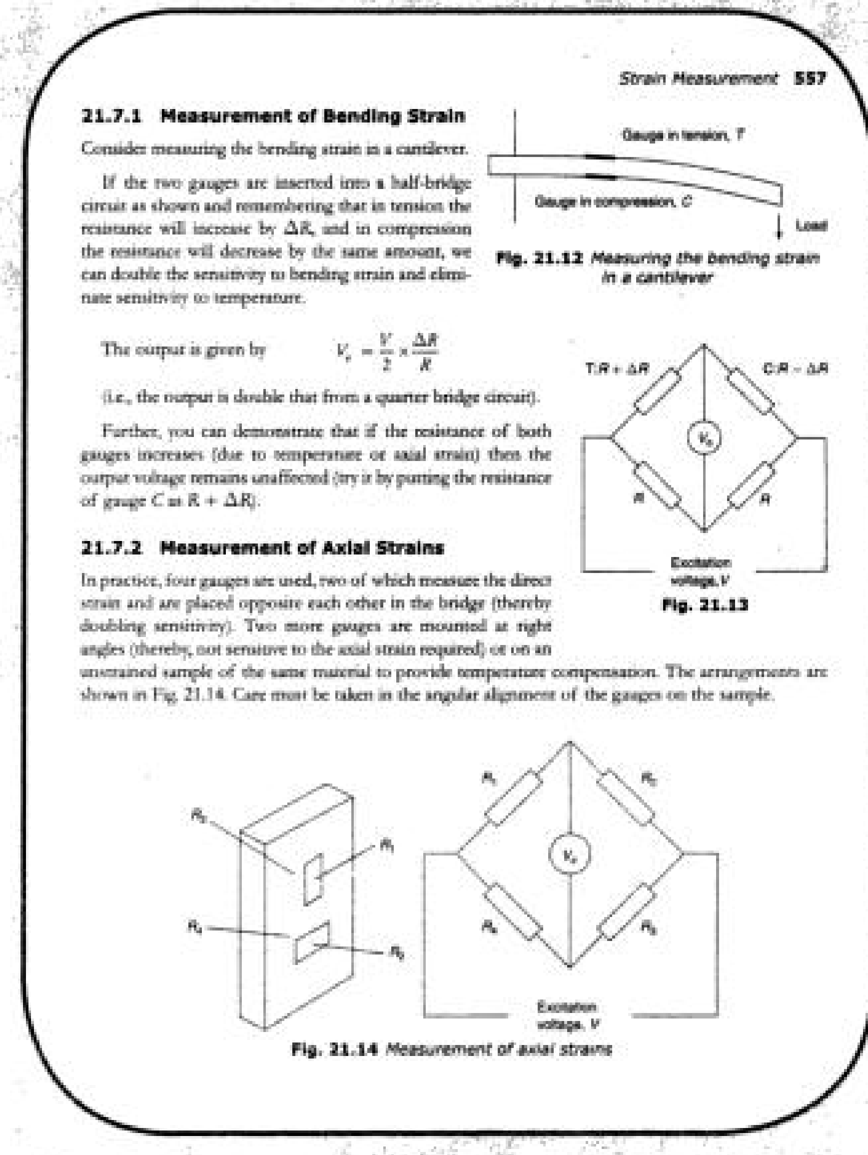
5.3 MACHINE-TOOL TESTING

5.3.1 Alignment Testing of Lathe

Table 5.1 Specifications of alignment testing of lathe

Sl. No.	Test Item	Figure	Measuring Instruments	Permissible Error (mm)
1.	Levelling of machines (Straightness of sideway—carriage) (a) Longitudinal direction—straightness of sideways in vertical plane (b) In transverse direction	(a) (b)	Precision level or any other optical instruments	0.01 to 0.02
2.	Straightness of carriage movement in horizontal plane or possibly in a plane defined by the axis of centres and tool point (Whenever test (b) is carried out, test (a) is not necessary)	(a) (b)	Dial gauge and test mandrel or straight edges with parallel faces, between centres	0.015 to 0.02
3.	Parallelism of tailstock movement to the carriage movement (a) In horizontal plane, and (b) in vertical plane	Constant	Dial gauge	0.02 to 0.04

(Continued)


Strain Measurement 557

21.7.1 Measurement of Bending Strain

Consider measuring the bending strain in a cantilever.

If the two gauges are inserted into a half-bridge circuit as shown and remembering that in tension the resistance will increase by ΔR, and in compression the resistance will decrease by the same amount, we can double the sensitivity to bending strain and eliminate sensitivity to temperature.

Fig. 21.12 Measuring the bending strain in a cantilever

The output is given by $V_o = \frac{V}{2} \times \frac{\Delta R}{R}$

(i.e., the output is double that from a quarter bridge circuit).

Further, you can demonstrate that if the resistance of both gauges increases (due to temperature or axial strain) then the output voltage remains unaffected (try it by putting the resistance of gauge C as $R + \Delta R$).

Fig. 21.13

21.7.2 Measurement of Axial Strains

In practice, four gauges are used, two of which measure the direct strain and are placed opposite each other in the bridge (thereby doubling sensitivity). Two more gauges are mounted at right angles (thereby, not sensitive to the axial strain required) or on an unstrained sample of the same material to provide temperature compensation. The arrangements are shown in Fig. 21.14. Care must be taken in the angular alignment of the gauges on the sample.

Fig. 21.14 Measurement of axial strains

Illustrations

Illustrations are essential tools in books on engineering subjects. Ample illustrations are provided in each chapter to illustrate the concepts, functional relationships and to provide definition sketches for mathematical models.

Case Studies

Case Studies are an important part of books on engineering subjects. Many case studies are provided in the chapters to explain the concepts and their practical significances.

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also designed a much thicker membrane (1.5 mm) to come into contact with the process fluid, but instead of transmitting the pressure value by a liquid such as oil or mercury, a solid 'push rod' was designed to do the job. The membrane and push rod are indicated in Fig. 19.19; the sensor is mounted just behind the push rod and connected to it with a special connector so that the two may be separated during the installation phases on the machine.

The resulting sensor package has impressive specifications—it measures pressures from 100 to 1000 bar at operating temperatures up to 350°C, with a degree of accuracy of 0.25% full scale. The greater thickness of the membrane—it is 10 to 15 times thicker than membranes on previous instruments—is the key to the long life of Impact. There are no longer any concerns about the wear and tear of the membrane due to charged polymers.

Fig. 19.18 *Chip mounted on its carrier*

Fig. 19.19 *Process contact membrane and push rod*

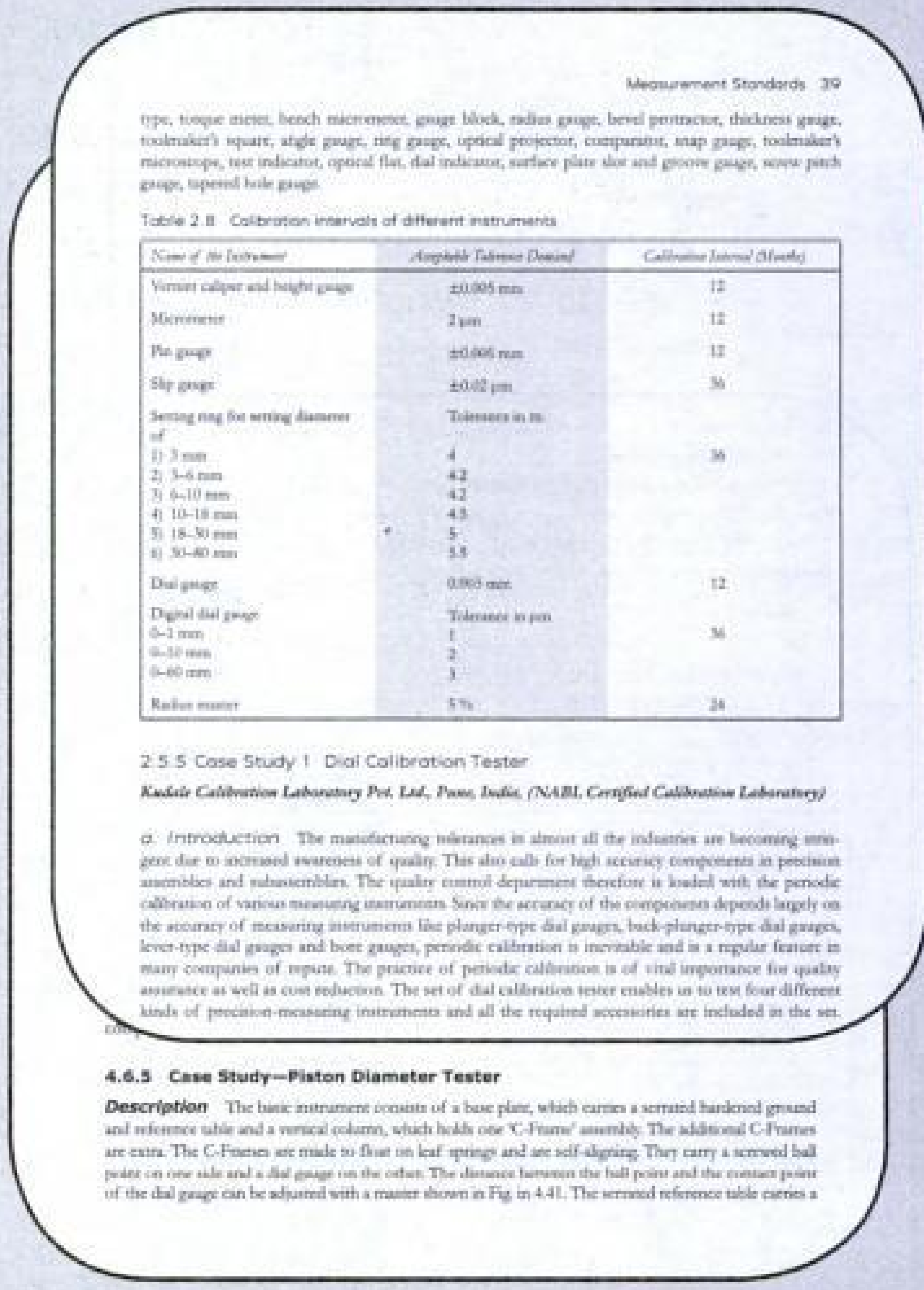
19.8 CASE STUDY OF PRESSURE MEASUREMENT AND MONITORING

19.8.1 Vehicle Tyre-Pressure Monitoring

Tyre-pressure monitoring systems (TPM or TPMS) were implemented a number of years ago as a factory-installed feature found only on high-end vehicles. TPMS, as an embedded electronic system, is expected to be standard equipment in the next few years.

System Overview To do real-time sensing of the exact pressure inside the tyre, the sensing device must be located in the tyre. This pressure-measurement information must then be carried to the driver and displayed in the cabin of the car. The remote-sensing module is comprised of a pressure sensor, a signal processor, and an RF transmitter. The system must compensate pressure variations due to temperature. Hence, a temperature sensor is also required.

The power supply is provided by a long-life battery that the embedded intelligence helps to manage as effectively as possible. The receiver could be either dedicated to TPM use, or shared with the other functions in the car.



Measurement Standards 39

type, torque meter, bench micrometer, gauge block, radius gauge, bevel protractor, thickness gauge, toolmaker's square, angle gauge, ring gauge, optical projector, comparator, snap gauge, toolmaker's microscope, test indicator, optical flat, dial indicator, surface plate slot and groove gauge, screw pitch gauge, tapered hole gauge.

Table 2.8 Calibration intervals of different instruments

Name of the Instrument	*Acceptable Tolerance Desired*	*Calibration Interval (Months)*
Vernier caliper and height gauge	±0.005 mm	12
Micrometer	2 μm	12
Pin gauge	±0.006 mm	12
Slip gauge	±0.02 μm	36
Setting ring for setting diameter of 1) 3 mm 2) 3–6 mm 3) 6–10 mm 4) 10–18 mm 5) 18–30 mm 6) 30–80 mm	Tolerance in μm 4 4.2 4.2 4.5 5 5.5	36
Dial gauge	0.003 mm	12
Digital dial gauge 0–1 mm 0–30 mm 0–60 mm	Tolerance in μm 1 2 3	36
Radius master	5%	24

2.5.5 Case Study 1 Dial Calibration Tester

Kudale Calibration Laboratory Pvt. Ltd., Pune, India, (NABL Certified Calibration Laboratory)

a. Introduction The manufacturing tolerances in almost all the industries are becoming stringent due to increased awareness of quality. This also calls for high accuracy components in precision assemblies and subassemblies. The quality control department therefore is loaded with the periodic calibration of various measuring instruments. Since the accuracy of the components depends largely on the accuracy of measuring instruments like plunger-type dial gauges, back-plunger-type dial gauges, lever-type dial gauges and bore gauges, periodic calibration is inevitable and is a regular feature in many companies of repute. The practice of periodic calibration is of vital importance for quality assurance as well as cost reduction. The set of dial calibration tester enables us to test four different kinds of precision-measuring instruments and all the required accessories are included in the set.

4.6.5 Case Study—Piston Diameter Tester

Description The basic instrument consists of a base plate, which carries a serrated hardened ground and reference table and a vertical column, which holds one 'C-Frame' assembly. The additional C-Frames are extra. The C-Frames are made to float on leaf springs and are self-aligning. They carry a screwed ball point on one side and a dial gauge on the other. The distance between the ball point and the contact point of the dial gauge can be adjusted with a master shown in Fig. in 4.41. The serrated reference table carries a

1 Introduction to Metrology

Metrology—Making Measurement Work For Us...

MANKIND MEASURES

Measurement has become a natural part of our everyday life. Planks of wood and cartons of tea are both bought by size and weight; water, electricity and heat are metered, and we feel the effect on our pockets. Bathroom scales affect our moods and sense of humour—as do police speed traps and the possible financial consequences. The quantity of active substances in medicine, blood-sample measurements, and the effect of the surgeon's scalpel must also be precise if patients' health is not to be jeopardised. We find it almost impossible to describe anything without measuring it—hours of sunshine, chest width, alcohol percentages, weights of letters, room temperatures, tyre pressures ... and so on. The pilot carefully observes his altitude, course, fuel consumption and speed; the food inspector measures bacteria content; maritime authorities measure buoyancy; companies purchase raw materials by weights and measures, and specify their products using the same units. Processes are regulated and alarms are set off because of measurements. Systematic measurement with known degrees of uncertainty is one of the foundations in industrial quality control and generally speaking, in most modern industries, the costs incurred in taking measurements constitute 10–15% of production costs. Just for fun, try holding a conversation without using words that refer to weights or measures.

To explain the importance of measurement, Lord Kelvin said "I *often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge but you have scarcely in your thought advanced to the stage of science.*" Measurement is defined as the set of operations having the objective of determining the value of a quantity.

Science is completely dependent on measurement. Geologists measure shock waves when the gigantic forces behind earthquakes make themselves felt; astronomers patiently measure the light from distant stars in order to determine their age; atomic physicists feel jubilant when by taking measurements in millionths of a second, they are able at last to confirm the presence of an almost infinitely small particle. The availability of measuring equipment and the ability to use them are essential if scientists are to be able to objectively document the results they achieve. The science of measurement, *metrology*, is probably the oldest science in the world and knowledge of how it is applied is a fundamental necessity in practically all science-based professions! Measurement requires common knowledge.

Metrology is hardly ostentatious and the calm surface it shows covers vast areas of knowledge that only a few are familiar with, but which most make use of, confident that they are sharing a common perception of what is meant by expressions such as metre, kilogram, litre, watt, etc. Mankind has thousands of years of experience to confirm that life really does become easier when people cooperate on metrology.

Metrology is a word derived from two Greek words: *Metro*–Measurement, *Logy*–Science. Metrology includes all aspects with reference to measurements, whatever their level of accuracy.

1.1 DEFINITIONS OF METROLOGY

i. Metrology is the field of knowledge concerned with measurement and includes both theoretical and practical problems with reference to measurement, whatever their level of accuracy and in whatever fields of science and technology they occur. (Source: BS 5233:1975).
ii. Metrology is the science of measurement.
iii. Metrology is the science of weights and measures.
iv. Metrology is the process of making extremely precise measurements of the relative positions and orientations of different optical and mechanical components.
v. Metrology is the documented control that all equipment is suitably calibrated and maintained in order to perform as intended and to give reliable results.
vi. Metrology is the science concerned with the establishment, reproduction, conversion and transfer of units of measurements and their standards.

The principal fields of metrology and its related applications are as follows:

a. Establishing units of measurement and their standards such as their establishment, reproduction, conservation, dissemination and quality assurance
b. Measurements, methods, execution, and estimation of their accuracy
c. *Measuring instruments*—Properties examined from the point of view of their intended purpose
d. Observers' capabilities with reference to making measurements, e.g., reading of instrument indications
e. Design, manufacturing and testing of gauges of all kinds

1.2 TYPES OF METROLOGY

Metrology is separated into three categories with different levels of complexity and accuracy:

1. Scientific Metrology deals with the organization and development of measurement standards and with their maintenance (highest level).

2. Industrial Metrology has to ensure the adequate functioning of measuring instruments used in industry as well as in production and testing processes. The metrological activities, testing and measurements are generally valuable inputs to work with quality in industrial activities. This includes the need for traceability, which is becoming just as important as measurement itself. Recognition of metrological competence at each level of the traceability chain of standards can be established by mutual recognition agreements or arrangements.

3. Legal Metrology is concerned with the accuracy of measurements where these have influence on the transparency of economical transactions, and health and safety, e.g., the volume of petrol purchased at a pump or the weight of prepackaged flour. It seeks to protect the public against inaccuracy in trade. It includes a number of international organizations aiming at maintaining the uniformity of measurement throughout the world. Legal metrology is directed by a national organization which is known as National Service of Legal Metrology.

The functions of legal metrology are to ensure the conversion of national standards and to guarantee their accuracies by comparison with international standards; to regulate, advise, supervise and control the manufacture and calibration of measuring instruments; to inspect the use of these instruments with measurement procedures for public interest; to organize training sessions on legal metrology and to represent a country in international activities related with metrology.

4. Fundamental Metrology may be described as scientific metrology, supplemented by those parts of legal and industrial metrology that require scientific competence. It signifies the highest level of accuracy in the field of metrology.

Fundamental metrology is divided in accordance with the following eleven fields: mass, electricity, length, time and frequency, thermometry, ionizing radiation and radioactivity, photometry and radiometry, flow, acoustics, amount of substance and interdisciplinary metrology.

1.3 NEED OF INSPECTION

Inspection is necessary to check all materials, products, and component parts at various stages during manufacturing, assembly, packaging and installation in the customer's environment. It is the quality-assurance method that compares materials, products or processes with established standards. When the production rate is on a smaller scale, parts are made and assembled by a single manufacturing cell. If the parts do not fit correctly, the necessary adjustments can be made within a short period of time. The changes can be made to either of the mating parts in such a way that each assembly functions correctly. For large-scale manufacturing, it is essential to make exactly alike similar parts or with the same accuracy. These accuracy levels need to be endorsed frequently. The recent industrial mass-production system is based on interchangeability. The products that are manufactured on a large scale are categorised into various component parts, thus making the production of each component an independent process. Many of these parts are produced in-house while some parts are purchased from outside sources and then assembled at one place. It becomes very necessary that any part chosen at random fits correctly with other randomly selected mating parts. For it to happen, the dimensions of component parts are made with close dimensional tolerances and inspected at various stages during manufacturing. When large numbers of identical parts are manufactured on the basis of interchangeability, actual dimension measurement is not required. Instead, to save time, gauges are used which can assure whether the manufactured part is within the prescribed limits or not. If the interchangeability is difficult to maintain, assorted groups of the product are formed. In such a case, the products X and Y are grouped according to their dimensional variations. For example, if shafts are made within the range of 59.95 mm to 60.05 mm, and if the diameters of bearing holes are made within the range 60.00 mm to 60.1 mm then the shafts are grouped for sizes of 59.95 mm to 60.00 mm and 60.01 mm to 60.05 mm. Similarly, two bearing-hole groups are formed as sizes of 60.00 mm to 60.05 mm and 60.06 mm to 60.10 mm. The lower-sized shaft group gets assembled with the lower-sized hole group, and the higher-sized shaft group gets assembled with higher-sized hole group. This is known as selective assembly which demands for inspection at every stage of manufacturing and makes the assemblies feasible for any odd combinations controlling the assembly variations in terms of loose (clearance) fit or tight (interference) fit.

The inspection activity is required to

i. ensure the material, parts, and components conform to the established standards,
ii. meet the interchangeability of manufacture,
iii. provide the means of finding the problem area for not meeting the established standards,
iv. produce the parts having acceptable quality levels with reduced scrap and wastages,
v. purchase good quality of raw materials, tools, and equipments that govern the quality of finished products,
vi. take necessary efforts to measure and reduce the rejection percentage for forthcoming production batches by matching the technical specification of the product with the process capability, and
vii. judge the possibility of rework of defective parts and re-engineer the process.

1.4 METROLOGICAL TERMINOLOGIES

Many companies today are concerned with quality management or are in the process of introducing some form of quality system in their work. This brings them into contact with quality standards such as EN 45001–General Criteria for the Operation of Testing Laboratories, or with the standards in the ISO 9000 series or the DIN system. A feature common to all quality standards is that they specify requirements in respect of measurements and their traceability.

The quality context employs a number of measurement technology terms that can cause difficulties if their meanings are not correctly understood.

Accuracy is the closeness of agreement between a test result and the accepted reference value [ISO 5725].

Bias is the difference between the expectation of the test results and an accepted reference value [ISO 5725].

Calibration is a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or values represented by a material measure and the corresponding values realized by standards. The result of a calibration may be recorded in a document, e.g., a calibration certificate. The result can be expressed as corrections with respect to the indications of the instrument.

Confirmation is a set of operations required to ensure that an item of measuring equipment is in a state of compliance with requirements for its intended use. Metrological confirmation normally includes, for example, calibration, any necessary adjustment or repair and subsequent recalibration, as well as any required sealing and labelling.

Correction is the value which, added algebraically to the uncorrected result of a measurement, compensates for an assumed systematic error. The correction is equal to the assumed systematic error, but of the opposite sign. Since the systematic error cannot be known exactly, the correction is subject to uncertainty.

Drift is a slow change of a metrological characteristic of a measuring instrument.

Error of a measuring instrument is the indication of a measuring instrument minus a 'true' value of the corresponding input quantity, i.e., the error has a sign.

Expectation of the measurable quantity is the mean of a specified population of measurements.

Fiducial error (of a measuring instrument) is the error of a measuring instrument divided by a (fiducial) value specified for the instrument. Fiducial value can be the span or upper limit of a nominal range of a measuring instrument.

Group standard is a set of standards of chosen values that, individually or in combination, provide a series of values of quantities of the same kind.

Inspection involves measurement, investigation or testing of one or more characteristics of a product, and includes a comparison of the results with specified requirements in order to determine whether the requirements have been fulfilled.

Magnification In order to measure small difference in dimensions, the movement of the measuring tip in contact with work must be magnified and, therefore, the output signal from a measuring instrument is to be magnified many times to make it more readable. In a measuring instrument, magnification may be either mechanical, electrical, electronic, optical, pneumatic principle or a combination of these.

Measurand is a particular quantity subject to measurement.

National (measurement) standard is a standard recognized by a national decision to serve, in a country, as the basis for assigning values to other standards of the quantity concerned.

Nominal value is a rounded or approximate value of a characteristic of a measuring instrument that provides a guide to its use.

Precision is the closeness of agreement between independent test results obtained under stipulated conditions [ISO 5725].

Range is the capacity within which an instrument is capable of measuring.

Readability refers to the ease with which the readings of a measuring instrument can be read. It is the susceptibility of a measuring device to have its indicators converted into meaningful numbers. If the graduation lines are very finely spaced, the scale will be more readable by using a microscope, but the readability will be poor with the naked eye.

Reference, accepted value serves as an agreed-on reference for comparison, and which is derived as theoretical or established value, based on scientific principles; an assigned or certified value, based on experimental work of some national or international organization; or consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group, when these are not available according to the expected value of the measurable quantity.

Repeatability conditions are where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time [ISO 5725].

Reproducibility is a precision under reproducibility conditions.

Reproducibility conditions are where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment.

Response time is the time which elapses after a sudden change of the measured quantity until the instrument gives an indication different from the true value by an amount less than the given permissible value.

Resolution is the smallest change of the measured quantity which changes the indication of a measuring instrument.

Sensitivity of the instrument denotes the smallest change in the value of the measured variable to which the instrument responds. In other words, sensitivity denotes the maximum change in an input signal that will not initiate a response on the output.

Stability refers to the ability of a measuring instrument to constanty maintain its metrological characteristics with time.

The terms **measurement Standard, Etalon** material measure, measuring instrument, reference material or measuring system are intended to define, realise, conserve or reproduce a unit or one or more values of a quantity to serve as a reference.

Standardization is a process of formulating and applying rules for orderly approach to a specific activity for the benefit and with the cooperation of all concerned in particular. This is done for the promotion of overall economy, taking due account of functional conditions and safety requirements.

Testing is a technical investigation, e.g., as to whether a product fulfils its specified performance.

Traceability means that a measured result can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties.

Trueness is the closeness of agreement between the average value obtained from a large series of test results and an accepted reference value [ISO 5725]. The measure of trueness is usually expressed in terms of bias.

Uncertainty of measurement is a parameter, associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand. It can also be expressed as an estimate characterizing the range of values within which the true value of a measurand lies. When specifying the uncertainty of a measurement, it is necessary to indicate the principle on which the calculation has been made.

Verification is an investigation that shows that specified requirements are fulfilled.

1.5 PRINCIPAL ASPECTS OF MEASUREMENT

Accuracy Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The accuracy of a method of measurement is referred to its absence of bias to the conformity of results to the true value of quality characteristics being measured. As the exact measurement of a true value is difficult, a set of observations are made whose mean value is taken as the true value of the quantity to be measured. The various attributes of the workpiece such as dimensions, hardness, tensile strength and other quality characteristics may creep in while measuring. Therefore, the measured value is the sum of the quantity measured and the error of the instrument. As both of them are independent of each other, the standard deviation of the measured value is the square root of the square of the standard deviation of the true value (σ_{true}) and the square of the standard deviation of the error of measurement (σ_{error}).

$$\sigma \text{ measured value} = \sqrt{\sigma^2_{true} + \sigma^2_{error}}$$

For example, a micrometer measures a part dimension as 10 mm and if the selected accuracy is ±0.01 mm then the true dimension may lie between 9. 99 mm to 10.01 mm. Thus, the accuracy of the micrometer is ±0.01 mm means that the results obtained by the micrometer are inaccurate between ±0.01 mm or there is an uncertainty of ±0.01 mm of the measured value (1% error in the instrument).

Precision Precision is the degree of repeatability in the measuring process. Precision of a method of measurement refers to its variability when used to make repeated measurements under carefully controlled conditions. A numerical measure of a precision is the standard deviation of the frequency distribution that would be obtained from such repeated measurements. This is referred as σ_{error}.

Precision is mainly achieved by selecting a correct instrument technology for application. The general guideline for determining the right level of precision is that the measuring device must be ten times more precise than the specified tolerances, e.g., if the tolerance to be measured is ±0.01 mm, the measuring device must have a precision of ±0.001 mm. The master gauge applied should be ten times more precise than the inspection device.

1.6 METHODS OF MEASUREMENTS

Measurement is a set of operations done with the aim of determining the value of a quantity which can be measured by various methods of measurements depending upon the accuracy required and the amount of permissible error.

The methods of measurements are classified as follows:

1. Direct Method This is the simplest method of measurement in which the value of the quantity to be measured is obtained directly without any calculations, e.g., measurements by scales, vernier calipers, micrometers for linear measurement, bevel protractor for angular measurement, etc. It involves contact or non-contact type of inspections. In case of contact type of inspections, mechanical probes make manual or automatic contact with the object being inspected. On the other hand, the non-contact type of method utilizes a sensor located at a certain distance from the object under inspection. Human insensitiveness can affect the accuracy of measurement.

2. Indirect Method The value of the quantity to be measured is obtained by measuring other quantities, which are frequently related with the required value, e.g., angle measurement by sine bar, three-wire method for measuring the screw pitch diameter, density calculation by measuring mass and dimensions for calculating volume.

3. Absolute Method This is also called *fundamental method* and is based on the measurement of the base quantities used to define a particular quantity, e.g., measuring a quantity (length) directly in accordance with the definition of that quantity (definition of length in units).

4. Comparison Method The value of a quantity to be measured is compared with a known value of the same quantity or another quantity related to it. In this method, only deviations from master gauges are noted, e.g., dial indicators or other comparators.

5. Substitution Method The quantity is measured by direct comparison on an indicating device by replacing the measurable quantity with another which produces the same effect on the indicating device, e.g., measuring a mass by means of the Borda method.

6. Coincidence Method It is also called the differential method of measurement. In this, there is a very small difference between the value of the quantity to be measured and the reference. The reference is determined by the observation of the coincidence of certain lines or signals, e.g., measurement by vernier calipers (LC × vernier scale reading) and micrometer (LC × circular scale reading).

7. Transposition Method It is the method of measurement by direct comparisons in which the value of the quantity measured is first balanced by an initial known value P of the same quantity. Then the value of the quantity measured is put in place of that known value and is balanced again by another known value Q. If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is $\sqrt{PQ}$, e.g., determination of a mass by means of balance and known weights, using the Gauss double weighing method.

8. Deflection Method The value of the quantity to be measured is directly indicated by the deflection of a pointer on a calibrated scale, e.g., dial indicator.

9. Complementary Method The value of the quantity to be measured is combined with a known value of the same quantity, e.g., determination of the volume of a solid by liquid displacement.

10. Method of Null Measurement It is a method of differential measurement. In this method, the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero (null), e.g., measurement by potentiometer.

1.7 MEASURING INSTRUMENTS AND THEIR SELECTION

Transformation of a measurable quantity into the required information is a function of measuring instruments. The important characteristics which govern the selection of instruments are measuring range, accuracy and precision. No measuring instrument can be built that has perfect accuracy and perfect precision. The usage of measuring instruments depends on the range of application, e.g., in case of waiting to avoid poor accuracy at the lower end of a scale, the instrument to be used should be highly accurate having a large range of measurement. Alternatively, two instruments with different ranges may be used—one for lower range and another for full range. The precision of an instrument is an important feature as it gives repeatable readings with required accuracy levels.

Steel rules, vernier calipers, micrometers, height gauges, etc., are commonly used for length measurement. But there are a number of other instruments that are also used for length measurements. Measuring instruments are also developed for measuring such dimensional features like angle, surface finish, form, etc. *Resolution*, or sensitivity, is also an important aspect to be considered for selecting instruments for measurement purposes as it represents the smallest change in the measured quantity which can reproduce a perceptible movement of the pointer on a calibrated scale. Generally, measuring instruments are classified as follows:

i. **On the basis of function**
   a. Length-measuring instruments
   b. Angle-measuring instruments
   c. Surface-roughness-measuring instruments
   d. Geometrical-form-checking instruments

ii. **On the basis of accuracy**
   a. Most accurate instruments
   b. Moderate accurate instruments
   c. Below-moderate accurate instruments

iii. On the basis of precision

a. Precision measuring instruments
b. Non-precision measuring instruments

1.7.1 Factors Affecting Accuracy of Measuring Instruments

1. Standards of Calibration for Setting Accuracy Traceability, calibration methods, coefficient of thermal expansion, elastic properties of measuring instruments, geometric compatibility

2. Workpiece Control during Measurement Cleanliness, surface finish, waviness, scratch depth, surface defects, hidden geometry, definable datum(s), thermal stability

3. Inherent Characteristics of Measuring Instrument Range of scale, amplification (amplifying system functioning within prescribed limit of the instrument), effect of friction, hysteresis loss, backlash, drift error, handling, calibration errors, readability, repeatability of measurement, sensitivity, contact geometry, thermal expansion effects

4. Inspector (Human Factor) Skill, training, awareness of precision measurement, selection of instruments, working attitude, socio-economic awareness, consistent efforts towards minimizing inspection time and cost

5. Environmental Conditions Noise, vibration, temperature, humidity, electrical parameter variations, adequate lighting, atmospheric refraction, clean surrounding

To ensure higher accuracy during measuring, the above sources of error are required to be analyzed frequently and necessary steps should be taken to eliminate them.

1.8 ERRORS IN MEASUREMENT

The error in measurement is the difference between the measured value and the true value of the measured dimension. Error may be absolute or relative.

$$\text{Error in Measurement} = \text{Measured Value} - \text{True Value}$$

The actual value or true value is a theoretical size of dimension free from any error of measurement which helps to examine the errors in a measurement system that lead to uncertainties. Generally, the errors in measurements are classified into two testing types—one, which should not occur and can be eliminated by careful work and attention; and the other, which is inherent in the measuring process/system. Therefore, the errors are either controllable or random in occurrence.

Absolute Error

It is divided into two types:

True Absolute Error It is defined as the algebraic difference between the result of measurement and the conventional true value of the quantity measured.

Apparent Absolute Error It is defined as the algebraic difference between the arithmetic mean and one of the results of measurement when a series of measurements are made.

Absolute Error (E_A)

$$\therefore \text{ Absolute Error} = |\text{Actual Value} - \text{Approximate Value}|$$

If, absolute value $= x$ and

approximate value $= x + dx$, then

$$\text{Absolute Error} = dx$$

Relative Error

It is the quotient of the absolute error and the value of comparison (may be true value or the arithmetic mean of a series of measurements) used for calculation of the absolute error.

It is an error with respect to the actual value.

$$\text{Relative Error} = \frac{|\text{Actual Value} - \text{Approximate Value}|}{|\text{Actual Value}|}$$

For the above example,

$$\text{Relative Error} = \frac{dx}{x}$$

Percentile Error (E_p) Relative error is expressed in percentage form.

$$\text{Percentile Error} = \frac{|\text{Actual Value} - \text{Approximate Value}|}{|\text{Actual Value}|} \times 100$$

$$\text{Percentile Error} = \frac{\text{Absolute Error}}{|\text{Actual Value}|} \times 100$$

$$\text{Percentile Error} = \text{Relative Error} \times 100$$

For example, if a number has actual value = 0.8597 and approximate value = 0.85, calculate the absolute, relative and percentile error.

$$\text{Absolute Error} = |0.8597 - 0.85| = 0.0097$$

$$\text{Relative Error} = \frac{|0.8597 - 0.85|}{|0.8597|} = 0.11283$$

$$\text{Percentile Error} = \text{Relative Error} \times 100 = 0.11283 \times 100 = 11.283\%$$

Static Error

These are the result of physical nature of the various components of a measuring system, i.e., intrinsic imperfection or limitations of apparatus/instrument. Static error may occur due to existence of either characteristic errors or reading errors or environmental errors, as the environmental effect and other external factors influence the operating capabilities of an instrument or inspection procedure. This error can be reduced or eliminated by employing relatively simple techniques.

a. Reading Error These types of errors apply exclusively to instruments. These errors may be the result of parallax, optical resolution/readability, and interpolation.

Parallax error creeps in when the line of sight is not perpendicular to the measuring scale. The magnitude of parallax error increases if the measuring scale is not made flush to the component. This may be one of the common causes of error. It occurs when either the scale and pointer of an instrument are not in the same plane or the line of vision is not in line of the measuring scale.

In Fig. 1.1, let, Y be the distance between the pointer and the eye of the observer, X be the separation distance of the scale and the pointer, and θ be the angle between the line of sight and the normal to the scale.

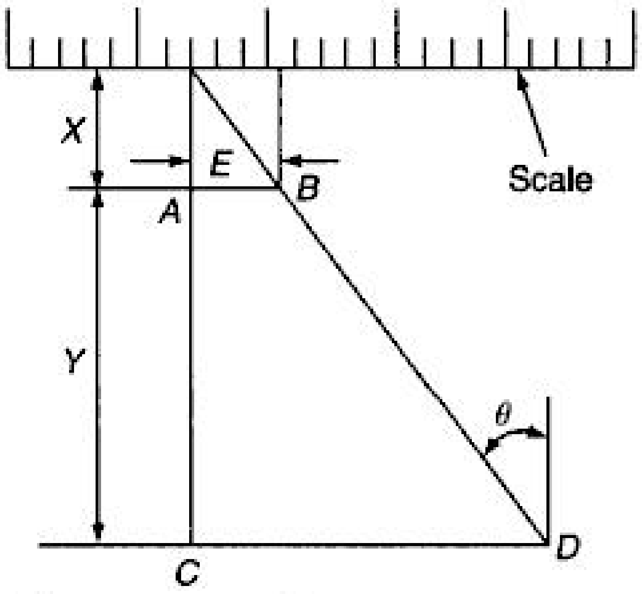


Fig. 1.1 *Parallax error*

Now, $[(PA)/(NE)] = \{X/(X - Y)\}$

And the error will be

$$(PA) = \{X/(X - Y)\} \{(X - Y) \tan \theta\}$$

$$\text{Error} = X \tan \theta$$

Generally, is very small.

$\therefore \tan \theta = \theta$ and $E = X\theta$

For least error, X should be as minimal as possible. This error can be eliminated by placing a mirror behind the pointer, which helps to ensure normal reading of the scale.

b. Alignment Error This occurs if the checking of an instrument is not correctly aligned with the direction of the desired measurement. In Fig. 1.2 (a), the dimension D is being measured with a dial indicator. But the dial indicator plunger is not held vertical and makes an angle θ with the line of measurement. This leads to misalignment error getting introduced in the measurement, which has a value equal to $D(1 - \cos \theta)$. To avoid the alignment error, Abbe's alignment principle is to be followed. It states that *the axis or line of measurement should coincide with the axis of the measuring instrument or the line of the measuring scale.*

Now consider Fig. 1.2 (b). While measuring the length of a workpiece, the measuring scale is inclined to the true line of dimension being measured and there will be an error in the measurement. The length L measured will be more than the true length, which will be equal to $L \cos \theta$. This error is called *cosine error*. In many cases the angle θ is very small and the error will be negligible.

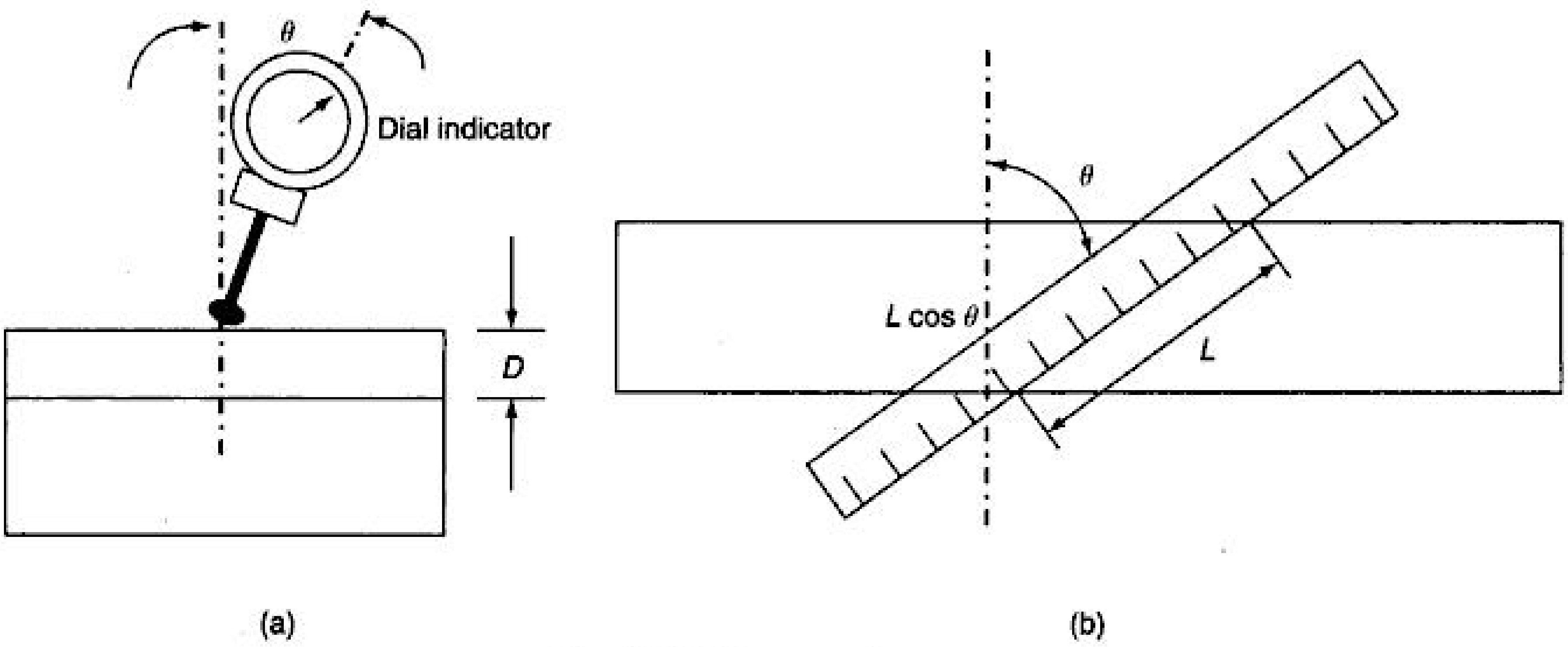


Fig. 1.2 *Alignment error*

c. Characteristic Error It is the deviation of the output of the measuring system from the theoretical predicted performance or from the nominal performance specifications. Linearity, repeatability, hysteresis and resolution error are the examples of characteristic error.

d. Environmental Error These are the errors arising from the effect of the surrounding temperature, pressure and humidity on the measuring system. Magnetic and electric fields, nuclear radiations, vibration or shocks may also lead to errors. Environmental error can be controlled by controlling the atmospheric factors.

Loading Error The part to be measured is located on the surface table (datum for comparison with standards). If the datum surface is not flat or if foreign matter like dirt, chips, etc., get entrapped between the datum and workpiece then an error will be introduced while taking readings, as shown in Fig. 1.3.

Also, poor contact between the working gauge or a the instrument and workpiece causes an error as shown in Fig. 1.4. To avoid such error, an instrument with a wide area of contact should not be used

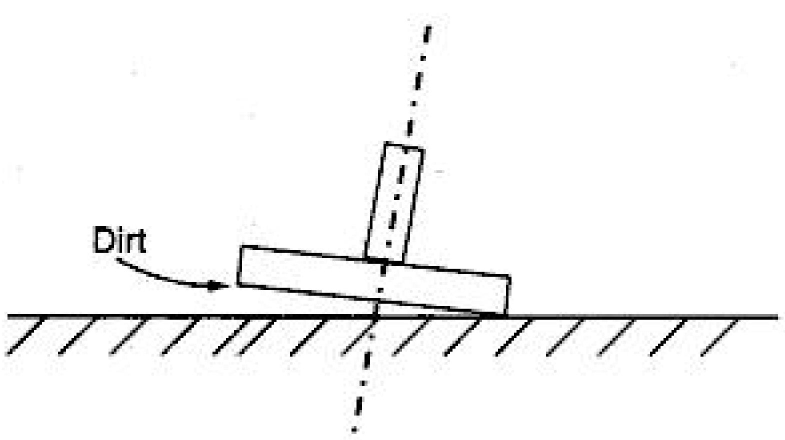


Fig. 1.3 *Instrument surface displacement*

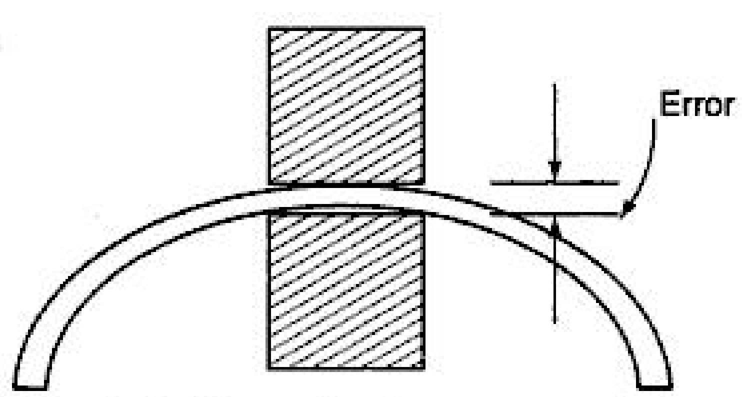


Fig. 1.4 *Error due to poor contact*

while measuring irregular or curved surfaces, and the correct contact pressure must be applied. Therefore, instrument loading error is the difference between the value of the measurand before and after the measuring system is connected or contacted for measurement.

Dynamic Error It is caused by time variation in the measurand. It is the result of incapability of the system to respond reliably to time-varying measurement. Inertia, damping, friction or other physical constraints in sensing or readout or the display system are the main causes of dynamic errors.

Analysis of accumulation of error by the statistical method categorizes errors as controllable and random errors.

Controllable Error

These are controllable in both magnitude and sense. These types of errors are regularly repetitive in nature and are of similar form after systematic analysis is reduced effectively. These errors are also called *systematic errors.*

Controllable errors include the following:

a. Calibration Error These are caused due to the variation in the calibrated scale from its normal indicating value. The length standard, such as the slip gauge, will vary from the nominal value by a small amount. This will cause a calibration error of constant magnitude.

b. Stylus Pressure Error The too small or too large pressure applied on a workpiece while measuring, causes stylus pressure. This error causes an appreciable deformation of the stylus and the workpiece.

c. Avoidable Error These errors occur due to parallax, non-alignment of workpiece centres, incorrect location of measuring instruments for temporary storage, and misalignment of the centre line of a workpiece.

Random Error Random errors are accidental, non-consistent in nature and as they occur randomly, they cannot be eliminated since no definite cause can be located. It is difficult to eliminate such errors that vary in an unpredictable manner. Small variations in the position of setting standards and the workpiece, slight displacement of lever joints in instruments, transit fluctuations in friction in measuring instruments and pointer-type display, or in reading engraved scale positions are the likely sources of this type of error.

1.9 UNITS OF MEASUREMENT

On 23 September, 1999, the Mars Climate Orbiter was lost during an orbit injection maneuver when the spacecraft crashed onto the surface of Mars. The principal cause of the mishap was traced to a thruster calibration table in which British units were used instead of metric units. The software for celestial navigation at the Jet Propulsion Laboratory expected the thruster impulse data to be expressed in newton seconds, but Lockheed Martin Astronautics in Denver, which built the orbiter, provided the values in pound-force seconds, causing the impulse to be interpreted as roughly one-fourth its actual value. This reveals the importance of the requirement of using a common unit of measurement. The historical perspective in this effect must be seen for further study of metrology.

The metric system was one of the many reforms introduced in France during the period between 1789 and 1799, known for the French Revolution. The need for reform in the system of weights and measures, as in other affairs, had long been recognized and this aspect of applied science affected the course of human activity directly and universally.

Prior to the metric system, there had existed in France a disorderly variety of measures, such as for length, volume, or mass, that were arbitrary in size and varied from one town to the next. In Paris, the unit of length was the *Pied de Roi* and the unit of mass was the *Livre poids de marc*. However, all attempts to impose the Parisian units on the whole country were fruitless, as the guilds and nobles who benefited from the confusion opposed this move.

The advocates of reform sought to guarantee the uniformity and permanence of the units of measure by taking them from properties derived from nature. In 1670, the abbe Gabriel Mouton of Lyons proposed a unit of length equal to one minute of an arc on the earth's surface, which he divided into decimal fractions. He suggested a pendulum of specified period as a means of preserving one of these submultiples.

The conditions required for the creation of a new measurement system were made possible by the French Revolution. In 1787, King Louis XVI convened the Estates General, an institution that had last met in 1614, for the purpose of imposing new taxes to avert a state of bankruptcy. As they assembled in 1789, the commoners, representing the Third Estate, declared themselves to be the only legitimate representatives of the people, and succeeded in having the clergy and nobility join them in the formation of the National Assembly. Over the next two years, they drafted a new constitution.

In 1790, Charles-Maurice de Talleyrand, Bishop of Autun, presented to the National Assembly a plan to devise a system of units based on the length of a pendulum beating seconds at latitude 45. The new order was envisioned as an 'enterprise whose result should belong some day to the whole world.' He sought, but failed to obtain, the collaboration of England, which was concurrently considering a similar proposal by Sir John Riggs Miller.

The two founding principles were that the system would be based on scientific observation and that it would be a decimal system. A distinguished commission of the French Academy of Sciences, including J L Lagrange and Pierre Simon Laplace, considered redefining the unit of length. Rejecting the seconds pendulum as insufficiently precise, the commission defined the unit, given the name *metre* in 1793, as one ten-millionth of a quarter of the earth's meridian passing through Paris. The proposal was accepted by the National Assembly on 26 March, 1791.

The definition of the metre reflected the extensive interest of French scientists in the shape of the earth. Surveys in Lapland by Maupertuis in 1736 and in France by LaCaille in 1740 had refined

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standards were made legal by an Act of Parliament in 1855 and are preserved in the Board of Trade in London. The United States received copies of the British imperial pound and yard, which became the official US standards from 1857 until 1893.

In 1893, under a directive from Thomas C Mendenhall, Superintendent of Standard Weights and Measures of the Coast and Geodetic Survey, the US customary units were redefined in terms of the metric units. The primary standards of length and mass adopted were the prototype metre No. 27 and the prototype kilogram No. 20 that the United States had received in 1889 as a signatory to the Treaty of the Metre. The yard was defined as 3600/3937 of a metre and the *avoirdupois* pound-mass was defined as 0.4535924277 kilogram. The conversion for mass was based on a comparison performed between the British imperial standard pound and the international prototype kilogram in 1883. These definitions were used by the National Bureau of Standards (now the National Institute of Standards and Technology) from its founding in 1901 until 1959. On 1 July, 1959, the definitions were fixed by international agreement among the English-speaking countries to be 1 yard = 0.9144 metre and 1 pound-mass = 0.45359237 kilogram exactly. The definition of the yard is equivalent to the relations 1 foot = 0.3048 metre and 1 inch = 2.54 centimetres exactly.

A fundamental principle was that the system should be coherent. That is, the system is founded upon certain base units for length, mass, and time, and derived units are obtained as products or quotients without requiring numerical factors. The metre, gram, and mean solar second were selected as base units. In 1873, a second committee recommended a centimetre-gram-second (CGS) system of units because in this system, the density of water is unity.

In 1889, the international prototype kilogram was adopted as the standard for mass. The prototype kilogram is a platinum–iridium cylinder with equal height, a diameter of 3.9 cm and slightly rounded edges. For a cylinder, these dimensions present the smallest surface-area-to-volume ratio to minimize wear. The standard is carefully preserved in a vault at the International Bureau of Weights and Measures and is used only on rare occasions. It remains the standard till today. The kilogram is the only unit still defined in terms of an arbitrary artifact instead of a natural phenomenon.

Historically, the unit of time, the second, was defined in terms of the period of rotation of the earth on its axis as 1/86 400 of a mean solar day. Meaning 'second minute', it was first applied to timekeeping in about the seventeenth century when pendulum clocks were invented that could maintain time to this precision.

By the twentieth century, astronomers realized that the rotation of the earth is not constant. Due to gravitational tidal forces produced by the moon on the shallow seas, the length of the day increases by about 1.4 milliseconds per century. The effect can be measured by comparing the computed paths of ancient solar eclipses on the assumption of uniform rotation with the recorded locations on earth where they were actually observed. Consequently, in 1956 the second was redefined in terms of the period of revolution of the earth about the sun for the epoch 1900, as represented by the Tables of the Sun computed by the astronomer Simon Newcomb of the US Naval Observatory in Washington, DC. The operational significance of this definition was to adopt the linear coefficient in Newcomb's formula for the mean longitude of the sun to determine the unit of time.

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Figure 2.2(b) (Plate 1) shows the actual International Standard Prototype Metre and Historical Standard platinum–iridium metre bar. The 1889 definition of the metre, based upon the international prototype of platinum–iridium, was replaced by the 11th CGPM (Conférence Générale des Poids et Mesures, 1960) using a definition based upon the wavelength of krypton-86 radiations. This definition was adopted in order to improve the accuracy with which the metre may be realized. This was replaced in 1983 by the 17th CGPM as per Resolution 1.

The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

The effect of this definition is to fix the speed of light at exactly 299 792 458 $m \cdot s^{-1}$. The original international prototype of the metre, which was sanctioned by the 1st CGPM in 1889 (CR, 34–38), is still kept at the BIPM under conditions specified in 1889. The metre is *realized* on the primary level by the wavelength from an iodine-stabilized helium–neon laser. On sub-levels, material measures like gauge blocks are used, and traceability is ensured by using optical interferometry to determine the length of the gauge blocks with *reference* to the above-mentioned laser light wavelength. Accuracy of measurement using this standard is limited up to ±0.2 mm. For higher accuracy, scales along with a magnifying glass on the microscope may be used which makes measurement quick and easy. Scale markings are not subjected to wear even after periodic use but parallax error may get introduced while measuring. The example of line standard includes metre, yard, steel rule (Scale).

2.3.2 End Standard

The need of an end standard arises as the use of line standards and their copies was difficult at various places in workshops. End standards can be made to a high degree of accuracy by a simple method devised by A J C Brookes in 1920. End standards are used for all practical measurements in workshops and general use in precision engineering in standard laboratories. These are in the form of end bars and slip gauges. In case of vernier calipers and micrometers, the job is held between the jaws/anvils of the measuring instrument and the corresponding reading is noted, while a length bar and slip gauges are used to set the required length to be used as a reference dimension.

a. End Bar End bars made of steel having cylindrical cross section of 22.2-mm diameter with the faces lapped and hardened at the ends are available in sets of various lengths. Parallelity of the ends is within few tenths of micrometres. Reference- and calibration-grade end bars have plane end faces, but the set of inspection- and workshop-grade end bars can be joined together by studs, screwed into a tapped hole in their ends. Although from time to time, various types of end bars have been constructed with some of them having flat, spherical faces, but flat and parallel-faced end bars are firmly established as the most practical end standard used for measurement. It is essential to retain their accuracy while measuring when used in a horizontal plane, by supporting them, keeping end faces parallel.

End bars are made from high-carbon chromium steel, ensuring that faces are hardened to 64 RC (800 HV). The bars have a round section of 30 mm for greater stability. Both the ends are threaded, recessed and precision lapped to meet requirements of finish, flatness, parallelism and gauge length.

Table 2.7

Blocks	*Steps*	*Number*	*Blocks*	*Steps*	*Number*
0.1001–0.1009	0.0001	9	0.1001–0.1009	0.0001	9
0.101–0.149	0.001	49	0.101–0.109	0.001	9
0.050–0.950	0.05	19	0.110–0.190	0.01	9
1–4	1	4	0.050		1
			0.100–0.900	0.1	9
			1–4	1	4
Total		81	Total		41

Also available in a combination of M47/1,M32/1,M18/1,M9/1 and 1-mm wear protectors.

The individual gauge blocks required to build up a length of 6.905 mm from the set of M88/1 would be as follows:

1st gauge 1.005 mm **2nd gauge** 1.40 mm **3rd gauge** 4.50 mm 6,905 mm

Note the 6,905-mm length could be achieved by using more than three gauge blocks. However, it is important that a minimum number of gauge blocks per combination size should be used.

2.3.3 Wavelength Standards

Line and end standards are physical standards and are made up of materials that can change their size with temperature and other environmental conditions. The correct lab conditions are required to be maintained so that the length standard remains unchanged. High-sensitivity length measurements are therefore very important as these measurements are widely used in science, technology and industry and they are of type that have highest accuracy after time frequency measurements. In search for a suitable unit of length, length-standard realization by improving primary-level wavelength sources is used for wavelength comparisons and gauge block measurements in a sensitive way. Fitting in a new definition of 'metre', the primary-level wavelength standard can be a laser standard, which has its frequency compared with Cs time, and frequency standard. High-frequency accuracy, high-frequency stability and high re-producebility help in high-accuracy interferometry length measurements.

BIPM (Bureau International des Poids et Measures) made the first verification of the national prototypes by intercomparisons among the available standards along with comparisons with the international prototype. This included new and improved determinations of the thermal expansion of metre bars. The international accord, using the 1893 and 1906 determinations of the wavelength of the red line of cadmium, defined the ångström which was used as the spectroscopic unit of length, but this was abandoned in 1960. The CIPM decided to investigate the possibility of redefining the metre in

For the standard at 633-mm wavelength, three He–Ne/ I_2 laser set-ups have been built such that their frequencies are locked to the transition of I_2 molecules. The I_2 cells, which are placed in the He–Ne laser resonators, provide the interaction between the He–Ne laser beam and I_2 molecules. Absorption signals are detected by the tuning laser frequency around the energy transition of I_2 molecules. By using an electronic servo system, these absorption signals of the I_2 molecules are used to lock the laser frequency to the energy transition of the I_2 molecules with a stability of 1×10^{-13} in an average time interval of 1000 s. In addition to its substantial programme related to the He–Ne stabilized lasers, the BIPM also carried out a small research programme in the performance and metrological qualities of the frequency-doubled Nd-YAG laser at 532 nm. This relatively high-power system turned out to have excellent short-term stability and it is often used in a number of applications. The BIPM's comparison programme therefore included Nd-YAG systems by heterodyne and, more recently, by absolute frequency measurements.

For the standard at 532-mm wavelength, two Nd-YAG laser frequencies tuned to the energy transitions of I_2 molecules are locked. In the establishment of these standards, lasers with wavelengths of 532 nm and with an output power of 50 mW are used. In the locking process of the laser frequency I_2 cells are used outside the resonator. At present, the frequencies of each of the two lasers are tuned to the energy transition of I_2 molecules and fluorescent signals are observed as the result of the interaction between the laser and the molecules in the cells. The frequencies of two Nd-YAG lasers are changed in the range of the absorption spectrum of the I_2 molecules by using a servo system. So the third deviation of the resonance absorption signal is obtained by the affection of the iodine molecules with the laser beam. The CIPM-recommended value is 473 612 353 604 ±10,0 kHz for He–Ne/I_2 lasers using beat-frequency methods. The international comparison of the portable optical frequency standard of He–Ne/CH_4 (λ = 3.39 μm) with PTB was realized in Braunschweig between the dates of 15th and 30th December 2000. The absolute frequency value is measured as 88 376 181 000 253 ±23 Hz.

The 3.39-μm laser programme dealt with a well-characterized system that was a critical element in the frequency chains used in the earlier measurements of the speed of light. They also have applications in infrared spectroscopy. The BIPM has, therefore, maintained a high-performance system and participated in a number of comparisons with several NMIs. A similar facility was provided for 778 nm Rb-stabilized systems, which were of interest to the telecommunications industry. Both programmes are now drawing to a close in the light of the frequency-comb technique. With the introduction of the new comb techniques allowing direct frequency measurements of optical laser frequencies, the activity of heterodyne frequency comparisons between laser standards has been reduced and as such, nonphysical wave standards are least affected by environmental conditions and remain practically unchanged, making it convenient to reproduce them with a great degree of accuracy.

2.4 SUBDIVISION OF STANDARDS

The International Prototype Metre cannot be used for every general-purpose application. The original international prototype of the metre, which was sanctioned by the first CGPM in 1889, is still kept under the specified conditions by BIPM in 1889. Therefore, a practical hierarchy of working standards has been created depending upon the importance of the accuracy required.

Material standards are divided into four basic types:

i. Primary standards
ii. Secondary standards
iii. Tertiary standards
iv. Working standards

1. Primary Standards To define a unit most precisely, there is only one material standard which is preserved under very specifically created conditions. Such type of a material standard is known as a primary standard. The International Metre is the example of a primary standard. This should be used only for comparison with secondary standards and cannot be used for direct application.

2. Secondary Standards Secondary standards should be exactly alike the primary standards by all aspects including design, material and length. Initially, they are compared with primary standards after long intervals and the records of deviation are noted. These standards should be kept at a number of places in custody for occasional comparison with tertiary standards.

3. Tertiary Standards The primary and secondary standards are applicable only as ultimate controls. Tertiary standards are used for reference purposes in laboratories and workshops. They can again be used for comparison at intervals with working standards.

4. Working Standards Working standards developed for laboratories and workshops are derived from fundamental standards. Standards are also classified as

i. Reference standards
ii. Calibration standards

2.5 CALIBRATION

The ultimate goal of manufacturing industries is to provide a quality product to customers. Initially, the main thrust of any business is to offer potential customers value for their business revenue. Coupled with this, is the immediate need to garner customers, which is critical to the success of the enterprise. Keeping customers requires that the product meets appropriate quality levels, which, in turn, requires calibration knowledge. The aim of the product is to not only fulfill the requirement of the user but also to have specified dimensions. Measurement of dimensions can't be perfect and reliable unless and until measuring instruments are calibrated accurately. Thus, calibration plays a vital role in maintaining quality control. Calibration of measuring instruments is not only an advantage to any company but it is a necessity for every manufacturing industry.

The advantages of calibration are accuracy in performing manufacturing operations, reduced inspection, and ensured quality products by reducing errors in measurement.

2.5.1 Defining Calibration

Calibration is a comparison of instrument performance to standards of known accuracy; calibrations directly link customers' measurement equipment to national and international standards.

According to the ISO, calibration is the quantitative determination of errors of measuring instruments and adjusting them to a minimum. In other words, calibration means to find out whether the instrument gives the correct reading or not. It also includes minor adjustments in the instrument to minimize error.

As the measurement standards are referred at different levels owing to their availability for applications, calibration is required to be carried out as per set standards. This creates a need for setting up calibration labs at different levels, which are explained as follows.

a. In-house Calibration Lab These labs are set up within a company itself for calibration of in-house instruments.

b. Professional Calibration Labs These are set up by professionals whose main business is calibration of measuring instruments and who use all dedicated and sophisticated calibrating instruments, e.g., Kudale Calibration Lab in Pune, India.

c. NABL Certification to Professional Labs According to the National Accreditation Board for Testing and Calibration Laboratory, certification is given to only those laboratories which have the entire norms (instruments) as per NABL norms. In-house calibration labs need not have this certificate.

2.5.2 Status of Calibration

1. Active This status is given to an instrument if it gives an exact reading or the error shown in the reading is within the tolerable limit.

2. Calibrate Before Use [CBU] If a stock of some instrument is purchased by a company, and out of that only a few are being used currently while keeping the others in store then the instruments kept in stock are given the status of CBU as they will be used later.

3. Only For Indication [OFI] Instruments with this status can't be used for any measurement purpose, but can be used as non-measuring devices, e.g., a height gauge with OFI status can be used as a stand.

4. Rework This status indicates that the instrument should be reworked before use to get a correct reading, e.g., surface plate, base plate, etc.

5. Reject This status is provided to indicate that the error in the reading shown by the measuring instrument is not within the allowable limits.

6. Write-Off This status is given to that instrument which is to be directly scrapped.

Note: Rejected instruments can be used after repair, but instruments with a write-off status cannot be used for measurement in future.

2.5.3 Standard Procedure for Calibration

1. Cleaning of Instruments Every instrument should be first cleaned thoroughly.

2. Determination of Error The next step is to determine the errors in the instrument by various methods.

3. Check for Tolerable Limits After determination of error, the error is to be compared with the allowable tolerance.

4. Minor Changes These are made in the instrument, if possible, to minimize the error in the reading indicated by the instrument.

5. Allotment of Calibration Set Up Each instrument is allotted the set up as per its condition.

6. Next Calibration Date The instruments that are allotted an active status are also given the next calibration date as per standards.

A measuring instrument's normally allotted calibration interval based on guidelines is given in Table 2.8.

Table 2.9 shows the type of instruments generally calibrated to maintain their accuracy over a longer period of time.

2.5.4 List of Equipments used for Calibration of Measuring Instruments

Reference Gauge Standards Slip gauges, plain and threaded ring gauges, plain and threaded plug gauges, pin gauges, etc.

Devices with Variable Measurement Standards Comparators, exterior micrometers, bore meters, callipers, depth gauges, etc., on-site surface plates, measurement columns, three-dimensional measuring machines, profile projectors, horizontal measurement bench, slip-gauge controller, comparator calibration bench, laser-sweep beam micrometer, circularity, straightness, and length-gauge standards, contour-measuring equipment, single-dimensional measurement column, management software for measurement instrument stocks, high pressure gauge, OD caliper, dial, beam balance or digital scale, height-setting master, analytical type balance, ID caliper, dial, digital or vernier, ID micrometer, internal limit gauge, go/no-go type, OD micrometer, depth micrometer, force gauge, ID micrometer, tri-point type, torque meter, bench micrometer, gauge block, radius gauge, bevel protractor, thickness gauge,

Table 2.8 *Calibration intervals of different instruments*

Name of the Instrument	*Acceptable Tolerance Demand*	*Calibration Interval (Months)*
Vernier caliper and height gauge	±0.005 mm	12
Micrometer	2 μm	12
Pin gauge	±0.006 mm	12
Slip gauge	±0.02 μm	36
Setting ring for setting diameter of	Tolerance in m.	
1) 3 mm	4	36
2) 3–6 mm	4.2	
3) 6–10 mm	4.2	
4) 10–18 mm	4.5	
5) 18–30 mm	5	
6) 30–80 mm	5.5	
Dial gauge	0.003 mm	12
Digital dial gauge	Tolerance in μm	
0–1 mm	1	36
0–10 mm	2	
0–60 mm	3	
Radius master	5 %	24

Table 2.9 *Types of instruments*

Electrical	*Typical Equipment Calibrated*
ACOUSTICS	Sound Level Meter, Pistonphone and Octave Filter
VIBRATION	Accelerometer, Vibration Meter, Geophone 3-axis, Calibrator exciter Vibration Analyser, Vibration Exciter/Shaker, Portable Shaker System Vibration Machine (on-site calibration)
IMPEDANCE	Standard Capacitor, Standard Air Capacitor, Phase Meter, Standard Inductor, Capacitance Meter, Ratio Transformer
VT/CT	Current Transformer, Turn Ratio Meter, Current Transformer, Standard Current Transformer, Potential Transformer
POWER ENERGY	Test Device Digital Power Meter, Energy Meter, Kilowatt Meter, Standard Meter, Standard Watt Converter, Three Phase Measuring Assembly, Polyphase Watt Meter, Energy Analyser, Clip-on Power Meter

(*Continued*)

Table 2.9 *(Continued)*

Electrical	*Typical Equipment Calibrated*
AC/DC	Calibrator, Amplifier, Multimeter, DC Reference Standard, DC Power Supply voltage Standard, Oscilloscope Calibrator, DC Resister, Current Shunt, True RMS Voltmeter, LVDT, DC Voltage Standard
MAGNETIC	Gauss Meter, Magnets
RF AND MICROWAVE	Power Sensor/Meter, Step Attenuator, Standard Signal Generator, Automatic, Modulation Meter, Synthesized Sweeper, Vector Voltmeter, Doppler Radar, Gun, Signal Generator, Sp.
TIME AND FREQUENCY	Rubidium Frequency Standard, Quartz Oscillator, Frequency Counter, Universal Counter, Microwave Counter, Stop Watch
MECHANICAL	
DIMENSIONAL	Gauge Block, Long Gauge, Ring Gauge, Pin Gauge, Optical Flat Meter Comparator Optical Parallel, Glass Scale, Straight Edge Angle Gauge, Digital Caliper, Micro-Indicator, Height Gauge.
PRESSURE	Deadweight Pressure Balance/Gauge/Piston Gauge/Tester, Pressure Calibrator, Digital Test Gauge, Digital Manometer, Digital Barometer, Resonant Sensor Barometer, Digital Pressure Indicator, High Pressure Gauge, Micromanometer.
FORCE	Load Cell, Proving Ring Dynamometer, Calibration Box, Calibration Loop, Load Column, Hydraulic Jack, Force Gauge Tension Gauge, Force Transducer
THERMOPHYSICAL	
RESISTANCE THERMOMETRY	Standard Platinum Resistance Thermometer, Digital Thermometer Liquid in Glass Thermometer
HYGROMETER	Data Logger, Hygrometer
DENSITY VISCOSITY	Viscometer, Hydrometer
THERMOCOUPLE/THERMOMETRY	Thermocouple Probe/Wire
FLOW	
CAPICITY	Beaker, Measuring Cylinder, Prover Tank
FLOW	Pipe Prover, Gas Meter, Anemometer, Flow Meter
CHEMISTRY	Gas Analyser, Breath Analyser, Gas Detector

toolmaker's square, angle gauge, ring gauge, optical projector, comparator, snap gauge, toolmaker's microscope, test indicator, optical flat, dial indicator, surface plate slot and groove gauge, screw pitch gauge, tapered hole gauge.

2.5.5 Case Study 1: Dial Calibration Tester

Kudale Calibration Laboratory Pvt. Ltd., Pune, India, (NABL Certified Calibration Laboratory)

a. Introduction The manufacturing tolerances in almost all the industries are becoming stringent due to increased awareness of quality. This also calls for high accuracy components in precision assemblies and subassemblies. The quality control department therefore is loaded with the periodic

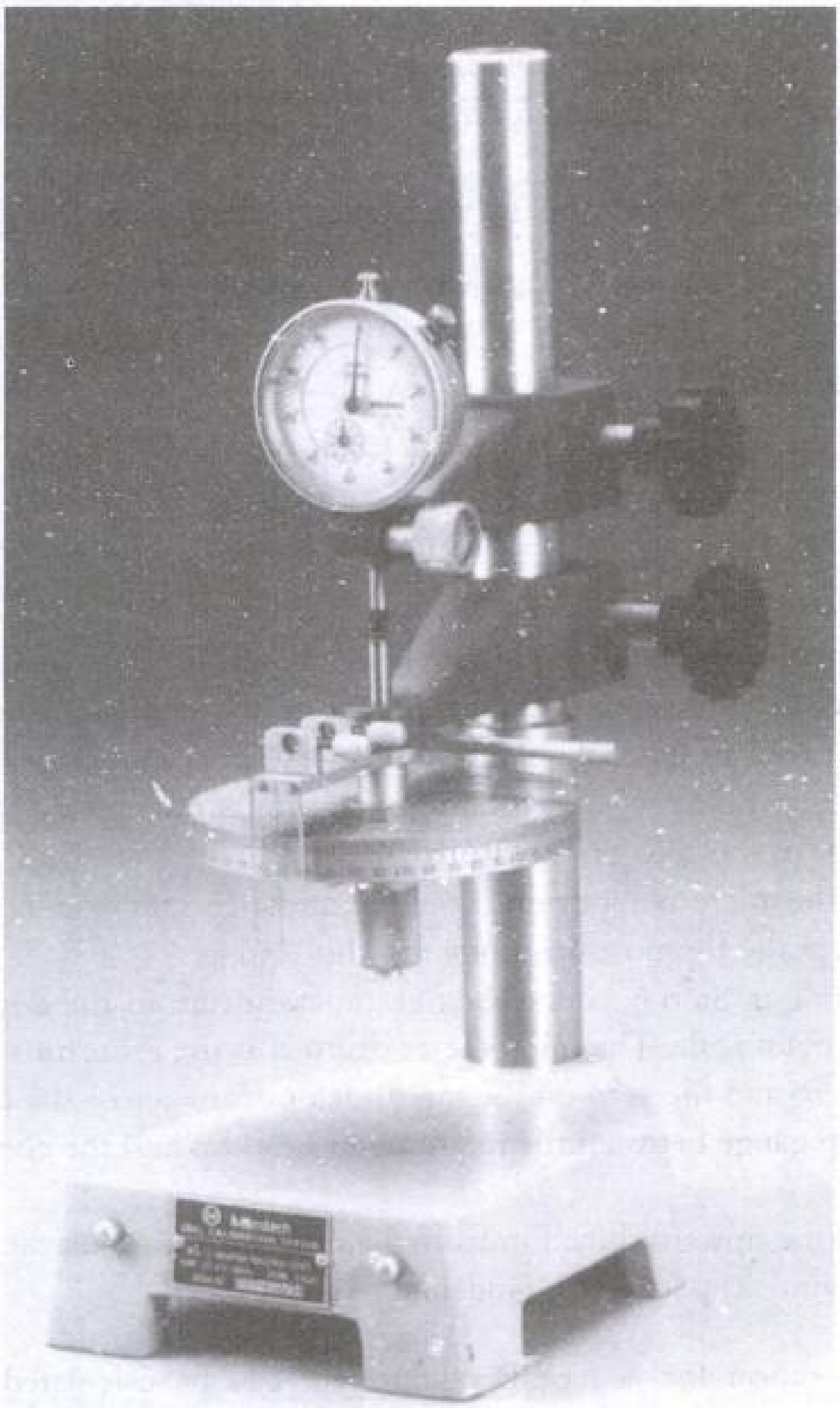

Fig. 2.6 *Dial calibration tester*

calibration of various measuring instruments. Since the accuracy of the components depends largely on the accuracy of measuring instruments like plunger-type dial gauges, back-plunger-type dial gauges, lever-type dial gauges and bore gauges, periodic calibration is inevitable and is a regular feature in many companies of repute. The practice of periodic calibration is of vital importance for quality assurance as well as cost reduction. The set of dial calibration tester enables us to test four different kinds of precision-measuring instruments and all the required accessories are included in the set. The habit of periodic calibration has to be cultivated right from the stage of technical education, viz., engineering colleges, polytechnics and other institutes.

Why is periodic calibration required?

i. To grade a dial according to its accuracy and thereby to choose the application where it can be safely used
ii. To determine the worn-out zone of travel facilitating full utilization of dials
iii. To inspect the dial after repairs and maintenance
iv. To ascertain the exact point of discardation

b. Scope This procedure is to cover the dial calibration tester for the following range.

Range = 0–25 mm and LC = 0.001 mm

c. Calibration Equipment

Electronic Probe – Maximum Acceptable Error = 3.0 μm

Slip Gauges = 0 Grade

d. Calibration Method

i. Clean the measuring faces of the dial calibration tester with the help of CTC.
ii. Place the micrometer drum assembly and dial holder on the stem, one above the other.
iii. Hold the electronic probe in the dial holder of the dial calibration tester.
iv. Set the zero of the electronic probe by rotating the drum in the upward direction.
v. Adjust the cursor line at the zero on the drum.
vi. With these settings, the micrometer drum should be at the 25-mm reading on the main scale. The micrometer drum is at the topmost position after this setting.
vii. After the above setting in Step 6, rotate the micrometer drum to the downward direction till it reaches zero on the main scale. The micrometer drum is at the lowermost position at this point.
viii. Set the main scale zero and the zero on the micrometer drum across the cursor line.
ix. Place the 25-mm slip gauge between the micrometer head tip and the contact point of the electronic probe.
x. Take the readings in the upward direction from 0.5 mm to 25 mm in a step size of 0.5 mm.
xi. Calculate the uncertainty as per NABL guideline 141.

e. Uncertainty Calibration for A type-B component can be calculated as per the following guidelines:

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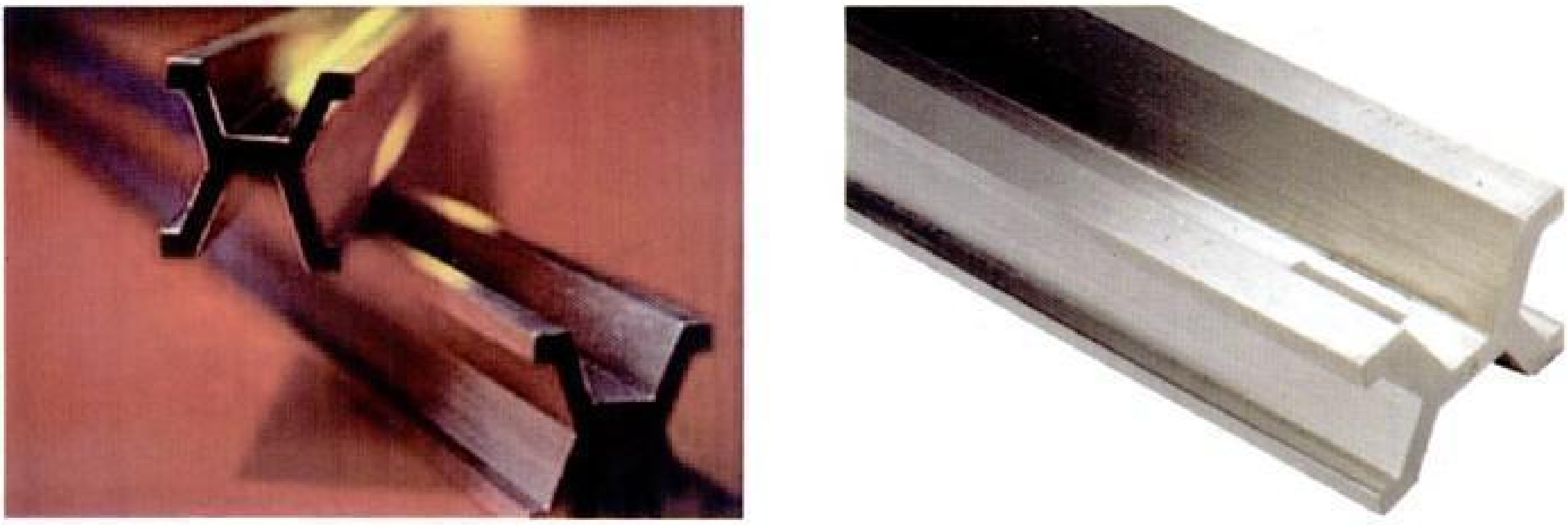


(b) (c)

Fig. 2.2(b) *International Standard Prototype Metre (c) Historical Standard platinum–iridium metre bars*

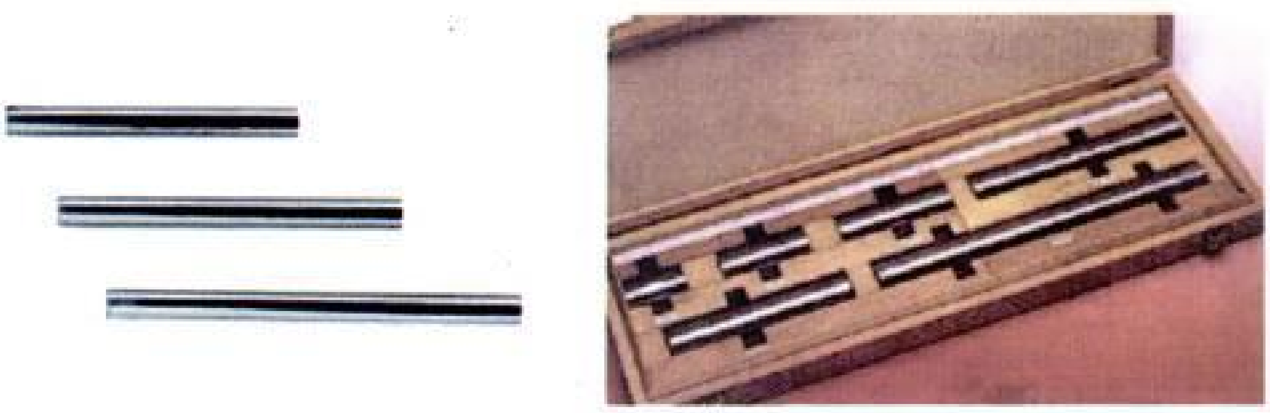
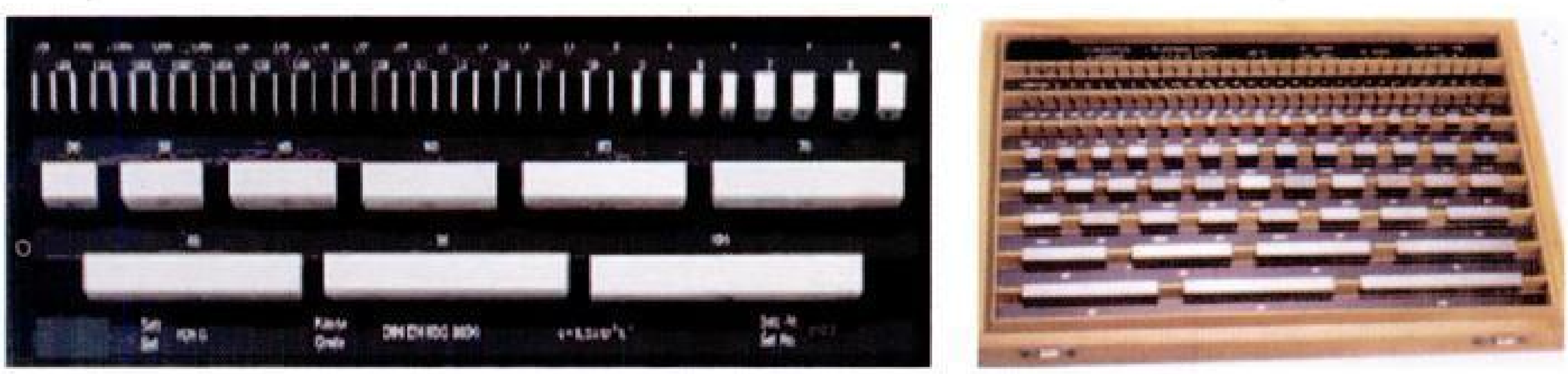


Fig. 2.3 *End bars*



(a) (b)

Fig. 2.4 *Set of slip gauges: (a) Set of ceramic slip gauges (b) Set of cast-steel slip gauges*

Review Questions

1. What are standards of measurements? Explain the classification of various standards.
2. Explain the terms: a) Metre b) Yard c) Wringing of slip gauges d) calibration.
3. Write short notes on

   a) Line standard b) End standard c) Grades of slip gauges
4. Explain the wringing of slip gauges.
5. Explain the need and standard procedure for calibration.
6. Explain what you mean by subdivision of standards.
7. Explain the optical definition of 'inch'.
8. State the section and the materials from which the following length standards are made of:

   (a) Imperial standard yard (b) International prototype metre (c) Wavelength standard;

   To which category do these standards belong?
9. Define 'metre' in optical terms.
10. Distinguish between primary, secondary and working standards.
11. Explain slip gauges as an end standard by stating their advantages.
12. Distinguish between 'line standards' and 'end standards'. How are the end standards derived from line standards?
13. Describe the standard procedure of calibrating a metrological instrument.
14. Explain the procedure of wringing of slip gauges.

Fig. 3.1(b) *Digital scale*
(Courtesy, Mahr Gmbh Esslingen)

3.3 CALIPERS

A caliper is an end-standard measuring instrument to measure the distance between two points. Calipers typically use a precise slide movement for inside, outside, depth or step measurements. Specialized slide-type calipers are available for centre, depth and gear-tooth measurement. Some caliper types such as spring/fay or firm-joint calipers do not usually have a graduated scale or display and are only used for comparing or transferring dimensions as secondary measuring instruments for indirect measurements. The caliper consists of two legs hinged at the top, with the ends of the legs spanning the part to be measured. The legs of a caliper are made from alloy steels and are identical in shape, with the contact points equidistant from the fulcrum. The measuring ends are suitably hardened and tempered. The accuracy of measurement using calipers depends on the sense of feel that can only be acquired by experience. Calipers should be held gently near the joint and square to the work by applying light gauging pressure to avoid disturbance during setting for accurate measurement.

3.3.1 Types of Calipers

Inside calipers are made with straight legs, which are bend outwards at the ends and are used for measuring hole diameters, distance between shoulders, etc. The opening of an inside caliper can be checked by a rule or micrometer.

Outside calipers have two legs which are bent inward and are used for measuring and comparing diameters, thicknesses and other outside dimensions by transferring the readings to a steel rule, micrometer or vernier caliper. It can be adjusted by tapping one leg or by adjusting the screw to straddle the work by its legs as shown in Fig. 3.2.

Spring calipers are an improved variety of ordinary friction-joint calipers. The two legs carry a curved spring (made from suitable steel alloy) at the top, fitted in notches used to force the spring apart. The distance between them can be adjusted by applying pressure against the spring pressure by tightening the nut. Inside and outside calipers are available in sizes of 75, 100, 150, 200, 250 and 300 mm.

A *centre-measuring caliper* has conically pointed jaws designed to measure the distance between the centres of two holes. A *gear-tooth caliper* has an adjustable tongue designed to measure the thickness of gear teeth at the pitch line. The adjustable tongue sets the measurement depth at the pitch line or addendum. *Machine travel calipers* are designed to measure the travel or position changes of a machine

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3.4.1 Instructions on Use

i. The vernier caliper is an extremely precise measuring instrument.
ii. Close the jaws lightly on the object to be measured.
iii. If you are measuring something with a round cross section, make sure that the axis of the object is perpendicular to the caliper. This is necessary to ensure that you are measuring the full diameter and not merely a chord.
iv. Ignore the top scale, which is calibrated in inches.
v. Use the bottom scale, which is in metric units.
vi. Notice that there is a fixed scale and a sliding scale.
vii. The boldface numbers on the fixed scale are in centimetres.
viii. The tick marks on the fixed scale between the boldface numbers are in millimetres.
ix. There are ten tick marks on the sliding scale. The leftmost tick mark on the sliding scale will let you read from the fixed scale the number of whole millimetres for which the jaws are opened.
x. In Fig. 3.5, the leftmost tick mark on the main scale is between 21 mm and 22 mm, so the number of whole millimetres is 21.

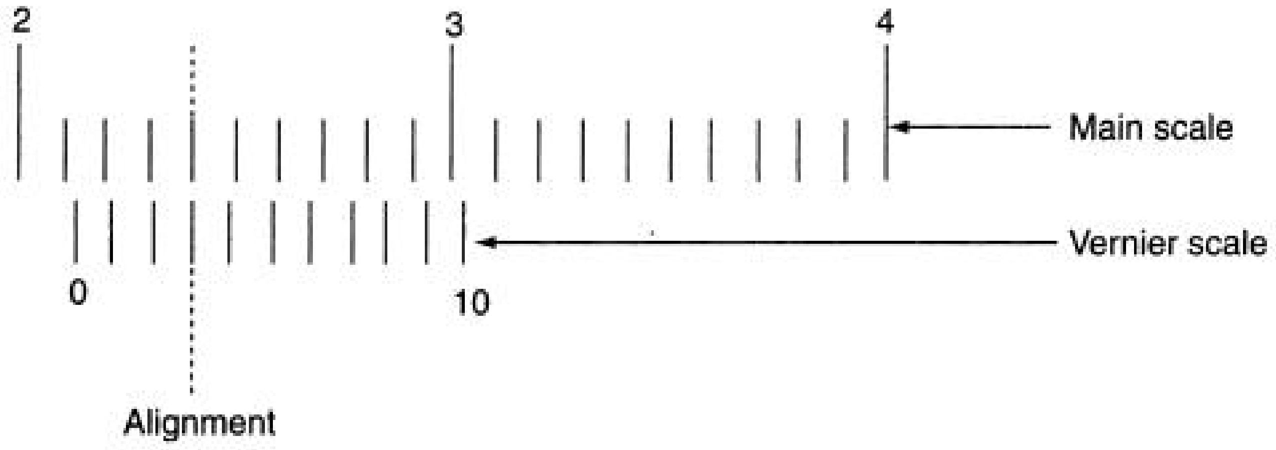

Fig. 3.5 *Scale comparison*

xi. Examine the vernier scale to determine which of its divisions coincide or are most coincident with a division on the main scale. The number of these divisions is added to the main scale reading.
xii. In Fig. 3.5, the third tick mark on the sliding scale is in coincidence with the one above it.

$$\text{Least count} = \frac{\text{Smallest division on main scale}}{\text{Total no. of divisions on vernier scale}}$$

$$= \frac{1\text{mm}}{10} = 0.1 \text{ mm}$$

Table 3.2 *Measuring the total reading by vernier caliper*

Sl. No.	*Main Scale Reading (MSR) (mm)*	*Vernier Scale Reading (VSR)*	*C (mm) = LC × VSR*	*Total Reading (mm) = MSR + C*
1.	21	3	0.3	21.30

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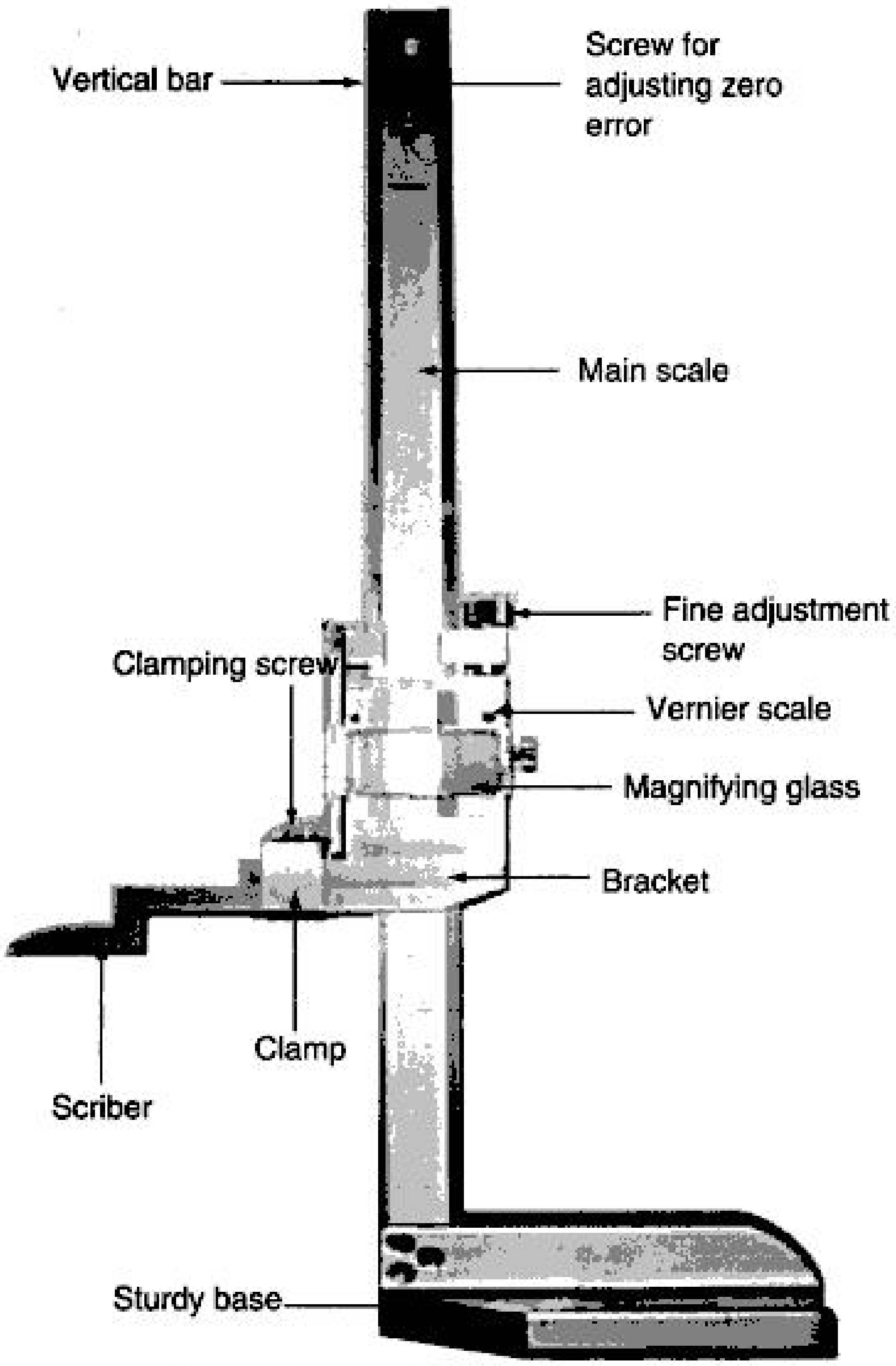


Fig. 3.9 *Vernier height gauge*

carries the vernier scale which slides vertically to match the main scale. The bracket also carries a rectangular clamp used for clamping a scriber blade. The whole arrangement is designed and assembled in such a way that when the tip of the scriber blade rests on the surface plate, the zero of the main scale and vernier scale coincides. The scriber tip is used to scribe horizontal lines for preset height dimensions. The scriber blade can be inverted with its face pointing upwards which enables determination of heights at inverted faces. The entire height gauge can be transferred on the surface plate by sliding its base. The height gauges can also be provided with dial gauges instead of a vernier, which makes reading of bracket movement by dial gauges easy and exact.

The electronic digital vernier height gauge shown in Fig. 3.10(b) provides an immediate digital readout of the measured value. It is possible to store the standard value in its memory, which could be used as datum for further readings, or for comparing with given tolerances. Digital pre-setting is possible in which reference dimensions can be entered digitally and automatically, allowed during each

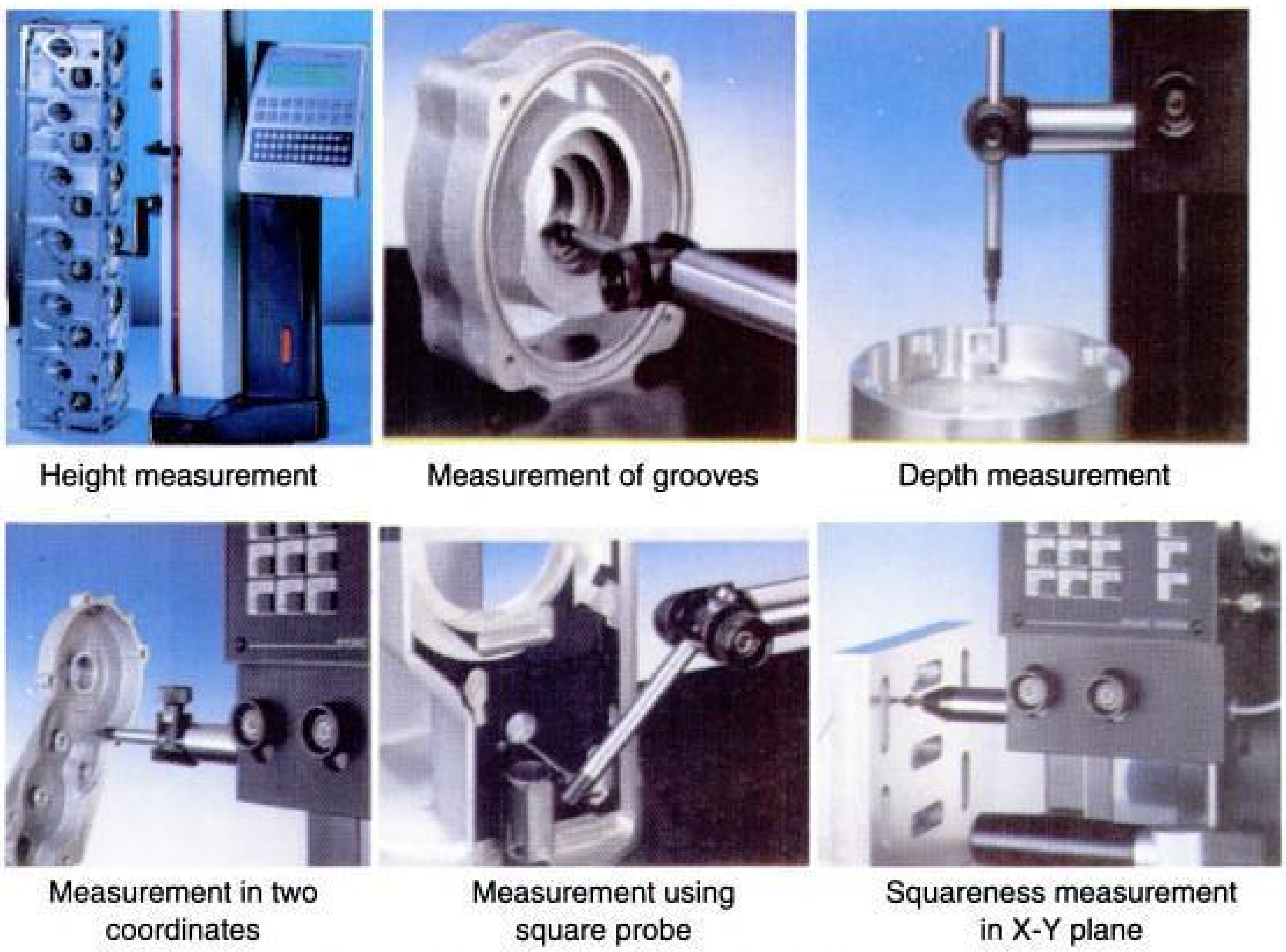


Fig. 3.11 *Applications of height gauges*
(Courtesy, Trimos SA Inc.)

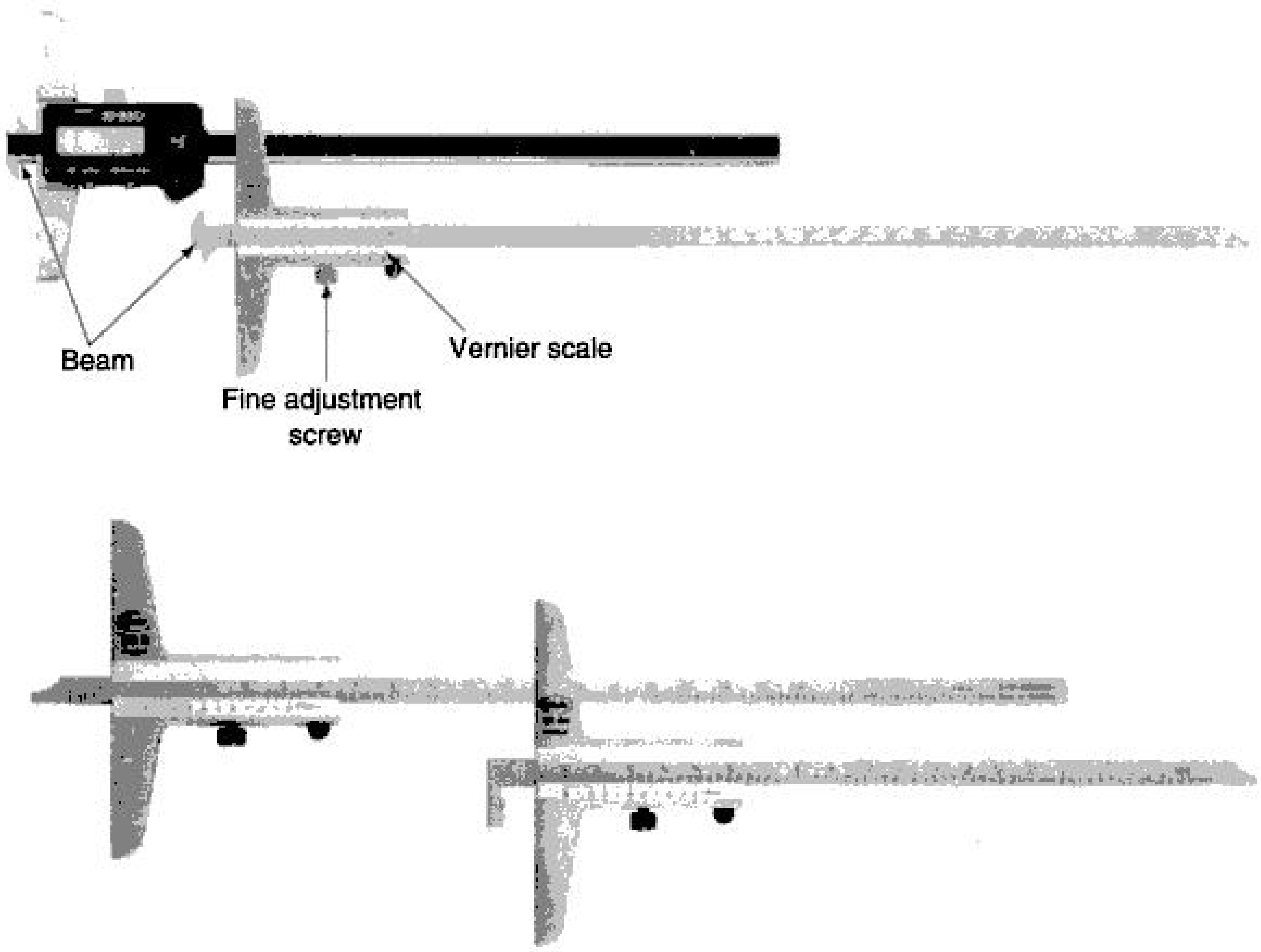


Fig. 3.12(a) *Vernier depth gauge*
(Mahr Gmbh Esslingen)

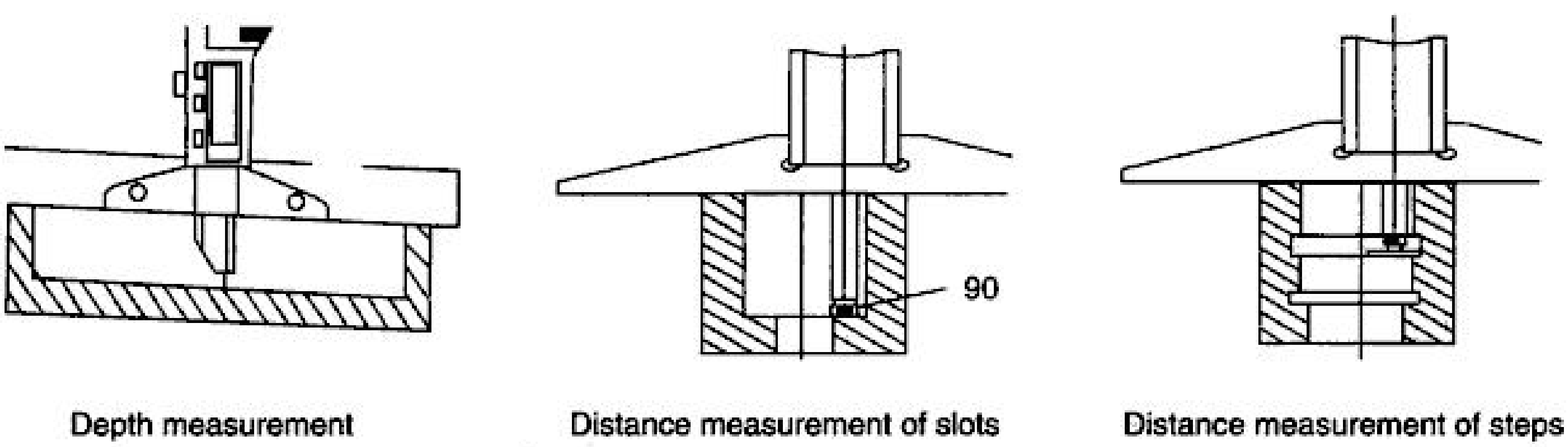


Fig. 3.12(b) *Vernier-depth-gauge applications*
(Mahr Gmbh Esslingen)

3.7 MICROMETERS

Next to calipers, micrometers are the most frequently used hand-measuring instruments in linear metrology. Micrometers have greater accuracy than vernier calipers and are used in most of the engineering precision work involving interchangeability of component parts. Micrometers having accuracy of 0.01 mm are generally available but micrometers with an accuracy of 0.001 mm are also available. Micrometers are used to measure small or fine measurements of length, width, thickness and diameter of a job.

Principle of Micrometer A micrometer is based on the principle of screw and nut. When a screw is turned through one revolution, the nut advances by one pitch distance, i.e., one rotation of the screw corresponds to a linear movement of the distance equal to the pitch of the thread. If the circumference of the screw is divided into *n* equal parts then its rotation of one division will cause the nut to advance through pitch/*n* length. The minimum length that can be used to measure in such a case will be pitch/*n* and by increasing the number of divisions on the circumference, the accuracy of the instrument can be increased considerably. If the screw has a pitch of 0.5 mm then after every rotation, the spindle travels axially by 0.5 mm and if the conical end of the thimble is divided by 50 divisions, the rotation of the thimble of one division on the micrometer scale will cause the axial movement of the screw equal to 0.5/50 mm = 0.01 mm, which is the least count of the micrometer and is given by the formula

$$\text{Least count} = \frac{\text{Smallest division on main scale}}{\text{Total no. of divisions on vernier (circular scale)}} = 0.05\ \text{mm}/50 = 0.01\ \text{mm}$$

Micrometers are classified into the following types:

1. Outside micrometer 2. Inside micrometer 3. Depth-gauge micrometer

3.7.1 Outside Micrometer

Figure 3.13 illustrates the design features of an outside (external micrometer). It is used to measure the outside diameter, length and thickness of small parts. Outside micrometers having an accuracy of 0.01 mm are generally used in precision engineering applications.

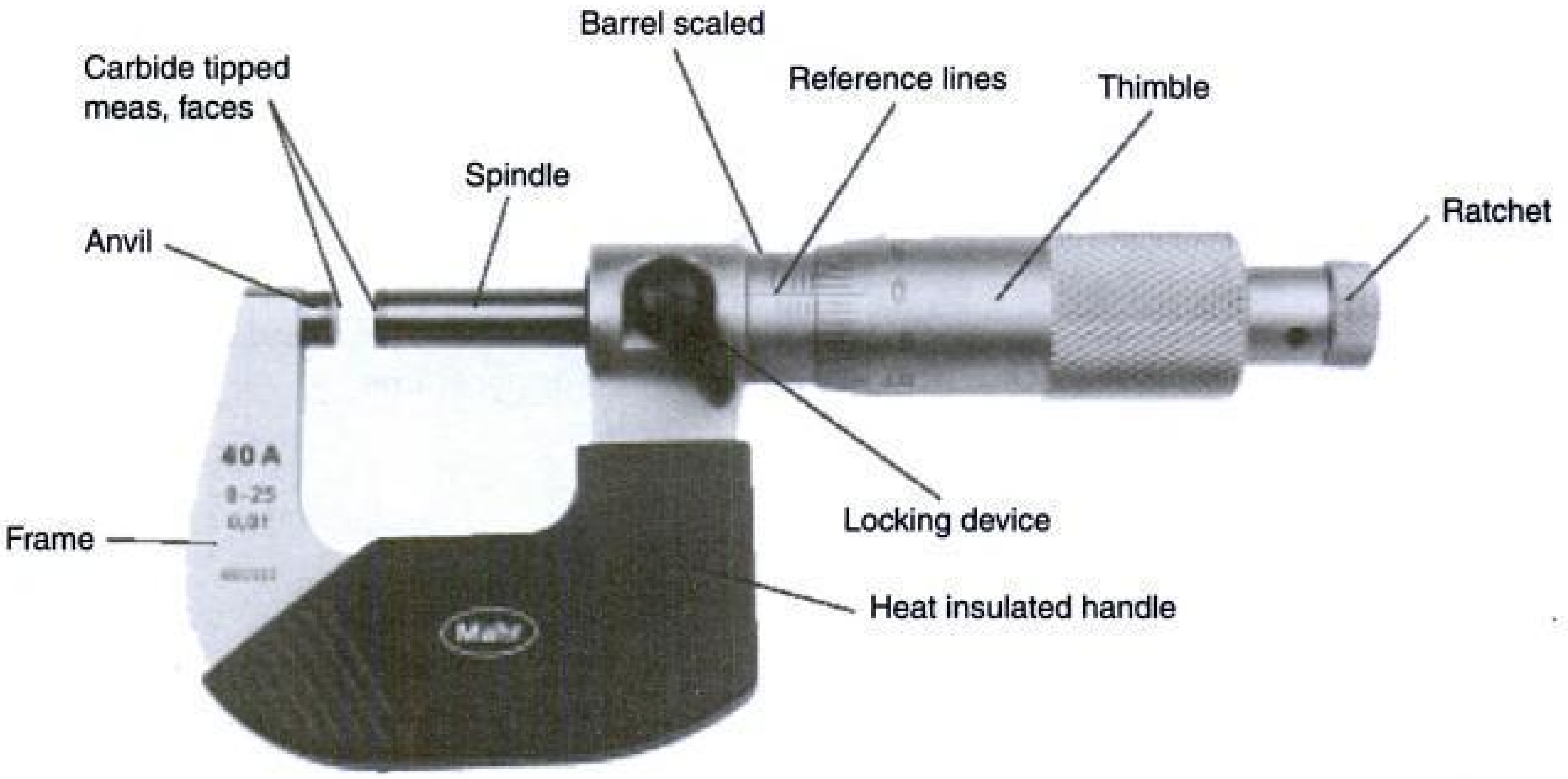


Fig. 3.13 *Outside micrometer with a measuring range of 0–25 mm and accuracy of 0.01 mm (Mahr Gmbh Esslingen)*

The main parts of outside micrometers are the following:

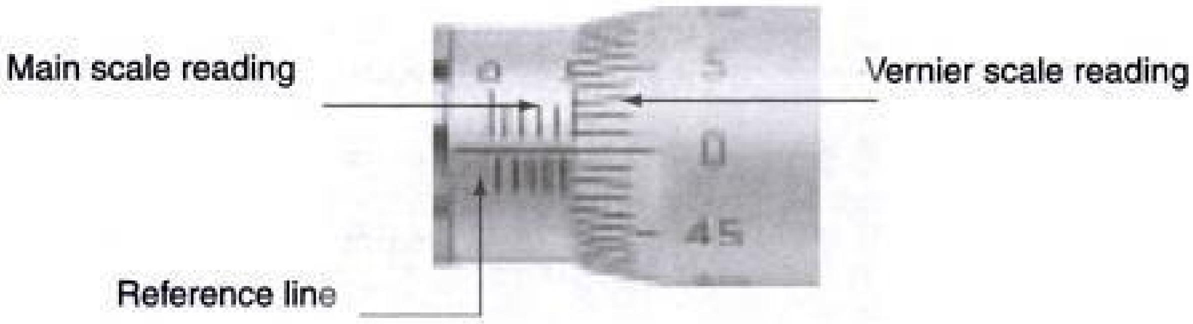
1. U-shaped or C-shaped Frame The micrometer consists of a U- or C-shaped rigid frame, which holds all parts of the micrometer together. The gap of the frame decides the maximum diameter or length of the job to be measured. The frame is generally made of steel, cast steel and other light alloys with satin-chromed finish to allow glare-free reading. A heat-insulating handle provides ease of finger gripping.

2. Carbide-Tipped Measuring Faces—Anvil and Spindle The micrometer has a fixed anvil and it is located at 3.5 mm from the left-hand side of the frame. The diameter of the anvil is the same as that of the spindle with exact alignment of their axes. The anvil is accurately ground and lapped with its measuring face flat and parallel to the measuring face of the spindle. The carbide-tipped anvil guarantees extreme precision and ensures long lifetime of the instrument. The anvil is rigidly fixed to one left end of the frame and it is also made up of a hardened steel-like spindle. The spindle is the movable measuring face with the anvil on the front side and it is engaged with the nut. The spindle should run freely and smoothly throughout its length of travel. There should not be any backlash (lost motion of the spindle when the direction of rotation of the thimble is changed) between the screw and nut and at the time of full reading, full engagement of the nut and screw must be possible.

When the spindle face is touched with the anvil face, the zero of the micrometer must match with the reference line on the main scale and the thimble is required to be set at zero division on the main scale. If this condition is not satisfied, the corresponding reading gives the value of zero present in the instrument, known as zero error. To compensate for the zero error, there is a provision to revolve the barrel slightly around its axis. The measuring range is the total travel of the spindle for a given micrometer.

3. Locking Device A locking device is provided on a micrometer spindle to lock it in exact position. This enables correct reading without altering the distance between the two measuring faces, thus retaining the spindle in perfect alignment.

4. Barrel A barrel has fixed engraved graduation marks on it and is provided with satin-chromium finish for glare-free reading. The graduations are above and below the reference line. The upper graduations are of 1-mm interval and are generally numbered in multiples of five as 0, 5, 10, 15, 20 and 25. The lower graduations are also at 1-mm interval but are placed at the middle of two successive upper graduations to enable the reading of 0.5 mm.



Reading = 5.00 mm

Fig. 3.14 *Graduations marked on barrel and thimble*

5. Thimble It is a tubular cover fastened and integrated with a screwed spindle (Fig. 3.14). When the thimble is rotated, the spindle moves in a forward or reverse axial direction, depending upon the direction of rotation. The conical edge of the spindle is divided into 50 equal parts as shown in Fig. 3.14. The multiples of 5 and 10 numbers are engraved on it and the thickness of graduations is between 0.15 to 0.20 mm.

6. Ratchet A ratchet is provided at the end of the thimble. It controls the pressure applied on the workpiece for accurate measurement and thereby avoids the excessive pressure being applied to the micrometer, thus maintaining the standard conditions of measurement. It is a small extension of the thimble. When the spindle reaches near the work surface which is to be measured, the operator uses the ratchet screw to tighten the thimble. The ratchet gives a clicking sound when the workpiece is correctly held and slips, thereafter preventing damage of the spindle tips. This arrangement is very important as a variation of finger efforts can create a difference of 0.04 to 0.05 mm of the measured readings.

Micrometers are available in various sizes and ranges as shown in Table 3.3.

3.7.2 Instructions for Use

- The micrometer is an extremely precise measuring instrument; the reading error is 4 microns when used for the range of 0–25 mm.
- Use the rachet knob (at the far right in the following picture) to close the jaws lightly on the object to be measured. It is not a C-clamp! When the rachet clicks, the jaws are closed sufficiently.
- The tick marks along the fixed barrel of the micrometer represent halves of millimetres.

Table 3.3 *Measuring range of micrometers*

Measuring Range	*Least Count*	*Limits of Error (DIN 863)*	*Pitch of Spindle Thread*
0–25 mm	0.01 mm	4 μm	0.5 mm
25–50 mm	0.01 mm	4 μm	0.5 mm
50–75 mm	0.01 mm	5 μm	0.5 mm
75–100 mm	0.01 mm	5 μm	0.5 mm
100–125 mm	0.01 mm	6 μm	0.5 mm
125–150 mm	0.01 mm	6 μm	0.5 mm
150–175 mm	0.01 mm	7 μm	0.5 mm
175–200 mm	0.01 mm	7 μm	0.5 mm

- The total reading for this micrometer will be (2.62 ± 0.004) mm, where 4 microns is the error of instrument.
- The micrometer may not be calibrated to read exactly zero when the jaws are completely closed. Compensate for this by closing the jaws with the rachet knob until it clicks. Then read the micrometer and subtract this offset from all measurements taken. (The offset can be positive or negative.)
- On those rare occasions when the reading just happens to be a 'nice' number like 2 mm, don't forget to include the zero decimal places showing the precision of the measurement and the reading error. So the reading should be recorded as not just 2 mm, but rather (2.000 ± 0.004) mm.

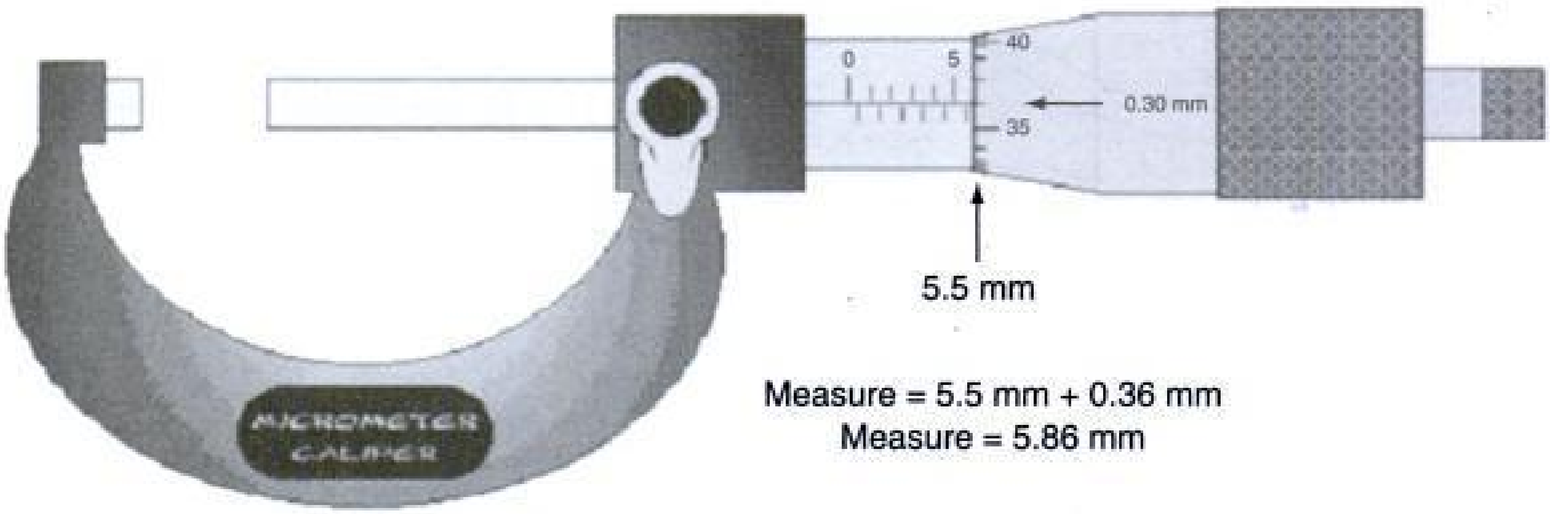


Fig. 3.16 *Micrometer measuring 5.86 mm*

Figure 3.17 shows micrometers with different types of indicators.

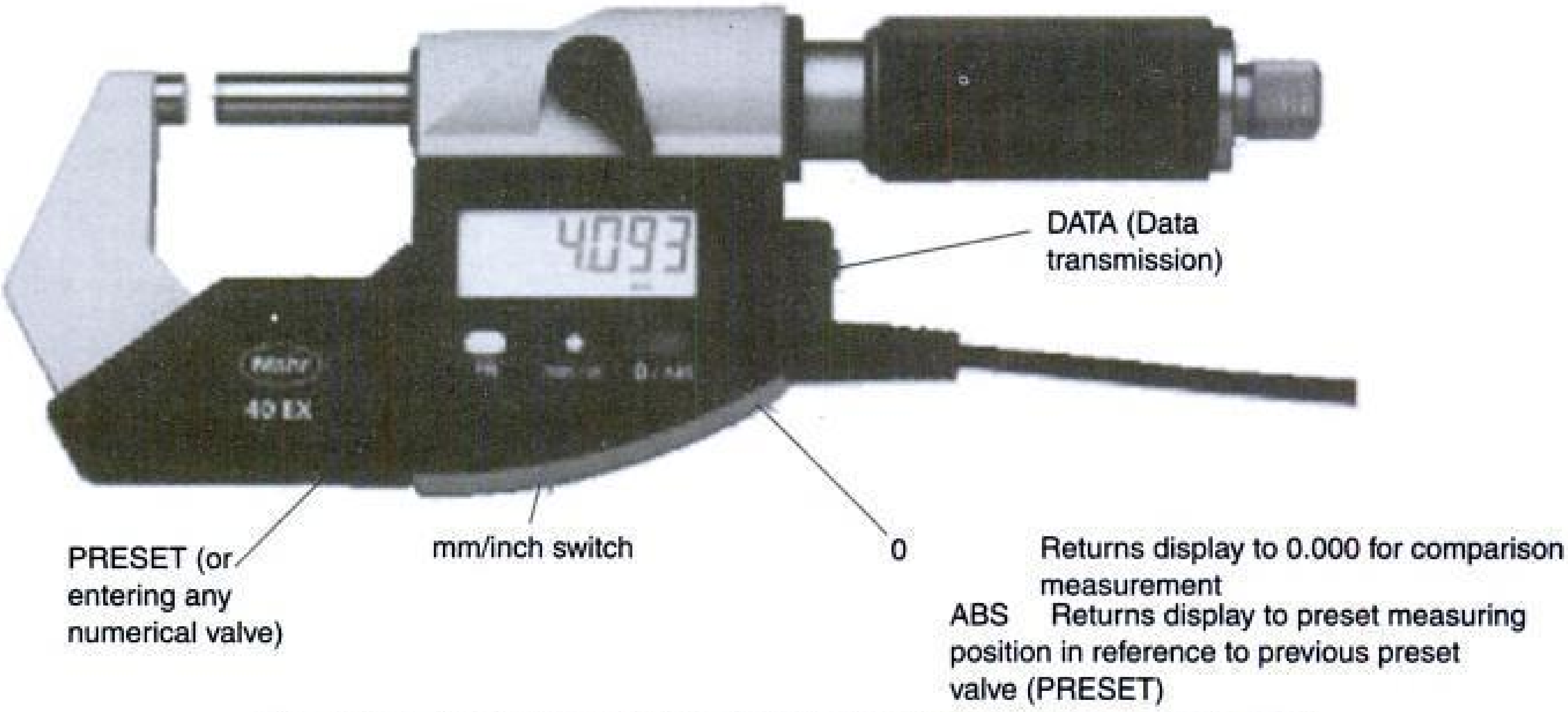


Fig. 3.17 *Micrometer with digital display (Mahr Gmbh Esslingen)*

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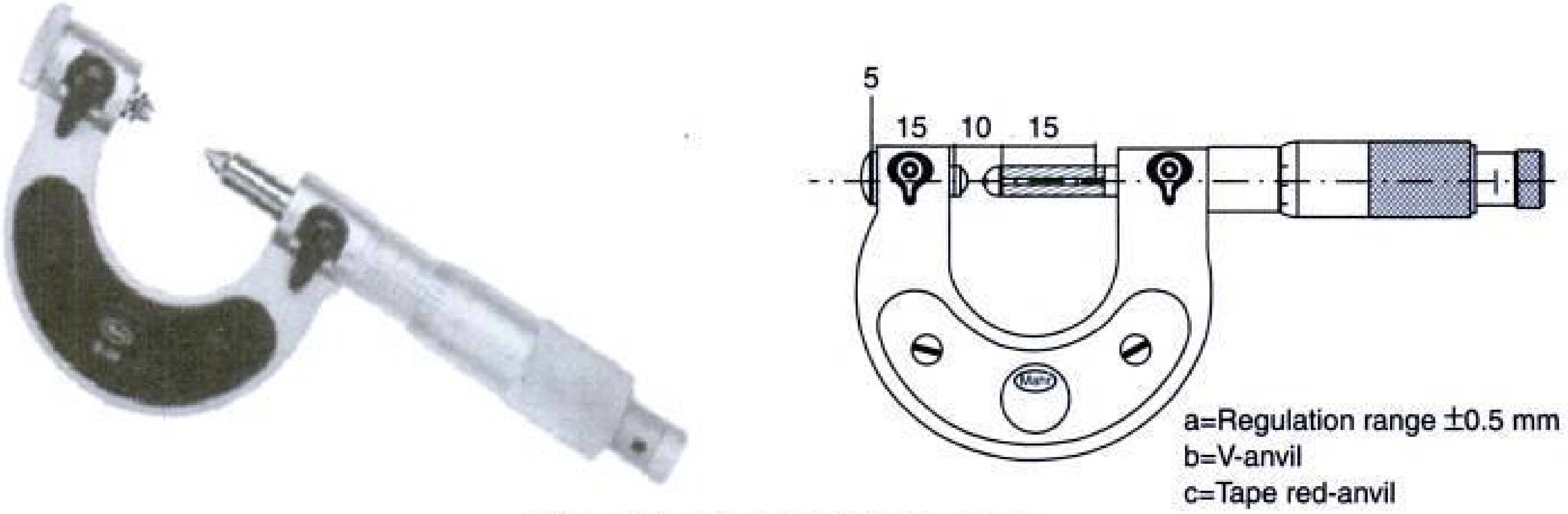

Fig. 3.24 *Thread micrometer*
(Mahr Gmbh Esslingen)

3.7.3 Thread Micrometers

This type of micrometer is used for measuring pitch, root and outside diameter. It consists of a rugged steel frame with heat-insulators of up to a 100-mm one-piece design of frame and spindle guide for maximum stability. The measuring spindle is hardened throughout the ground and is provided with a locking lever with an adjustable anvil. The measuring spindle and anvil holders are equipped with mounting bores for accommodation of interchangeable anvils.

A flat end surface of the anvil shank rests on a hardened steel ball in the bottom of a mounting bore. The frame and scales are provided with satin-chrome finish for glare-free readings.

A thread micrometer consists of a point on one side and a V-groove on the other, both matching the pitch angle of the thread to be checked. One setting is sufficient for two adjacent frame sizes.

a. Interchangeable Anvils for Thread Micrometers For measuring pitch, root and outside diameters, anvils made up of hardened wear-resistant special steels are used with a cylindrical mounting shank and retainer ring which ensures locking while permitting rotation in the bore of spindle and anvil.

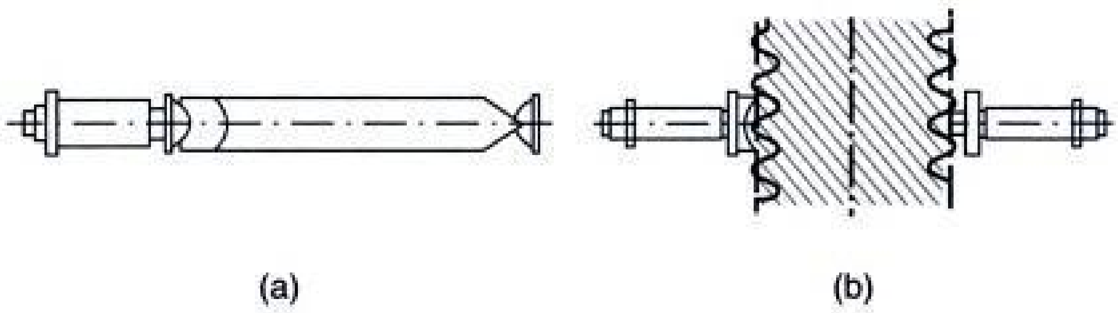

Fig. 3.25 *Setting standards for thread micrometers*

b. V and Tapered Anvils for Pitch Diameters The set of thread micrometers consists of V-anvils and tapered anvils for measuring pitch diameters.

It consists of a rugged design with a ground and hard-chromium-plated column while a movable arm holder is mounted in a precision ball guide to eliminate play and friction. The stationary arm holder can be moved on the column for rough setting and has high sensitivity and accuracy due to stability provided by the movable arm holder with a constant measuring force as a result of a built-in spring. A reversible measuring force direction is possible for both outside and inside measurements. Reversible arms can be located at any extent of the measuring range.

3.9 DIGITAL UNIVERSAL CALIPER

The digital universal caliper (Fig. 3.35) is used for measurement of outside and inside dimensions, registers, narrow calipers, external and internal tapers, dovetails, grooves, distances between hole-centres and for scribing the workpiece. This instrument has an outside measuring range of 0–300 mm and an inside measuring range of 25–325 mm, with a resolution of 0.01 mm within the error limit (DIN 862) of 0.03 mm.

The digital universal caliper provides functions such as On/Off, RESET (zero setting), mm/inch, HOLD (storage of measuring values), DATA (data transmission), PRESET (set buttons can be used to enter any numerical value) and TOL (tolerance display). The maximum measuring speed of the instrument is 1.5 m/s and a high-contrast 6-mm liquid crystal display is used with interchangeable arms. The arms are reversible for extending measuring range and both the arms can be moved on the beam, thus well-balancing the distribution of weight on small dimensions. The slide and beam are made up of hardened steel and the instrument is operated by battery. The following table explains the different anvils used for various applications.

At the beginning of the technological era, Carl Mahr, a mechanical engineer from Esslingen, realized that machines were becoming more and more accurate and required measuring tools to ensure the accuracy of their components. So he founded a company that dealt with the production of length-measuring tools. At that time, the individual German states used different units of measure. For this reason, his vernier calipers and scales were manufactured for all sorts of units, such as the Wurttemberger inch, the Rhenish inch, the Viennese inch, and the millimetre that already applied to France. Carl Mahr made a valuable contribution to the metric unit introduced after the foundation of the German Empire in 1871. He supplied metre rules, which were used as standards, first by the Weights and Measures offices in Wurttemberg and shortly thereafter in all German states. Measuring instruments for locomotives and railroad construction were a particular speciality. As the system of railroads in Europe expanded, demand was particularly great. The technology continued to develop and the

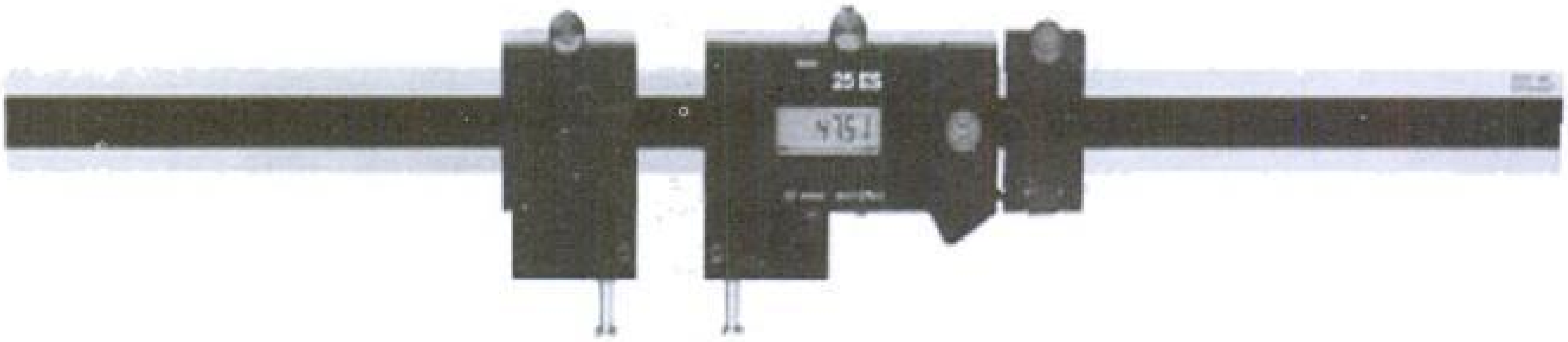

Fig. 3.35 *Digital universal caliper (Mahr Gmbh Esslingen)*

not on the length of its bearing surface. (A short level may be more sensitive than a long coarse one. However, it is advisable to use spirit levels which are so short that small deviations are obtained rather than mean values). The sensitivity E of the spirit level is the movement of the bubble in millimetres, which corresponds to the change in slope of 1 mm per 1000 mm.

$$E = \frac{\text{Movement of bubble}}{1\,\text{mm/metre}}$$

An auto-collimator can also be used to test the straightness. Spirit levels can be used only to measure/test straightness of horizontal surfaces while auto-collimators can be used on a surface in any plane. To test the surface for straightness, first of all draw a straight line on the surface. Then divide the line into a number of sections (in case of a spirit level, it is equal to the length of the spirit level base and length of the reflector's base in case of auto-collimator). Generally, bases of these instruments are fitted with two feet in order to get the line contact of feet with a surface instead of its whole body. In case of a spirit level, the block is moved along the marked line in steps equal to the pitch distance between the centrelines of the feet. The angular variations of the direction of the block are measured by the sensitive level on it, which ultimately gives the height difference between two points by knowing the least count of the spirit level. Figure 4.2 (Plate 4) shows a spirit level (only 63 mm long) is that perfectly useful, despite its small size, when it is placed on a carpenter's square or a steel rule. The screws do not exert any direct pressure on the rule. Steel balls are set in the level so that (a) the surface of the ruler is not damaged, and (b) the unit does not shift when it is fixed on the temporary base. The thickness of square or ruler is up to 2 mm.

2. Straight Edges In conjunction of surface plates and spirit levels, straight edges are used for checking straightness and flatness. It is a narrow/thin, deep and flat-sectioned measuring instrument. Its length varies from several millimetres to a few metres. These are made up of steels (available up to 2 m), cast iron (available up to 3 m). As shown in Fig. 4.3, straight edges are ribbed heavily and manufactured in bow shapes. The deep and narrow shape is provided to offer considerable resistance to bending in the plane of measurement without excessive weight. Straight edges with wide working

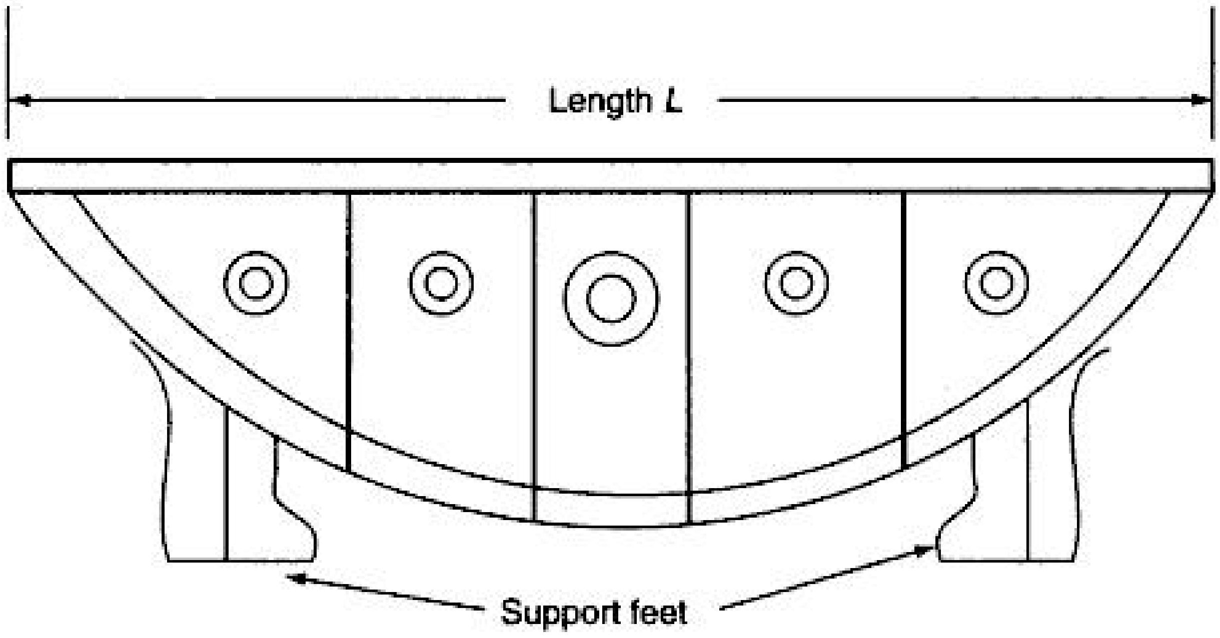

Fig. 4.3 *Straight edges*

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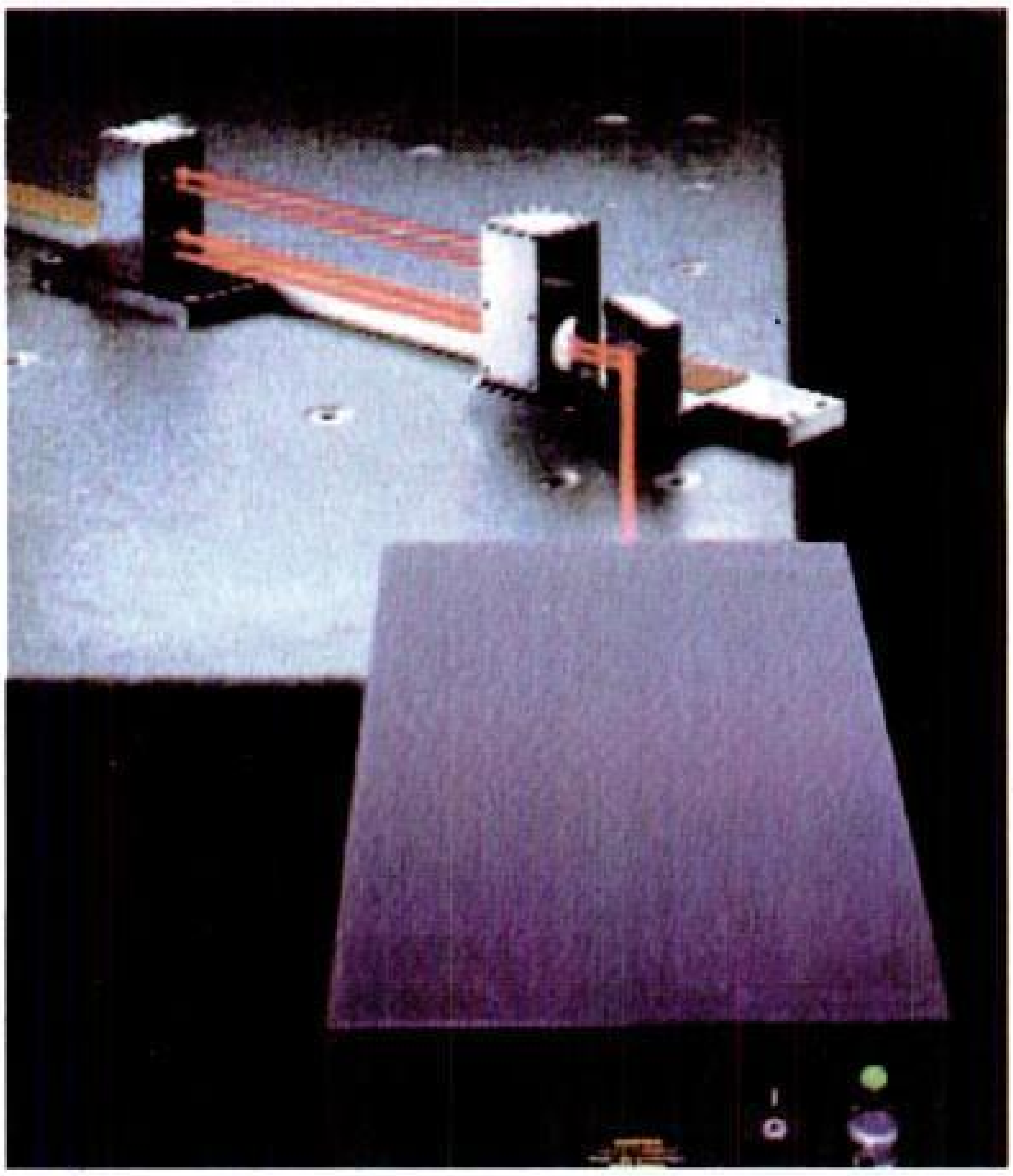

(a) System

(b) Flatness mirrors and bases

(c) Angular optics

Fig. 4.12 *Laser measurement system*

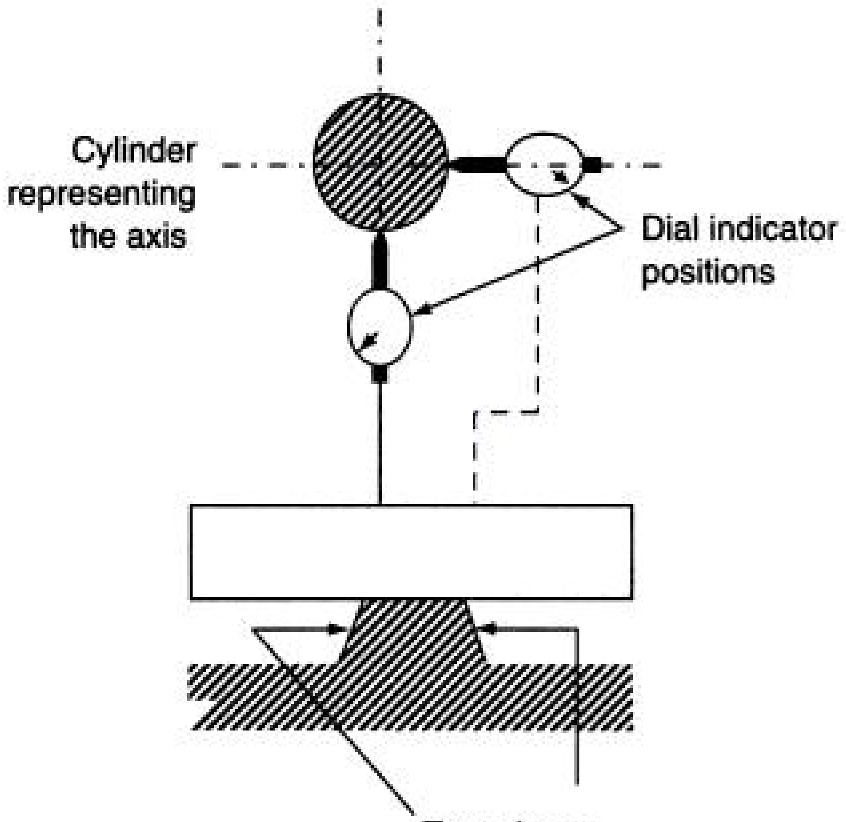

Fig. 4.17 *Parallelism of an axis to the interrsection of two planes*

3. Using an Autocollimator Smaller values of parallelism can be measured using the autocollimator, which allows differences as small as a few seconds of an arc to be measured on polished surfaces. The autocollimator consists of a reflecting telescope with a calibrated cross-wire eyepiece as shown in Fig. 4.20. Using an accurately parallel reference disc, a three-ball plane under the telescope is set precisely at right angles to the optical axis. The reference disc is then replaced by the sample.

If surfaces of the sample are not parallel, the reflected cross wire image from its upper surface will be displaced when viewed in the eyepiece. Samples can be assessed in position on the precision polishing jig and the out-of-flatness corrected using the micrometer tilt screws on the precision jig.

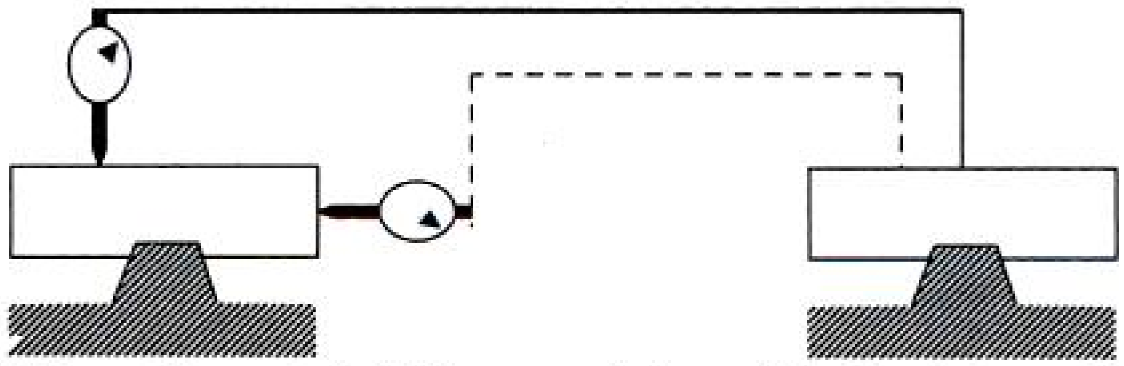

Fig. 4.18 *Parallelism of two straight lines, each formed by the intersection of two planes*

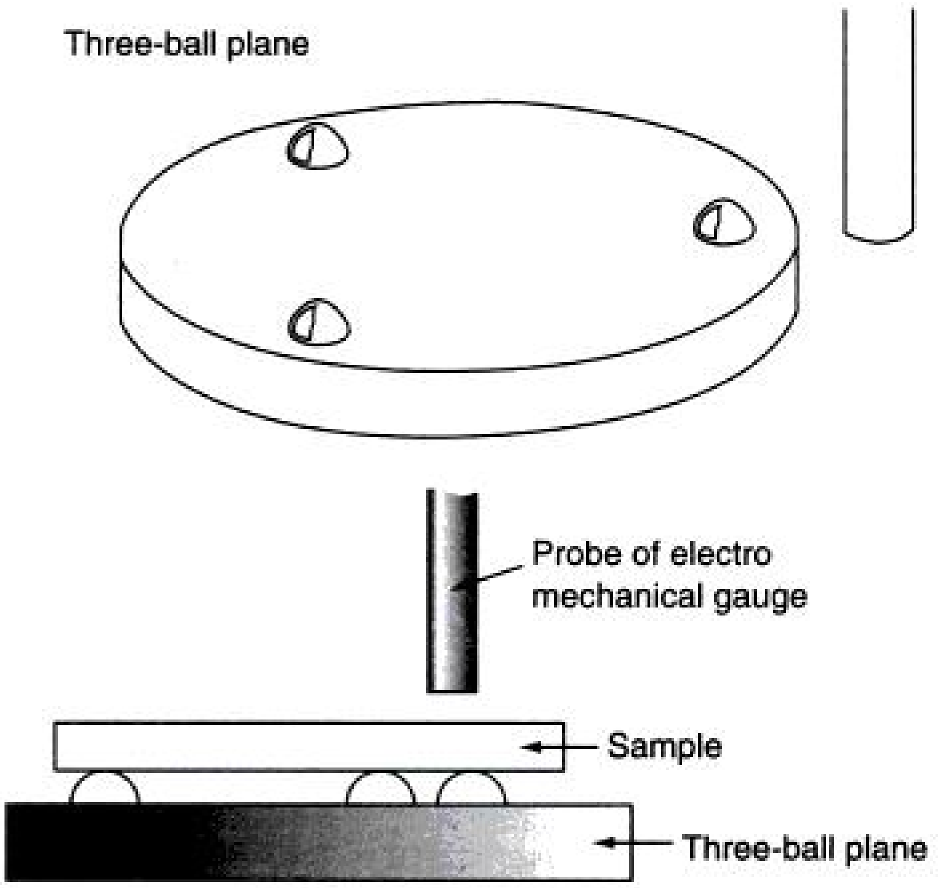

Fig. 4.19 *Electromechanical gauge*

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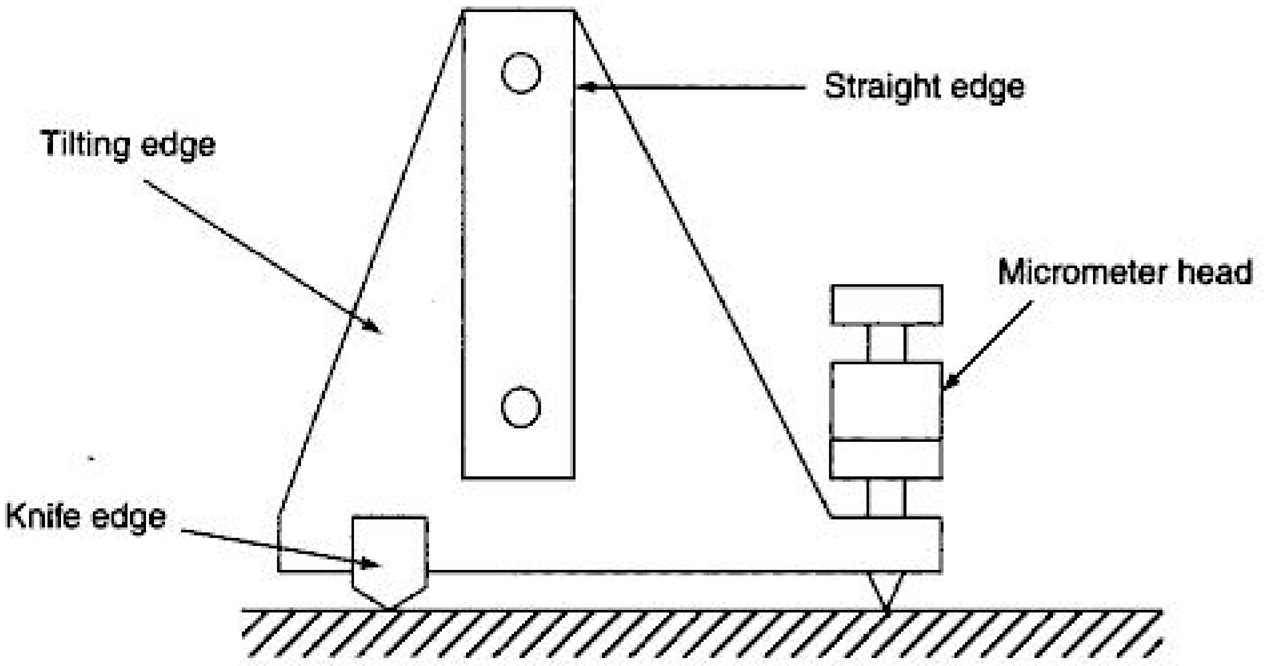

Fig. 4.24 *NPL Square tester*

carries a vertical straight edge with two parallel sides. This instrument is used to test the engineer's square. For the testing, it is kept on the surface plate. The angle of the straight edge with respect to the surface plate could be changed using the micrometer. The movement on the micrometer drum will tilt the entire frame and, in turn, the measuring surface of the straight edge. The square-ender test is placed against the surface of the straight edge. To get the contact along the total length of the straight edge, the micrometer height is to be adjusted. If the same reading is obtained on both the sides of the straight edges, the blade is truly square. If the two readings are not the same then half the difference between the two readings gives the error in squareness.

3. Checking of Squareness of Axis of Rotation with a Given Plane The squareness relationship of a rotating axis w r t a given plane can be determined by a set-up shown in Fig. 4. 25. A dial indicator is mounted on the arm attached to the spindle. The plunger of a dial gauge is adjusted parallel to the axis of rotation of the spindle. Therefore, when the spindle revolves, the plane on which the free end of the plunger is rotating will become perpendicular to the axis of rotation and parallel to the plane in which the free end of the plunger is rotating. Now, the plunger of the dial gauge is made to touch the plane under inspection and the spindle is revolved slowly. Readings are noted at various positions. The variations in the readings represent the deviation in the parallelism between the plane (under inspection) on which the free end of the plunger is rotating. It also represents the deviation in the squareness of the axis of rotation of the spindle with the plane under test.

4. Square Master This is an ideal instrument for standard rooms and machine shops, which involves single-axis measurement. Measurement of squareness, linear height, centre distance, diameters, step measurements are possible with this instrument. This is also an optional linear scale for vertical measurement.

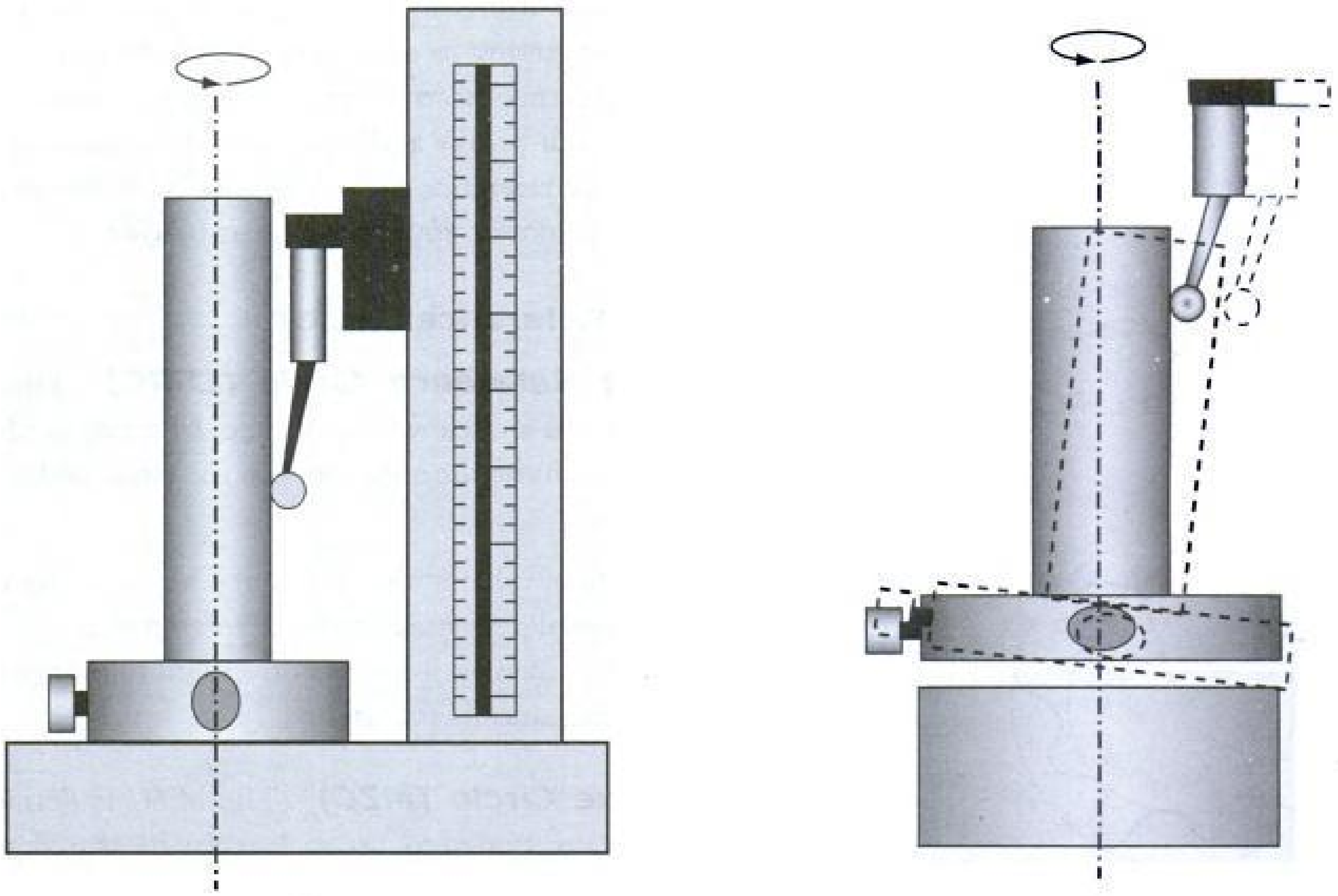

Fig. 4.34 *Component rotation*

The output of the gauge or transducer consists of three added components:

i. Instrument error
ii. Component set-up error
iii. Component form error

By using high-precision mechanics and stable electronics, instrument error (which is too small to be significant) and component set-up error is minimized firstly by accurate centering and leveling and then the residual error is removed by electronic or software means. Form error is the area of interest and once, the first two types of errors are excluded, this error can be highly magnified and used to derive a measure of the out-of-roundness.

b. Rotating Stylus An alternative method is to rotate the stylus while keeping the component stationary. This is usually performed on small high-precision components but is also useful for measuring large, non-circular components; for example, measurement of a cylinder bore using this method would not require rotation of the complete engine block. This type of measuring system tends to be more accurate due to continuous loading on the spindle, but is however limited by the reach of the stylus and spindle.

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Increasing the stylus length will also decrease the resolution of the results. This is not always a problem but may be on higher precision surfaces. On some systems, it is possible to increase the reach of the gauge connected to the stylus rather than increase the length of the stylus. These are sometimes known as gauge extension tubes.

i. Assessing Harmonics A harmonic is a repeated undulation in 360°. So in Fig. 4.39, a third harmonic has three undulations of equal wavelength in 360°. Any surface can be broken down into its individual harmonic elements. Below is an example of a third harmonic that has been caused by over-tightening of the machine tool chuck. UPR (Undulations Per Revolution) is a way to assess the same, for example, a part that has a three-lobed shape consists of three undulations in one revolution.

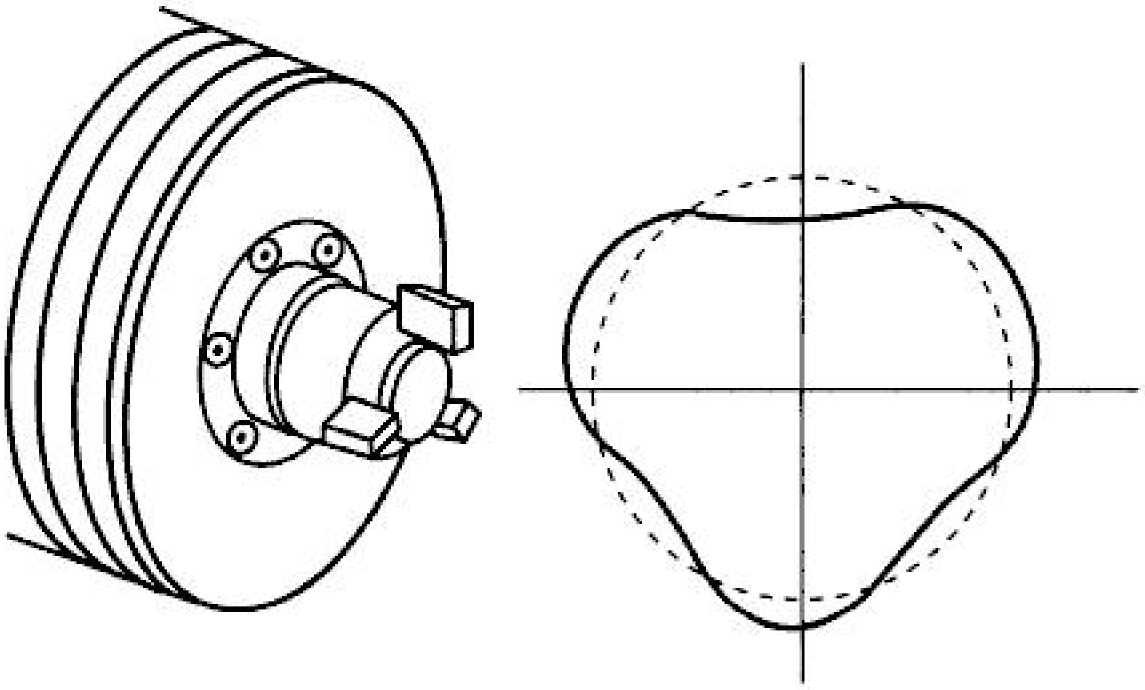

Fig. 4.39 *Undulations of a third harmonic*

The ability to analyze harmonics is very useful in order to predict a component's function or to control the process by which the component is manufactured. If there is data missing, it becomes difficult to determine the harmonic content of the surface. However, there are methods of calculating harmonics on interrupted surfaces but they are not widely used.

4.6.3 Roundness Measurement on Interrupted Surfaces

It is possible to measure roundness on interrupted surfaces. There are two problems to overcome when measuring roundness on a surface that has holes or gaps in the surface:

i. Firstly, the stylus will fall down the holes if they are quite large compared to the stylus tip radius. This will cause damage to the stylus and will be detrimental to the results.
ii. Secondly, even if there is no damage to the stylus, the results will show deviations where the stylus drops into the hole.

4.6.4 NPL Roundness Measuring Instrument

NPL provides a high-accuracy service for measuring the roundness of spheres and hemispheres up to 100 mm in diameter. This service, which is primarily intended for the measurement of glass hemi-

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d. Maximum Inscribed The maximum inscribed cylinder is the largest cylinder that is enclosed by the data.

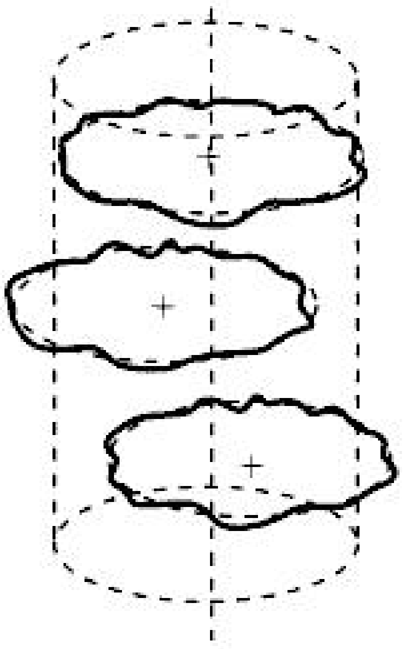


Fig. 4.44 *LS*

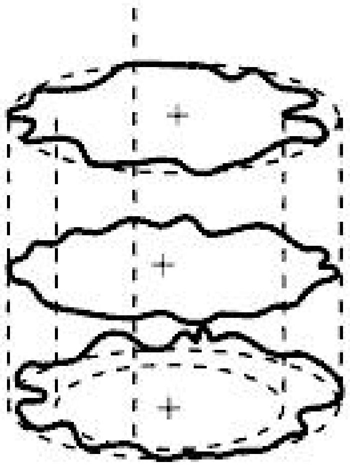


Fig. 4.45 *MZ*

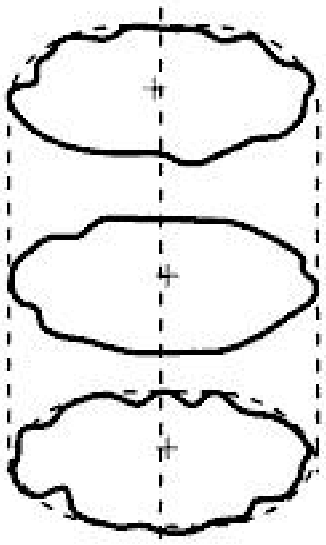


Fig. 4.46 *MC*

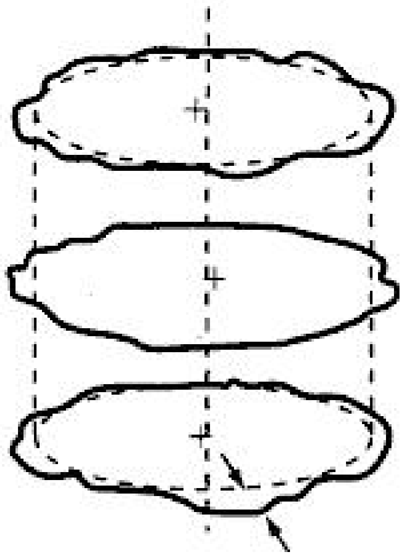


Fig. 4.47 *MI*

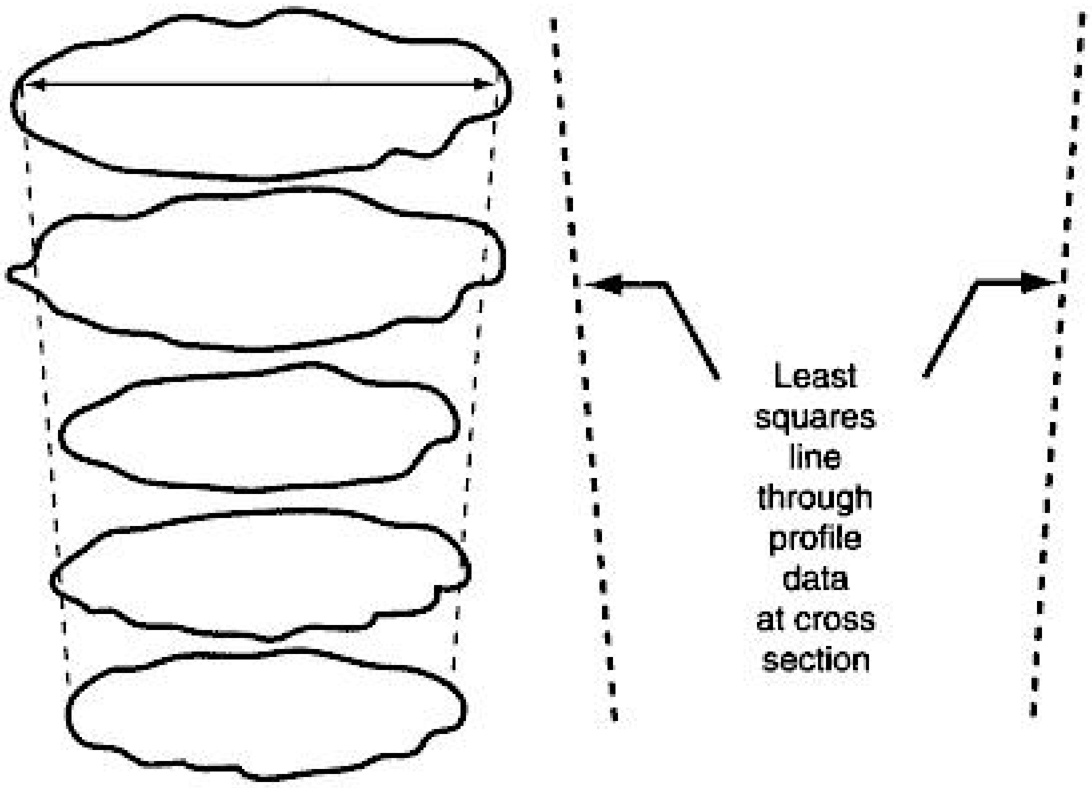


Fig. 4.48 *Least-squares cylinder*

4.7.2 Cylinder Parallelism

Cylinder parallelism is a measurement of the taper of the cylinder and is given as the parallelism of two least-square lines constructed through the vertical sides of the profile, usually, the maximum V.

The following are the examples of 'runout' (Fig. 4.49) which may be due to machining of the part on the machine tool (for example, lathe, drilling machine), or if its spindle is held in poor bearing, or due to deflection of the workpiece as the tool is brought to bear on it. The shaft ground between centres may lead to runout of dimension and may also be due to poor alignment of the centre or deflection of the shaft.

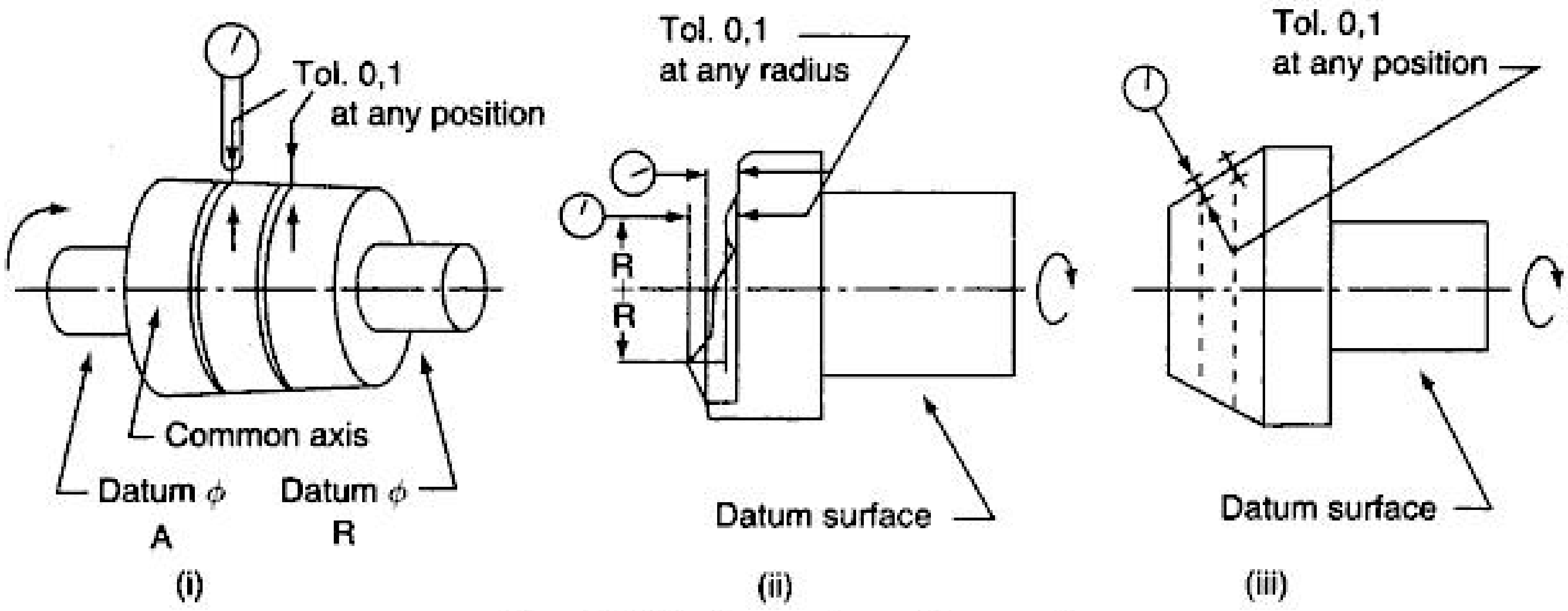


Fig. 4.49 *Examples of runout*

4.8 COAXIALITY

Coaxiality is the relationship of one axis to another. There are two recognized methods of calculating coaxiality.

i. **ISO** has defined coaxiality as the diameter of a cylinder that is coaxial with the datum axis and will just enclose the axis of the cylinder referred for coaxiality evaluation.
ii. **DIN** Standard has defined coaxiality as the diameter of a cylinder of defined length, with its axis co-axial to the datum axis that will totally enclose the centroids of the planes forming the cylinder axis under evaluation.

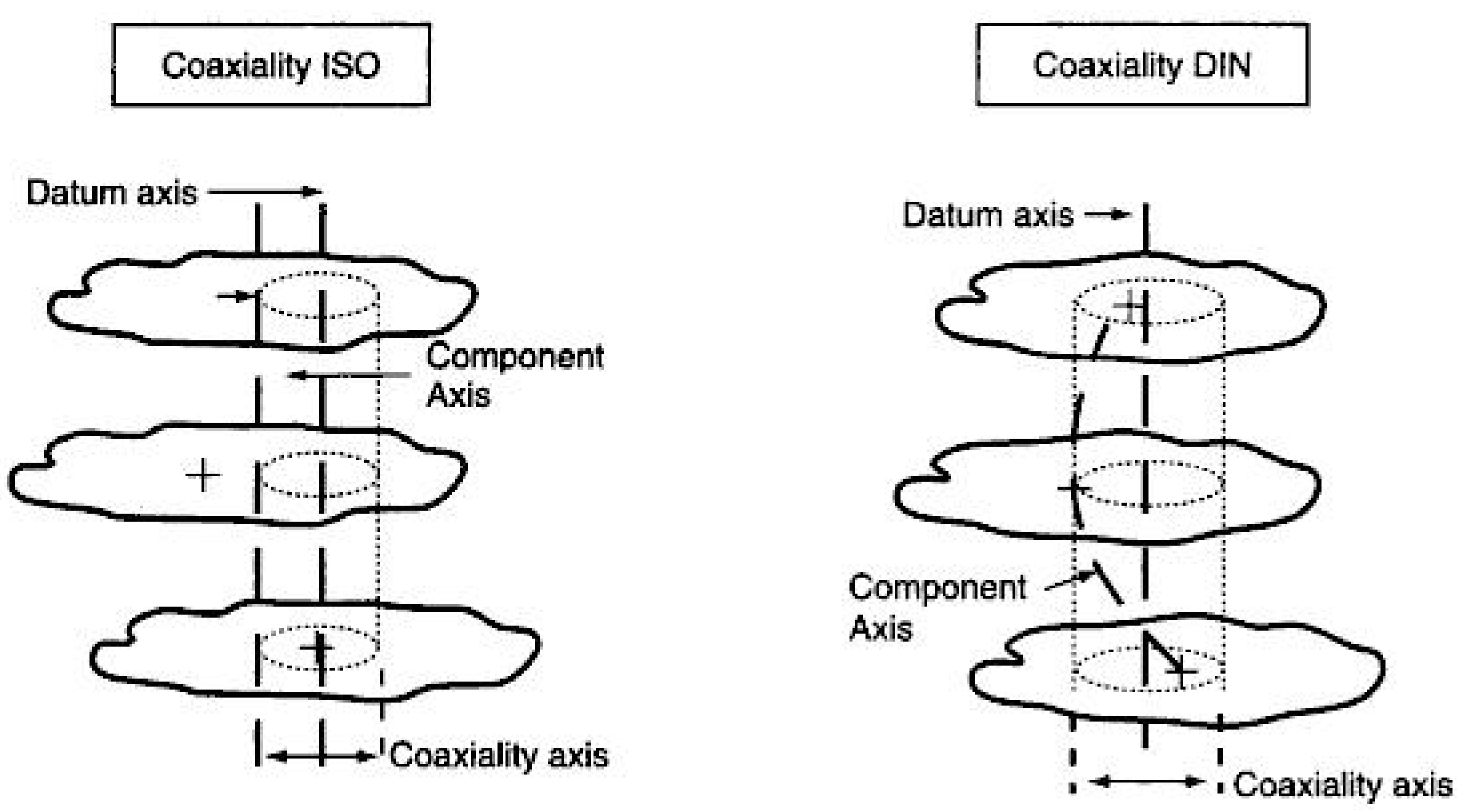


Fig. 4.50 *Coaxiality*

4.9 ECCENTRICITY AND CONCENTRICITY

Eccentricity is the term used to describe the position of the centre of a profile relative to some datum point. It is a vector quantity in that it has magnitude and direction. The magnitude of the eccentricity is expressed simply as the distance between the datum point and profile centre. The direction is expressed simply as an angle from the datum point to the profile centre. Concentricity is twice the eccentricity and is the diameter of a circle traced by the component centre orbiting about the datum axis.

4.10 INDUSTRIAL APPLICATIONS

1. Form-tester On-site measuring instruments for assessing form and location deviations as per DIN ISO 1101, e.g., roundness errors are indispensable today for rapidly determining and eliminating manufacturing errors and obtaining less rework and fewer rejects. Mahr meets this challenge with its easy-to-operate and flexible MMQ10 form-measuring station shown in Fig. 4.51. One can get this high-performance, high-quality measuring station at an incredibly low price. Benefit from our competence to increase your precision.

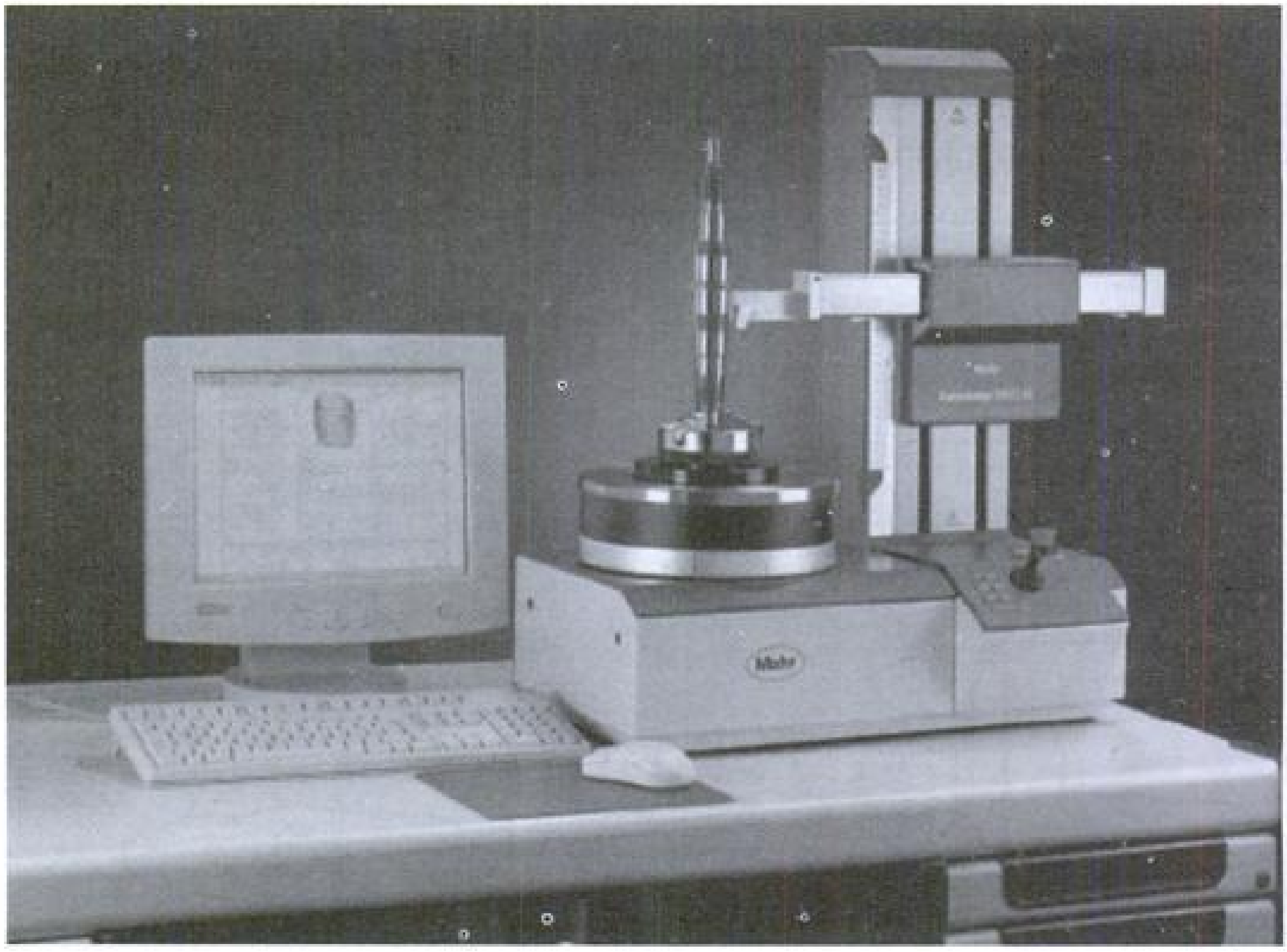


Fig. 4.51 *Form-tester*

(Courtesy: Mahr Gmbh Esslingen)

[***Features*** *• Compact with an integrated evaluation computer and printer• Mobile, low weight, and small dimensions • Rapid workpiece alignment with computer support and clever mechanics • Universal and reliable • Suited for shop-floor application; compressed air supply not required • High loading capacity*]

Plate - 6

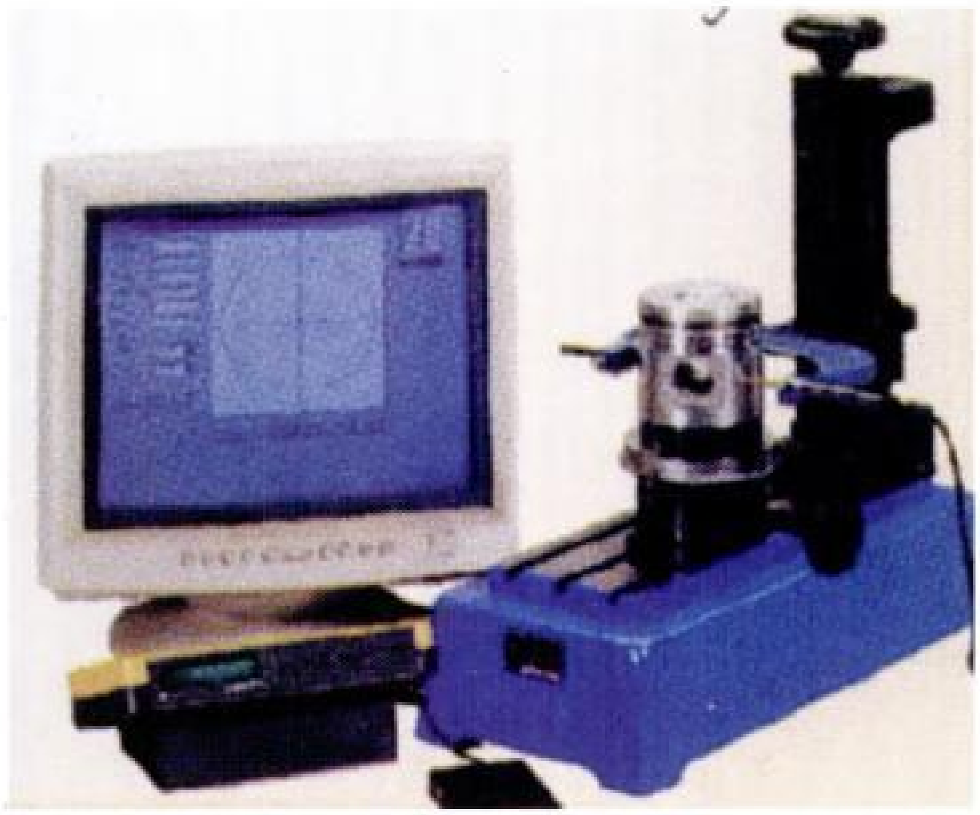
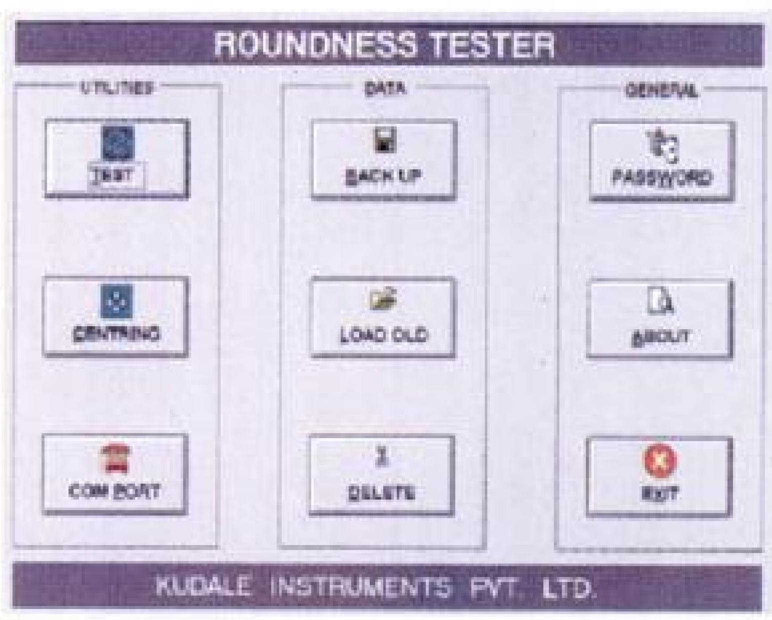
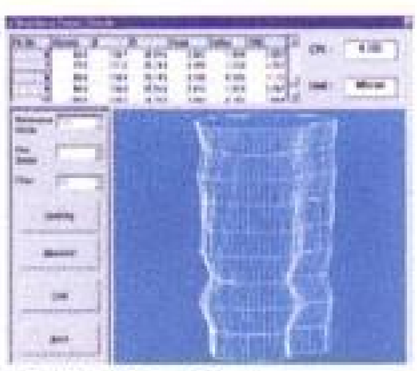


Fig. 4.52 *Piston profile tester*
(Courtesy, Kudale Instruments Pvt Ltd., Pune)

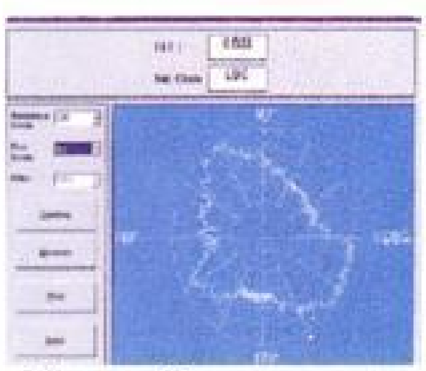
(a) Roundcyl 500



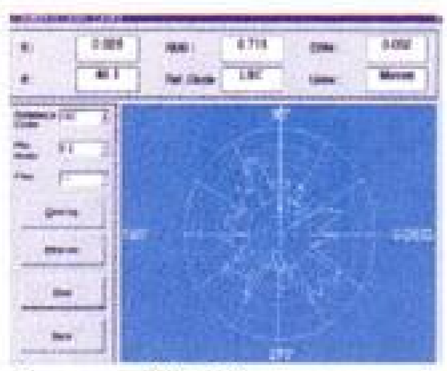
(b) User-friendly optional menu



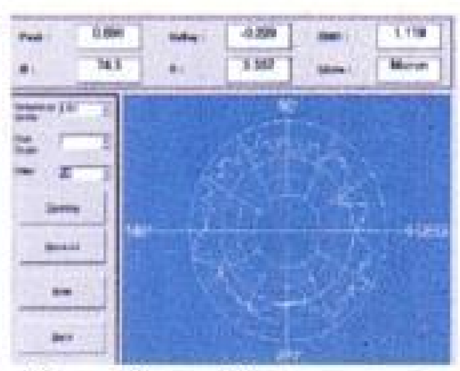
Cylindricity Measurement



Flatness Measurement



Concentricity Measurement



Roundness Measurement

Fig. 4.53 *Roundcyl-500 system*
(Courtesy, Kudale Instruments Pvt Ltd., Pune)

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5 Metrology of Machine Tools

'Machine tool metrology is necessary to ensure that a machine tool is capable of producing products with desired accuracy and precision...'

D Y Kulkarni, Inteltek Co. Ltd., Pune

TESTS FOR MACHINE TOOLS

The modern industry uses a large number of machine tools for producing various components with varying degrees of precision. The quality of manufactured products, apart from depending on the skills of operators, also depends largely upon the accuracy of machine tools being used while producing them. The quality of a machine tool depends on the rigidity and stiffness of the machine, fitment of the parts and their alignment with each other along with the accuracy and quality of supporting devices. The stiffness and rigidity values are finalized by the designer during the prototype testing and need not be reconsidered during the commissioning of a machine tool at the user's place. In addition to manufacturing accuracy, the working accuracy of a machine tool is influenced by the geometry of cutting tools, material properties of cutting tools and the workpiece, parameters of cutting conditions like speed, feed and depth of cut, work-holding and clamping devices, skill of the operator, working environment and like parameters.

Dr G Schlesinger was a pioneer in designing Machine Tool Alignment Tests. He was a great believer in the importance of international standardization. Before the Second World War, he was an active member of the committee ISO/TC39. Schlesinger's classic tests were intended to cover those portions of manually operated machines where a skilled operator measures the workpiece during the operation and is able to eliminate function effects such as deformations due to weights, clamping forces or thermal influences, and dynamic displacement errors of a machine and its related components.

Machine tools are very sensitive to impact or shock; even heavy castings may not be rigid enough to withstand stresses caused by a fall during transportation, resulting deformations and possibly cracks, rendering the entire machine tool useless. In general, machine tool tests must be carried out at the user's place and not only before the transportation. Machine tools are then carefully aligned during installation. According to Dr G Schlesinger, the steps to be followed for execution of an acceptance test are as follows:

1) Decision regarding suitable location of the machine tool

2) Layout of a proper foundation plan
3) Preparing the foundation, followed by curing
4) Lifting and erecting the machine tool on the foundation
5) Leveling the machine tool before starting the test
6) Connecting and grouting the foundation bolts
7) Carrying out second-leveling after setting of foundation bolts
8) Checking final leveling before testing and commissioning

The continuously increasing demand for highly accurate machine components has led to considerable research towards the means by which the geometric accuracies of a machine can be improved and maintained. To ensure that a machine tool is capable of manufacturing products with desired accuracy, certain tests are required to be performed on it. The machine tools are tested at different stages such as during manufacturing, assembling, installation and overhauling as per the accuracy test chart in order to check their confirmation of meeting the desired specification levels. In general, these tests are classified on a broad basis as practical (performance) tests and geometric (alignment) tests.

5.1 GEOMETRICAL (ALIGNMENT TESTS)

Geometric accuracy largely influences the product quality and precision to be maintained during the service life of a machine tool. The distinct field of metrology, primarily concerned with geometric tests (alignment) of machine tools under static and dynamic conditions, is defined as **machine tool metrology**. Geometric tests are carried out to check the grade of manufacturing accuracy describing the degree of accuracy with which a machine tool has been assembled. Alignment tests check the relationship between various elements such as forms and positions of machine-tool parts and displacement relative to one another, when the machine tool is unloaded. Various geometrical checks generally carried out on machine tools are as follows.

i. Work tables and slideways for flatness
ii. Guideways for straightness
iii. Columns, uprights and base plates for deviation from the vertical and horizontal planes
iv. True running and alignment of shafts and spindles relative to other areas at surfaces
v. Spindles for correct location and their accuracy of rotation
vi. Ensuring the accuracy of rotation involves checking eccentricity, out of roundness, periodical and axial slip, camming
vii. Parallelism, equidistance, alignment of sideways, and axis of various moving parts with respect to the reference plane
viii. Checking of lead screws, indexing devices and other subassemblies for specific errors

5.1.1 Equipments Required for Alignment Tests

For an alignment test, any type of equipment may be used as long as the specified measurement can be carried out with the required degree of accuracy. However, the following types of equipment are generally used to carry out alignment tests.

1. Dial Gauges These are mostly used for alignment tests. The dial gauges used should have a measuring accuracy in the order of 0.01 mm. The initial plunger pressure should vary between 40 to 100 grams and for very fine measurements, a pressure as low as 20 grams is desirable. Too low a spring pressure on the plunger is the source of error in case of swingover measurements as the upper-position spring pressure and plunger weight acts in the same direction, while in a lower position they act in the opposite direction. The dial gauge is fixed to a robust and stiff base (e.g., magnetic base) and bars to avoid displacements due to shock or vibration.

2. Test Mandrels These are used for checking the true running of the spindle. Test mandrels deliver quality checking such as straightness and roundness during the acceptance test. There are two types of test mandrels, namely, a) mandrel with a cylindrical measuring surface and taper shank that can be inserted into the taper bore of the main spindle, and b) cylindrical mandrels that can be held between centres. Test mandrels are hardened, stress-relieved and ground to ensure accuracy in testing. The deflection caused by the weight of the mandrel is known as 'natural sag', which is not affordable to get overlooked. Slag occurs when the mandrel is fixed between centres and is more marked when it is supported at one end only by the taper shank, while the outer end is free to overhang. To keep the slag within permissible limits, mandrels with a taper shank vary between 100 and 500 mm.

3. Spirit Levels Spirit levels are used in the form of bubble tubes, which are mounted on a cast-iron bases. Horizontal and frame are the two types of spirit levels used for alignment tests. Spirit levels are used for high-precision measurements having a tolerance of 0.02 mm to 0.04 mm per 1 m, and having a sensitivity of about 0.03 mm to 0.05 mm per 1 m for each division. A bubble movement of one division corresponds to a change in slope of 6 to 12 seconds.

4. Straight Edges and Squares Straight edges are made up of heavy, well ribbed cast iron or steel and are made free of internal stresses. Their bearing surfaces are as wide as possible. The error at the top of a standard square should be less than ±0.01 mm. A steel square is a precision tool used for engraving the lines and also for comparing the squareness of two surfaces with each other.

5. Optical Alignment Telescope It is used to indicate the errors of alignment in vertical as well as horizontal planes of the optical axis.

6. Waviness-Meter It is used for recording and examining the surface waviness with a magnification of 50:1.

7. Autocollimator This can be used for checking deflections of long beds in horizontal, vertical or an inclined plane, owing to its sensitivity in measuring.

5.2 PERFORMANCE TEST (PRACTICAL TEST)

The sequence in which the alignment/geometrical tests are given is related to the subassemblies of a machine and does not define the practical order of testing. In order to make checking or mounting of instruments easier, tests are carried out in any convenient sequence. When inspecting a machine, it is necessary to carry out all the tests described below, except for alignment test, which may be omitted in mutual agreement between the buyer and the manufacturer.

Alignment tests alone are inadequate for machine testing as they do not include variations in rigidity of machine-tool components, quality of their manufacture and assembly, the influence of the machine-fixture, cutting tool-workpiece, and system rigidity on accuracy of machining. It consists of checking the accuracy of a finished component under dynamic loading. Performance/practical test is carried out to know whether the machine tool is capable of producing the parts within the specified limits or not. These tests should be carried out after the primary idle running of the machine tool with essential parts of the machine having a stabilized working temperature. Moreover, these performance tests are carried out only with the finishing cuts and not with roughing cuts, which are liable to generate appreciable cutting forces. The manufacturer specifies the details of test pieces, cutting and test conditions.

Now let us consider the Indian Machine Tool Manufacturers Associations' Standard—IMTMAS: 5-1988, which describes both geometrical and practical tests for CNC turning centres with a horizontal spindle up to and including a 1250-mm turning diameter having corresponding permissible deviations with reference to the IS: 2063-1962-Code for testing machine tools. (For conducting a performance test, the specimens to be manufactured are also standardized, one such standard specimen is shown in Fig. 5.1.)

When establishing the tolerance for a measuring range different from that indicated in standards IS: 2063–1962, it is taken into consideration that the minimum tolerance is 0.002 mm for any proportional value, and the calculated value is rounded off to the nearest 0.001 mm. However, the least count of all measuring instruments need not be finer than 0.001 mm. The testing instruments are of approved type and are to be calibrated at a recognized temperature confirming to the relevant published Indian Standards. Whatever alternate methods of testings are suggested, the choice of a manual method of testing is left to the manufacturers.

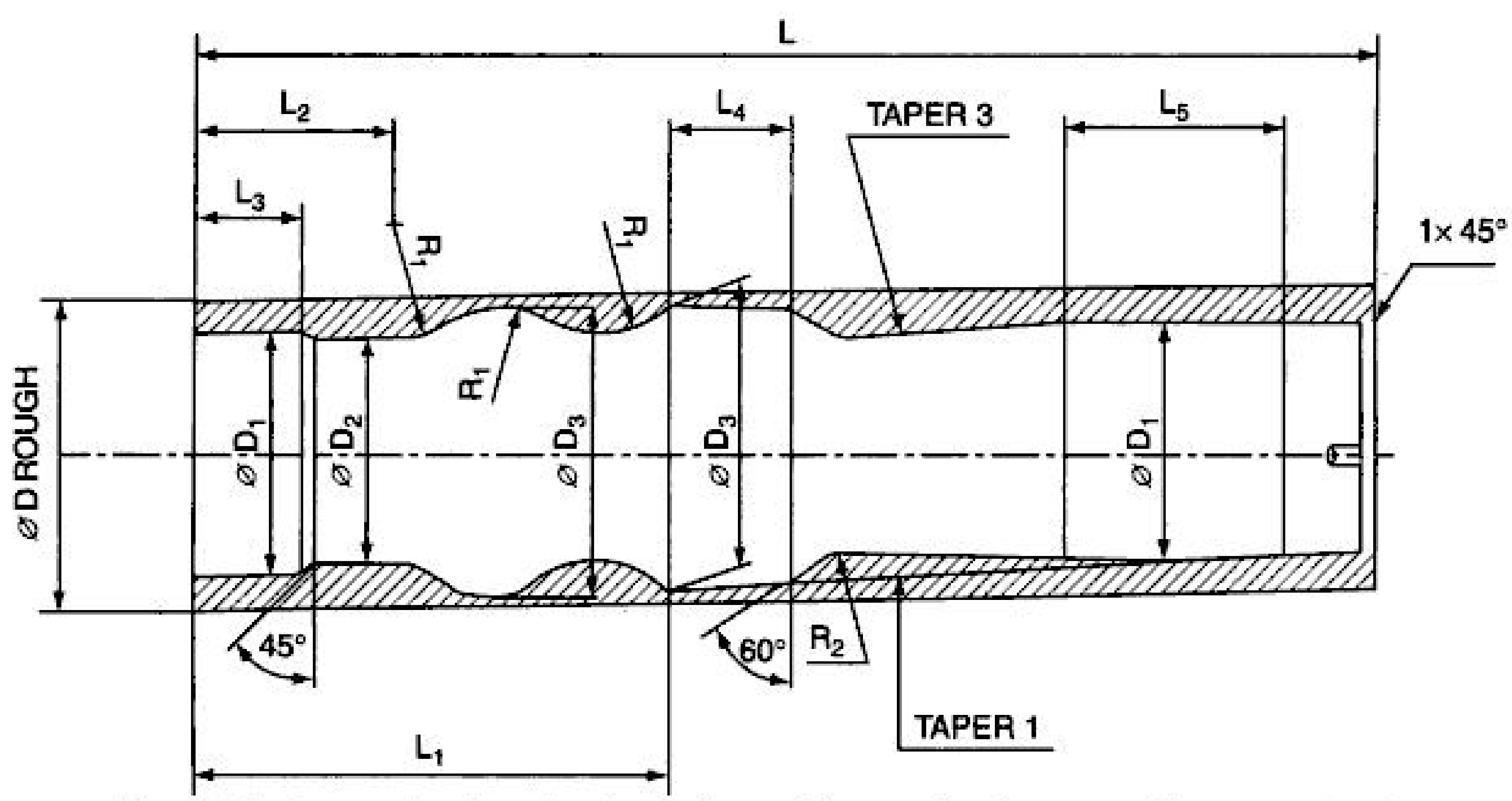


Fig. 5.1 *A sample standard specimen for conducting a performance test*

The methods employed are as follows:

000/000 for deviation of perpendicularity, which are the ratios

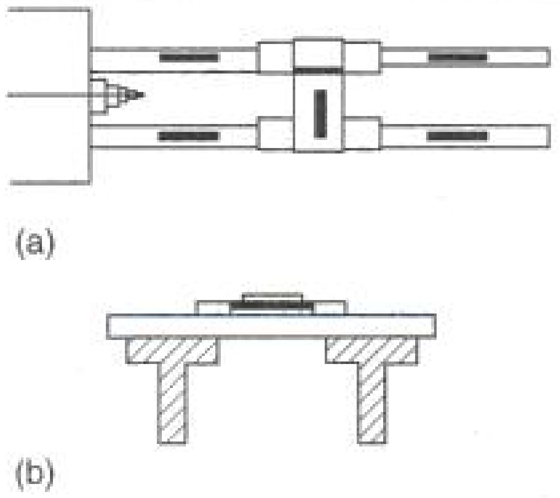
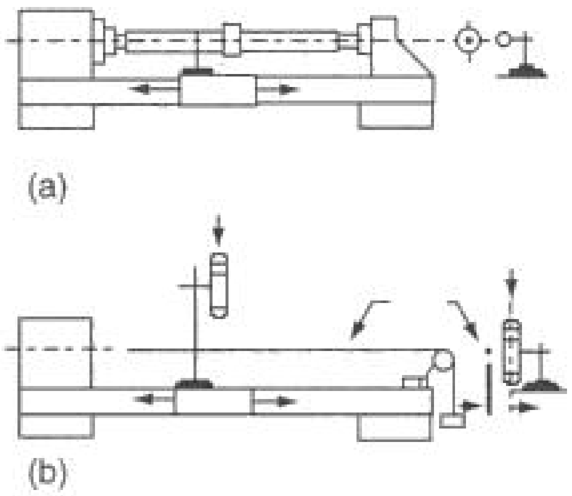
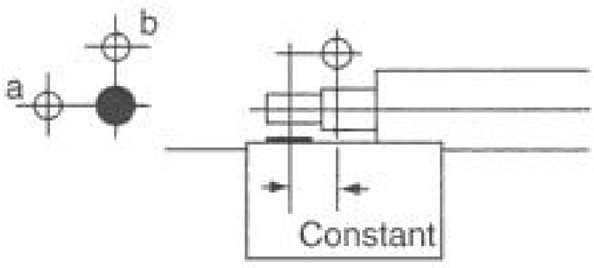
000 for any length of 000 for deviation of straightness and parallelism—this expression is used for local permissible deviation, the measuring length being obligatory

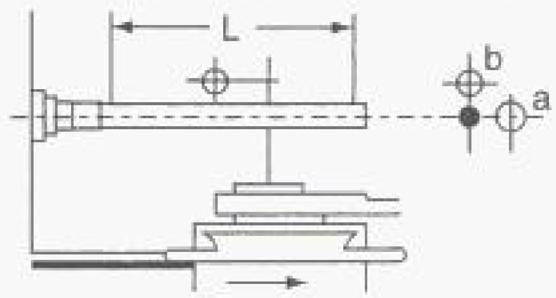
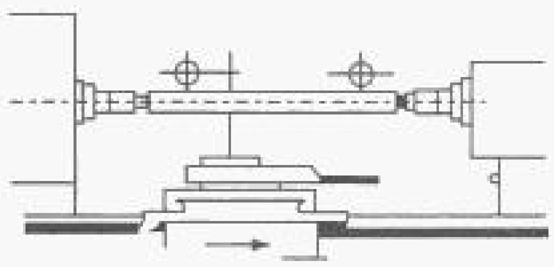
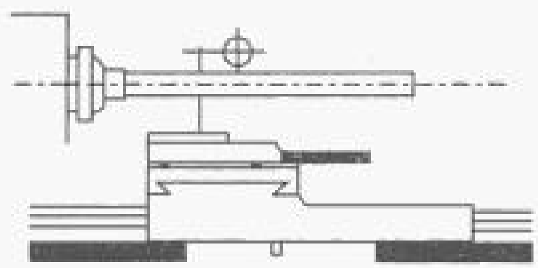
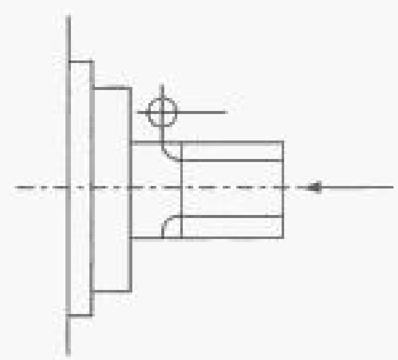
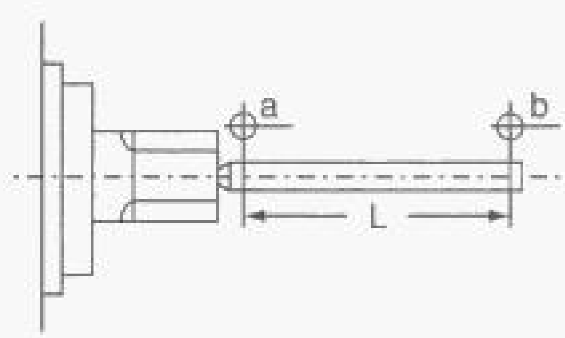
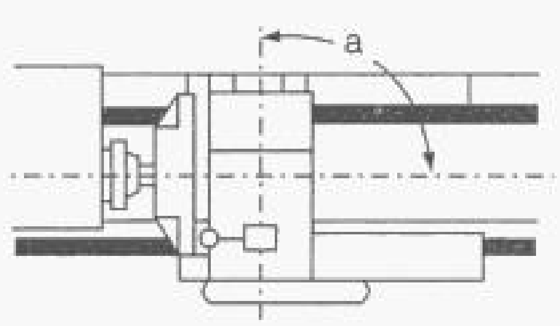
000 For deviation of straightness and parallelism—this expression is used to recommend a measuring length, but in case the proportionality rule comes into operation, the measuring length differs from those indicated.

5.3 MACHINE-TOOL TESTING

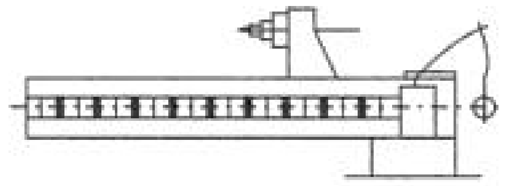
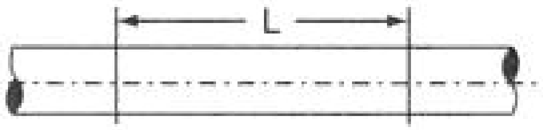
5.3.1 Alignment Testing of Lathe

Table 5.1 *Specifications of alignment testing of lathe*

Sl. No.	*Test Item*	*Figure*	*Measuring Instruments*	*Permissible Error (mm)*
1.	Leveling of machines (Straightness of sideway—carriage) (a) Longitudinal direction—straightness of sideways in vertical plane (b) In transverse direction		Precision level or any other optical instruments	0.01 to 0.02
2.	Straightness of carriage movement in horizontal plane or possibly in a plane defined by the axis of centres and tool point (Whenever test (b) is carried out, test (a) is not necessary)		Dial gauge and test mandrel or straight edges with parallel faces, between centres	0.015 to 0.02
3.	Parallelism of tailstock movement to the carriage movement (a) In horizontal plane, and (b) in vertical plane		Dial gauge	0.02 to 0.04

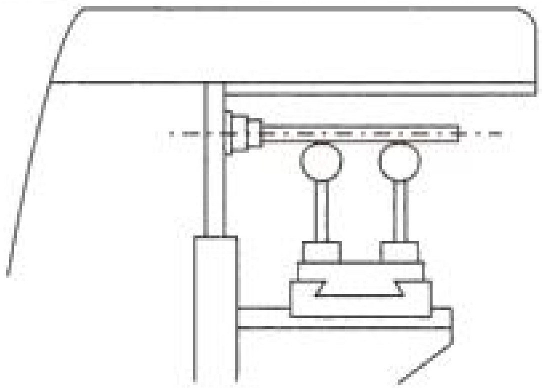
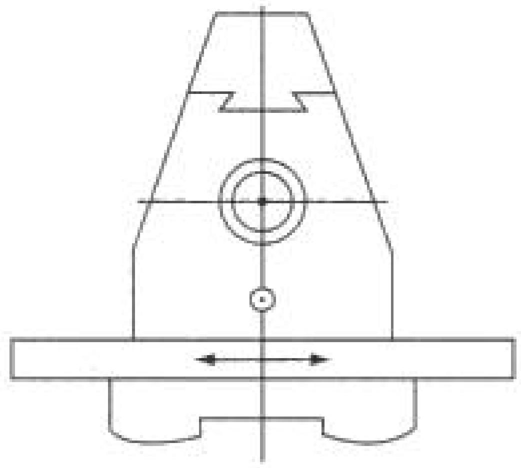
Sl. No.	*Test Item*	*Figure*	*Measuring Instruments*	*Permissible Error (mm)*
4.	Parallelism of spindle axis to the carriage movement (a) in horizontal plane, and (b) in vertical plane		Dial gauge and test mandrel	0.05 to 0.02
5.	Difference in the height between headstock and tailstock		Dial gauge and test mandrel	0.03
6.	Parallelism of longitudinal movement of tool slide to the spindle axis		Dial gauge and test mandrel	0.04/300 frees, end of the mandrel inclined up 0.03
7.	Run-out of spindle nose—centering sieve or cone		Dial gauge	0.01
8.	True running of the taper bore of the spindle (a) near to the spindle nose, and (b) at a distance L		Dial gauge and test mandrel	a) 0.01 b) 0.02 for $L = 300$
9.	Squareness of the transverse movement of the cross-slide to the spindle axis		Dial gauge and flat ground disc or straight edge.	0.02

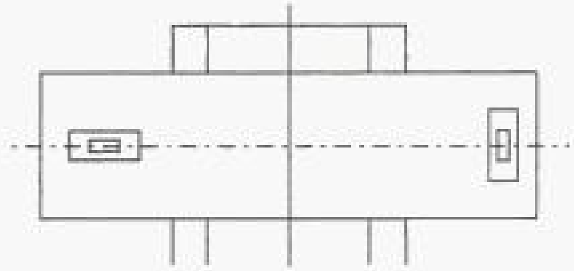
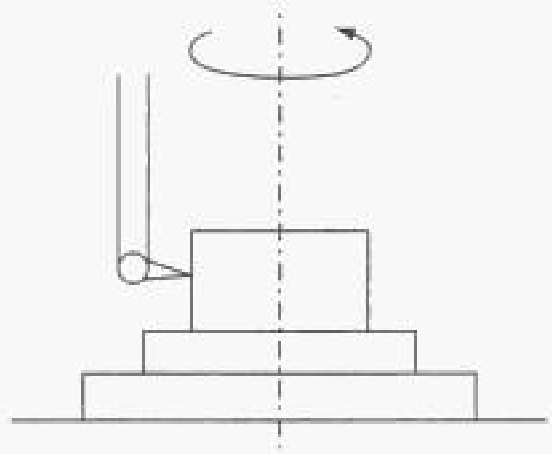
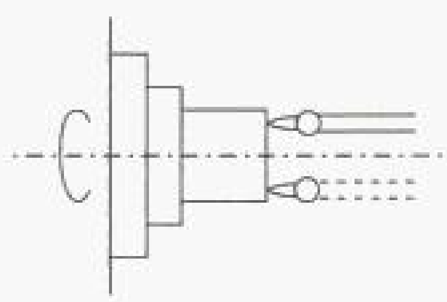
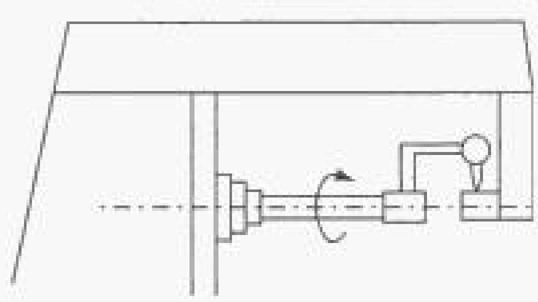
(*Continued*)

10.	Axial slip		Dial gauge	0.015
11.	Accuracy of the pitch, generated by lead screw (**Note:** this test is to be carried out only if the customer requires a certified lead screw.)		Dial gauge and height bars	0.015 to 0.04

5.3.2 Alignment Testing of Column and Knee Type of Milling Machine

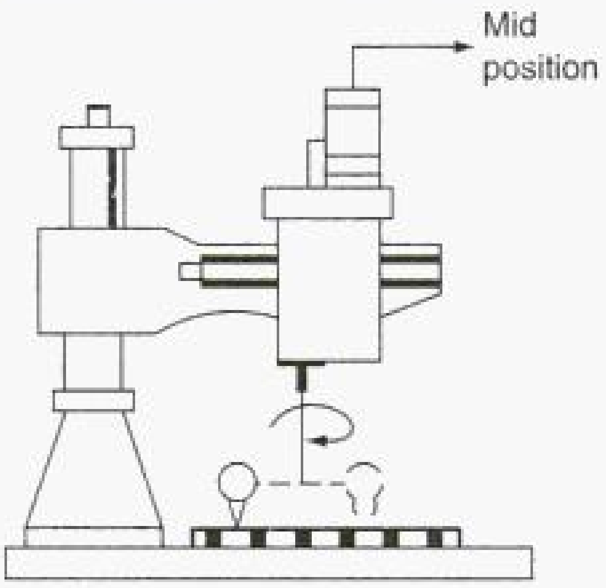
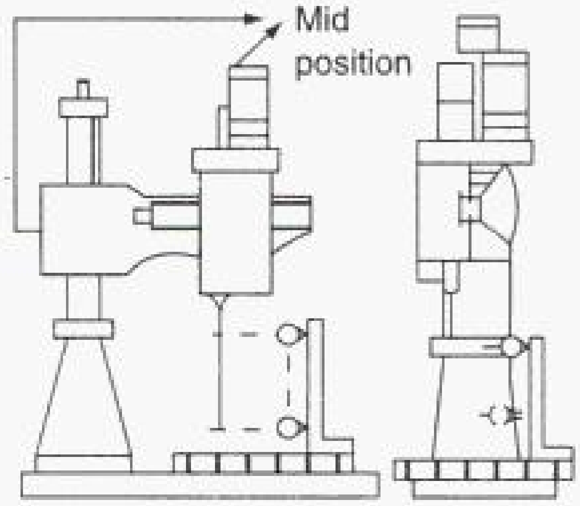
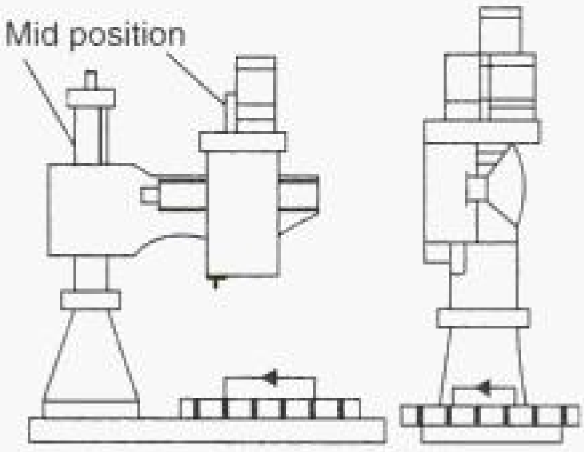
Table 5.2 *Specifications of alignment testing of column and knee type of milling machine*

Sl. No.	*Test Item*	*Figure*	*Measuring Instruments*	*Permissible Error (mm)*
1.	Table-top surface parallel with centre line of spindle (Position the table at the centre of the longitudinal movement direction. Insert the test bar into the spindle hole. Read the indicator at two places on the bar. The largest difference is the test value.)		Dial indicator with magnetic base for firm grip	0.02
2.	To check the parallelism of the table-top surface with longitudinal movement of the table (Fix dial indicator on the spindle or overarm. Let the indicator point touch the top surface. Note the reading while moving the table over all its length. The largest difference is the test value.)		Dial indicator with magnetic base for firm grip	i. 0.02 for 5000 mm ii. 0.01 for 1000 mm

Sl. No.	*Test Item*	*Figure*	*Measuring Instruments*	*Permissible Error (mm)*
3.	Testing of work-table flatness in longitudinal and cross direction (place the work table at the middle centre of all movement directions. Place the dial indicator on the surface of the table.)		Dial indicator with magnetic base for firm grip	0.01
4.	Checking of spindle periphery run-out (place the indicator point at the periphery of the spindle. Note the reading while rotating the spindle. The largest difference is the test value.)		Dial indicator with magnetic base for firm grip	0.06 to 0.1
5.	Testing of spindle end face runout (place the dial indicator and touch the edge of the spindle and face. Note the indicator while turning the spindle. The largest difference is the test value.)		Dial indicator with magnetic base for firm grip	0.2
6.	Alignment of arbor support with the spindle (insert the test bar into the arbor support hole. Fix the indicator on the spindle and allow its point to touch the bottom. Half of the largest difference of the reading in the spindle in revolution is a test value.)		Dial indicator with magnetic base for firm grip	0.02 to 0.03

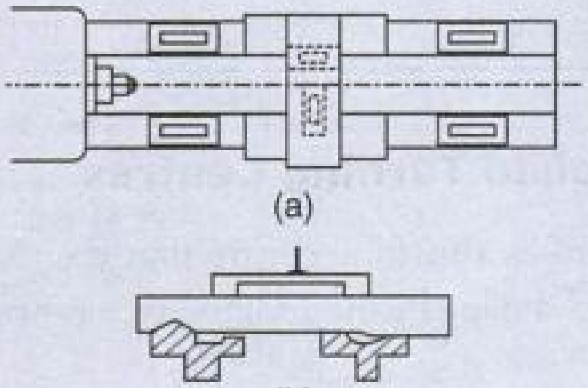
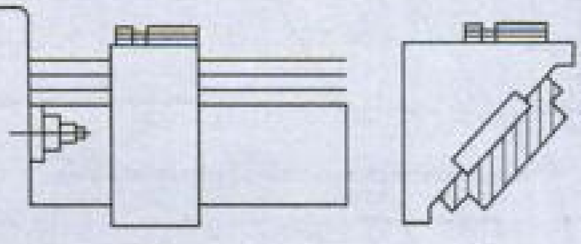
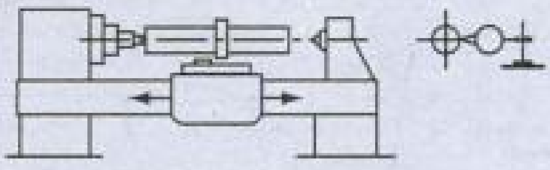
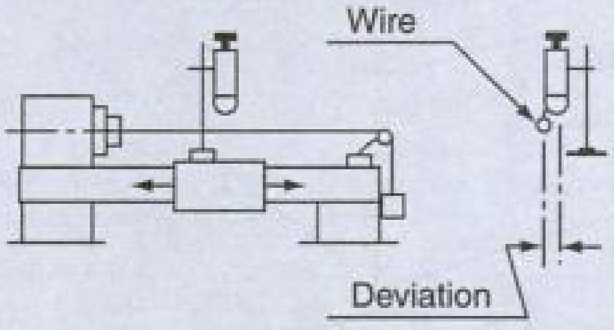
5.3.3 Alignment Testing of Radial Drilling Machine

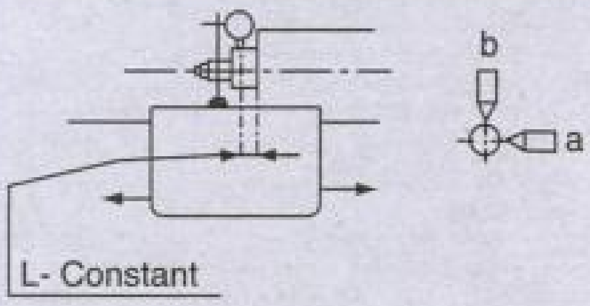
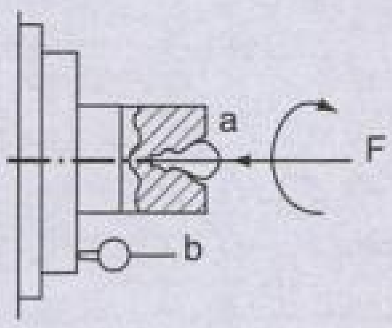
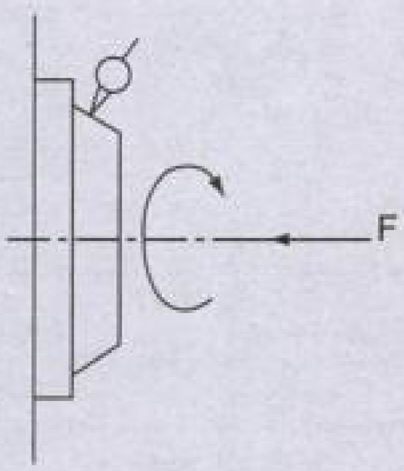
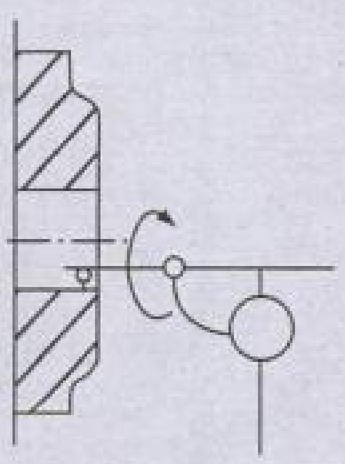
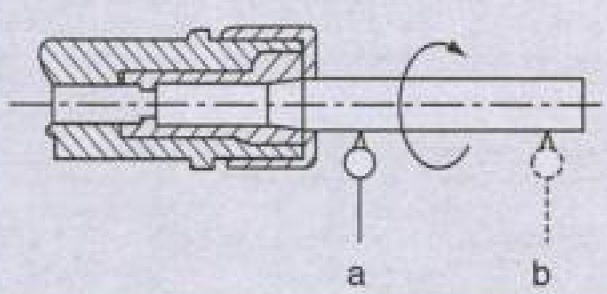
Table 5.3 *Specifications of alignment testing of radial drilling machine*

Sl. No.	*Test Item*	*Figure*	*Measuring Instruments*	*Permissible Error (mm)*
1.	Squareness of spindle axis to the base plate. Arm and drilling head locked before taking measurement. Check with the arm successively in its 1. Upper position 2. Mid-position 3. Lower position		Dial indicator with magnetic base for firm grip	0.01 to 0.1
2.	Squareness of vertical movement of the spindle in the base plate. (a) In a plate parallel to the plane of symmetry of the machine (b) In a plane perpendicular to the plane of symmetry of the machine [Lock the arm and drilling head.]		Dial indicator with magnetic base for firm grip	(a) 0.05 (b) 0.05
3.	Leveling of base plate		Dial indicator with magnetic base for firm grip	0.025 to 0.03

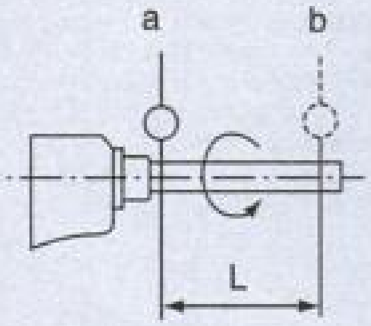
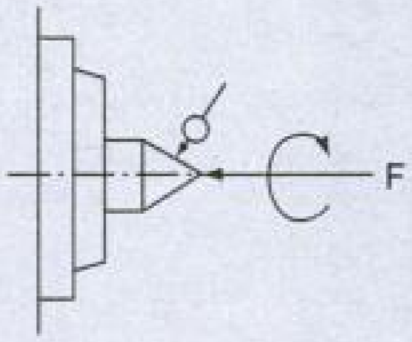
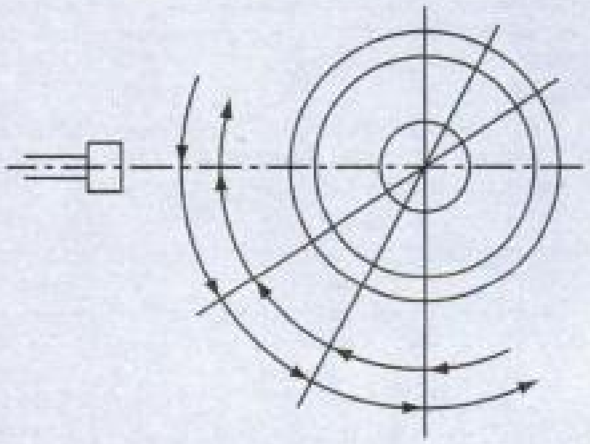
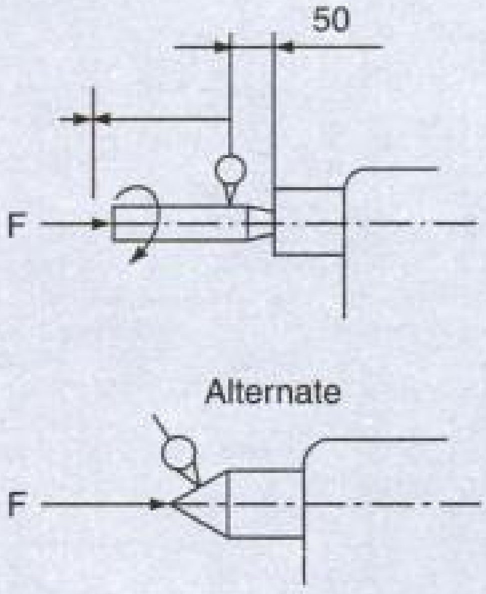
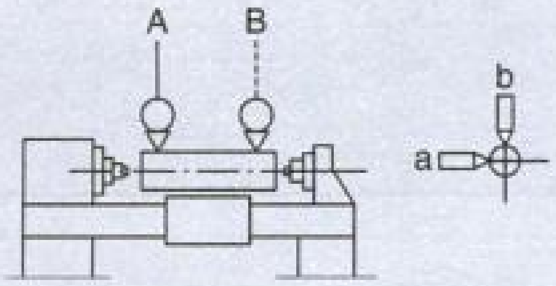
tool. It also has a work-holding spindle which can be oriented and driven discretely and/or as a feed axis. Machine size range—turning diameter (maximum diameter that can be turned over the bed) up to 160 mm, 160 mm to 315 mm, 315 mm to 630 mm, 630 mm to 1250 mm. While preparing this standard, IMTMAS considered assistance from UK proposal ISO TC 39/SC2 (Secr. 346) N-754, JIS B 6330 and JIS B 6331, ISO 1708 and ISO 6155 Part-I.

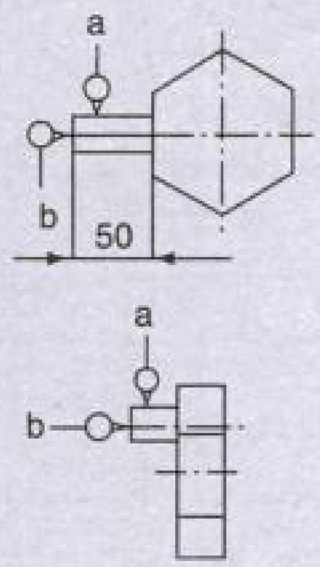
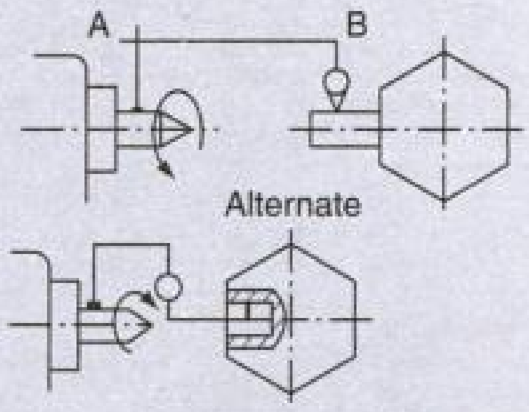
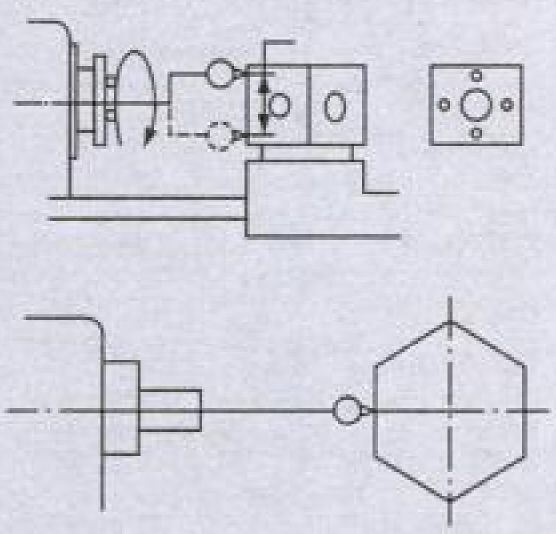
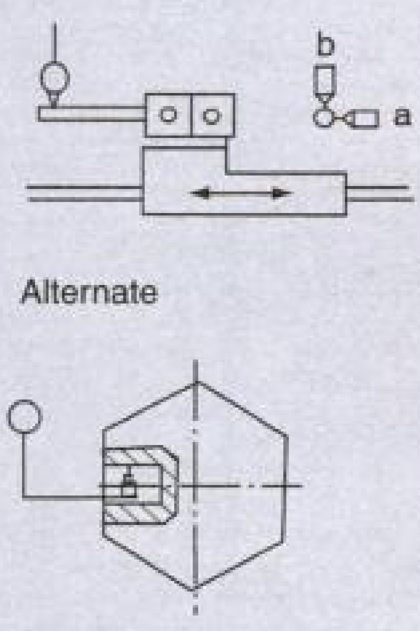
Table 5.4 *Specifications of a CNC turning centre*

Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
		(I) Geometrical Tests: all diameters are in mm		
		BED		
1.	 (a) (b) DC – Distance between Centers  (a) (b)	Leveling of carriage slide ways a) In longitudinal direction b) In transverse direction	Precision levels	DC ≤ 500 a) i) 0.015 (Convex) 500 < DC ≤ 1000 ii) 0.02 (Convex—local tolerance 0.008 for any length of 250) 0.03 Convex—local tolerance of 0.01 for any length of 250. b) 0.04/1000
		Carriage		
2.	 (a)  (b)			

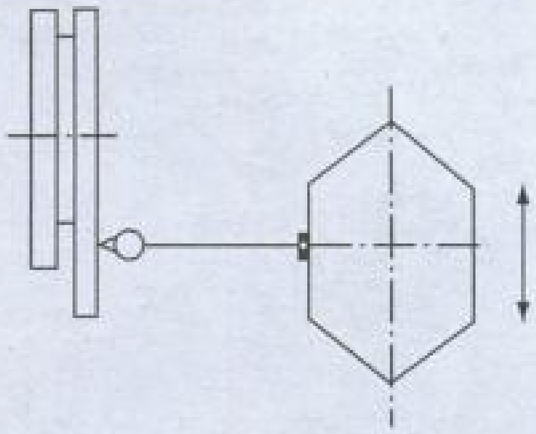
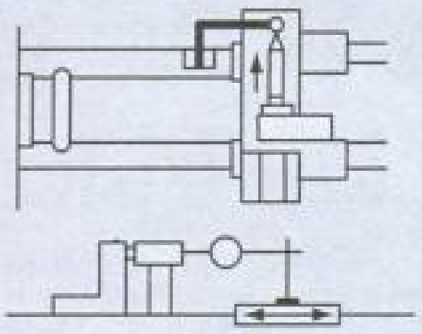
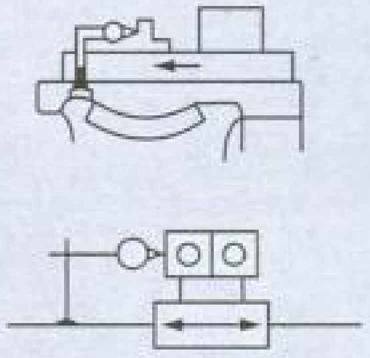
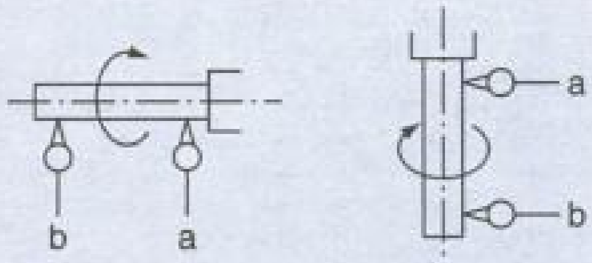
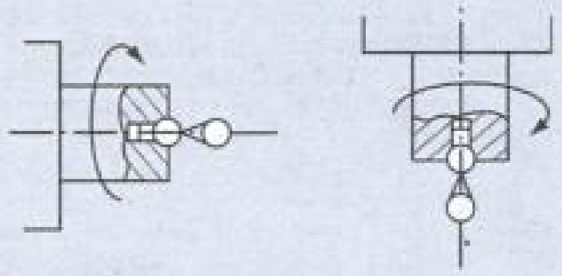
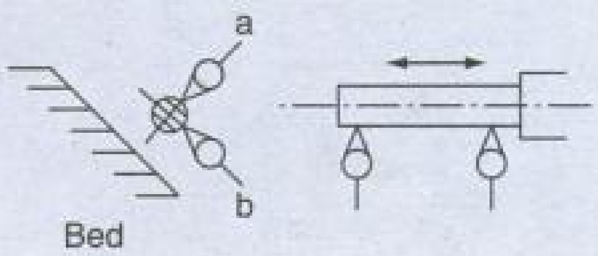
Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
3.				
4.		*Heat Stock Spindle*		
5.				
6.				
7.				

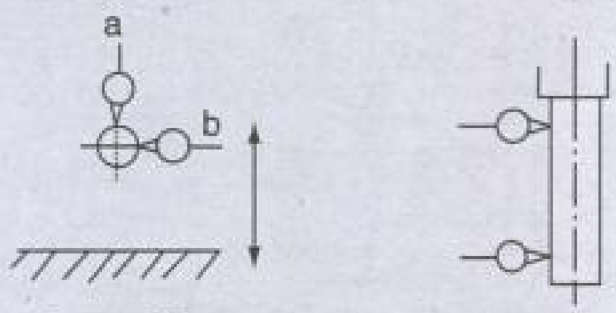
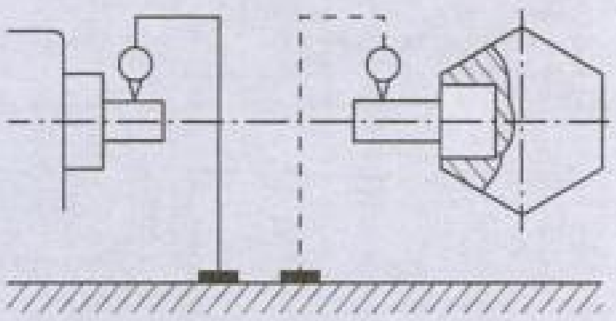
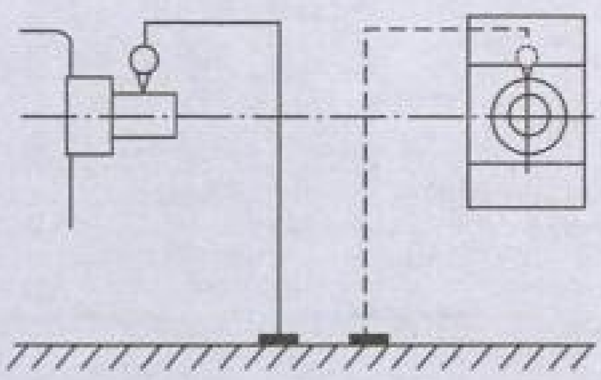
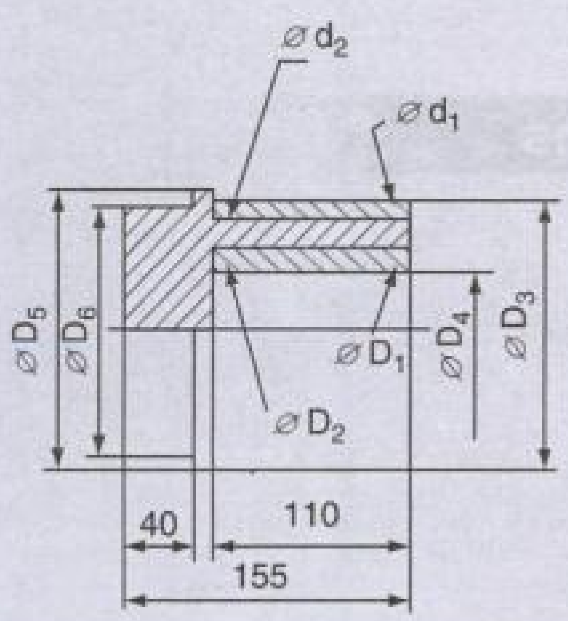
(*Continued*)

Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
8.				
9.				
10.				
11.				
12.				

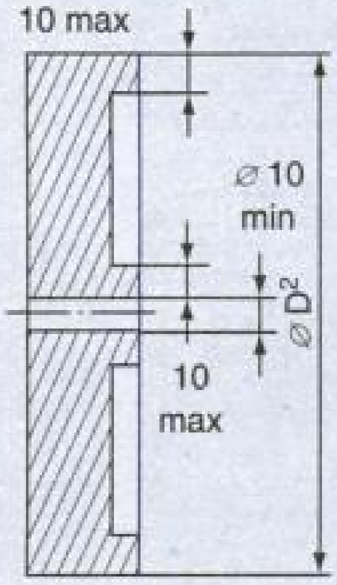
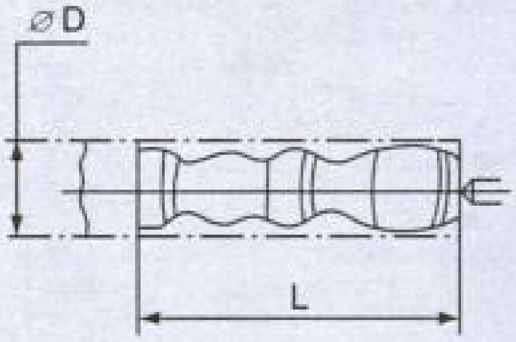
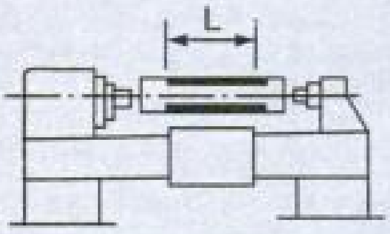
Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
13.				
14.				
15.				
16.				

(Continued)

Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
17.				
18.				
19.				
	Rotating Tool Spindle (Axial and Radial)			
20.				
21.				
22.				

Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
23.	 Cross slide			
24.	 Axial Tool			
25.	 Radial Tool			
	(II) Practical Tests : all dimensions are in mm.			
P1				

(Continued)

Sl. No.	*Figure*	*Object*	*Measuring Instruments*	*Permissible deviations for turning diameters*
P2				
P3				
P4				

Review Questions

1. What is the meaning of alignment test?
2. State the alignment test of a milling machine.
3. Write short notes on
   a. Alignment test of lathe machine
   b. Alignment test of radial drilling machine
   c. Acceptance tests for machine tools
4. Explain how an autocollimator can be used for straightness measurement.
5. Explain how the straightness of a lathe bed may be checked by using a spirit level.

6. Describe the set-up for testing the following in case of a horizontal milling machine.

   a. Work-table surface parallel with the longitudinal movement

   b. True running of the axis of rotation of labour

7. Explain the procedure with a neat sketch to check the alignment of both centres of a lathe machine in a vertical plane.

8. Explain the principle of alignment, as applied to measuring instruments and machine tools.

9. State the geometrical checks made on machine tools before acceptance.

10. Distinguish between 'alignment test' and 'performance test'.

11. Name the various instruments required for performing the alignment tests on machine tools.

12. Name the various alignment tests to be performed on the following machines. Describe any two of them in detail using appropriate sketches.

    a. Lathe

    b. Drilling Machine

6 Limits, Fits and Tolerances (Limit Gauge and its Design)

> 'Limit, Fits, and Tolerences'—Key terms... a base of Quality Control......
>
> *Timke N S (Director, Creative Tool India Ltd., Pune)*

INTRODUCING GAUGES

An exact size can't be obtained in practice repeatedly. It is therefore logical to consider the variations in the dimensions of the part as being acceptable, if its size is known to lie between a maximum and minimum limit. This difference between the size limits is called *tolerance*. These variations are permitted for unavoidable imperfections in manufacturing, but it is seen that they do not affect the functional requirements of the part under consideration. This is done intentionally to reduce the manufacturing cost.

Under certain conditions, the limits imposed on an assembly may be so close that to ensure random selection, the close limits imposed on the individual details would lead to an expensive method of manufacturing. A practical solution (alternative) to this problem is to mark individual parts to meet wider tolerances, and then to separate them into categories according to their actual sizes. An assembly is then made from the selected categories—this process being known as *selective assembly*. It is required ideally where the objective is to make a 'shaft' and 'hole' with a finite fit and not within a permissible range of limit. This fit is known as '*selective fit*', usually used to avoid extreme tightness and looseness. For the purpose of an assembly of machine parts, mainly the different types of fits for this purpose are clearence fit, transition fit and interference fit. IS: 2709 gives suitable guidelines for selecting various types of fits for intended applications. The Newall system was probably the first system in Great Britain that attempted to standardize the system of limits and fits. In India, we follow IS: 919-1963 for the system of limits and fits.

A gauge is an inspection tool without a scale, and is the direct or reverse physical replica of the object dimension to be measured. To avoid any dispute between the manufacturer and purchaser, IS: 3455-1971 gives the guidelines for selecting the types of gauges for specific applications. The advantages of using gauges for cylindrical work are that the GO ring gauge may detect errors that may not be detected by the GO gap gauge, such as lobbing and raised imperfections. As per W Taylor, the GO gauge should check a time dimension along with its related (geometrical) parameters.

6.1 INTRODUCTION

The proper functioning of a manufactured product for a designed life depends upon its correct size relationship between the various components of the assembly. This means that components must fit with each other in the required fashion. (For example, if the shaft is to slide in a hole, there must be enough clearance between the shaft and the hole to allow the oil film to be maintained for lubrication.) If the clearance between two parts is too small, it may lead to splitting of components. And if clearance is too large, there would be vibration and rapid wear ultimately leading to failure. To achieve the required conditions, the components must be produced with exact dimensions specified at the design stage in part drawing. But, every production process involves mainly three elements, viz., man, machine and materials (tool and job material). Each of these has some natural (inherent) variations, which are due to chance causes and are difficult to trace and control, as well as some unnatural variations which are due to assignable causes and can be systematically traced and controlled. Hence, it is very difficult to produce extremely similar or identical (sized) components. Thus, it can be concluded that due to inevitable inaccuracies of manufacturing methods, it is not possible to produce parts to specified dimensions but they can be manufactured economically to the required size that lies between two limits. The terms *shaft* and *hole* are referred for external and internal dimensions. Then by specifying a definite size for one and varying the other, we could obtain the desired condition of the relationship of the fitment between the shaft and the hole. Practically, it is impossible to do so. Hence, generally the degree of tightness or looseness between the two mating parts, which is called fit, is specified.

6.2 CONCEPT OF INTERCHANGEABILITY

The concept of mass production originated with the automobile industry. MODEL-T of Ford Motors was the first machine to be mass-produced. The concept of interchangeability was introduced first in the United States. But in the early days, it was aimed at quick and easy replacement of damaged parts by attaining greater precision in manufacture and not at achieving chip products in large quantities. Till the 1940's, every component was manufactured in-house. After the 1940's, however, the automobile companies started outsourcing for carrying out roughing operations. Slowly and gradually, the outsourcing moved on from roughing components to finished components and from finished components to finished assemblies. The automobile industry started asking suppliers to plan for the design, development and manufacture of products to be used in producing cars and trucks.

In mass production, the repetitive production of products and their components entirely depends upon interchangeability. When one component assembles properly (and which satisfies the functionality aspect of the assembly/product) with any mating component, both chosen at random, then it is known as *interchangeability*. In other words, it is a condition which exists when two or more items possess such functional and physical characteristics so as to be equivalent in performance and durability; and are capable of being exchanged one for the other without alteration of the items themselves, or of adjoining items, except for adjustment, and without selection for fit and performance. As per ISO-IEC, interchangeability is the ability of one product, process or service to be used in place of another to fulfill the same requirements.

This condition that exists between devices or systems that exhibit equivalent functionality, interface features and performance to allow one to be exchanged for another, without alteration, and achieve the same operational service is called interchangeability. Moreover, we could say, it is an alternative term for compatibility. And hence it requires the uniformity of the size of components produced, which ensures interchangeability. The manufacturing time is reduced and parts, if needed, may be replaced without any difficulty. For example, if we buy a spark plug of a scooter from the market and then we find that it fits in the threaded hole positioned in a cylinder head of a scooter automatically. We just need to specify the size of the spark plug to the shopkeeper. The threaded-hole and spark-plug dimensions are standardized and designed to fit with each other. Standardization is necessary for interchangeable parts and is important for economic reasons. Some examples are shown in Fig. 6.1.

In mass production, since the parts need to be produced in minimum time, certain variations are allowed in the sizes of parts. Shafts and hole sizes are specified and acceptable variation in the size is specified. This allows deviation from size in such a way that any shaft will mate with any hole and functions correctly for the designed life of the assembly. But the manufacturing system must have the ability to interchange the system components with minimum effect on the system accuracy. And interchangeability ensures the universal exchange of a mechanism or assembly. Another parallel terminology, 'exchangeability' is the quality of being capable of exchange or interchange.

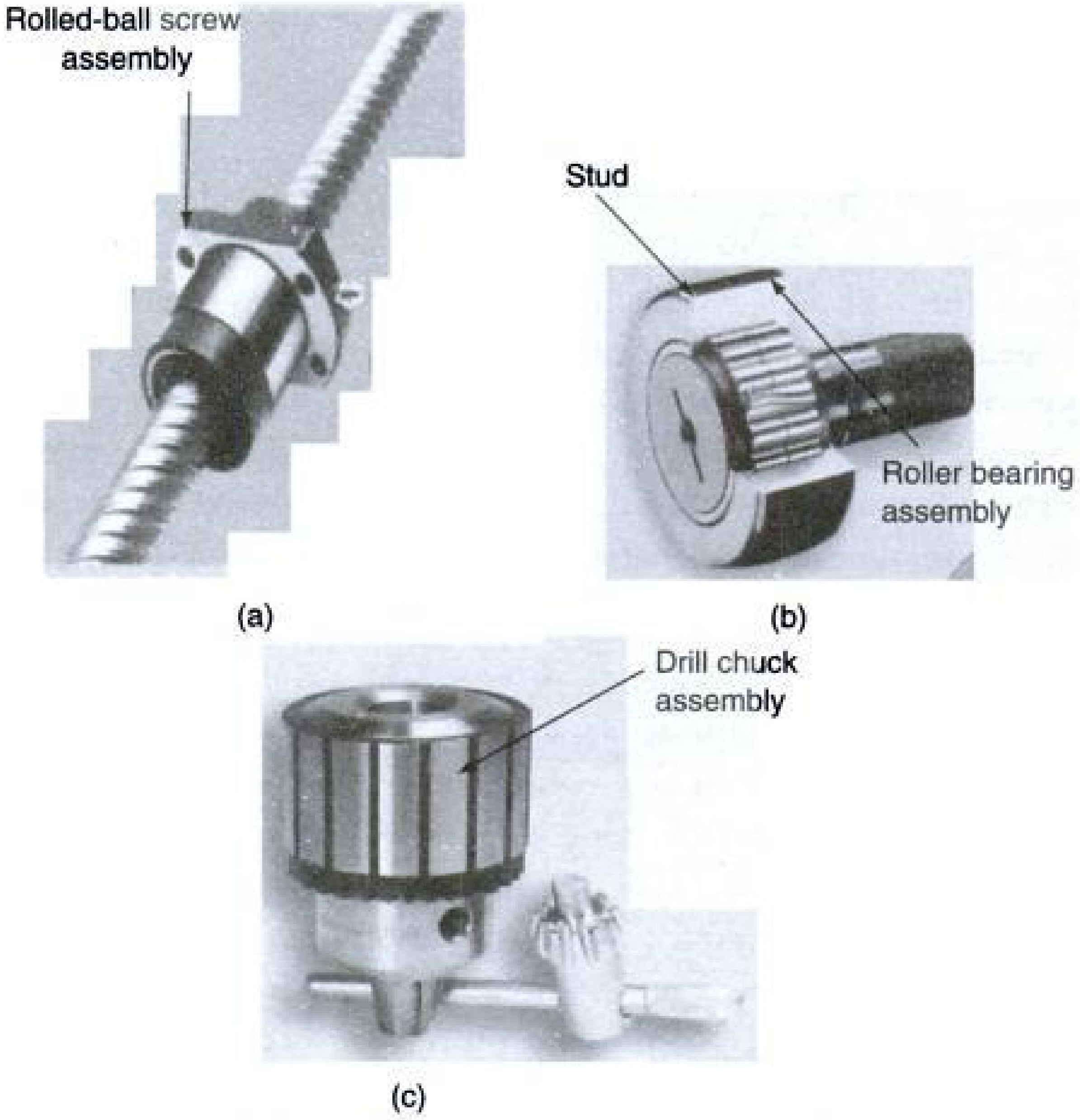


Fig. 6.1 *Examples of interchangeability*

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limit of size is greater than the basic size, it is a positive quantity and when the minimum limit of size is less than the basic size then it is a negative quantity.

12. Lower Deviation It is designated as *EI* (for hole) and *ei* (for shaft). It is the algebraic difference between the minimum limits of size and the corresponding basic size. When the minimum limit of size is greater than the basic size, it is a positive quantity and when the minimum limit of size is less than the basic size then it is a negative quantity.

13. Fundamental Deviations (FD) This is the deviation, either upper or the lower deviation, which is the nearest one to the zero line for either a hole or a shaft. It fixes the position of the tolerance zone in relation to the zero line (refer Fig. 6.4).

14. Actual Deviation It is the algebraic difference between an actual size and the corresponding basic size.

15. Mean Deviation It is the arithmetical mean between the upper and lower deviation.

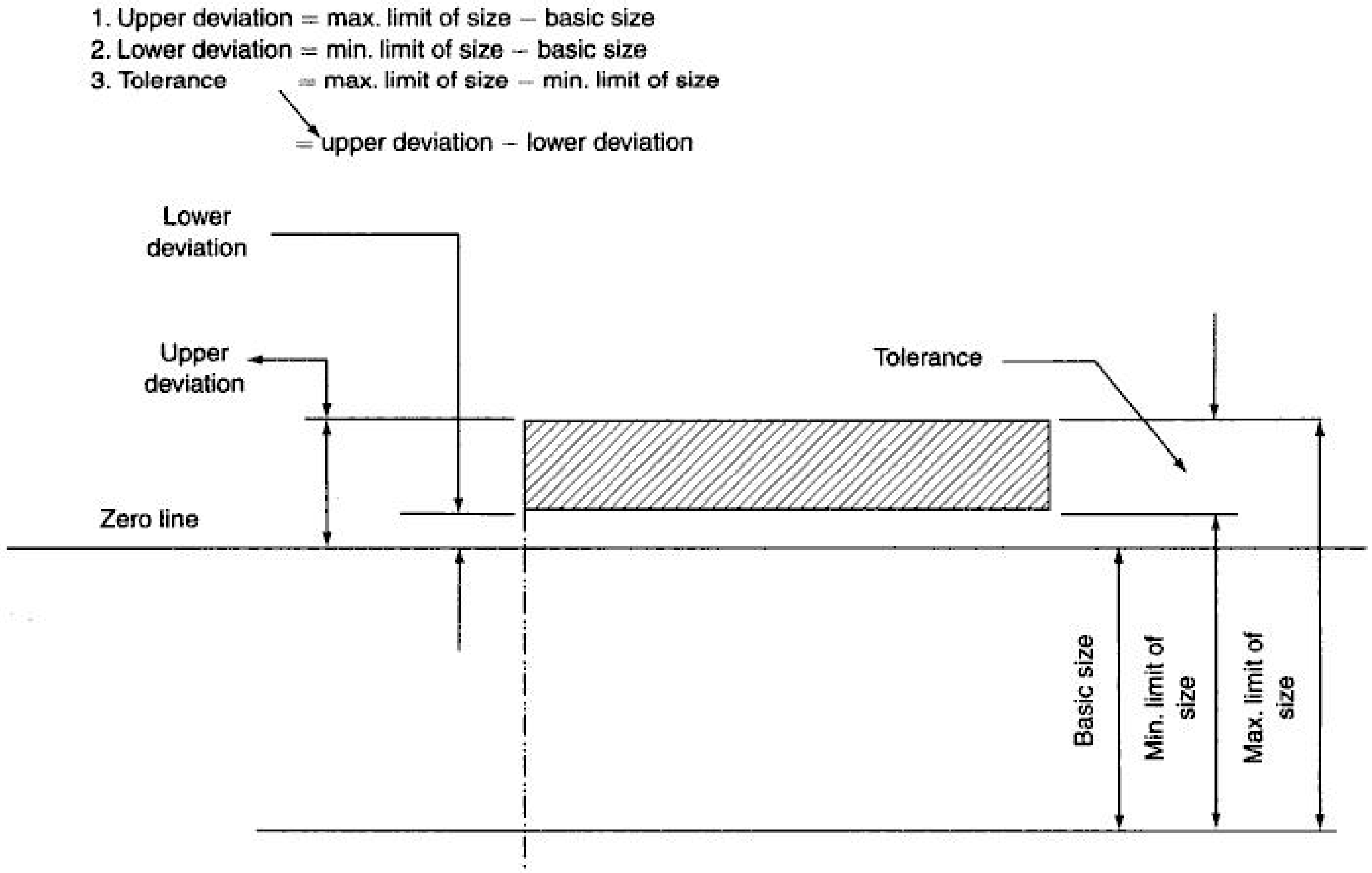

Fig. 6.4 *Deviations and tolerance*

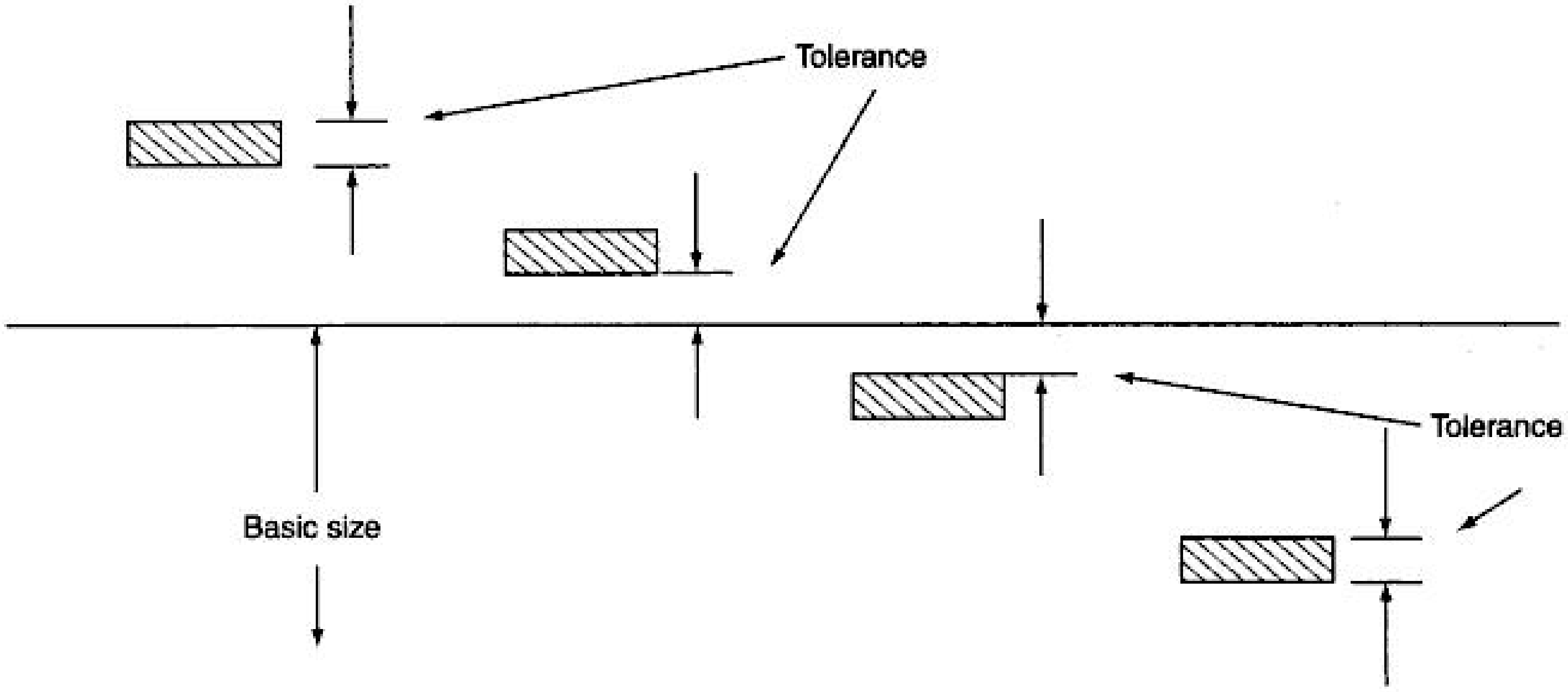

Fig. 6.8 *Unilateral tolerance system*

6.5.3 Maximum and Minimum Metal Limits

Consider the tolerance value of a tolerance specified for a shaft along with a basic dimension given as $30^{\pm 0.04}$ mm. Hence, the upper dimension limit will be 30.04 mm and the lower dimension limit will be 29.96 mm. Then, the Maximum Metal Limit (MML) for the shaft is 30.04 mm, as this limit indicates the maximum allowable amount of metal. And the Least (minimum) Metal Limit (LML) of the shaft dimension is 29.96 mm, as it gives a minimum allowable amount of metal. Similar terminologies are used for a hole. Figure 6.9 explains the concept clearly.

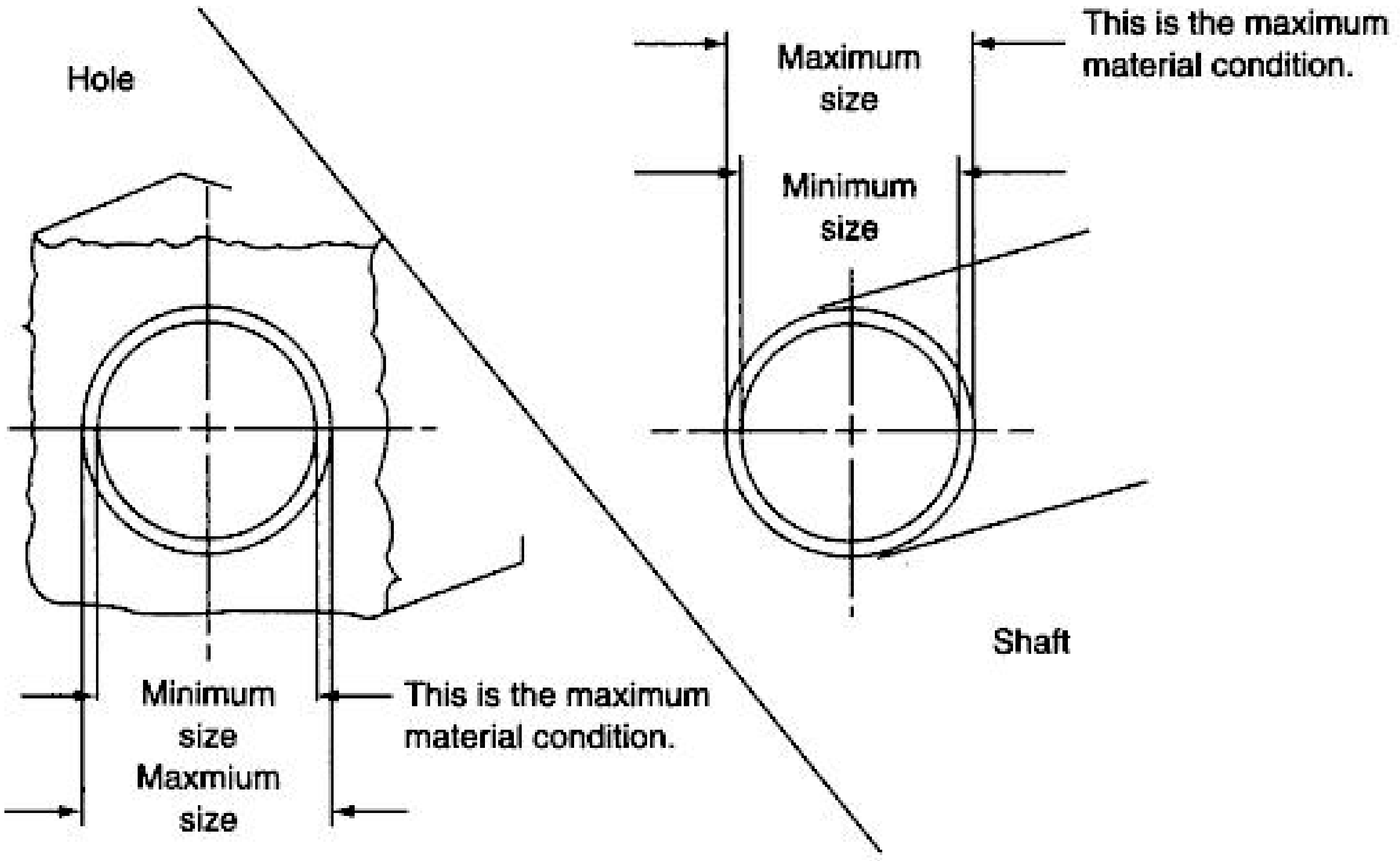

Fig. 6.9 *Maximum and minimum metal limits*

RC 7 Free running fits without any special requirements for precise guiding of shafts. Suitable for great temperature variations.

RC 8, RC 9 Loose running fits with great clearances and parts having great tolerances. Fits exposed to effects of corrosion, contamination by dust and thermal or mechanical deformations.

6.6.2 Interference Fit

When the difference between the sizes of the hole and shaft before assembly is negative then the fit is called interference fit.

For example,

Maximum size of hole—49.85 mm; Maximum size of shaft—50.1 mm

Minimum size of hole—49.65 mm; Minimum size of shaft—49.9 mm

Minimum Clearance In case of interference fit, it is the arithmetical difference between maximum size of the hole and the minimum size of shaft before assembly.

Maximum Interference In case of interference fit, it is the arithmetical difference between the minimum size of the hole and the maximum size of the shaft before assembly.

Interference fits are rigid (fixed) fits based on the principle of constant elastic pre-stressing of connected parts using interference in their contact area. Outer loading is transferred by friction between the shaft and hole created in the fit during assembly. The friction is caused by inner normal forces created as a result of elastic deformations of connected parts.

Interference fits are suitable for transfer of both large torques and axial forces in rarely disassembled couplings of the shaft and hub. These fits enable high reliability of transfer of even high loads; including alternating loads or loads with impacts. They are typically used for fastening geared wheels, pulleys, bearings, flywheels, turbine rotors and electromotors onto their shafts, with gear rings pressed onto wheel bodies, and arms and journals pressed onto crankshafts.

Press on, in general, means inserting a shaft of larger diameter into a hub opening, which is smaller. After the parts have been connected (pressed-on), the shaft diameter decreases and the hub opening increases, in the process of which both parts settle on the common diameter. Pressure in the contact area is then evenly distributed, shown in Fig. 6.12. The interference *d*, given by the difference between the assembly-shaft diameter and hub-opening diameter, is a characteristic feature and a basic quantity of interference fit. The value of contact pressure, as well as loading capacity and strength of the fit, depends on the interference size.

With respect to the fact that it is not practically possible to manufacture contact area diameters of connected parts with absolute accuracy, the manufacturing (assembly) interference is a vague and accidental value. Its size is defined by two tabular values of marginal interferences, which are given by the selected fit (by allowed manufacturing tolerances of connected parts). Interference fits are then

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6.8 INDIAN STANDARDS SPECIFICATIONS AND APPLICATION

As discussed in the earlier article, in India we have IS: 919 recommendation for limits and fits for engineering. This standard is mostly based on British Standards BS: 1916-1953. This IS standard was first published in 1963 and modified several times, the last modification being in 1990. In the Indian Standard, the total range of sizes up to 3150 mm has been covered in two parts. Sizes up to 500 mm are covered in IS: 919 and sizes above 500 mm, up to 3150 mm, are covered in IS: 2101. However, it is yet to adopt several recommendations of ISO: 286. All these standards make use of two entities of the standard limits, fits and tolerences terminology system—standard tolerances and fundamental deviation.

6.8.1 Tolerances Grades and Fundamental Deviation

The tolerance of a size is defined as the difference between the upper and lower limit dimensions of the part. When choosing a suitable dimension, it is necessary to also take into account the used method of machining of the part in the production process. In order to meet the requirements of various production methods for accuracy of the product, the Indian Standard, in line with the IS: 919 system, implements 18 grades of accuracy (tolerances). Each of the tolerances of this system is marked IT with the attached grade of accuracy (IT01, IT0, IT1 ... IT16). But, ISO: 286: 1988 specifies 20 grades of tolerances (i.e., from IT01 to IT18).

As the class of work required and the type of machine tool used governs the selection of the grade of tolerance, the type of fit to be obtained depends upon the magnitudes of the fundamental deviations, since the qualitative criterion for selection of a fit includes a sum of deviations (in absolute values) of limit values of the clearance or interference respectively of the designed fit from the desired values. IS: 919 recommends 25 types of fundamental deviations. But, ISO: 286: 1988 recommends 28 numbers of fundamental deviations. The relationship between basic size, tolerance, and fundamental deviations is diagrammatically represented in Fig. 6.14 and 6.15(a) and (b). In general arrangement of a system, for any basic size there are 25 different holes. These fundamental deviations are indicated by letters symbols for shafts and holes.

The 25 holes are designated by the capital letters A,B,C,D,E,F,G,H,I,J,K,L,M,N,O,P,Q,R,S,T,U,V, W,X,Y,Z,ZA,ZB,ZC. And the shafts are designated with the lowercase letters: a,b,c,d,e,f,g,h,i,j,k,l,m,n, o,p,q,r,s,t,u,v,w,x,y,z,z_a,z_b,z_c. As per IS recommendations, each of the 25 holes has a choice of 18 tolerances, as discussed earlier. Also for shafts, for any given size there are 25 different shafts designated

Table 6.1 *Field of use of individual tolerances of the ISO system*

IT01 to IT6	For production of gauges and measuring instruments
IT5 to IT12	For fits in precision and general engineering
IT11 to IT16	For production of semi-products
IT16 to IT18	For structures
IT11 to IT18	For specification of limit deviations of non-tolerated dimensions

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7 = the tolerance grade, i.e., IT7. By knowing this value, the limits for 55-mm size can be found out.

2) Shaft = **60 m9** means

60 = the basic size of the shaft.

m = the position of the shaft w.r.t zero line. In this case, it is above the zero line.

9 = the tolerance grade, i.e., IT9. By knowing this value, the limits for 60-mm size can be found out.

For deciding limits we have to find out the value of tolerance grades, first for hole and then of the shaft (as the hole basis system has been followed) to suit the requirements for the type of fit to be employed in the application under consideration. So, the calculation for tolerance grade is done as follows:

The fundamental tolerance unit is denoted as i (in microns). It is used to express various IT grades from IT5 to IT16, where the value of i in terms of the diameter D (in mm) can be calculated as

$$i = 0.45\sqrt[3]{D} + 0.001D$$

The diameter 'D' (in mm) is the geometric mean of the diameter steps (please refer Table 6.3). Tolerances are same for all diameter sizes, which fall in the specific range of the diameter step. These steps are the recommendations of IS: 919.

The values of tolerances for tolerance grades IT5 to IT16 are given in Table 6.4.

For the values of tolerance grades IT01 to IT4, the formulae are

$$\text{For IT01} = 0.3 + 0.008D$$

$$\text{For IT0} = 0.5 + 0.012D$$

$$\text{For IT1} = 0.8 + 0.02D$$

Table 6.3 *Geometric mean of diameter steps*

General Cases (mm)	0–3, 6–10, 18–30, 30–50, 50–80, 80–120, 120–180, 180–250, 250–315, 315–400, 400–500
Special Cases (mm)	10–14, 14–18, 18–24, 24–30, 30–40, 40–50, 50–65, 65–80, 80–100, 100–120, 120–140, 140–160, 160–180, 180–200, 200–225, 225–250, 250–280, 280–315, 315–355, 355–400, 400–450, 450–500

Table 6.4 *Tolerance grades IT5 to IT16*

Grade	IT5	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Tolerance	$7i$	$10i$	$16i$	$25i$	$40i$	$64i$	$100i$	$160i$	$250i$	$400i$	$640i$	$1000i$

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Table 6.8 *As per IS: 2709–1964*

Type of	*Class of Fits*	*With Holes* H6	H7	H8	H11	*Remarks*
Clearance Fit	Shaft a	-	-	-	a 11	Loose clearence fit not widely used
	Shaft b	-	-	-	-	--- do ---
	Shaft c	-	c8	c9	c11	Slack running fit
	Shaft d	-	d8	d9	d11	Loose running fit
	Shaft e	e7	e8	e8-e9	-	Easy running fit
	Shaft f	f6	f7	f8	-	Normal running fit
	Shaft g	g6	g7	g7	-	Close running fit or sliding fit, also spigot and location fit
	Shaft h	h5	h6	h7-h8	h11	Precision sliding fit; also fine spigot fit and location fit
Transition Fit	Shaft j	j5	j6	j7	-	Push fit for very accurate location with easy assembly and dismantling
	Shaft k	k5	k6	k7	-	Light keying fit (true transition fit) for keyed shaft, non-running locked pin, etc.
	Shaft m	m5	m6	m7	-	Medium keying fit
	Shaft n	n5	n6	n7	-	Heavy keying fit (for tight assembly of meeting surface)
Interference Fit	Shaft p	p5	p6	-	-	Light press fit with easy dismantling for non-ferrous parts; standard press fit with easy dismantling for ferrous and non-ferrous parts assembly
	Shaft r	r5	r6	-	-	Medium drive fit with easy dismantling for ferrous parts assembly; Light drive fit with easy dismantling for non-ferrous fit for non-ferrous parts.
	Shaft s	s5	s6	s7	-	Heavy drive for ferrous parts, permanent or semi-permanent assembled press and for non-ferrous parts.
	Shaft t	t5	t6	t7	-	Force fit on for ferrous parts for permanent assembly
	Shaft u	u5	u6	u7	-	Heavy force fit or shrink fit
	Shaft v, x,y and z	-	-	-	-	Very large interference fit; not recommended for use

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Table 6.10 *Hole tolerance zones for general use*

								A9	A10	A11	A12	A13					
							B8	B9	B10	B11	B12	B13					
							C8	C9	C10	C11	C12	C13					
					CD6	CD7	CD8	CD9	CD10								
					D6	D7	D8	D9	D10	D11	D12	D13					
				E5	E6	E7	E8	E9	E10								
		EF3	EF4	EF5	EF6	EF7	EF8	EF9	EF10								
		F3	F4	F5	F6	F7	F8	F9	F10								
		FG3	FG4	FG5	FG6	FG7	FG8	FG9	FG10								
		G3	G4	G5	G6	G7	G8	G9	G10								
H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18
JS1	JS2	JS3	JS4	JS5	JS6	JS7	JS8	JS9	JS10	JS11	JS12	JS13	JS14	JS15	JS16	JS17	JS18
					J6	J7	J8										
		K3	K4	K5	K6	K7	K8										
		M3	M4	M5	M6	M7	M8	M9	M10								
		N3	N4	N5	N6	N7	N8	N9	N10	N11							
		P3	P4	P5	P6	P7	P8	P9	P10								
		R3	R4	R5	R6	R7	R8	R9	R10								
		S3	S4	S5	S6	S7	S8	S9	S10								
				T5	T6	T7	T8										
				U5	U6	U7	U8	U9	U10								
				V5	V6	V7	V8										
				X5	X6	X7	X8	X9	X10								
					Y6	Y7	Y8	Y9	Y10								
					Z6	Z7	Z8	Z9	Z10	Z11							
					ZA6	ZA7	ZA8	ZA9	ZA10	ZA11							
						ZB7	ZB8	ZB9	ZB10	ZB11							
						ZC7	ZC8	ZC9	ZC10	ZC11							

used. An overview of tolerance zones for general use can be found in Table 6.11. The tolerance zones not included in this table are considered special zones and their use is recommended only in technically well-grounded cases.

Prescribed hole tolerance zones for routine use (**for basic sizes up to 3150 mm**)

Note: Tolerance zones with thin print are specified only for basic sizes up to 500 mm.

Hint: For hole tolerances, tolerance zones H7, H8, H9 and H11 are preferably used.

Table 6.12 *Equivalent fits for the hole-basis and shaft-basis system*

Clearance		*Transition*		*Interference*	
Hole Basis	*Shaft Basis*	*Hole Basis*	*Shaft Basis*	*Hole Basis*	*Shaft Basis*
H7-c8	C8-h8	H6-j5	J6-h5	H6-n5	N6-h5
H8-c9	C9-h8	H7-j6	J7-h6		
H11-c11	C11-h11	H8-j7	J8-h7	H6-p5	P6-h5
				H7-p6	P7-h6
H7-d8	D8-h7	H6-k5	K6-h5		
H8-d9	D9-h8	H7-k6	K7-h6	H6-r5	R6-h5
H1-d11	D11-h11	K8-k7	K8-h7	H7-r6	R7-h6
H6-e7	E7-h6	H6-m5	M6-h5	H6-s5	S6-h6
H7-e8	E8-h8	H7-m6	M7-h6	H7-s6	S7-h6
H6-f6	F6-h6	H8-m7	M8-h7	H8-s7	S8-h7
H7-f7	F7-h7	H7-n6	N7-h6	H7-t6	T7-h6
H8-f8	F8-h8	H8-n7	N8-h7	H7-t6	T7-h6
				H8-t7	T8-h7
H6-g5	G7-h5	H8-p7	P8-h7		
H7-g6	G7-h6			H6-u5	U6-h5
H8-g7	G8-h7	H8-r7	R8-h7	H7-u6	U7-h6
				H8-u7	U8-h7

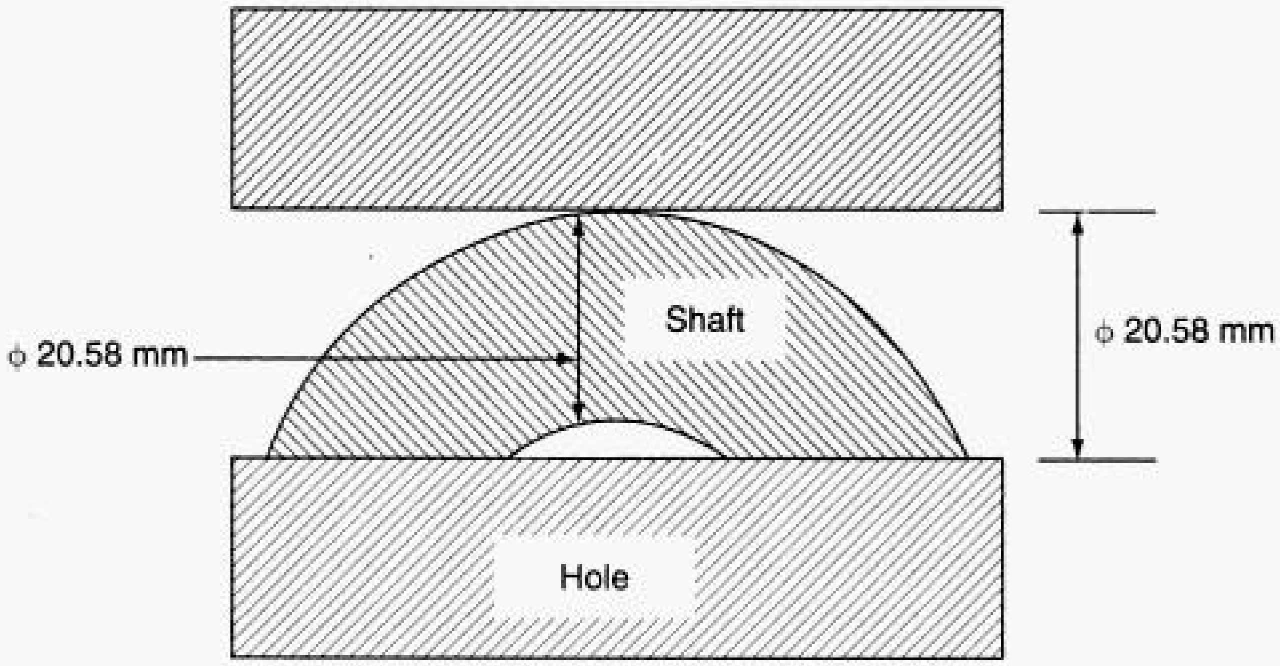
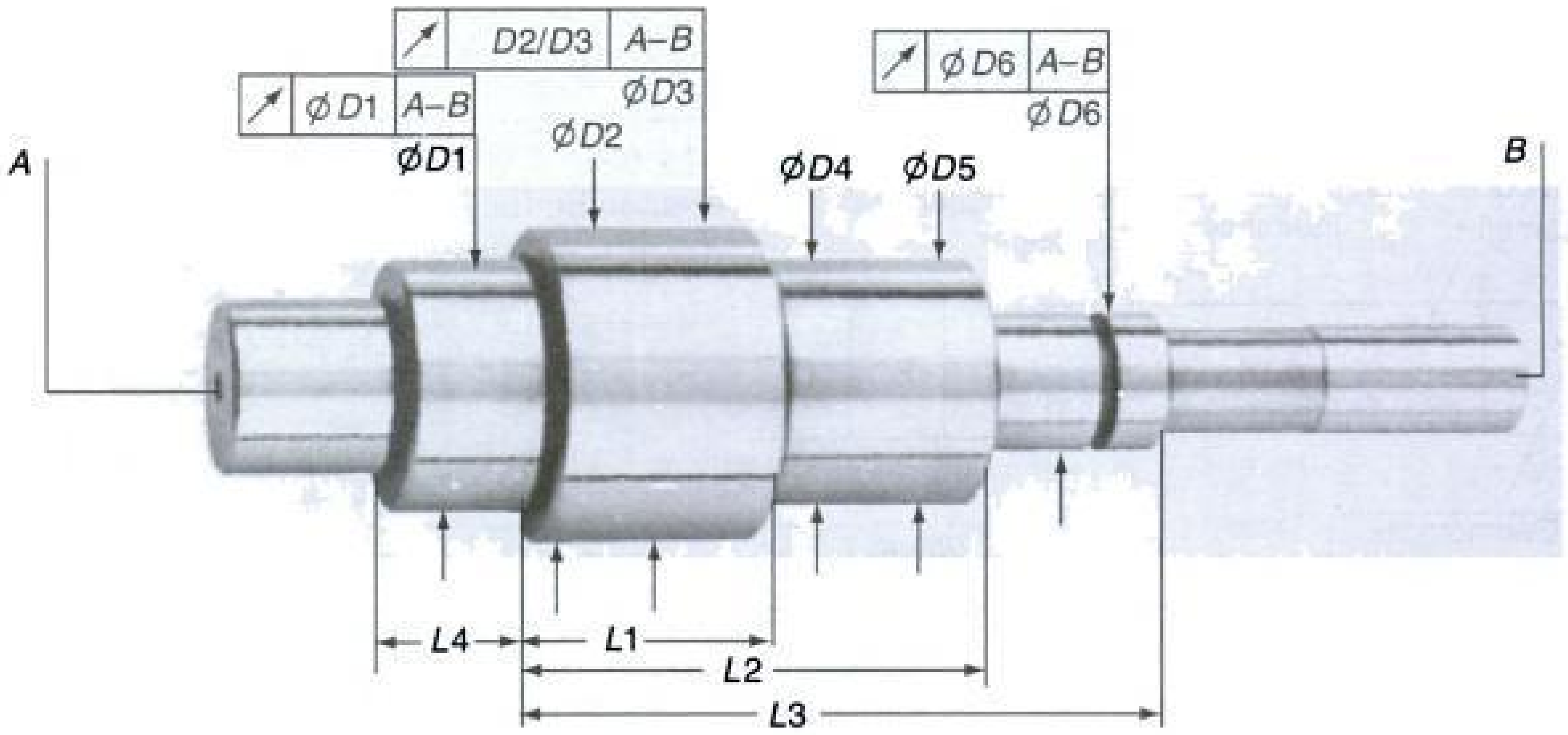


Fig. 6.19 *Assembly of shaft and hole*



(b)

Fig. 6.20(b) *Examples of representation of features of geometric tolerances in engineering drawing of parts*

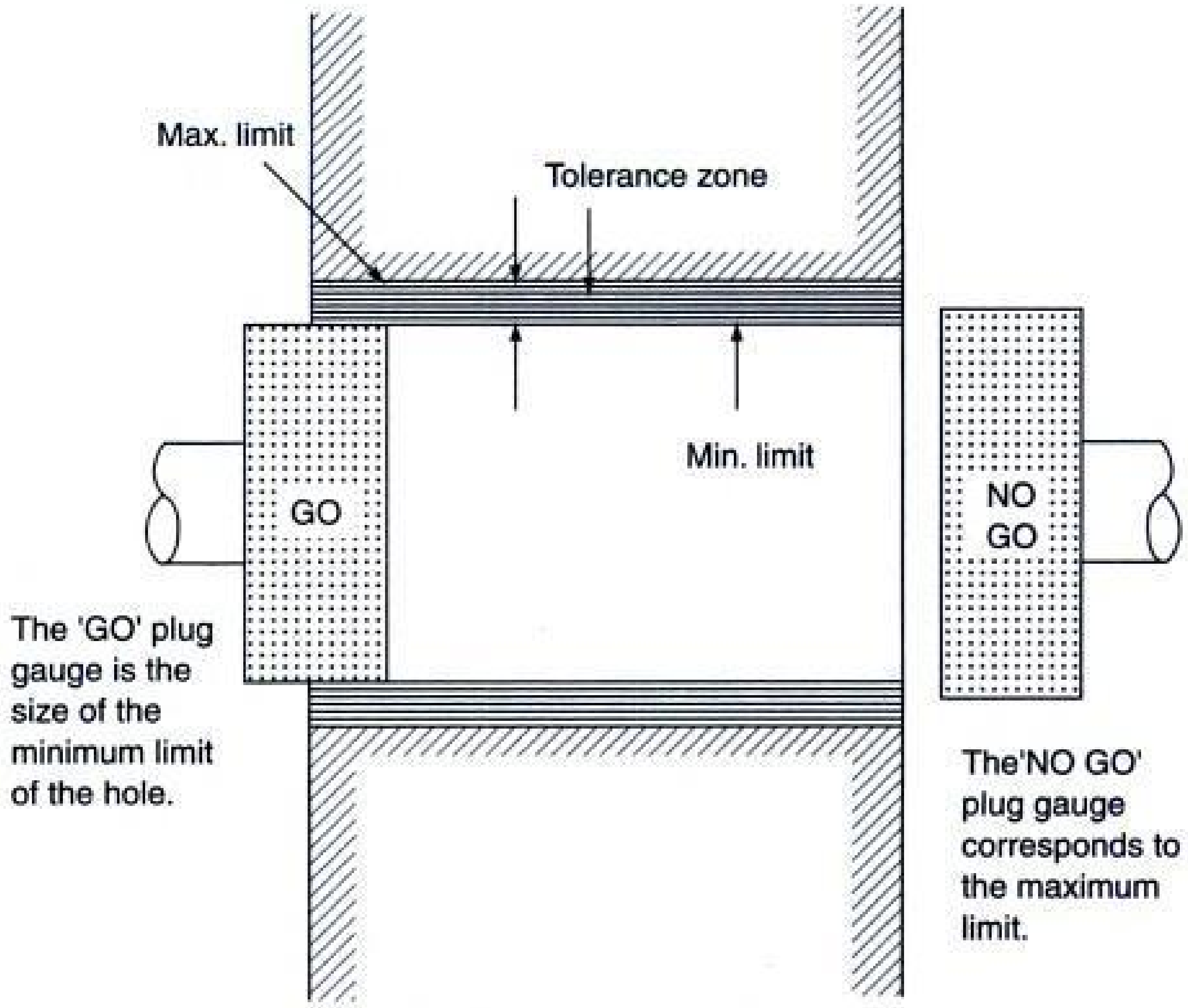


Fig. 6.21 *Plug gauge*

'NO GO' Limit This designation is applied to that limit between the two size limits which corresponds to the minimum material condition, i.e., the lower limit of a shaft and the upper limit of a hole.

and English dimensions for master, setting or working applications. Rings are available in plain (smooth, unthreaded), threaded, cylindrical and tapered forms to GO, NO-GO or nominal tolerances. There are three main types of ring gauges: GO, NO-GO, and master or setting ring gauges.

GO ring gauges provide a precision tool for production of comparative gauging based on a fixed limit. GO gauges consist of a fixed limit gauge with a gauging limit based on the plus or minus tolerances of the inspected part. A GO ring gauge's dimensions are based on the maximum OD tolerance of the round bar or part being gauged. A GO plug gauge's dimensions are based on the minimum ID tolerance of the hole or part being gauged. The GO plug (ID) gauge should be specified to a plus gaugemakers' tolerance from the minimum part tolerance. The GO ring (OD) gauge should be specified to a minus gaugemakers' tolerance from the maximum part tolerance. NO-GO, or NOT-GO, gauges provide a precision tool for production of comparative gauging based on a fixed limit. NO-GO gauges consist of a fixed limit gauge with a gauging limit based on the minimum or maximum tolerances of the inspected part. A NO-GO ring gauge's dimensions are based on the minimum OD tolerance of the round bar or part being gauged. The NO GO ring (OD) gauge should be specified to a plus gaugemakers' tolerance from the minimum part tolerance. Master and setting ring gauges include gauge blocks, master or setting discs. Setting rings are types of master gauges used to calibrate or set micrometers, comparators,

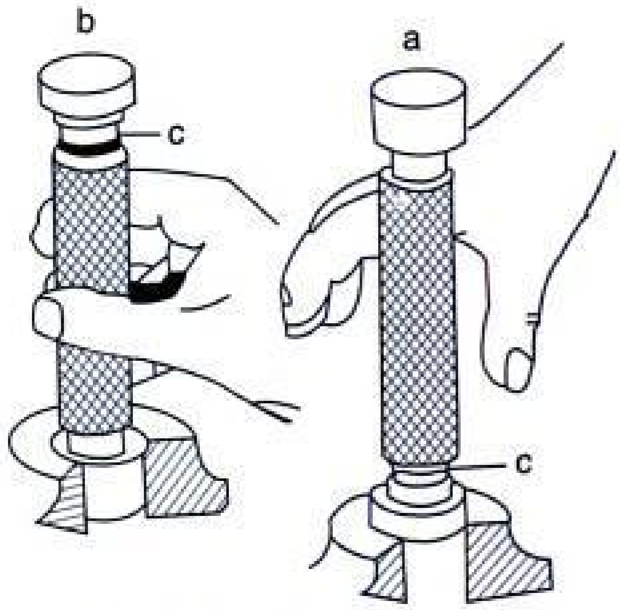
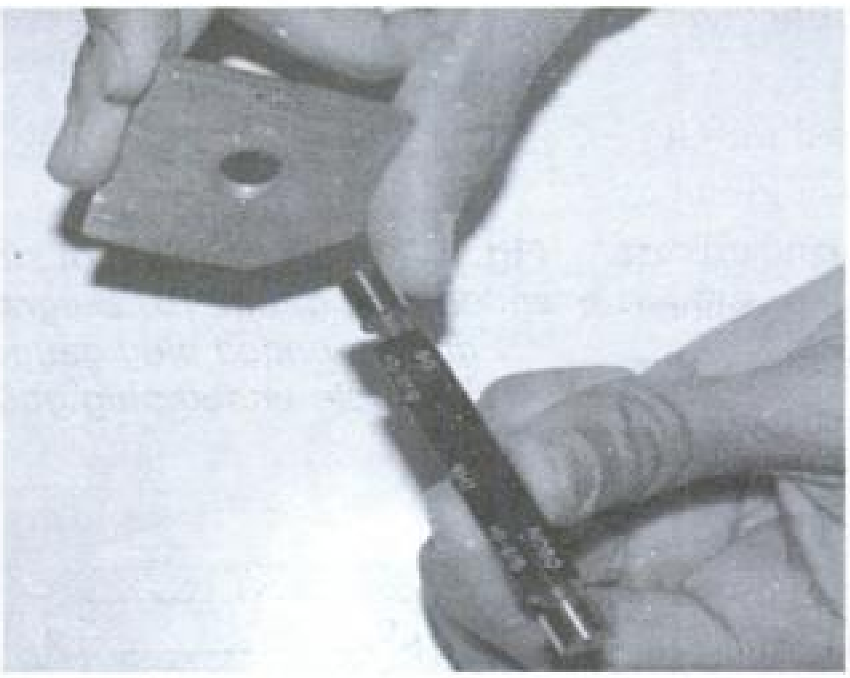
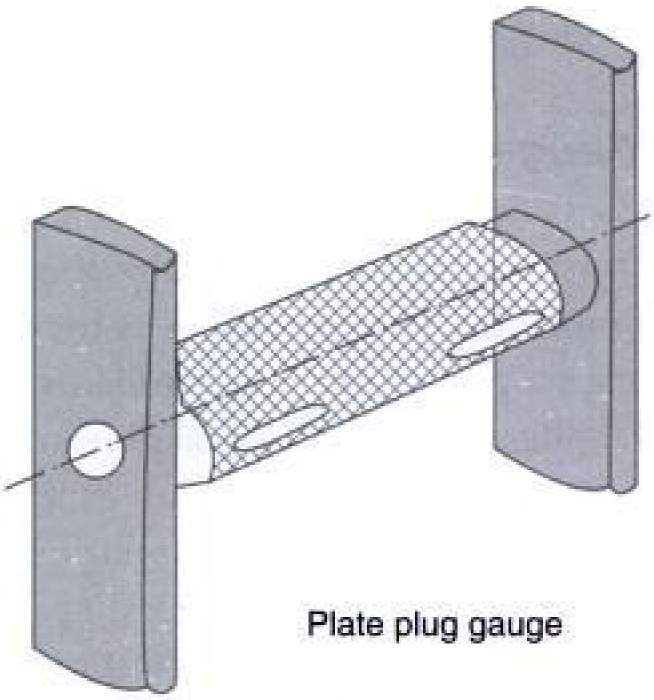


Fig. 6.27 *Use of limit plug gauge*





(a) (b)

Fig. 6.28 *(a) How to use double-ended plug gauge (b) Plate plug gauge*
(Courtesy, Metrology Lab, Sinhgad C.O.E., Pune, India.)

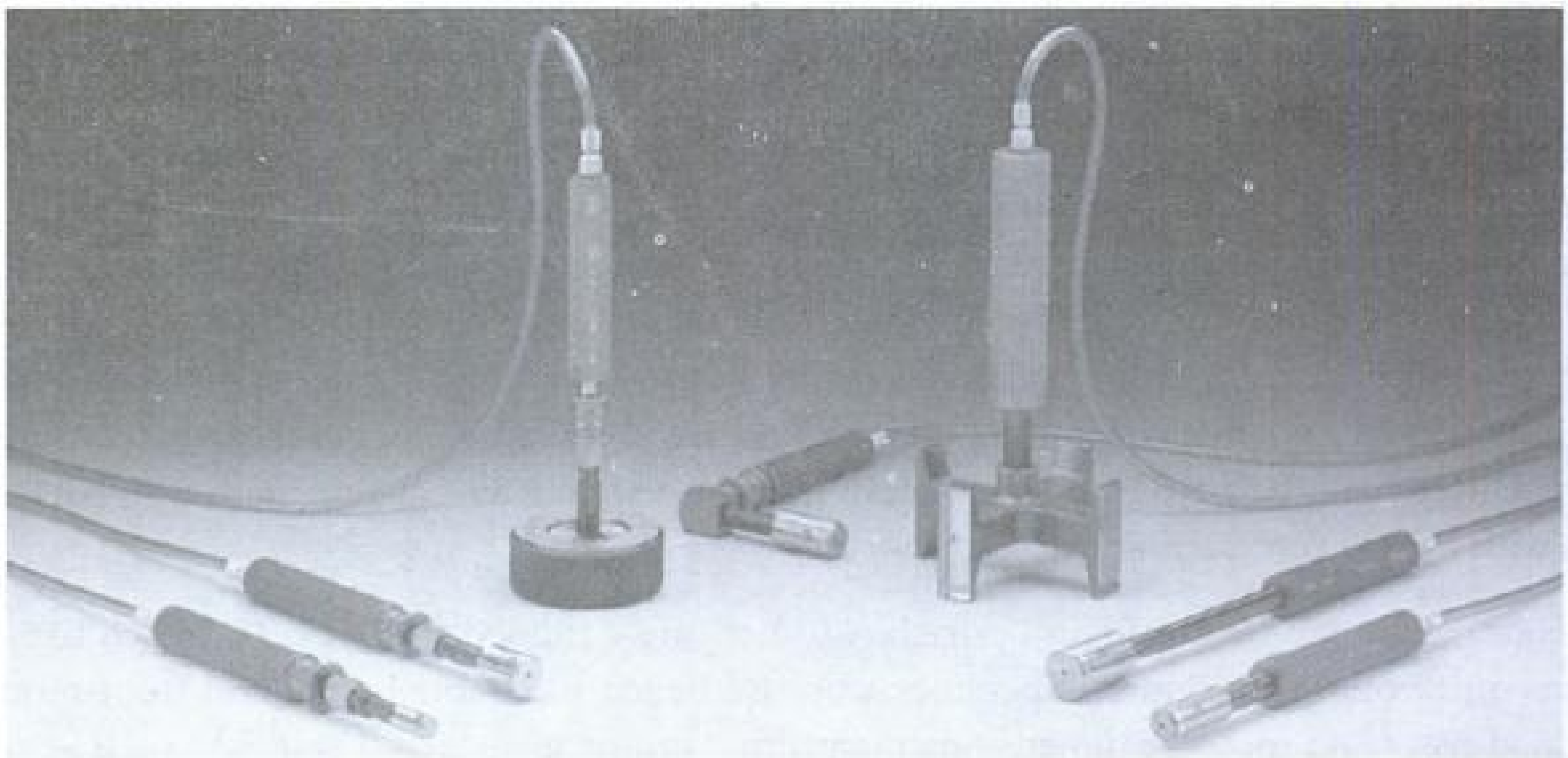


Fig. 6.31 *Jet air plug gauges*
(Courtesy, Mahr GMBH, Esslingen)

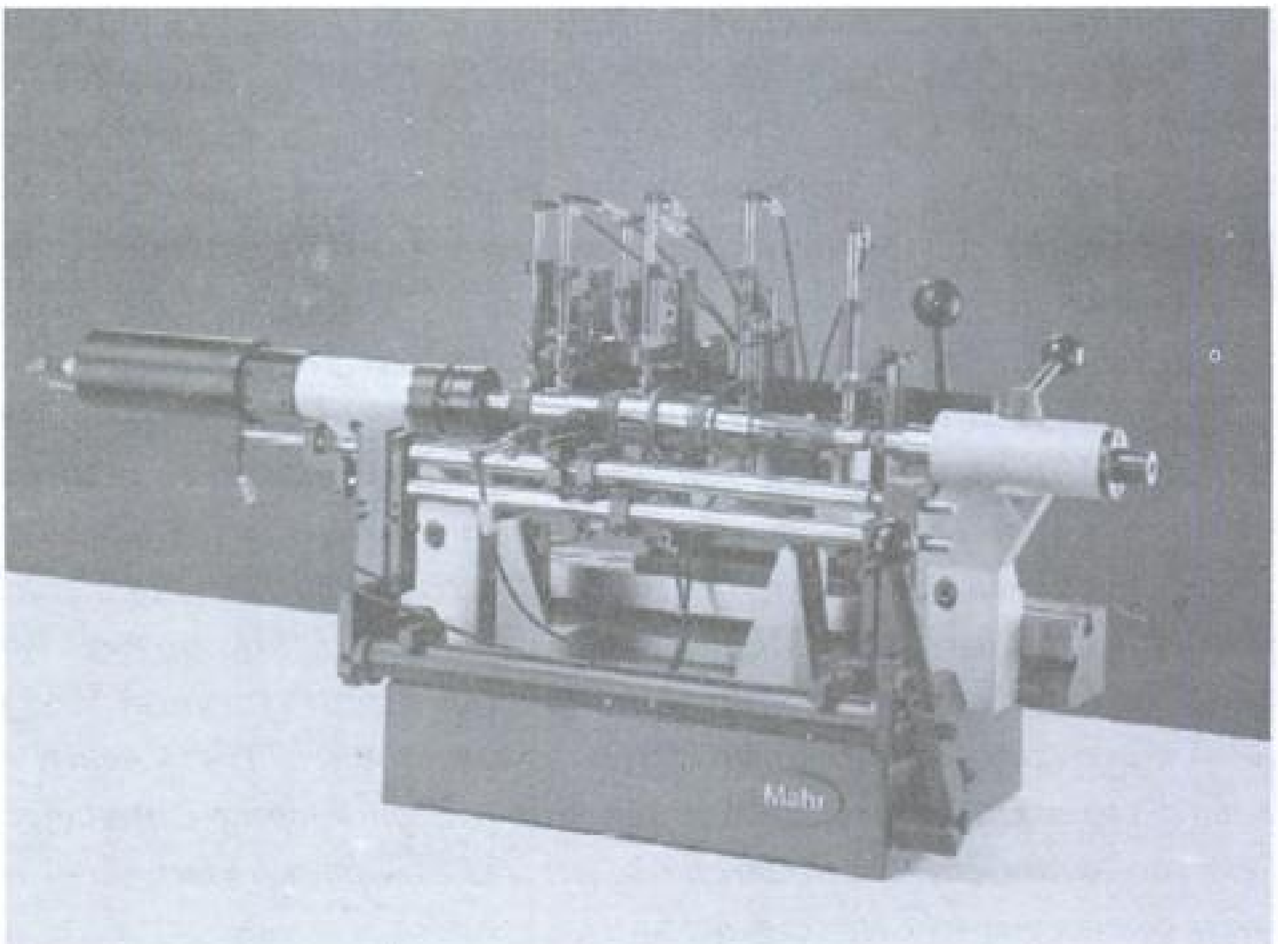


Fig. 6.32 *Automatic gauge system*
(Courtesy, Mahr GMBH, Esslingen)

diametric roundness deviation can be tested by rotation around 180° and the cylindricity by movement in a longitudinal direction. The measuring range of the jet air plug gauges is a maximal 76 μm (.003 in). Jet air plug gauges are supplied as standard in hardened or chrome-plated versions and, if required, with a shut-off valve in the handle.

part tolerances and gauging frequency (shop vs, high-volume production).

Thread gauges can be one of any number of types of gauges. These include plug, ring, 3-wire, micrometer, tri-roll comparator, measuring wire, screw thread insert (STI), and thread-gauging roll-thread gauges. Thread plug gauges measure GO/NO-GO assessment of hole and slot dimensions or locations compared to specified tolerances. Thread ring gauges measure GO/NO-GO assessment compared to specified tolerances of the dimensions or attributes of pins, shafts or threaded studs. Three-wire thread gauges are gauges that use thread wires to gauge thread size with one wire mounted in one holder and two wires mounted in a second holder. The holders are placed in the measuring gauge and brought in contact with the threads.

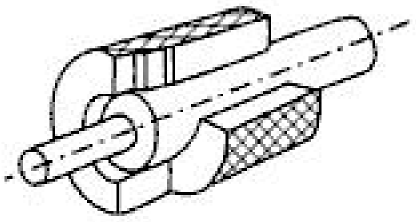


Fig. 6.37 *Use of taper gauges*

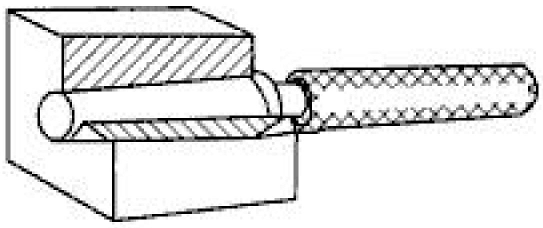


Fig. 6.38 *Use of taper holes*

Thread micrometers are micrometers for measuring threads. A tri-roll comparator is a specialized thread gauge employing three threads roll and a digital or dial display. The thread-gauging rolls can be interchanged to measure different thread sizes. A measuring wire is a specialized wire manufactured to precise gauge sizes for measuring external threads. The wire is wrapped or placed in the thread cavity and then a measurement is made with a micrometer or other OD gauge. STI gauges, also referred as helical coils or helicoils, are used where a screw thread insert will be used. STI gauges are widely applied in the automotive industry. Thread-gauging rolls are threaded rolls for use on roll-thread comparators.

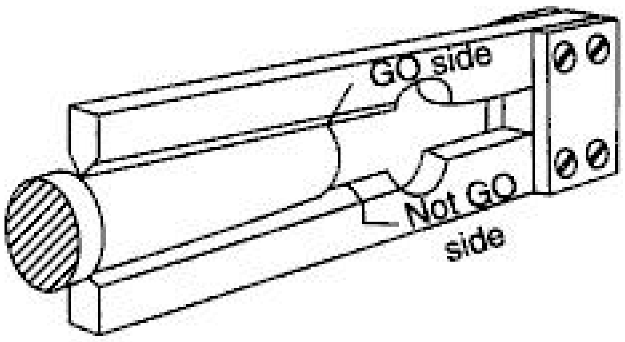
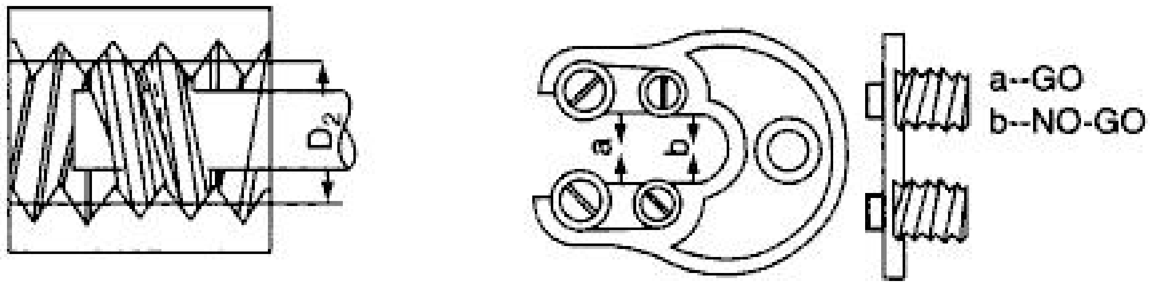


Fig. 6.39 *Flat taper gauges used for testing of tapers in accordance with light gap method*

Different thread types, profiles, and geometries provide different functionalities. Thread designations include UNC, UNF, UNEF, UN, M/MJ (metric), NPT, NPTF, NPSF, ANPT, BSPT, BSPP, ACME, and buttress. Thread gauges measure the size or diameter of the feature being measured. English pitch is the threads per inch that the gauge can measure. Metric pitch is the metric thread spacing that the gauge can measure.

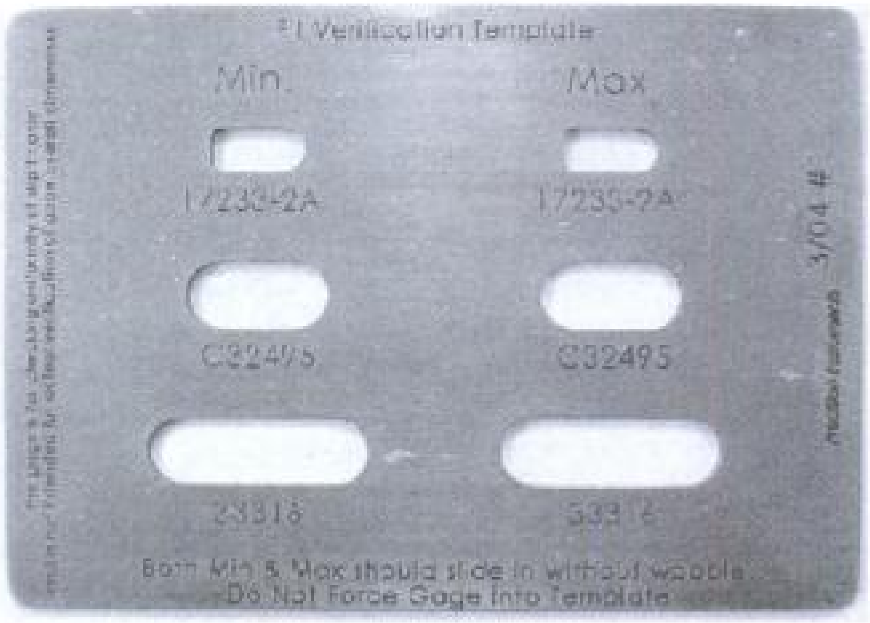


Testing of flank D_2 with the NO-GO side of the limit gauge

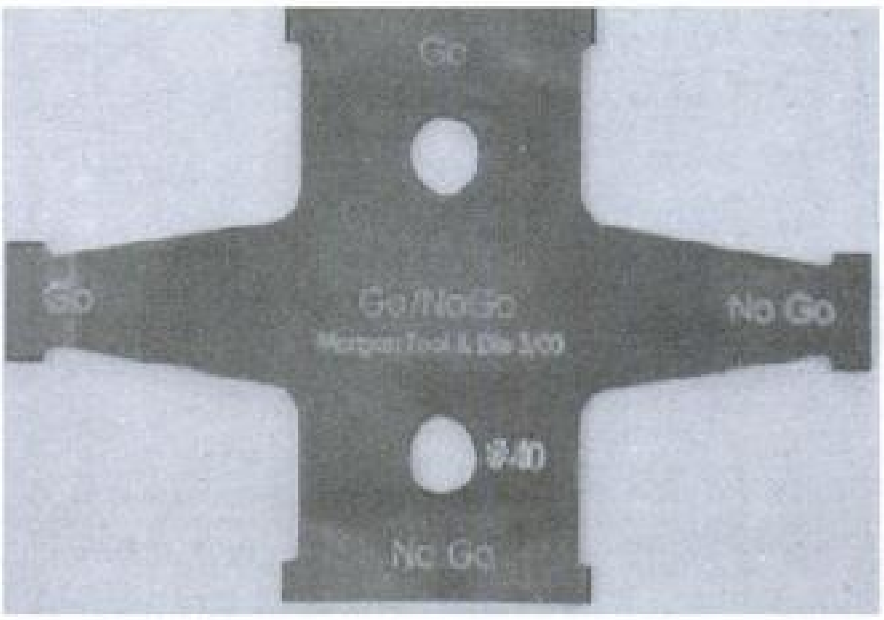
Thread limit snap gauge

Fig. 6.40 *Thread gauges*

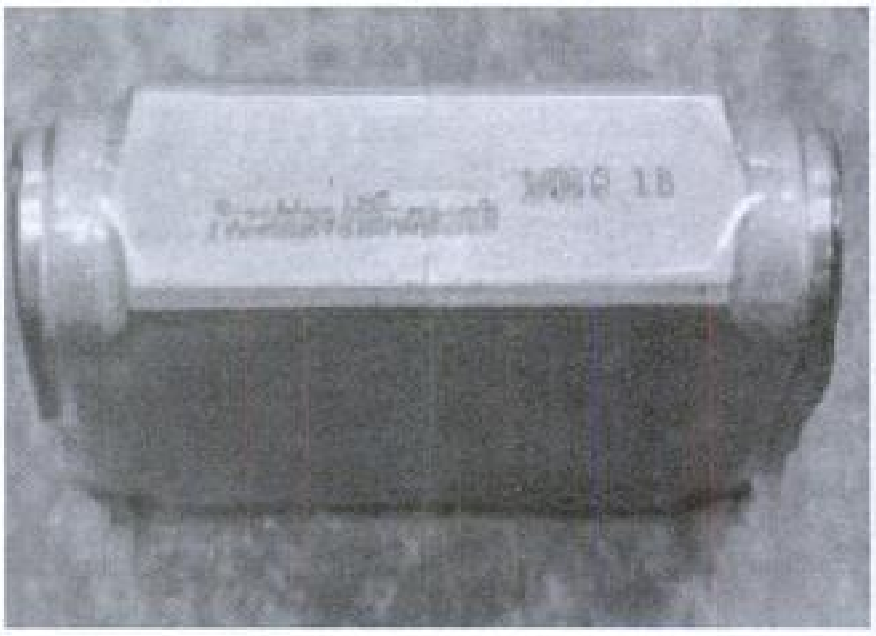
(a)



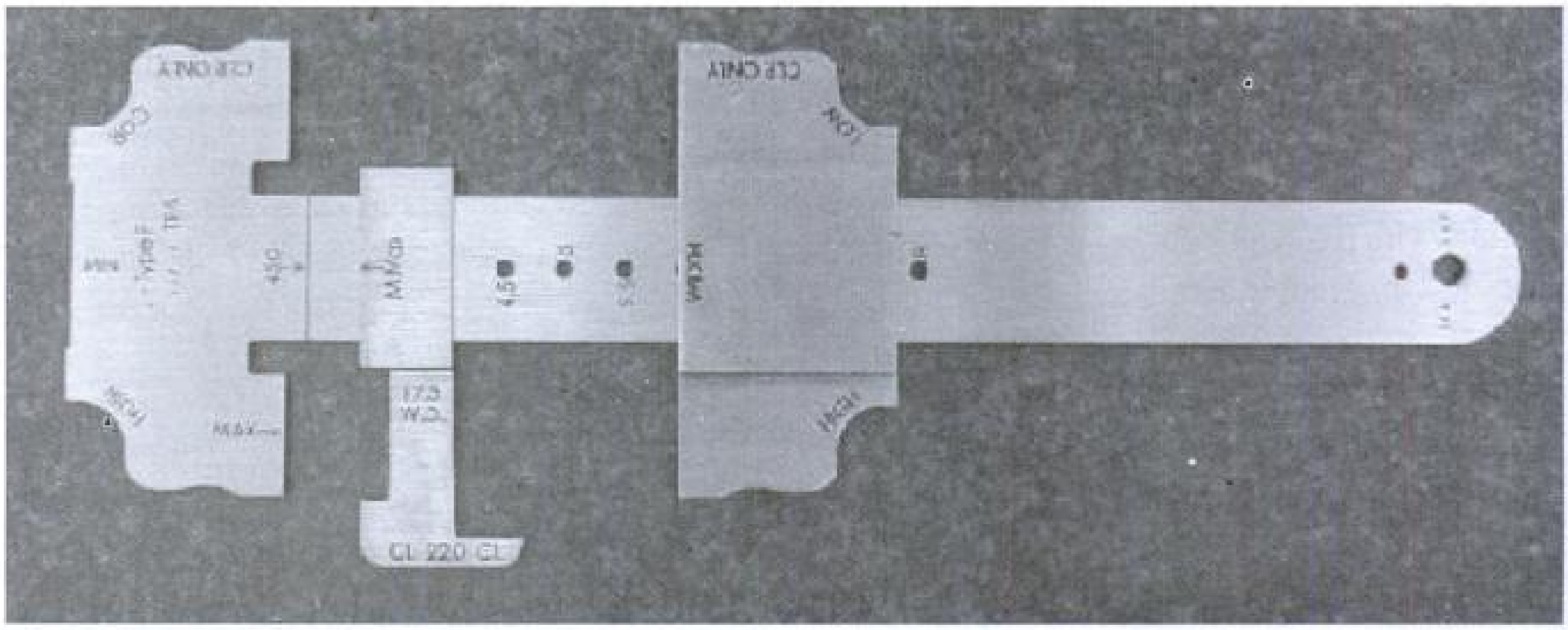
(b)



(c)



(d)



(e)

(Continued)

5. *Allocation of Gauge Tolerance and Wear Allowance* Allocation of gauge tolerance is as per policy decision. According to purpose, gauges can be classified as workshop gauges, inspection gauges and general gauges. For allocating gauge tolerance and wear allowance for the abovesaid gauges, the following guiding principles are used:

1. No work should be produced by workshops or accepted by the inspection department which lies outside the prescribed limits of size.
2. No work should be rejected which lies within the prescribed limits of size.

These two principles pertain to two situations and the common conclusion (solution) to this is to employ two sets of gauges, one set to be used during manufacturing (known as workshop gauge) and the other (inspection gauges) to be used for final inspection of parts. Tolerances on workshop gauges are arranged to fall inside the work tolerances, and tolerances on inspection gauges are arranged to fall outside the work tolerances. To approach the first principle, general gauges are recommended. In this type of gauges, the tolerance zone for a GO gauge is placed inside the work tolerance and the tolerance zone for a NOT-GO gauge is placed outside the work tolerance (refer Fig. 6.48).

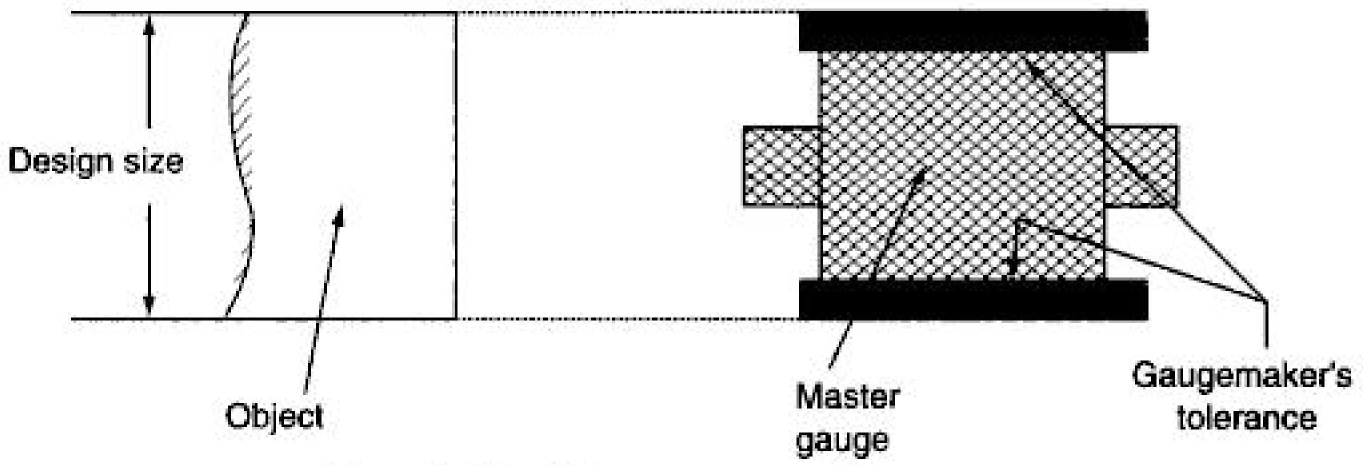


Fig. 6.48 *Tolerance zone for gauges*

In case of a master gauge (setting gauge for comparator instruments), the gaugemaker's tolerances are distributed bilaterally. It is done by using two parameters, the first is the size of the object and the other is the median size of the permissible object size limits.

6. *Gauging Force* It is the amount of force applied for inserting the gauge into the part geometry during inspection of the part-using gauge. In this process so many parameters are involved, viz., material of part, elasticity of material, gauging dimensions and conditions, etc. Therefore, it is very difficult to standardize the gauging force. In practice, if a GO gauge fails to assemble with the part then it is quite definitely outside the maximum metal limit. Similarly, if a NO-GO gauge assembles freely under its own weight then the part under inspection is obviously rejected. Chamfering is provided on GO gauges to avoid jamming.

7. *Twelve Questions for Dimensional Gauge Selection* How do we select a dimensional gauge? There are literally thousands of varieties, many of which could perform the inspection

Solution:

(a) Firstly, find out the dimension of hole specified, i.e., 22 *D*8.

For a diameter of 22-mm step size (refer Table 6.3) = (18 − 30) mm

$$\therefore D = \sqrt{d_1 \times d_2} = \sqrt{18 \times 30} = 23.2379 \text{ mm}$$

$$\text{And, } i = 0.45\sqrt[3]{D} + 0.001D$$

$$\therefore i = 0.45\sqrt[3]{23.2379} + 0.001(23.2379)$$

$$= 1.3074 \text{ microns}$$

Tolerance value for IT8 = 25 i ....(refer Table 6.4)

= 25 (1.3074) = 32.685 microns = 0.03268 mm.

(b) Now Fundamental Deviation (FD) for hole,

$D = 16^{(0.44)}$

$D = 16\ [23.2379]^{(0.44)}$

$D = 63.86$ microns = 0.06386 mm.

Lower limit of the hole = basic size + FD

= (22.00 + 0.06386) mm

= 22.06386 mm

And upper limit of the hole = Lower limit + Tolerance

= (22.06386 + 0.03268) mm

= 22.0965 mm

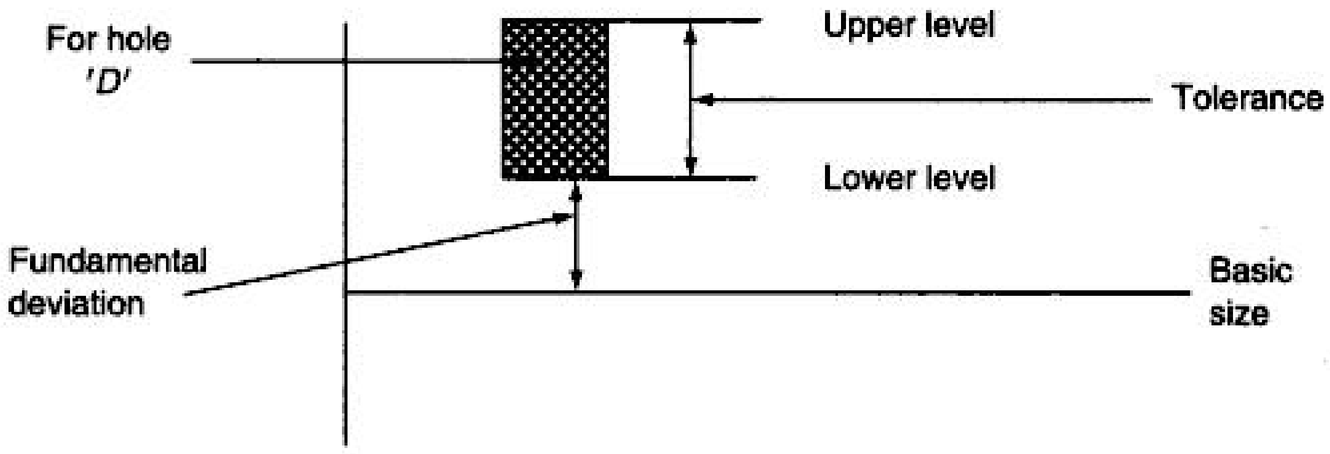


Fig. 6.50

Limits for shaft $f8\ 25.00^{+0.010}_{-0.043}$ mm.

(d) Now consider gaugemaker's tolerance for hole gauging [refer Article 6.9.4 (c)] = 10% of work tolerance.

∴ tolerance on GO Gauge = 0.0021 mm.

(e) Wear allowance [refer Article 6.9.4 (d)] is considered as 10% of gaugemaker's tolerance

∴ wear allowance = 0.1(0.0021) = 0.00021 mm

(f) Now consider gaugemaker's tolerance for shaft gauging [refer Article 6.9.4 (c)] = 10% of work tolerance.

∴ tolerance on GO Gauge = 0.0033 mm

(g) Wear allowance [refer Article 6.9.4 (d)] is considered as 10% of gaugemaker's tolerance

∴ wear allowance = 0.1 (0.0033) = 0.00033 mm

(h) Now the gauge limits can be calculated by referring Fig. 6.49 and the values are tabulated as follows:

Table 6.18

Types of Gauges	*Plug Gauge (for hole gauging)*		*Ring Gauge (for shaft gauging)*	
	GO gauge	*NO-GO gauge*	*GO gauge*	*NO-GO gauge*
Workshop	$25.00^{+0.00231}_{+0.00021}$	$25.00^{+0.0201}_{+0.00021}$	$25.00^{-0.01033}_{-0.01363}$	$25.00^{-0.0397}_{-0.0430}$
Inspection	$25.00^{-0.0000}_{-0.0021}$	$25.00^{+0.0231}_{+0.0210}$	$25.00^{-0.0067}_{-0.0100}$	$25.00^{-0.0463}_{-0.0430}$
General	$25.00^{+0.00231}_{+0.00021}$	$25.00^{+0.0231}_{+0.0210}$	$25.00^{-0.01033}_{-0.01363}$	$25.00^{-0.0463}_{-0.0430}$

7 Angular Metrology

Checking of surfaces ends with angular metrology...

Prof. A P Deshmukh, Production Engineering Dept., D Y Patil College of Engineering, Pune

ANGULAR MEASUREMENT—THEN AND NOW

In ancient ages, angular measurement was used for setting up direction while traveling. Sailors on the high seas completely relied upon their prismatic compasses for finding out a desired direction. Today, precise angular measurements help in the navigation of ships and airplanes. They are also used in land surveys, in astronomy for computing distances between stars and planets, measuring the distance of air travel by projection, identifying the positions of flying objects, and so on.

As an angle is the measure of the opening between two lines, absolute standards are not required. The circle obtained by rotating a line can be divided into sixty parts to form a degree, which can be further subdivided into minutes and seconds. This serves as essential part of linear measurement.

New age production methods demand for precise interchangeable parts and assemblies to increase the reliability of a product. The helix angle of a shaving cutter derives the surface finish of the product by defining its grain flow on the face. The normal pressure angle of the gear decides the quality of the gear to cater to the needs of DIN/ISO/AGMA tolerances. The contacting angle of the probe with the surface decides the quality of measurement obtained by CMM. Various types of measuring instruments have different kinds of attachments set at appropriate angles for extensive modular systems. The applications of angular measurements are versatile and are essential if the linear measurement values are not smaller.

7.1 INTRODUCTION

The concept of an angle is one of the most important concepts in geometry. The concepts of equality, and sums and differences of angles are important and are used throughout geometry; but the subject of trigonometry is based on the *measurement* of angles.

2. Squares Since the most common angles are right or perpendicular angles, squares are the most common devices for drawing them. These range from the small machinist to large framing or rafter types. Among the most useful for model making is the machinist square with blades starting at 2" and up. These are precision ground on all surfaces, any of which can be used. The inside handle corner is relieved and the outside blade corner is notched for clearance. Although they are designed for alignment of machine tools and work, they fit nicely inside rolling stock and structures for squaring corners. Do not overlook the use of bar stock, of shape similar to the handle, for tighter fits.

3. Sheetrock or Drywall Used for drywall, a tee-square type that spans a 4' sheet of plywood has a movable cross-piece that can be turned to the marked side or any angle for laying out parallel yard tracks, or made straight for storage as shown in Fig. 7.2.

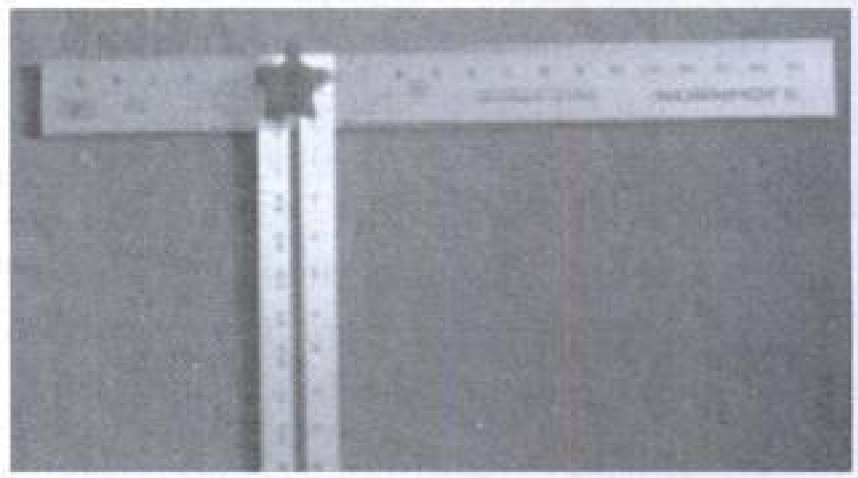


Fig. 7.2 *Sheetrock*

4. Five in One Square To avoid using cumbersome framing squares, newer, smaller aluminum or plastic triangular substitutes have been developed with added features. This one claims to replace a try square, miter, protractor, line guide and saw guide. Instructions include a table for rafter settings. An 8" × 8" square is shown in Fig. 7.3. A lip on either side can help align vises and pieces on milling and drilling tables for more critical work.

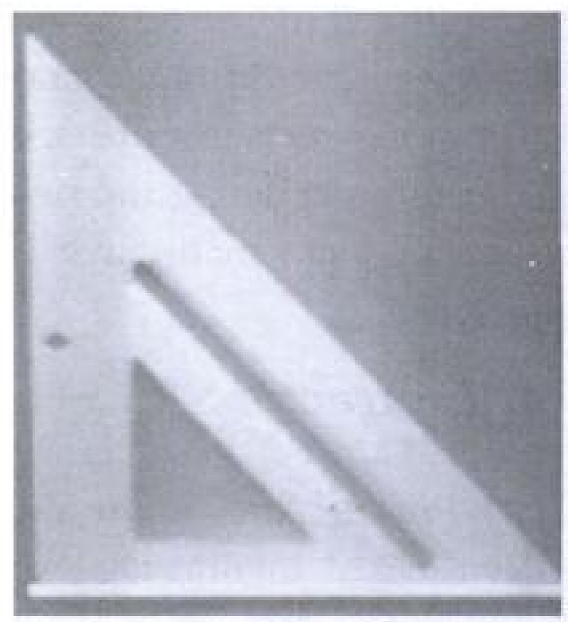


Fig. 7.3 *8" × 8" square*

5. Bevels and Miters Fixed common angles are usually set up with various triangles. Some may be flat like drafting triangles, while others may have guides, similar to square handles, to align with established references such as table edges or slots, shown in Fig. 7.4.

Fig. 7.4 *Bevels and miters*

6. Universal Bevel Vernier Protractor These angular-measuring tools range from vernier protractors reading to 5 minutes of a degree, to regular protractors reading to a degree and easily being able to estimate to 30 minutes.

With this, all of our angular measurements are in degrees and minutes. Figure 7.5 explains the construction of a vernier bevel protractor.

It consists of a (sliding) blade (150 mm and 300 mm), which can be set at any angle with the stock. The angle of any position is shown by degree graduations on the scale disc, which is graduated from 0° to 90° in either direction. The reading of an angle should be noted comparing the angular scale (main scale) reading with the vernier scale reading. The vernier scale has 12 divisions on each side of the centre zero. Each division marked equals 5 minutes of an arc. These 12 divisions occupy the same space as 23° on the main scale; therefore, each division of the vernier scale is equal to 1/12 of 23°.

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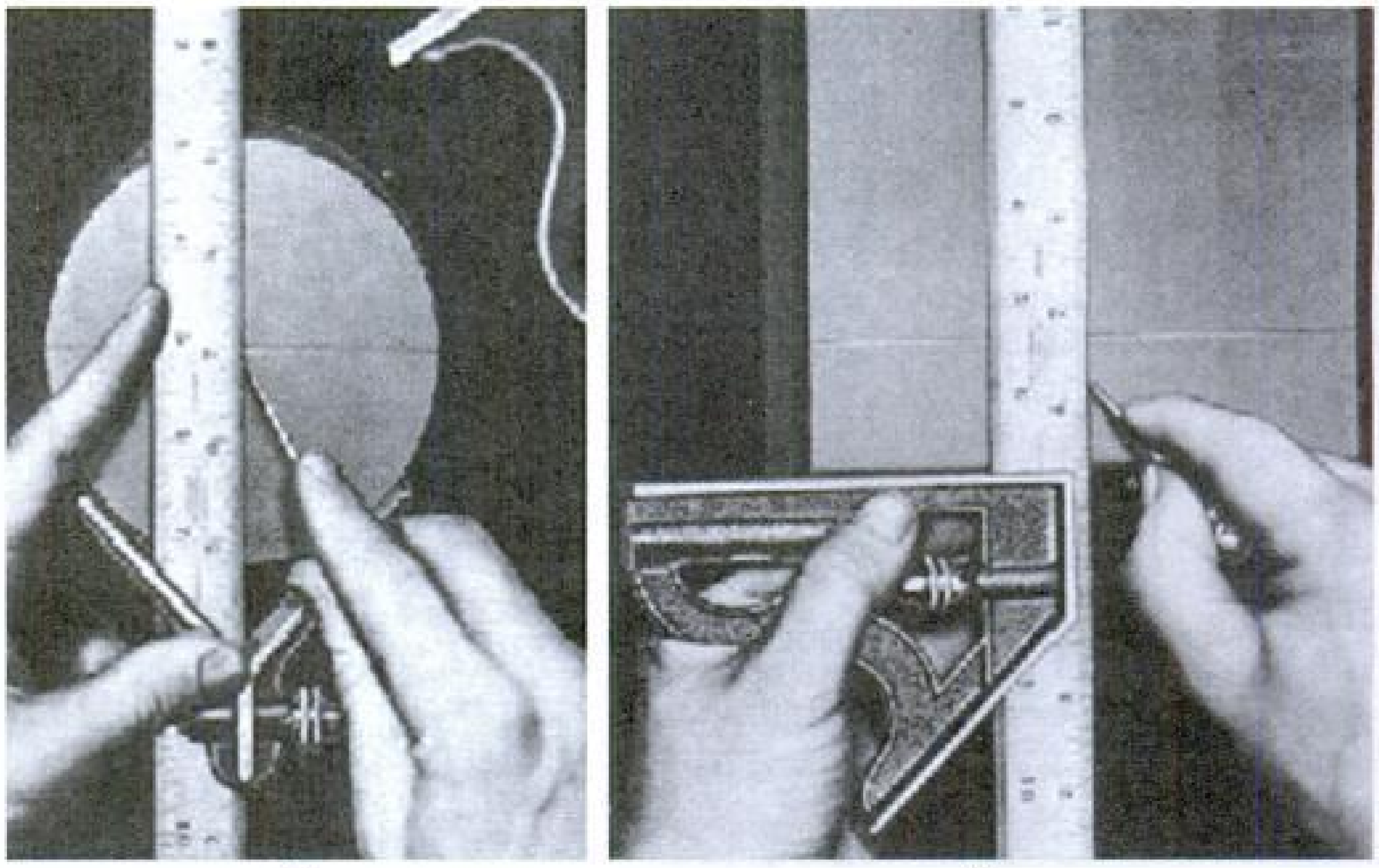
(a) (b)

Fig. 7.11 *(a) and (b) Use of centre head and square head of combination set respectively*

Dr Tomlinson developed angle gauges in 1941. By making different permutations and combinations of the gauge setting, we could set an angle nearest to 3". The dimensions of angle gauges are 75 mm length and 16 mm width. Common materials of construction for angle gauges include aluminium, brass or bronze, cast metal or iron, plastic, fiberglass, glass, granite, stainless steel, steel, and wood. These are hardened and stabilized. The measuring faces are lapped and polished to a high degree of accuracy and flatness. Angle gauges are available in two sets (one set is shown in Fig. 7.12). One set consists of 12 pieces along with a square block. Their values are

$1°, 3°, 9°\ 27°$ and $41°$

$1', 3', 9'$, and $27'$ and

$6'', 18''$, and $30''$

The other set contains 13 pieces with values of

$1°, 3°, 9°\ 27°$ and $41°$

$1', 3', 9'$, and $27'$ and

$3'', 6'', 18''$, and $30''$

The angle can be build up by proper combination of gauges, i.e., addition or subtraction, as shown in Figs 7.13 and 7.14. Figure 7.15 shows a square plate used in conjunction with angle gauges. All its faces are at right angles to each other. With the help of a square plate, the angle can be extended with the range of an angle block set in degrees, minutes or seconds.

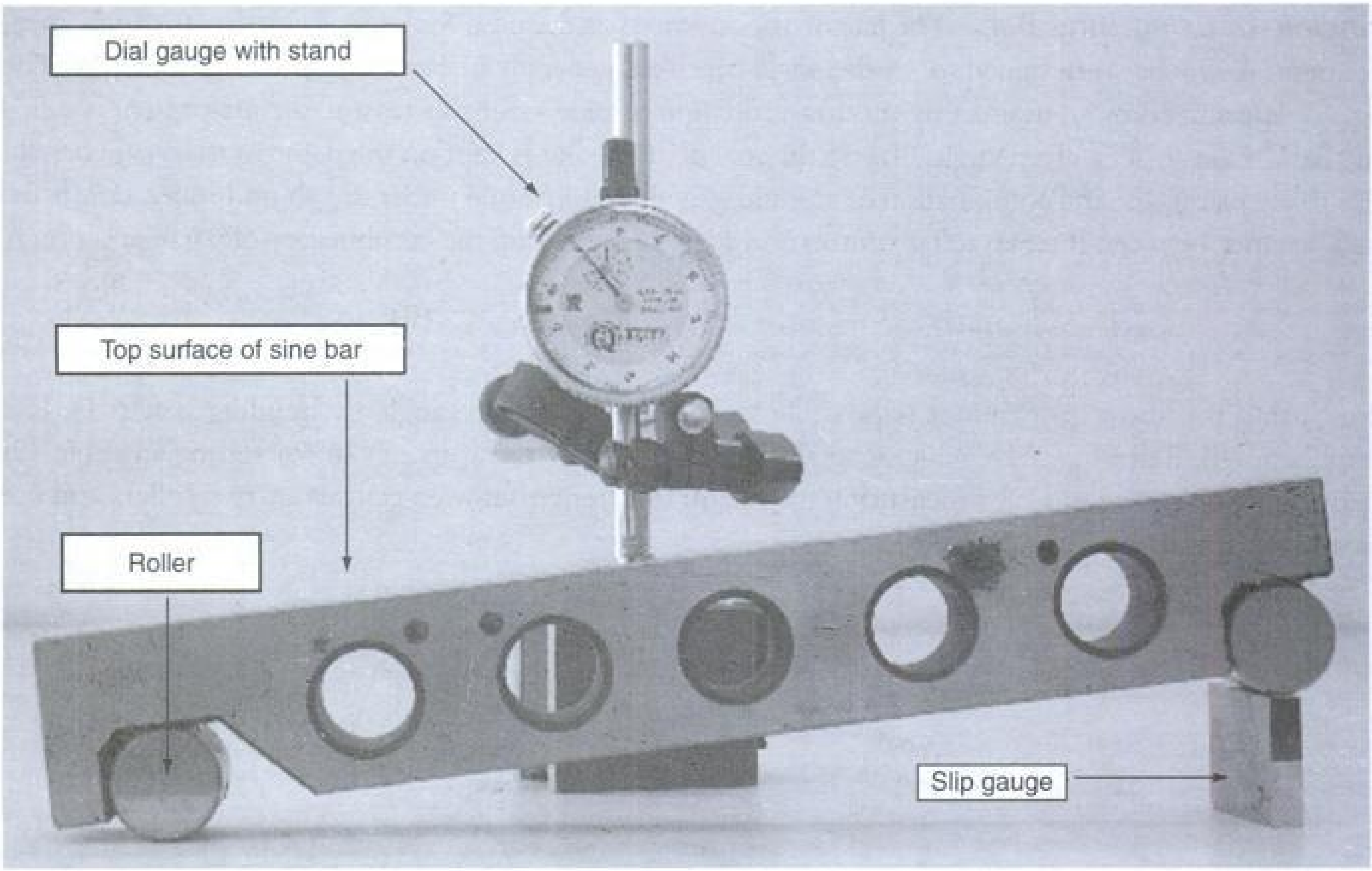

Fig. 7.19 *Set of sine bar, slip gauge and dial indicator*
(Courtesy, Metrology Lab Sinhgad C.O.E., Pune.)

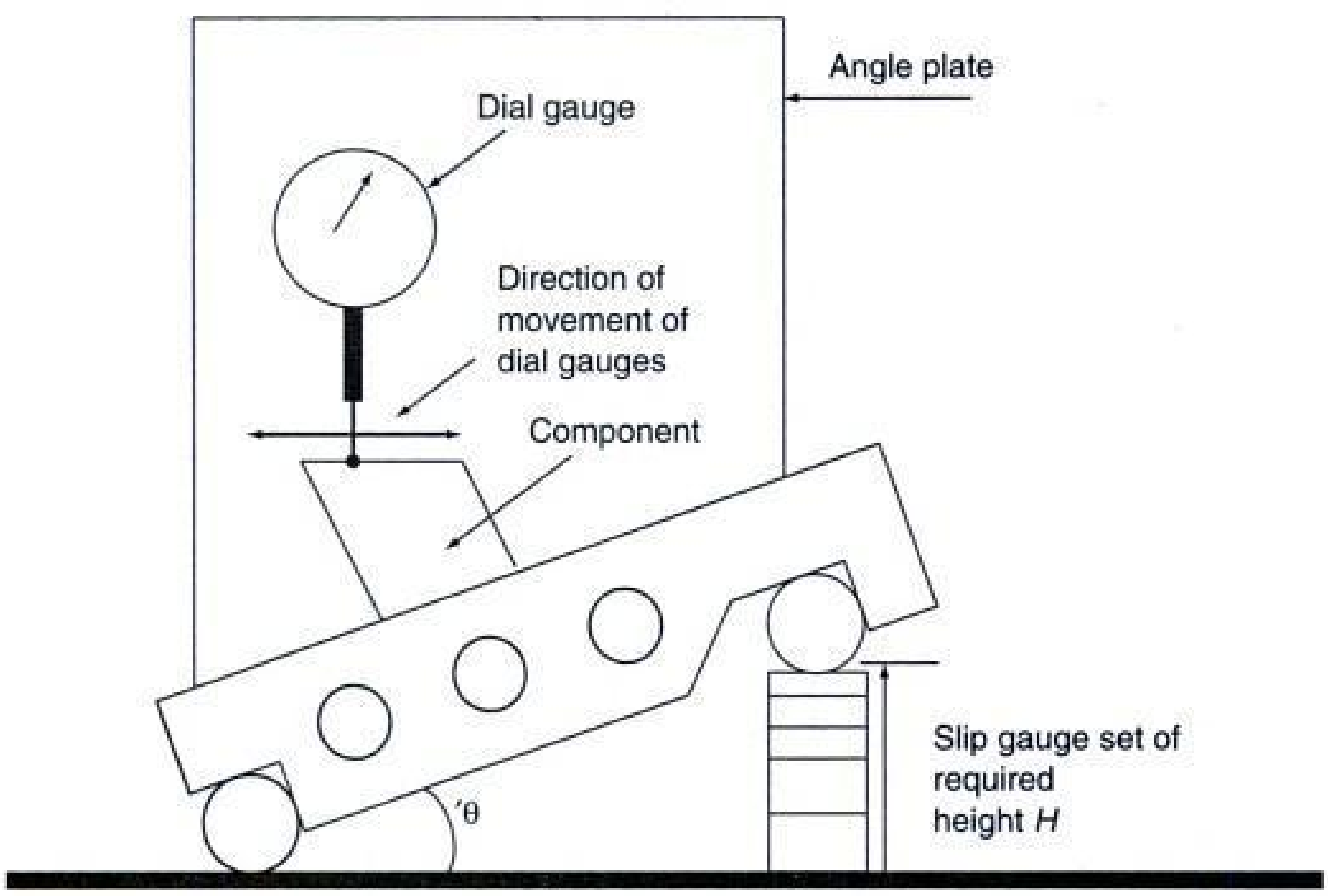

Fig. 7.20 *Sine bar used for small component*

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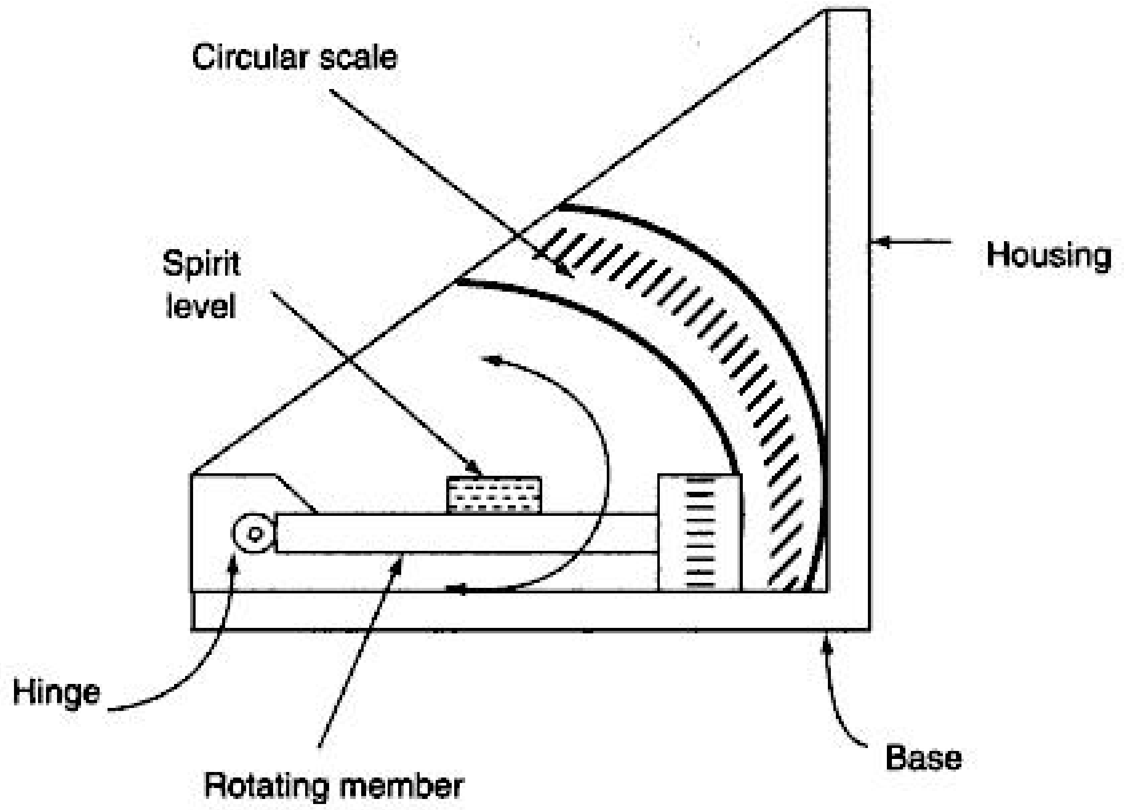


Fig. 7.24 *Vernier clinometer*

A further modification in the Vernier clinometer is the micrometer clinometer (refer Fig. 7.25). It consists of a spirit level whose one end is attached to the barrel of a micrometer and the outer end is hinged on the base. The base is placed on the surface whose angle is to be measured. The micrometer is adjusted till the level is horizontal. It is generally used for measuring small angles.

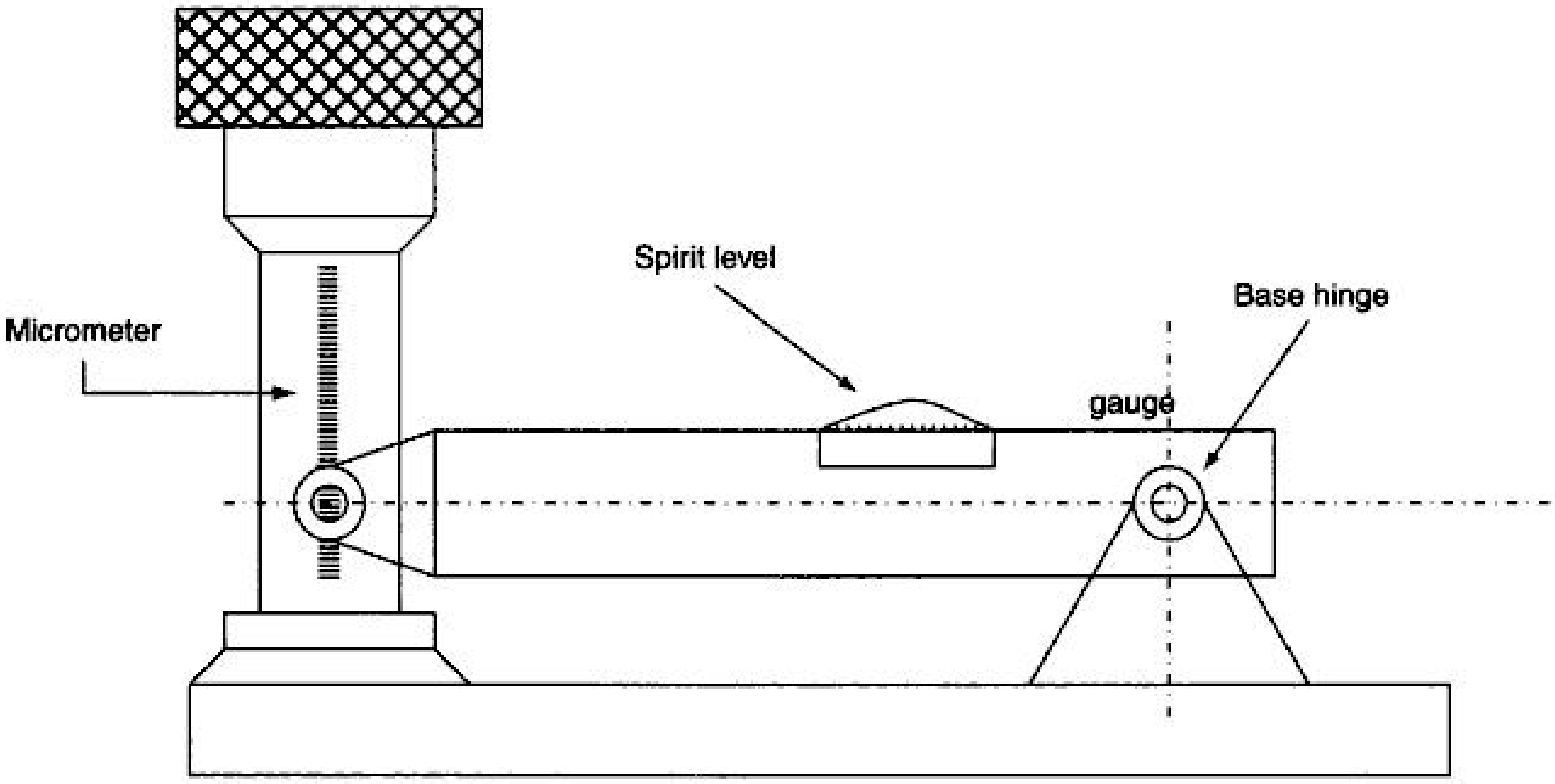


Fig. 7.25 *Micrometer clinometer*

Other types of clinometers are dial clinometer and optical clinometer, which use the same working principle used in the case of a bevel protractor (and optical bevel protractor). The whole angle can be observed through an opening in the dial on the circular scale and the fraction of an angle can be read

The service has the following advantages over the previous service: (1) calibrations can be made at any number of user-defined calibration points; and (2) improved measurement uncertainty.

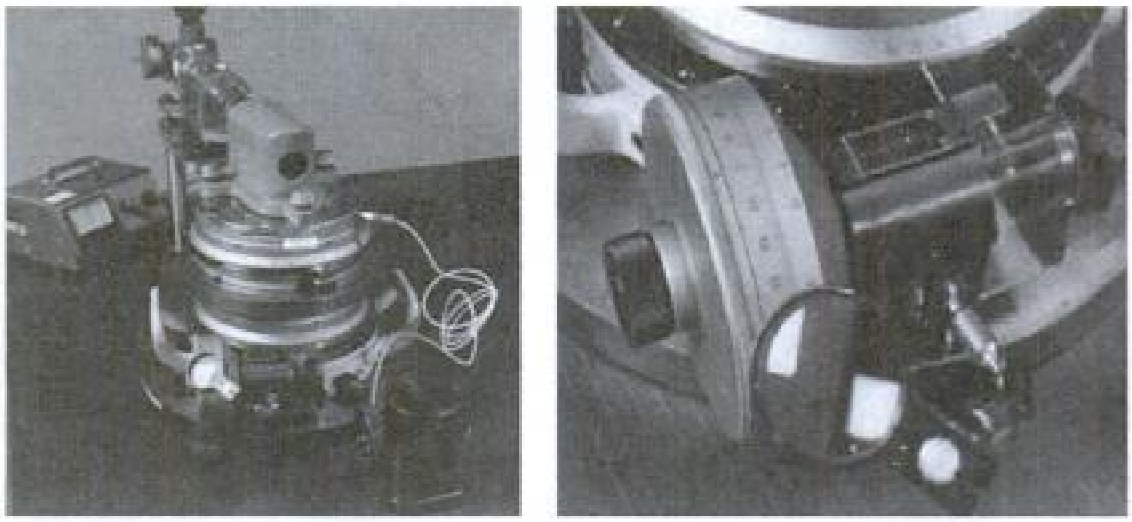
The system has a total operating range of ±10 degrees but with an increased and yet to be quantified measurement uncertainty.

13. *Precision Angular Measurement*

Case Study Generation of angles by indexing tables is achieved by the meshing of two similar sets of serrations. Calibration of such tables submitted for test is effected by mounting the table under test on top of one of the NPL indexing tables and using a mirror-autocollimator system to compare angles generated by the table under test with similar angles generated by the NPL table. For the purpose of assessing the accuracy of performance of the serrated type of table, it is considered sufficient to intercompare each successive 30-degree interval with the NPL table, thus providing 144 comparative measurements. The small angular differences between the two tables are measured by a photoelectric autocollimator capable of a discrimination of 0.02 second of an arc. A shortened test may be applied to indexing tables, which have a reproducibility of setting significantly poorer than the NPL tables, that is, greater than 0.05 second of an arc. For such tables, three sets of measurements of twelve consecutive 30-degree rotations of the table under test are compared with the NPL table. Between each set of measurements, the test table is moved through 120 degrees relative to the NPL table.

The uncertainty of measurement is largely dependent on the quality of the two sets of serrations. The criterion for assessing this quality is to check the reproducibility of angular positions of the upper table relative to the base. Indexing tables similar to the NPL tables will normally repeat angular positions in between 0.02 to 0.05 second of an arc. The uncertainty of measurement for the calibration of these tables, based on 144 comparative measurements, is ±0.07 second of an arc.

Indexing tables having a slightly lower precision of angular setting, say between 0.05 and 0.2 second of an arc, are calibrated by making 36 comparative measurements and the uncertainty of measurement of the calibrated values will be between ±0.25 and ±0.5 second of an arc.



(a) (b)

Fig. 7.30 *Indexing table*

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7. Write short notes on (a)Vernier bevel protector (b) Autocollimator (c) Sine bar (d) Angle dekkor.
8. Describe and sketch the principle of working of an autocollimator and state its applications.
9. Discuss the construction and use of a vernier and micrometer clinometer.
10. What are angle gauges? Explain with suitable examples how they are used for measuring angles.
11. Explain the construction, working and uses of the universal bevel vernier proctor.
12. Sketch two forms of a sine bar in general use. Explain the precautions to be taken while using it to measure angles.
13. Write a technical note on angle gauge blocks by specifying their limitations. Also explain that to what accuracy can the angles be generated with angle blocks.
14. Describe the principle of an angle-dekkor and mention its various uses.

iv. If at the same point D_1, the ray path difference is equal to half the wavelength $(S_2D_1 - S_1D_1 = \lambda/2)$, it results into an out-of-phase condition producing zero intensity or a dark band due to destructive interference. The phenomenon remains the same for D_2.

v. Thus, a series of bright and dark bands are produced. The dark bands are called *interference fringes*. The central bright band is flanked on both the sides by dark bands, which are alternatively of minimum and maximum intensities and are known as interference bands.

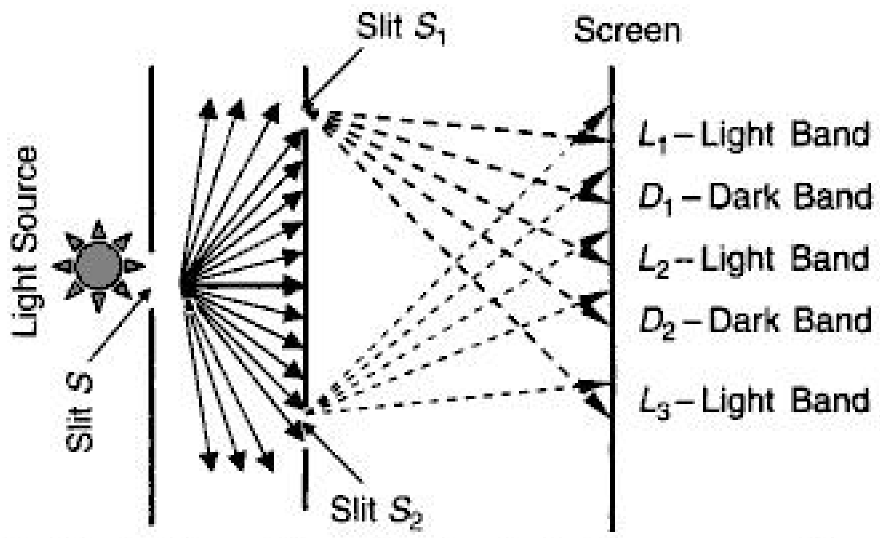

Fig. 8.4 *Way of producing interference pattern*

8.4 INTERFERENCE BANDS USING OPTICAL FLAT

Another simple method of producing interference fringes is by illuminating an optical flat over a plane-reflecting surface. An optical flat is a disc of glass or quartz whose faces are highly polished and flat within a few microns. When it is kept on the surface' nearly flat dark bands can be seen. These are cylindrical pieces whose diameters range from 25 mm to 300 mm with the thickness of $1/6^{th}$ of the diameter. For measuring flatness, in addition to an optical flat, a monochromatic light source is also required. The yellow – orange light radiated by helium gas can be satisfactorily used. Such an arrangement is shown in Fig. 8.5. Optical flats are of two types, namely, Type *A* and Type *B*. A Type-*A* optical flat has a single flat surface and is used for testing precision measuring surfaces, e.g., surfaces of slip gauges, measuring tables, etc.

A Type-*B* optical flat has both the working surfaces flat and parallel to each other. These are used for testing the measuring surfaces of instruments like micrometers, measuring anvils and similar other devices for their flatness and parallelism.

As per IS 5440–1963, optical flats are also characterized by the grades as their specifications: Grade 1 is a reference grade whose flatness is 0.05 micron and Grade 2 is used as a working grade with tolerance for flatness as 0.10 micron.

8.4.1 Designations of Optical Flats

Grade 1, Type *A*, of 250-mm diameter is designed according to specifications laid down by IS 5440 and is designated as Optical Flat IA 25 – IS: 5440. Grade 2, Type *B* of optical flats with 12.125-mm thickness are designated as II B 12.125 – IS: 5440. Generally, an arrow is made on the flat to indicate the finished surface. Sometimes these optical flats are coated with a thin film of titanium oxide, which reduces loss of light due to reflection to get more clear bands. These optical flats are used in constant temperature environment and handled with proper care.

An optical flat is used for testing of flat surfaces. Consider the case when an optical flat kept on the surface of a workpiece, of which the flatness is to be checked, and due to some reason

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Similarly, at another point along the surface the ray L again splits up into two components whose path difference length def is an odd number of half-wavelengths and the rays from d and f interfere to cause darkness. The second dark band is shown by the point e (refer Fig. 8.8).

The amount of inaccuracies of a surface tested by the optical flat method can readily be estimated by measuring the distance between the bands; thus there will be a surface inaccuracy of 0.00001 inches over the distance of each consecutive band. For accurate measurements, the distance between the colour fringes should be taken from the dark centre or from the edge of the red colour, nearest the centre of the colour fringe.

8.5 EXAMPLES OF INTERFERENCE PATTERNS

The development of a typical type of interference pattern mainly depends upon the relationship of the geometry of the surface and the position of the optical flat. The following are some of the interference patterns in different situations. (See Fig. 8.10(a), Plate 7.)

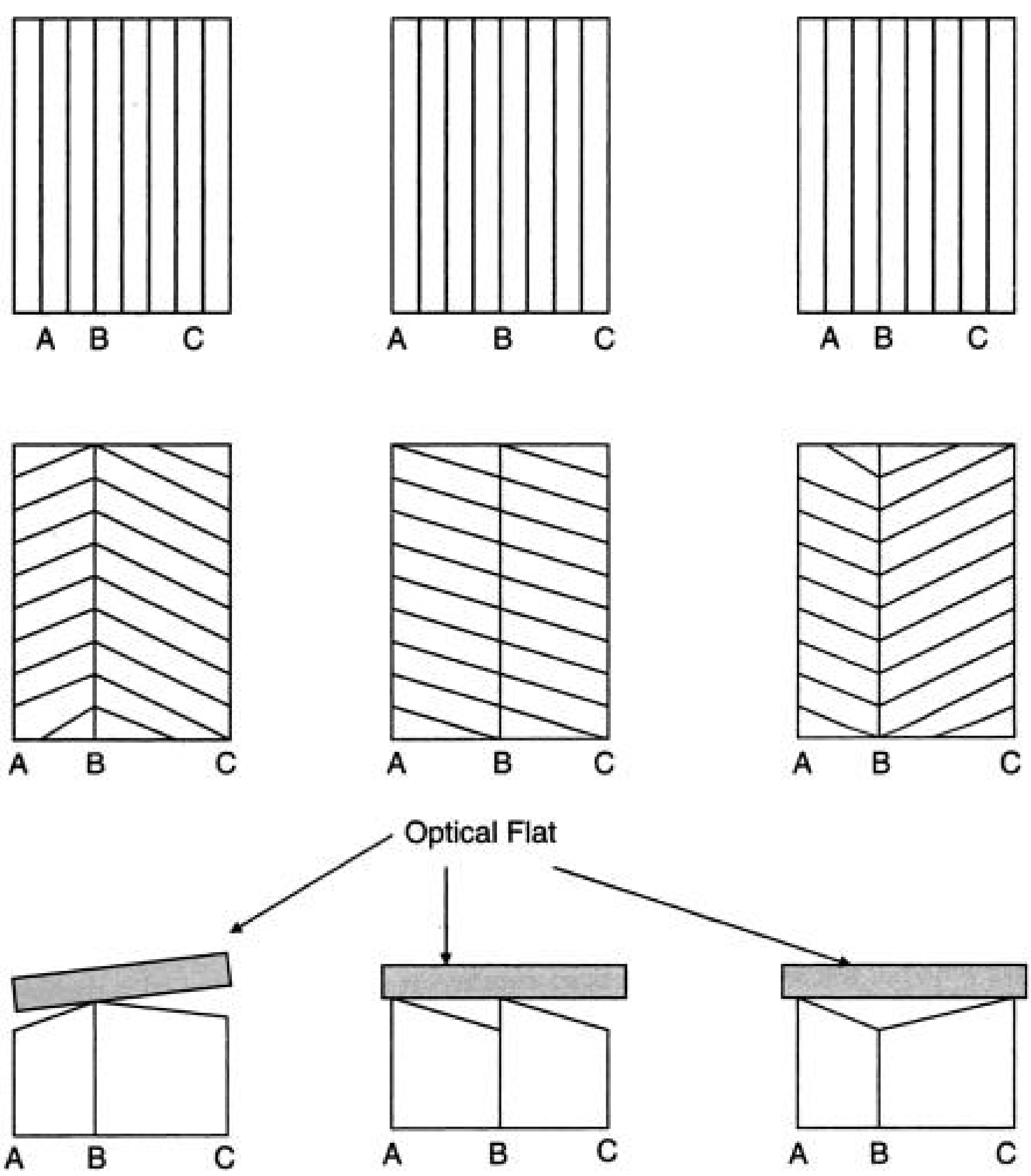

Fig. 8.9 *Interference patterns obtained at different positions of an optical flat*

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Now, the beam is directed on to the gauge under test which is wrung on the base plate via an optical flat in such a way that interference fringes are formed across the face of the gauge. The fringes obtained can be viewed directly above the means of a thick glass plate semi-reflector set at 45° to the optical axis. The various results can be studied for comparison.

In case of large-length slip gauges, the parallelism of surfaces can also be measured by placing the gauge on a rotary table in a specific position and reading number 1 can be taken. The number of fringes obtained is the result of the angle that the gauge surface makes with the optical flat. This number is noted. Then the table is turned through 180° and reading number 2 can be taken. Now, fringes are observed and their number is to be noted. Then the error in the parallelism can be obtained by the following calculations.

The change in distance between the gauge and optical flat = $\lambda/2$.

Then, error in parallelism = $\dfrac{(n_2 - n_1) \times \lambda}{4}$

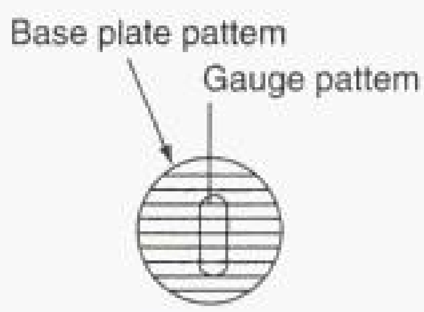
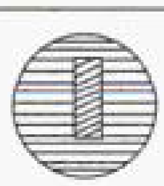
where, n_1 = number of fringes in the first position

and n_2 = number of fringes in the second position.

8.7 GAUGE LENGTH INTERFEROMETER

This is also known as the Pitter – NPL Gauge Interferometer. It is used to determine the actual dimensions or absolute length of a gauge.

Table 8.2 *Typical fringe pattern examples*

Fringe Pattern Obtained	*Description*
	Gauge is flat and parallel.
	Gauge is flat but not parallel from one side to another side.
	Surface under test may be convex or concave.
	Gauge is flat but not parallel from one end to the other end.

6. What do you mean by the term 'interferometer'? What are their advantages over optical flats?
7. Sketch the optical arrangement of an NPL gauge-length interferometer and explain how it is used to compute the thickness of a slip gauge.
8. Write short notes on

   (a) Optical flat (b) Gauge-length interferometer (c) NPL flatness interferometer
9. Explain the formation of interference fringes when light falls on an optical flat resting on a lapped surface. What is the effect of using a monochromatic beam, instead of white light?
10. Sketch the typical fringe pattern observed through an optical flat which illustrates surfaces: (a) flat (b) concave (c) convex (d) ridged. Explain the test on an optical flat which reveals whether a surface is convex of concave.
11. Explain the basic difference between a flatness interferometer and length interferometer.
12. A 1-mm slip gauge is being measured on a gauge-length interferometer using a cadmium lamp. The wavelengths emitted by this lamp are

    Red: 0.643850537 μm

    Green: 0.50858483 μm

    Blue: 0.47999360 μm

    Violet: 0.46781743 μm

    Calculate the nominal fractions expected for the gauge for the four wavelengths.

electronic, mechanical or pneumatic technology in the amplification process; e.g., dial indicators, digital indicators and electronic amplifiers or columns. These gauging amplifiers or instruments are available in three main types:

1. Comparators or high-precision amplifiers (including columns or electronic amplifiers).
2. Indicators (higher precision compared to test indicators, used for inspection).
3. Test indicators (lowest precision, widely applied in production checking).

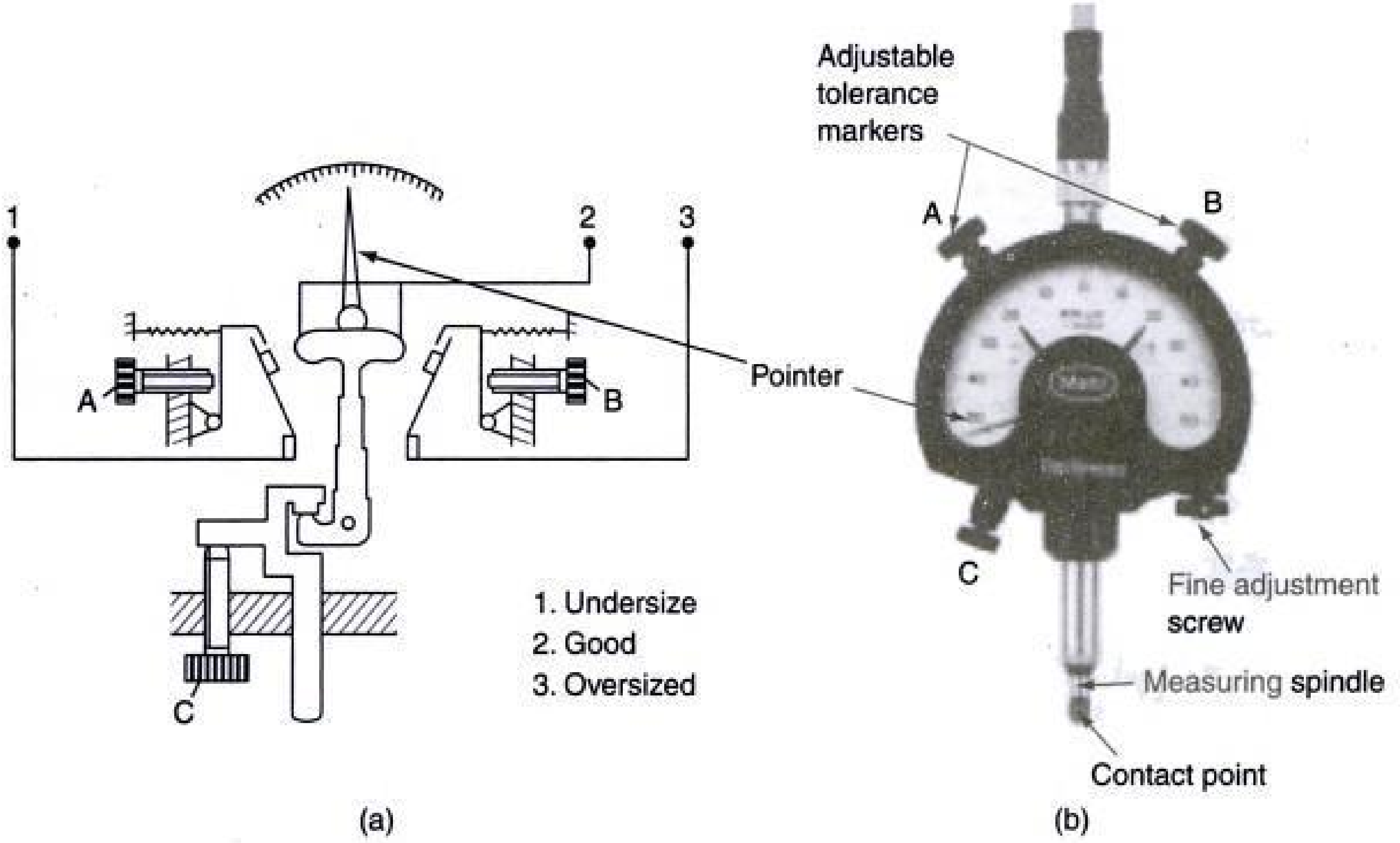
Mechanical comparators, electronic comparators, or appliers, and pneumatic or air comparators are gauging devices for comparative measurements where the linear movement of a precision spindle is amplified and displayed on a dial/analog amplifier, column, or digital display. Mechanical comparators have sophisticated, low-friction mechanism, better discrimination (~0.00001"), and lower range (~+/− 0.0005") compared to indicators. Comparators have a higher level of precision and less span error compared to conventional dial or digital indicators. The level or precision is sufficient for measurement of high-precision ground parts and for the calibration of other gauges.

Indicators are gauging devices for comparative measurements where the linear movement of a spindle or plunger is amplified and displayed on a dial, column or digital display. Typically, indicators have a lower discrimination (~0.001" to 0.0001") and greater range (~+/− 1.000" to +/− 0.050" total) compared to comparators. The level or precision is sufficient for final-part inspection. Test indicators have the lowest discrimination when compared with indicators and comparators. Test indicators used are mainly for set up and comparative production part checking. Test indicators often use a cantilevered stylus or level style probe that facilitates inspection of hard-to-reach part features, but results in high cosine errors. A cosine error of 0.0006" may result over a travel range of 0.010″. Test indicators are not considered absolute measuring instruments, but comparative tools for checking components against standard or zeroing-out set-ups. Other devices that fall within the category of indicators and comparators include gauge sets, gauging stations and gauging systems.

9.3.1 Mechanical Comparator

Mechanical comparators fall in the broad category of measuring instruments and comprise some basic types that belong to the most widely used tools of dimensional measurements in metal-working production. These instruments utilize the mechanical mean of magnifying the small movement of the measuring stylus/contact plunger, which may consist of gear trains, levers, cams, torsion strips, reeds and/or a combination of these systems. The magnification range is about 250 to 1000 times. A mechanical comparator uses pointers as an indicator pivoted around a suspended axis and moving against a circular dial scale. Some of the versatile, commonly and frequently used mechanical comparators are the following:

Dial Indicator Dial indicators are mechanical instruments for sensing measuring-distance variations. The mechanism of the dial indicator converts the axial displacement of a measuring spindle into rotational movement. This movement is amplified by either mechanical or inductive means and displayed by either a pointer rotating over the face of a graduated scale or digital display.



(1, 2, 3) are the relays, (A, B) are adjusting screws for electric contacts (C) Lifting screw

Fig. 9.5 *Mechanical dial indicator (comparator) with limit contacts (Courtesy, Mahr GMBH Esslingen)*

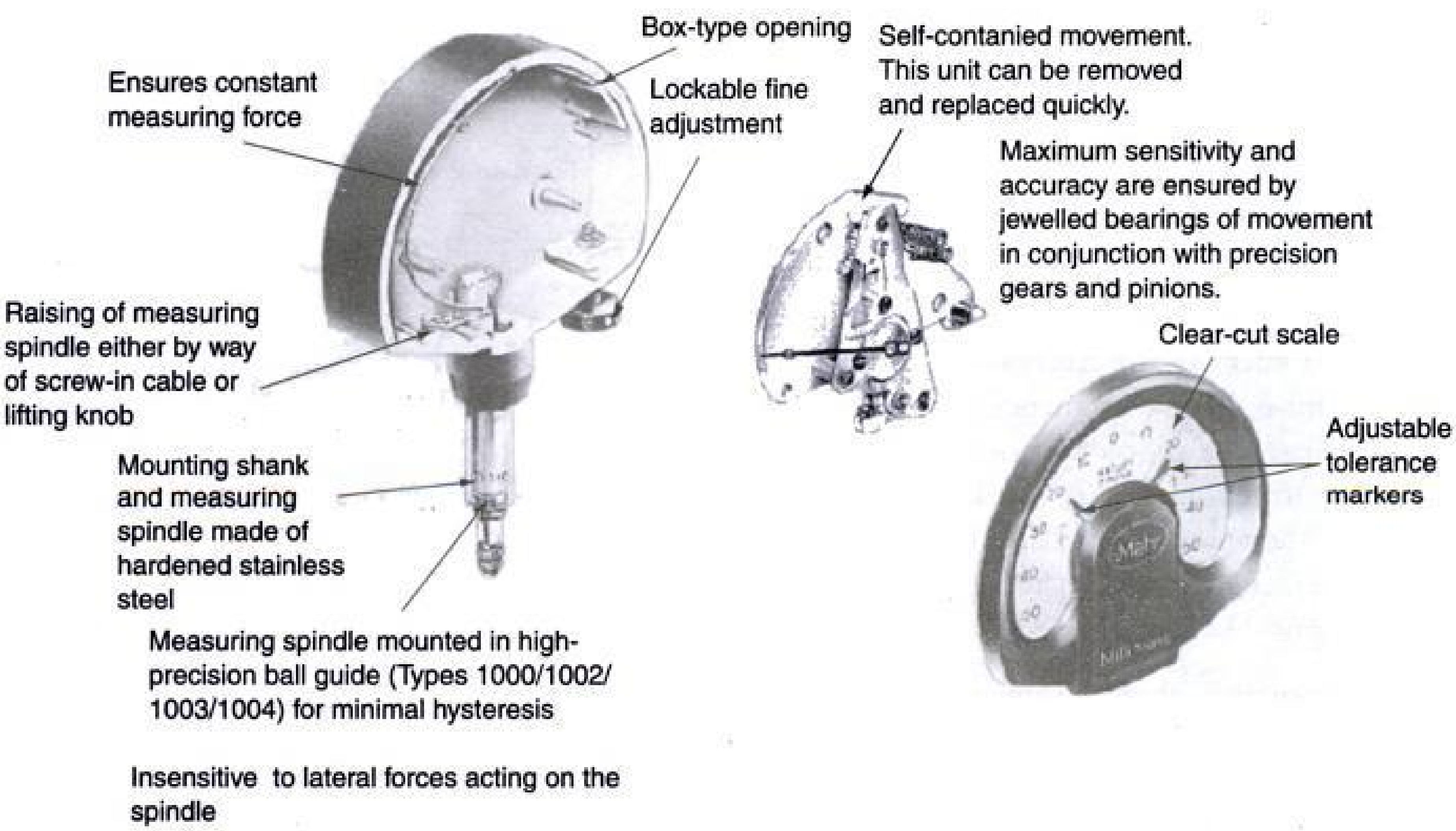


Fig. 9.6 *Exploded view of mechanical dial comparator with limit contacts*

Example

Angle α: 30° (estimated)

Reading on dial: 0.38 mm

Measured value: $0.38 \times 0.87 = 0.33$ mm

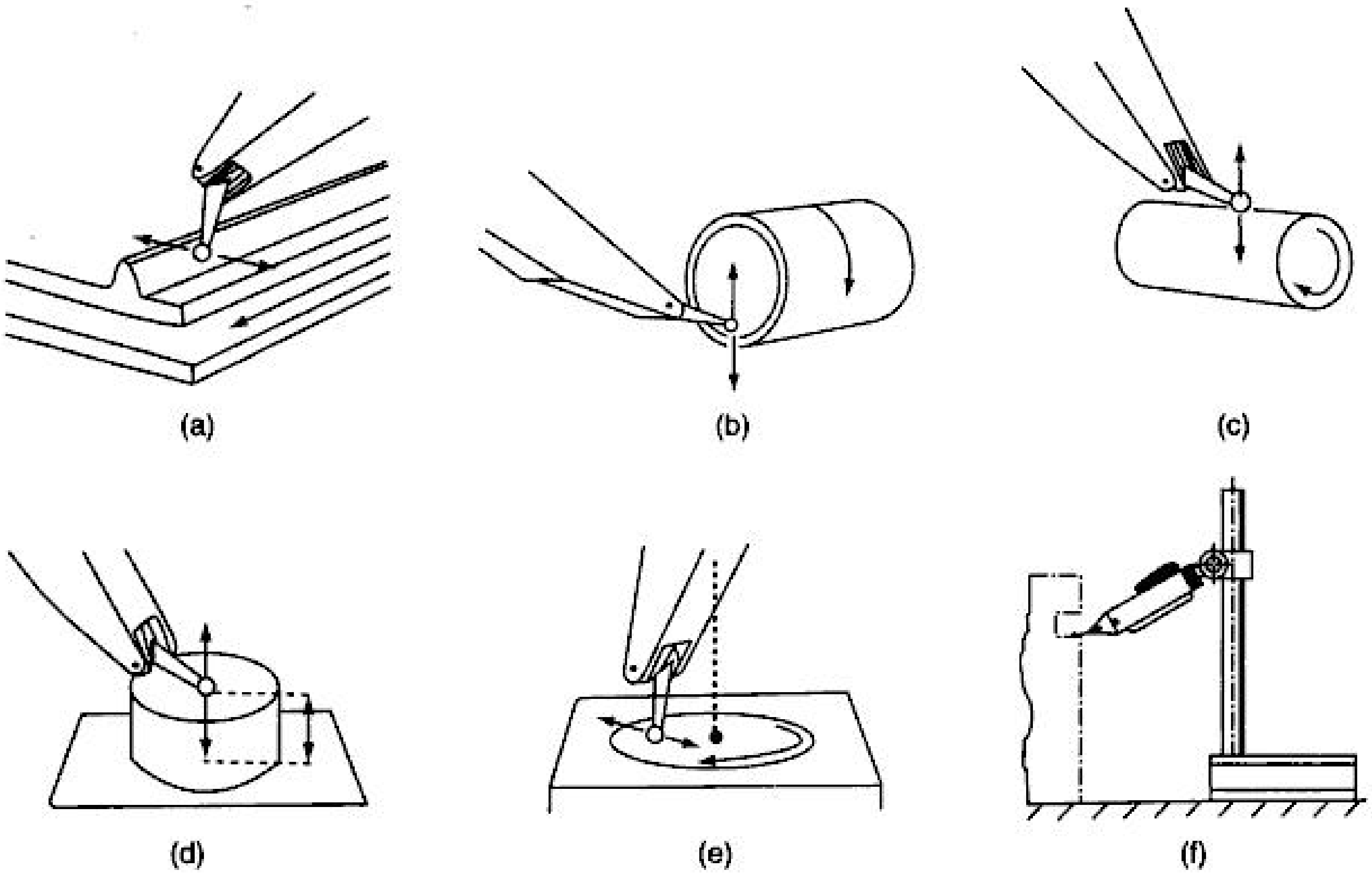


Fig. 9.12 *Applications of mechanical lever-type dial comparator*

Johansson Mikrokator The Johansson Mikrokator was developed by H. Abramson, a Swedish engineer and manufactured by C E Johansson Ltd., hence the name. The construction of the instrument is shown in Fig. 9.13. It uses a twisted strip with a pointer attached, as the plunger is depressed, causing the strip to stretch. As the twisted strip is stretched, it changes the angle of the pointer, and thus of the indicated deflection. In this instrument, the twisted strip is made up of a phospor-bronze rectangular cross-section. This twisted band principle of displacement amplification permits good flexibility of instrument design, which provides a wide range of measurement.

It is one of the important types of mechanical comparators. The actual measuring range depends upon the rate of amplification and the scale used. Its mechanical means of amplification is the ratio of $(d\theta/dl) = -[(9.1*l)/(W^{2}*n)]$, where l is the length of the twisted strip measured along the natural axis, W is a width of strip, n is the number of turns, θ is the twist of the mid-point of the strip with respect to the end. Measuring forces used for two famous models of the Johansson Mikrokator are 30 g and 250 g (refer Fig. 9.14). Accuracy of this instrument is ±1%.

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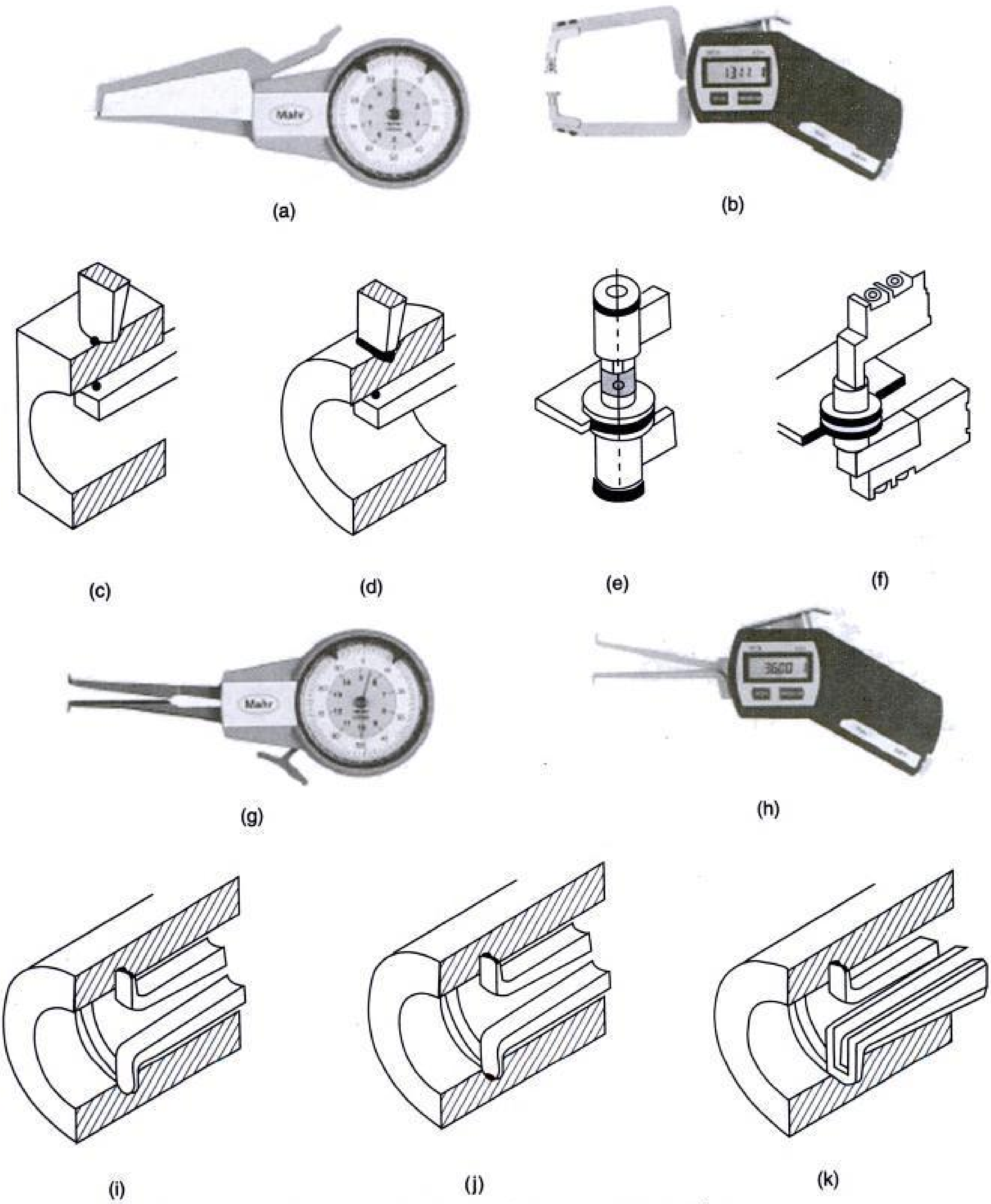

Fig. 9.17 *External and internal groove comparator gauges*
(Courtesy, Mahr GMBH Esslingen)

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∴ The second stage of amplification, i.e., optical amplification = $2(L_4 / L_3)$.

Zesis Ultra Optimeter This type of optical comparator gives very high magnification, as it works on a double magnification principle. As shown in Fig. 9.21, it consists of a light source from which light rays are made to fall on a green filter, which allows only green light to pass through it and, further, it passes through a condenser lens. These condensed light rays are made incident on a movable mirror M_1, then reflected on mirror M_2 and then reflected back to the movable mirror M_1. It gives double reflection. The second-time reflected rays are focused at the graticule by passing through the objective lens.

In this arrangement, magnification is calculated as follows:

Let the distance of the plunger centre to the movable mirror M_1 be 'x', plunger movement height be h and angular movement of mirror be $[h / x]$. f is the focal length of the lens then the movement of the scale is $2f\,\delta\theta$, i.e., $2f\,[h / x]$.

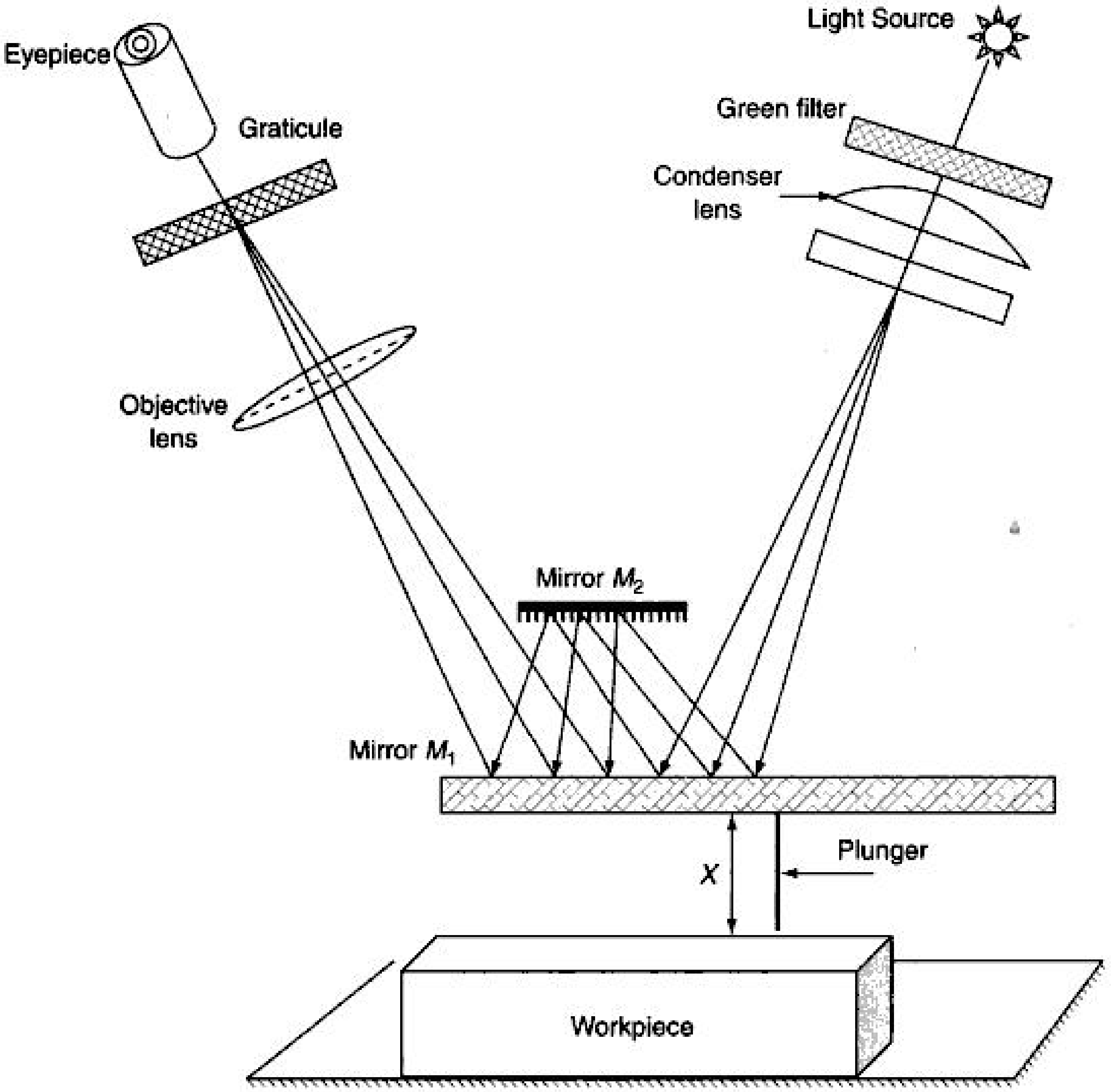

Fig. 9.21 *Optical system of Zesis Ultra Optimeter (optical comparator)*

Plate - 8

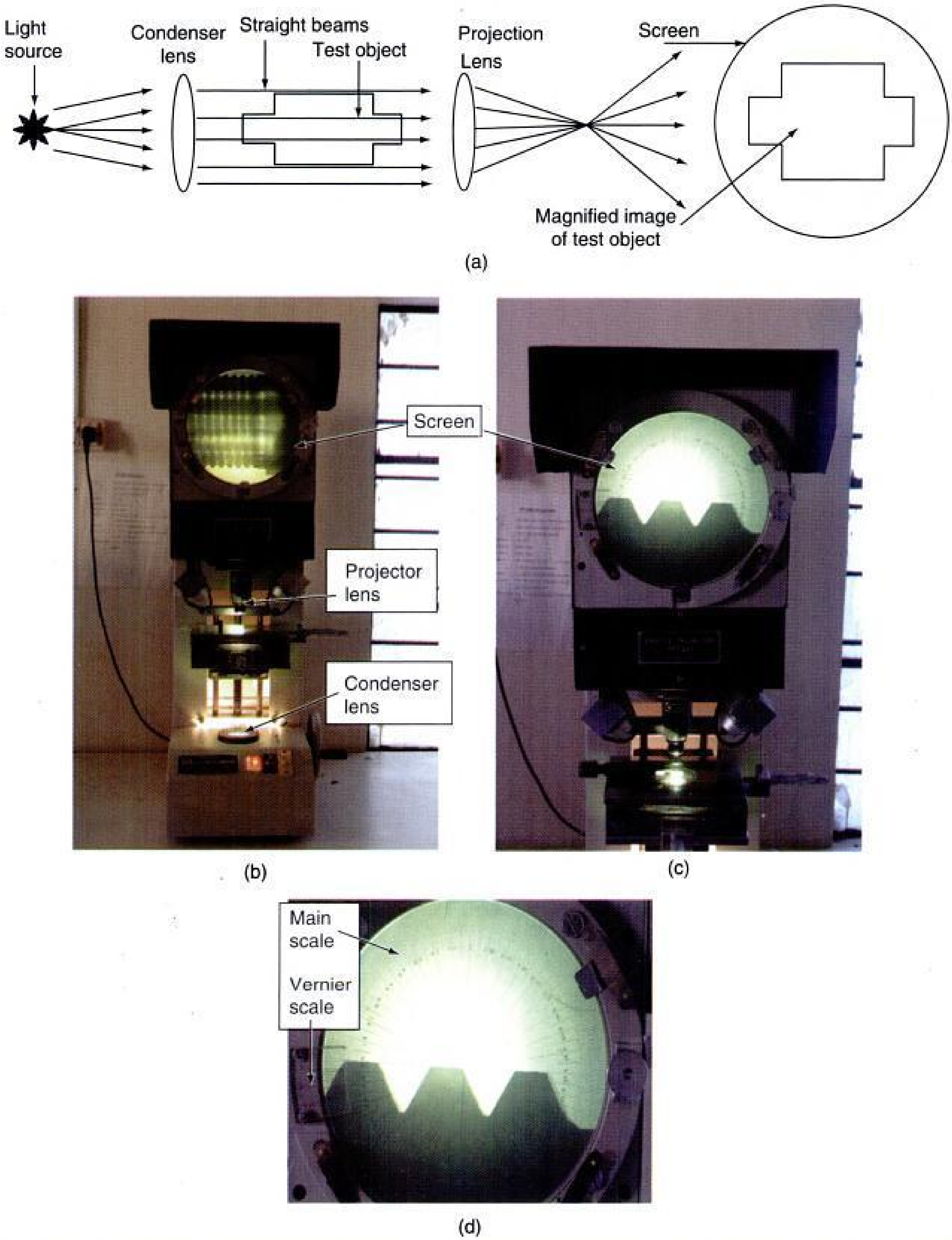

Fig. 9.19 *(a) Principle of profile projector, (b) Magnified image of small dimension plastic threads (c) Magnified image of small-sized gears of rack, (d) Enlarged view of profile projector screen (Courtesy, Metrology lab, Sinhgad College of Engg., Pune University, India)*

operating similar to LVDTs, on the principle of the differential transformer. The LVDT principle arrangement is shown in Fig. 9.27, and construction details of an inductive probe are shown in Fig. 9.28.

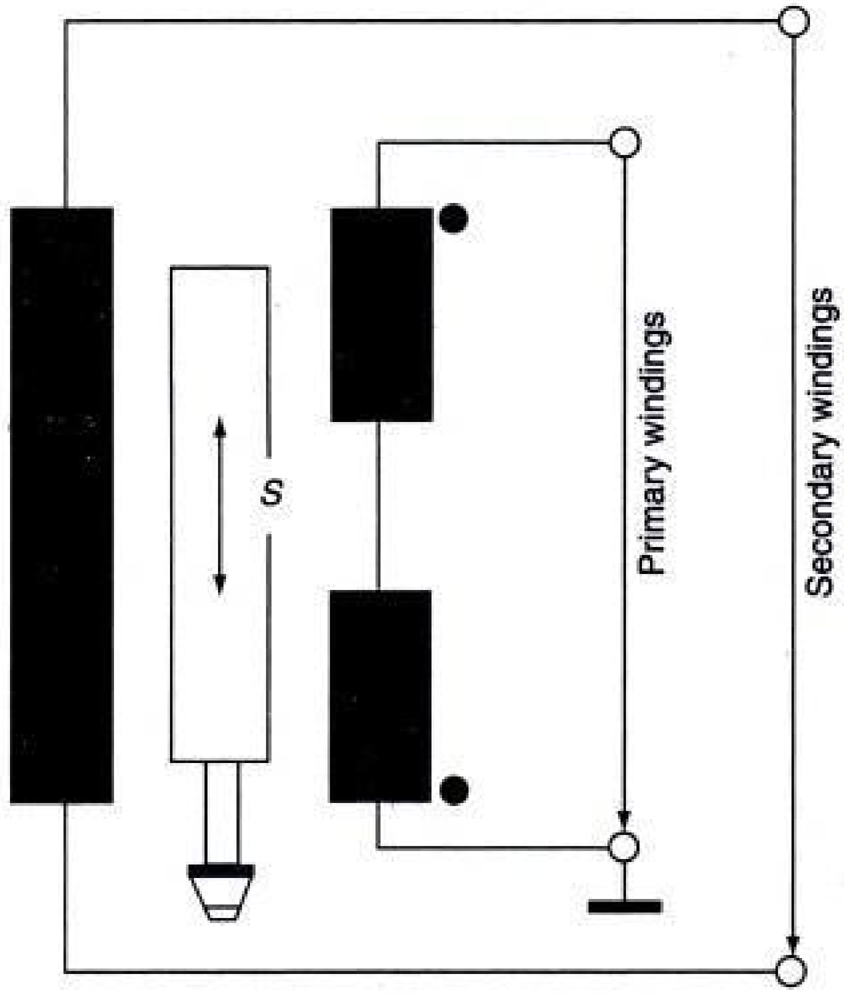

Fig. 9.27 *LVDT arrangement*

Construction of Inductive Probe

1. Stylus Various styli with M2.5 thread are used.

2. Sealing bellow is made up of the material Viton which is extremely resistant and ensures high performance even in critical environments.

3. Twist lock strongly influences the probes' operation characteristics and durability.

4. Clearance stroke adjustment When screwing the guide bush in, the lower limit stop of the measuring bolt can be shifted in the direction of the electrical zero point.

5. Rotary stroke bearing Only rotary stroke bearings made by Mahr are used for Mahr's inductive probe.

6. Measuring force spring The standard measuring force amounts to 0.75 N. For most probes, the measuring force can be changed without any problems by exchanging the measuring force spring.

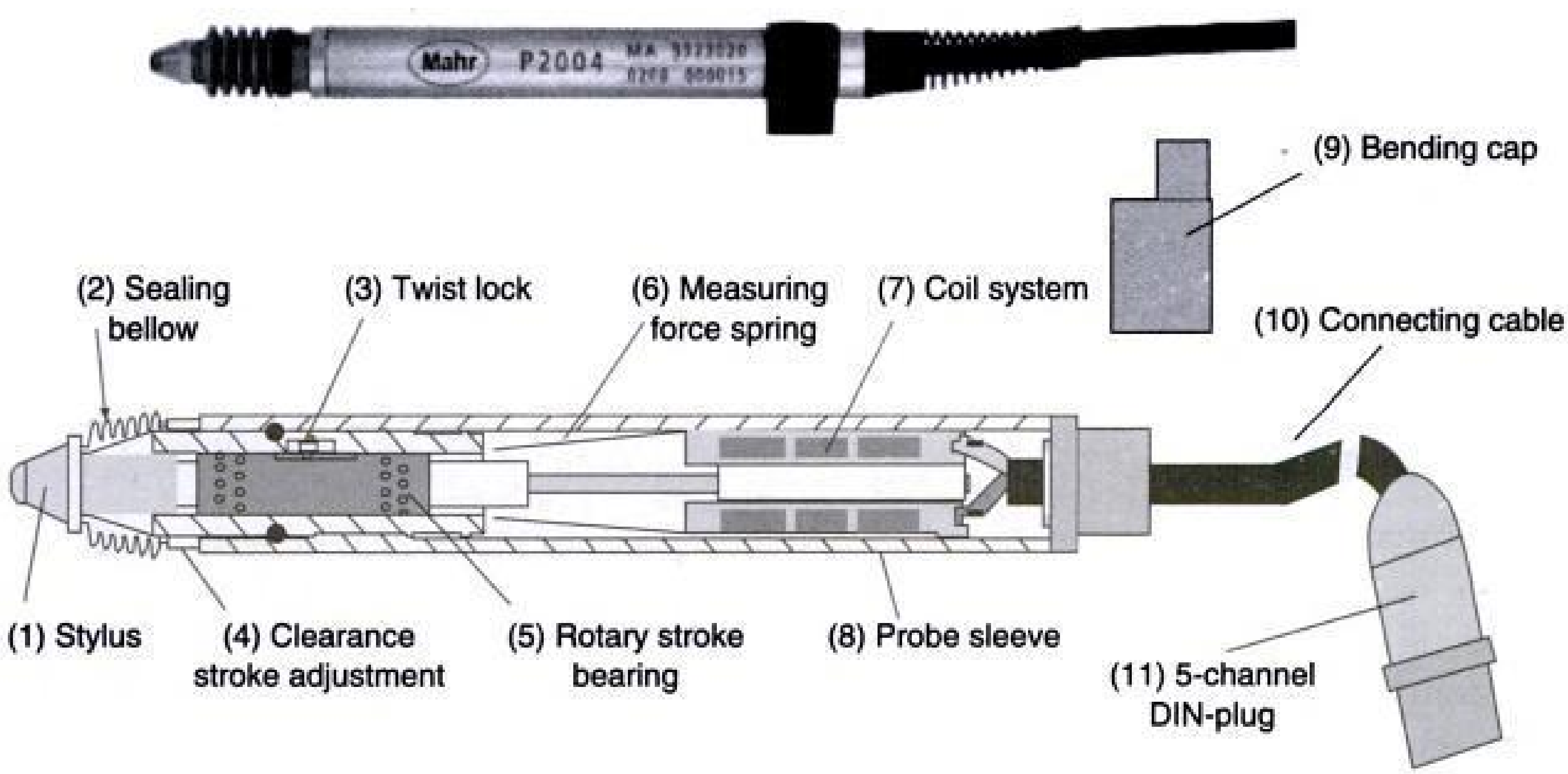

Fig. 9.28 *Inductive probes*
(Courtesy, Mahr GMBH Esslingen)

5. Differentiate between electrical and pneumatic comparators.
6. Differentiate between gauge and comparators.
7. State the advantages and limitations of optical comparators.
8. Explain with a neat sketch the working of Solex pneumatic comparators.
9. Describe the working principle, construction and advantages of any one optical comparator.
10. Write short notes on (a) Johansson circulatory comparator (b) Mechanical comparator (c) Pneumatic comparator (d) Electrical comparator (e) Optical comparator
11. Discuss the difference between the terms 'measuring' and 'comparing'.
12. What are the desirable functions expected by a comparator as a device used for meteorical measurement requirement?
13. State why comparators are used in engineering practices.
14. Name the mechanisms used in Sigma comparators and twisted strip comparators and mention their advantages.
15. Justify the statement: Comparators have been able to eliminate some common errors of measurement.
16. What is meant by the term 'magnification' and its significance as applied to a mechanical comparator?
17. Why is damping essential in mechanical comparators? Explain with a suitable example how it is achieved.
18. Explain the basic methods of magnifications and explain any one in detail by drawing its sketch.
19. Explain the principles of pneumatic gauging by the 'back-pressure' system and state the relationship by drawing a typical curve showing the back pressure/applied pressure and the ratio of cross-sectional areas over which it is used.
20. Explain the operating principle of an electrical comparator. How is change in displacement calibrated?

Waviness Height Waviness height is the peak-to-valley distance of the surface profile, measured in millimetres.

Difference between Roughness, Waviness and Form We analyze below the three main elements of surface texture—roughness, waviness and form.

Roughness This is usually the process marks or witness marks produced by the action of the cutting tool or machining process, but may include other factors such as the structure of the material.

Waviness This is usually produced by instabilities in the machining process, such as an imbalance in a grinding wheel, or by deliberate actions in the machining process. Waviness has a longer wavelength than roughness, which is superimposed on the waviness.

Form This is the general shape of the surface, ignoring variations due to roughness and waviness. Deviations from the desired form can be caused by many factors. For example, the part being held too firmly or not firmly enough, inaccuracies of slides or guide ways of machines, or due to stress patterns in the component.

Roughness, waviness and form (refer Fig. 10.3) are rarely found in isolation. Most surfaces are a combination of all three and it is usual to assess them separately. One should note that there is no set point at which roughness becomes waviness or vice versa, as this depends on the size and nature of the application. For example, the waviness element on an optical lens may be considered as roughness on an automotive part. Surface texture refers to the locally limited deviations of a surface from its ideal shape. The deviations can be categorized on the basis of their general patterns. Consider a theoretically smooth, flat surface. If this has a deviation in the form of a small hollow in the middle, it is still smooth but curved. Two or more equidistant hollows produce a wavy surface. As the spacing between each wave decreases, the resulting surface would be considered flat but rough. In fact, surfaces having the same height of irregularities are regarded as curved, wavy, or rough, according to the spacing of these irregularities.

In order to separate the three elements, we use filters. On most surface-texture measuring instruments, we can select either roughness or waviness filters. Selecting a roughness filter will remove

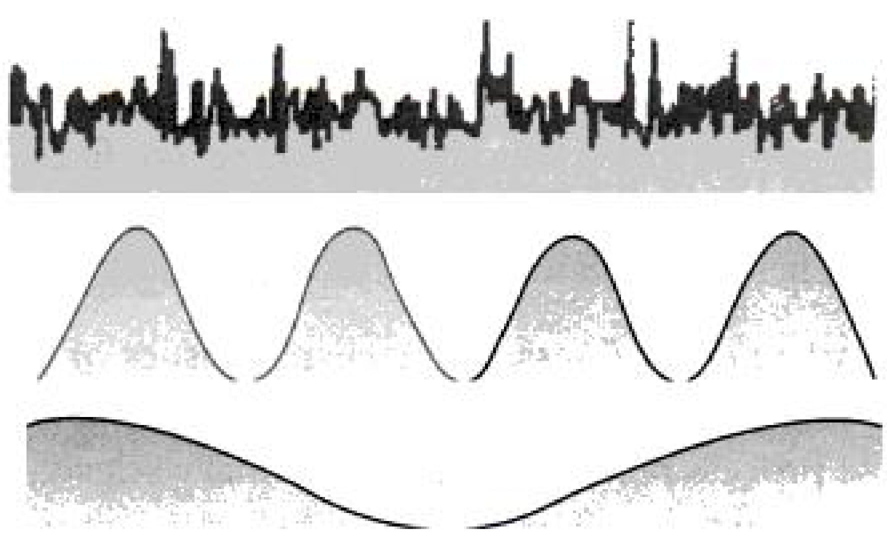

Fig. 10.3 *Roughness, waviness and form*

Practical cutting tools are usually provided with a rounded corner, and Fig. 11.5 shows the surface produced by such a tool under ideal conditions. It can be shown that the roughness value is closely related to the feed and corner radius by the following expression:

$$R_a = \frac{0.0321 f^2}{r}$$

where, r is the corner radius.

10.3.2 Natural Roughness

In practice, it is not usually possible to achieve conditions such as those described above, and normally the natural surface roughness forms a large proportion of the actual roughness. One of the main factors contributing to natural roughness is the occurrence of a built-up edge. Thus, larger the built-up edge, the rougher would be the surface produced, and factors tending to reduce chip-tool friction and to eliminate or reduce the built-up edge would give improved surface finish.

The measurement of surface roughness is defined by a collection of international standards. These standards cover characteristics of the measurement equipment as well as outline the mathematical definitions of the many parameters used today. This chapter discusses some of the key issues in this important field. The roughness of a surface can be measured in different ways, which are classified into three basic categories:

1. Statistical Descriptors These give the average behavior of the surface height. For example, average roughness $\boldsymbol{R_a}$; the root mean square roughness $\boldsymbol{R_q}$; the skewness $\boldsymbol{S_k}$ and the kurtosis $\boldsymbol{K}$.

2. Extreme Value Descriptors These depend on isolated events. Examples are the maximum peak height $\boldsymbol{R_p}$, the maximum valley height $\boldsymbol{R_v}$, and the maximum peak-to-valley height $\boldsymbol{R_{max}}$.

3. Texture Descriptors These describe variations of the surface based on multiple events. An example for this descriptor is the correlation length.

Among these descriptors, the $\boldsymbol{R_a}$ measure is one of the most effective surface-roughness measures commonly adopted in general engineering practice. It gives a good general description of the height variations in the surface. Figure 10.6 shows a cross section through the surface. A mean line is first found that is parallel to the general surface direction and divides the surface in such a way that the sum of the areas formed above the line is equal to the sum of the areas formed below the line. The surface roughness $\boldsymbol{R_a}$ is now given by the sum of the absolute values of all the areas above and below the mean line divided by the sampling length. Therefore, the surface roughness value is given by

$$R_a = \left[\frac{\left[\text{area}(abc) + \text{area}(cde)\right]}{f}\right]$$

where, f is **feed**

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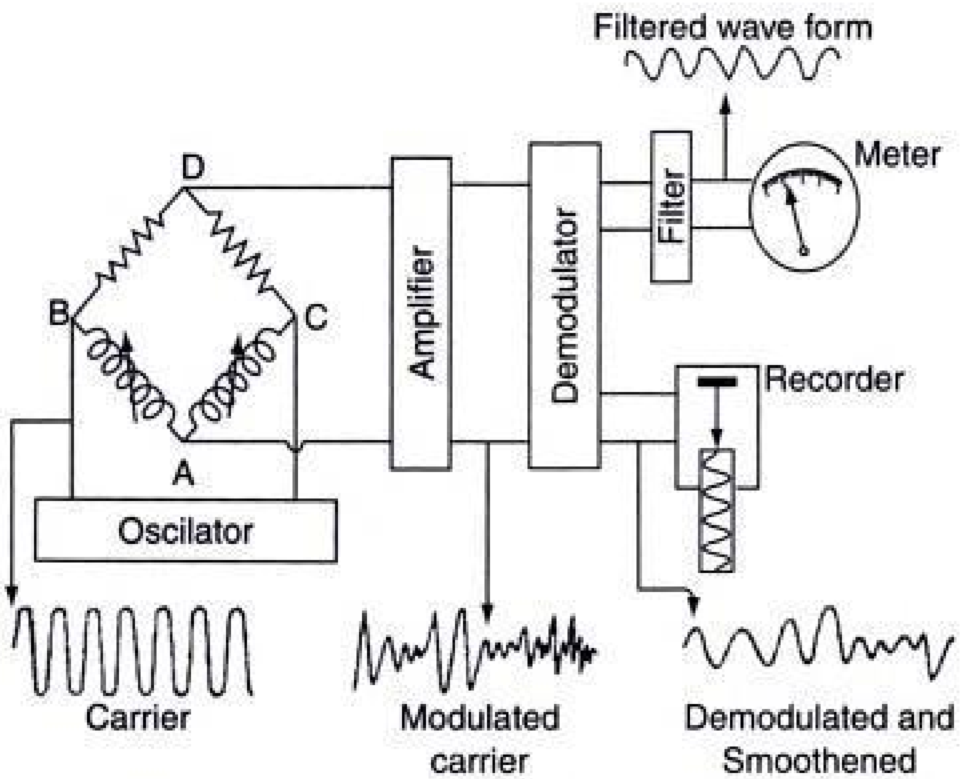

Fig. 10.10 *Talysurf Schematic Layout*

flowing through the coil is modulated. The output (modulated) of the bridge is further demodulated so that the current flow is directly proportional to the vertical displacement of the stylus (refer Fig. 10.10). This output causes a pen recorder to produce a permanent record. Nowadays microprocessor-based surface-roughness measuring instruments are used. One such instrument **'MarSurf'** is shown in Fig. 10.11 along with its specifications to understand the attributes of the capabilities of an instrument, viz., digital output, and print-outs of the form of surface under consideration.

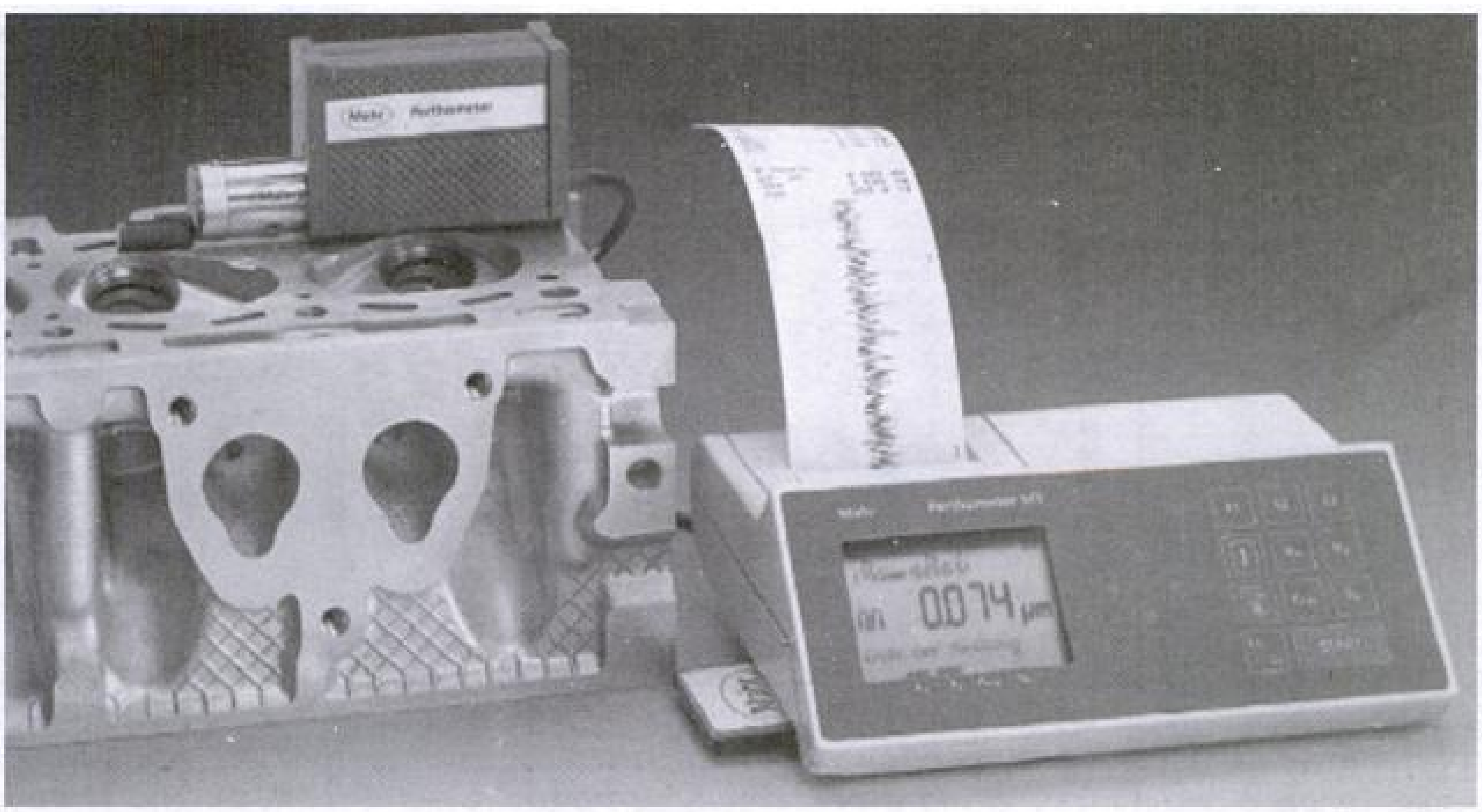

Fig. 10.11 *MarSurf*
(Courtesy, Mahr Gmbh Esslingen)

R_{ymax} (or R_{max}) Maximum Roughness Height Within a Sample Length

R_y and R_{max} are other names for R_{ti}. R_{max} is the older American name and R_y is the newer ISO and American name. For a standard five cut-off trace, there are five different values of R_y. R_y is the maximum peak-to-lowest-valley vertical distance within a single sample length.

R_{ymax}(ISO)—Maximum R_y

R_{ymax} is an ISO parameter that is the maximum of the individual or R_{max} (i.e., R_{ti}) values.

$$R_{ymax} = \max[R_{ti}], \quad 1 \le i \le M$$

It serves a purpose similar to R_t, but it finds extremes from peak to valley that are nearer to each other horizontally.

R_z (DIN), i.e. R_z according to the German DIN standard, is just another name for R_{tm} in the American nomenclature (over five cutoffs).

$$R_z[\text{DIN}] = R_{tm}$$

R_z(ISO) It is the sum of the height of the highest peak plus the lowest valley depth within a sampling length.

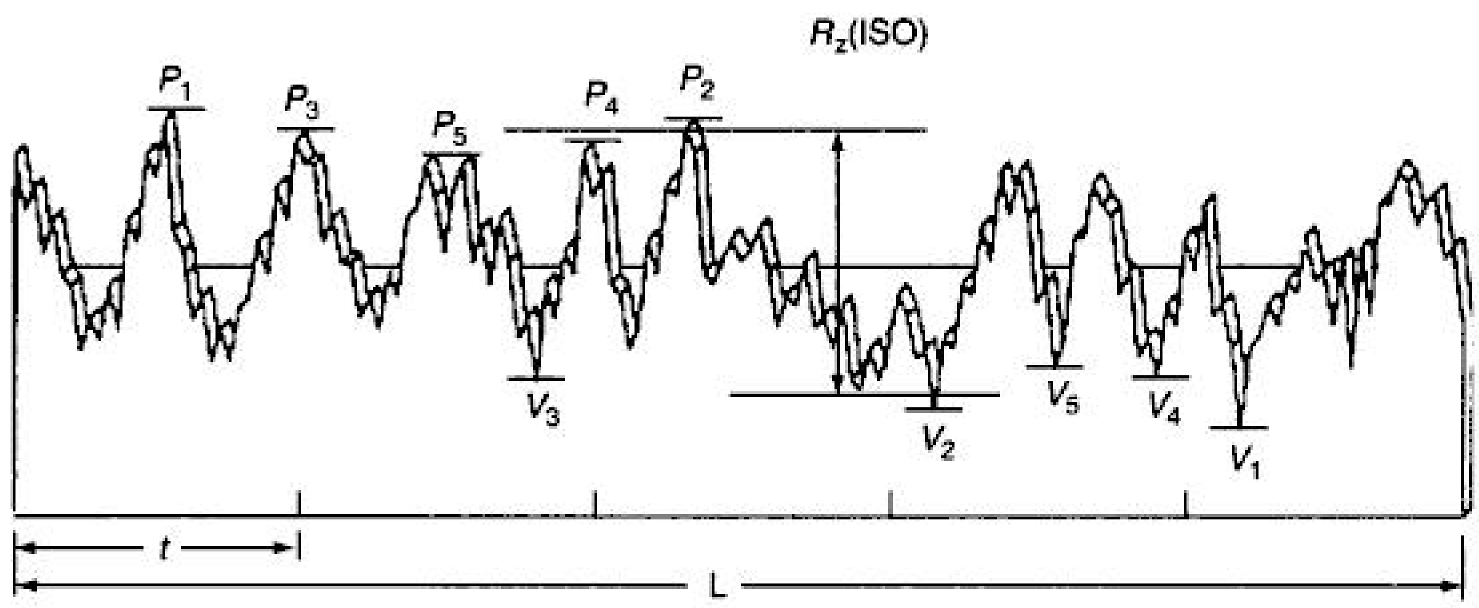

Fig. 10.19 *R_z (ISO) (the sum of the height of the highest peak plus the lowest valley depth within a sampling length)*

R_{3zi}* *Third Highest Peak to Third Lowest Valley Height The parameter R_{3zi} is the height from the third highest peak to the third lowest valley within one sample length.

R_{3z} Average third highest peak to third lowest valley height

R_{3z} is the average of the R_{3zi} values:

$$R_{3z} = \frac{1}{M}\sum_{i=1}^{M} R_{3zi}$$

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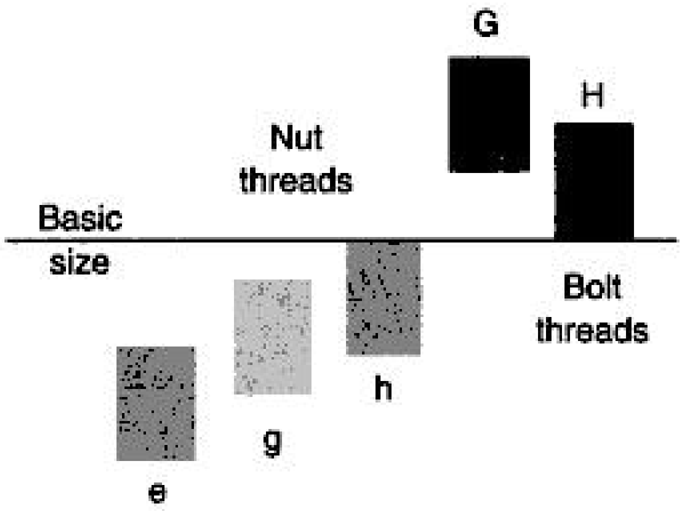

Fig. 11.2 *Tolerance position and grading for ISO threads*

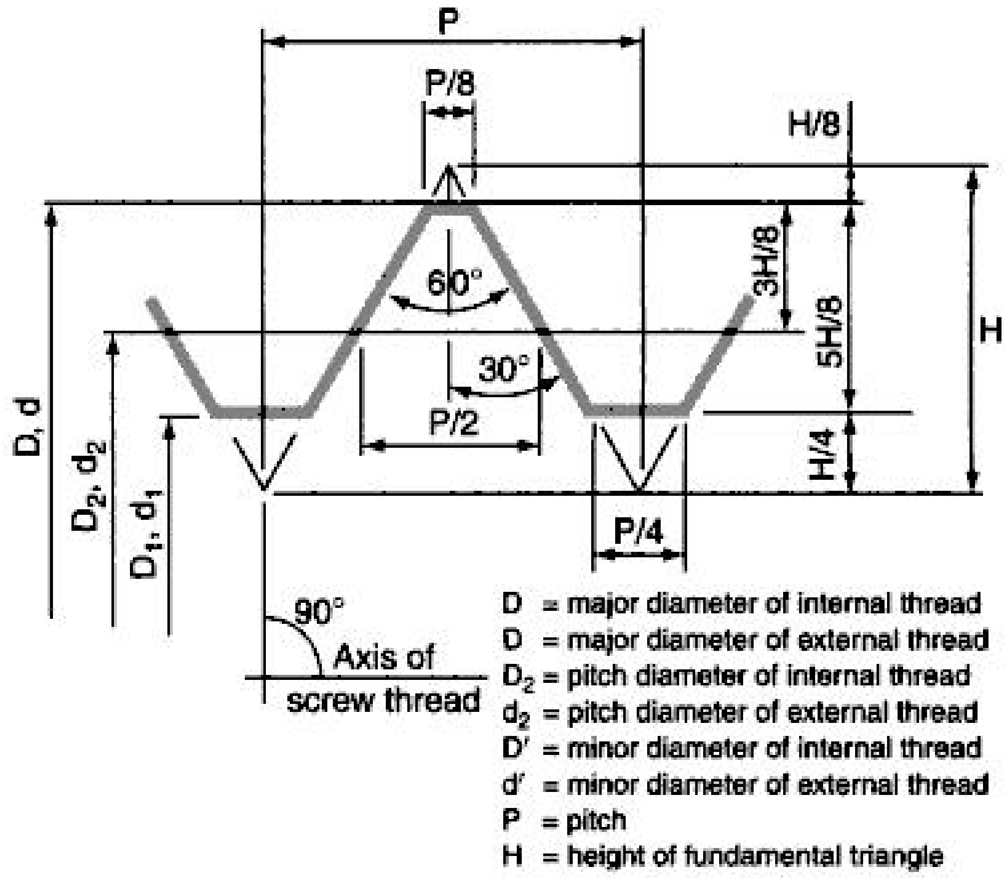

Fig. 11.3 *Basic profile of unified ISO thread form*

For bolt threads there are four tolerance positions—h has a zero fundamental deviation and e, f, and g have negative fundamental deviations. (A positive fundamental deviation indicates that the indicates that the size for the thread element will be smaller than the basic size).

11.2 SCREW THREAD TERMINOLOGY

1. Pitch Diameter (often called the effective diameter) of a parallel thread is the diameter of the imaginary co-axial cylinder which intersects the surface of the thread in such a manner that the intercept on a generator of the cylinder, between the points where it meets the opposite flanks of a thread groove, is equal to half the nominal pitch of the thread.

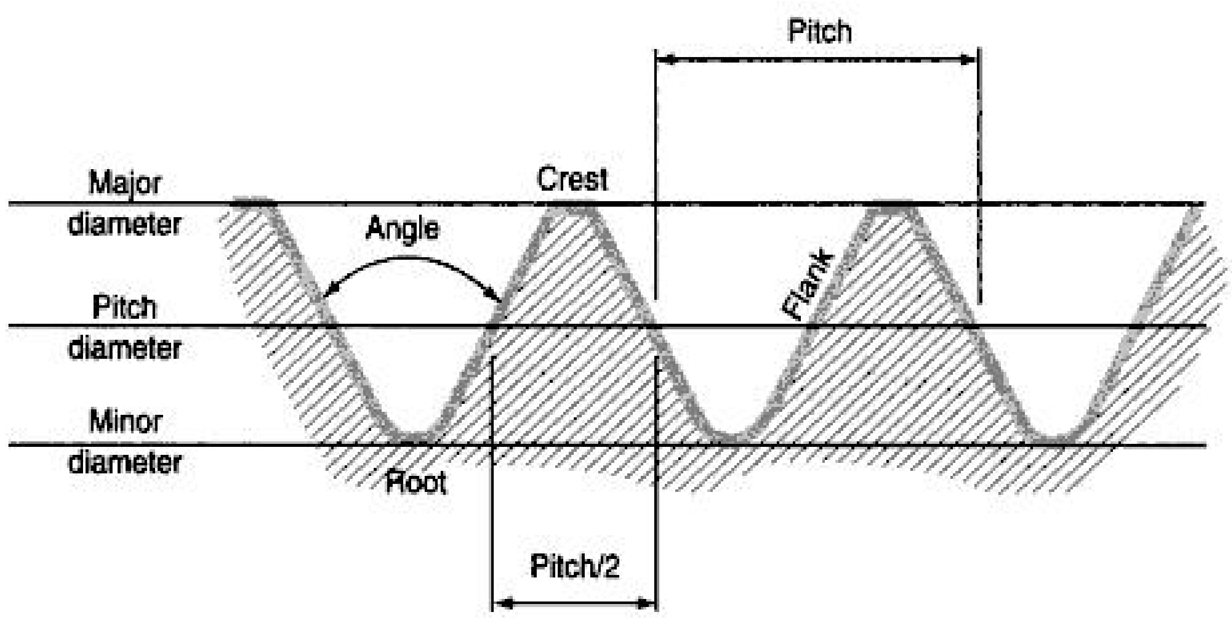

Fig. 11.4(a) *Screw thread terminology*

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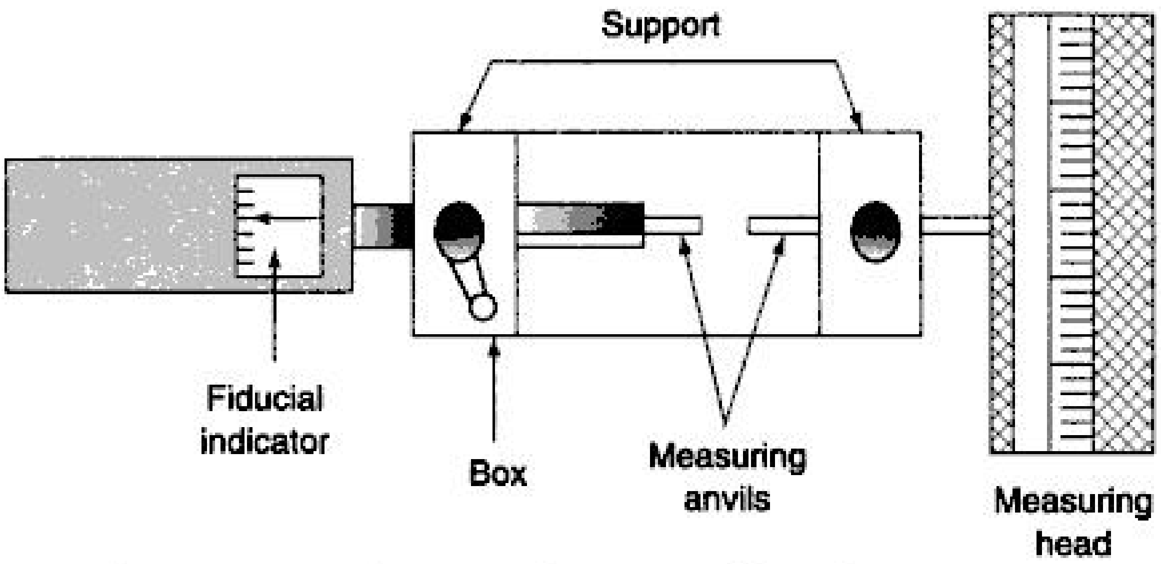

Fig. 11.10 *Schematic diagram of bench micrometer*

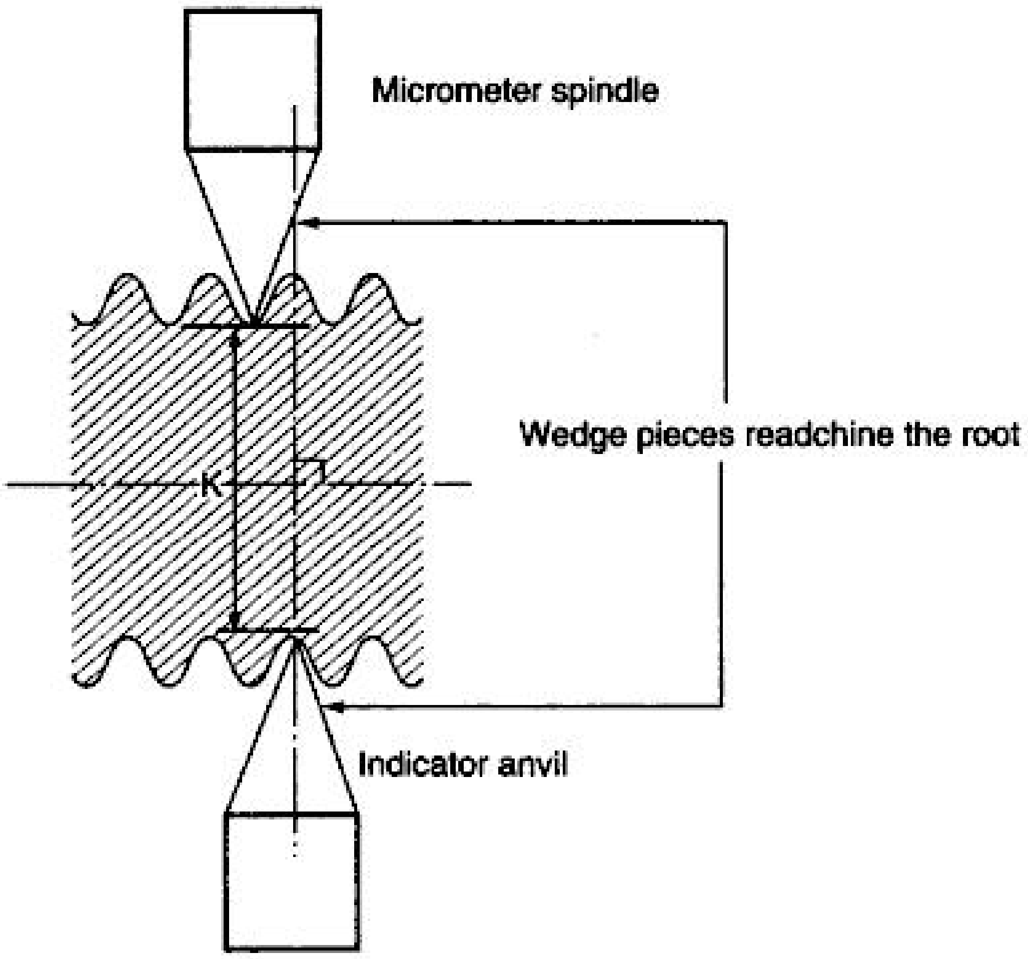

Fig. 11.11 *Vee wedge pieces contacting minor diameter*

cylindrical piece along with the wedge pieces. The procedure is also repeated along with the threaded component.

11.4.3 Floating Carriage Micrometer

This can also be used for measuring the minor diameter. This is a high-precision instrument with a least count of 0.2 microns and is used for checking thread elements on threads of screw plug gauges, which are used for high-precision measurements.

A floating carriage micrometer consists of a sturdy cast-iron base; and two accurately mounted and aligned centres. A freely moving slide mounted on hardened steel balls is freely moving at right angles

Therefore, $P = 2\,AQ$

$$= \frac{p}{2}\cot\theta/2 - d(\operatorname{cosec}\theta/2 - 1)$$

For, metric threads, $\theta = 60°$

$$P = 0.866p - d$$

For measuring T by using a floating carriage micrometer, place the master cylinder with wires and take the reading R. Now, replace the master cylinder with the threaded screw and take the reading as S. Then, $T = (R - S)$ + diameter of master cylinder.

11.4.4 Expression for Best Size Wire

This wire is of such a diameter that it makes contact with the flanks of the thread on the effective diameter or pitch line, i.e, the contact points of the wires must be on the pitch line or effective diameter. Refer Fig. 11.16. OP is perpendicular to the flank position of the thread. Let half the included angle of the thread be θ.

Therefore, in Δ OAP

$\sin POA = AP/OP$

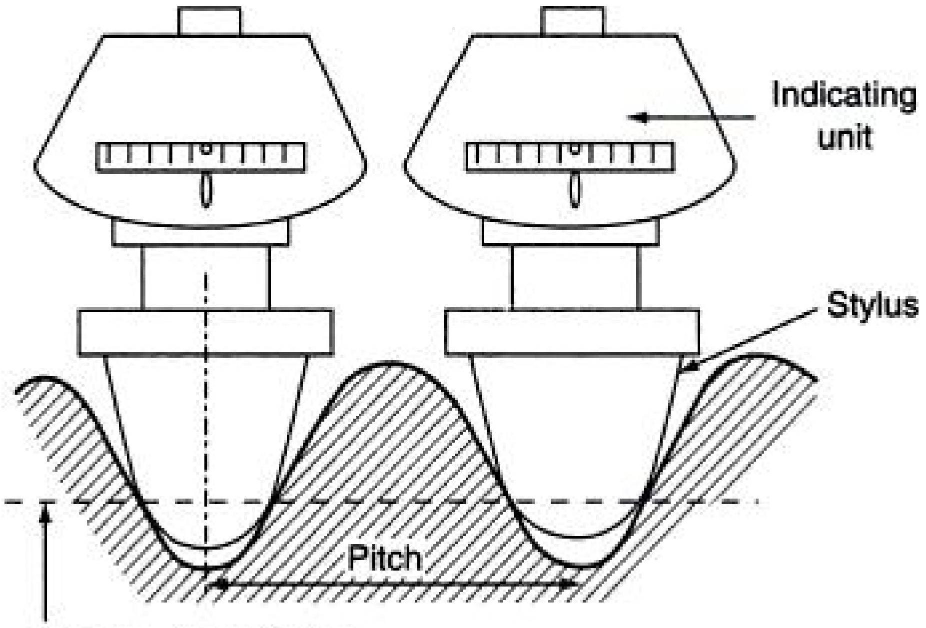

Fig. 11.15 *Stylus point on or near effective diameter*

Table 11.1 *P values of different thread forms*

Thread Form	*P Value*
ISO Metric	$0.866025\,p - W$
Unified	$0.866025\,p - W$
Whitworth	$0.960491\,p - 1.165681\,W$
B A	$0.136336\,p - 1.482950\,W$

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Example 4 *Calculate the effective diameter if*

(i) Micrometer reading over standard ***cylinder with two*** *wires of diameter = 15.64 mm*
(ii) Micrometer reading over the ***gauge with two wires as*** *15.26 mm and pitch of thread = 2.5 mm*
(iii) Wire of 2-mm diameter and ***standard cylinder*** *= 18 mm*

Solution: D_m = Diameter over standard cylinder = 15.64 mm

D_s = Diameter over plug screw gauge = 15.26 mm

p = Pitch thread = 2.5 mm

d = Diameter of wire =2 mm

D = Standard cylinder diameter = 18 mm

The wire diameter, d_b = 2 mm …… (given)

The pitch value, P

$\therefore P = 0.866\,p - d$

$P = [(0.866 \times 2.5) - 2]$

$P = 0.165$ mm.

Value of diameter under wire, T

$\therefore T = [D_s - D_m] + D$

$T = [15.26 - 15.64] - 18$

$T = 17.62$ mm

Effective diameter, E

$\therefore E = T + P$

$E = 17.62 + 0.165$

$E = 17.785$ mm

Example 5 *Calculate the effective diameter for* ***an*** *M 24 × 3* ***plug*** *gauge by using a floating carriage micrometer for which readings are taken as follows:*

(i) Micrometer reading over standard ***cylinder with*** *two wires of diameter = 12.9334 mm*
(ii) Micrometer reading over the plug ***screw gauge with*** *two wires as 12.1124 m*
(iii) Diameter of standard cylinder = ***22.001 mm.*** *Best wire size was used for the above.*

Solution: D_m = Diameter over standard cylinder = 12.9334 mm

D_s = Diameter over plug screw gauge = 12.1124 mm

p = Pitch thread = 3 mm

$\theta = 60°$ (metric thread)

D = Standard cylinder diameter = 22.001 mm

Best size wire diameter, d_b

$d_b = (P/2) \times \sec(\theta/2) = (3/2) \times \sec(60/2) = 1.732$ mm

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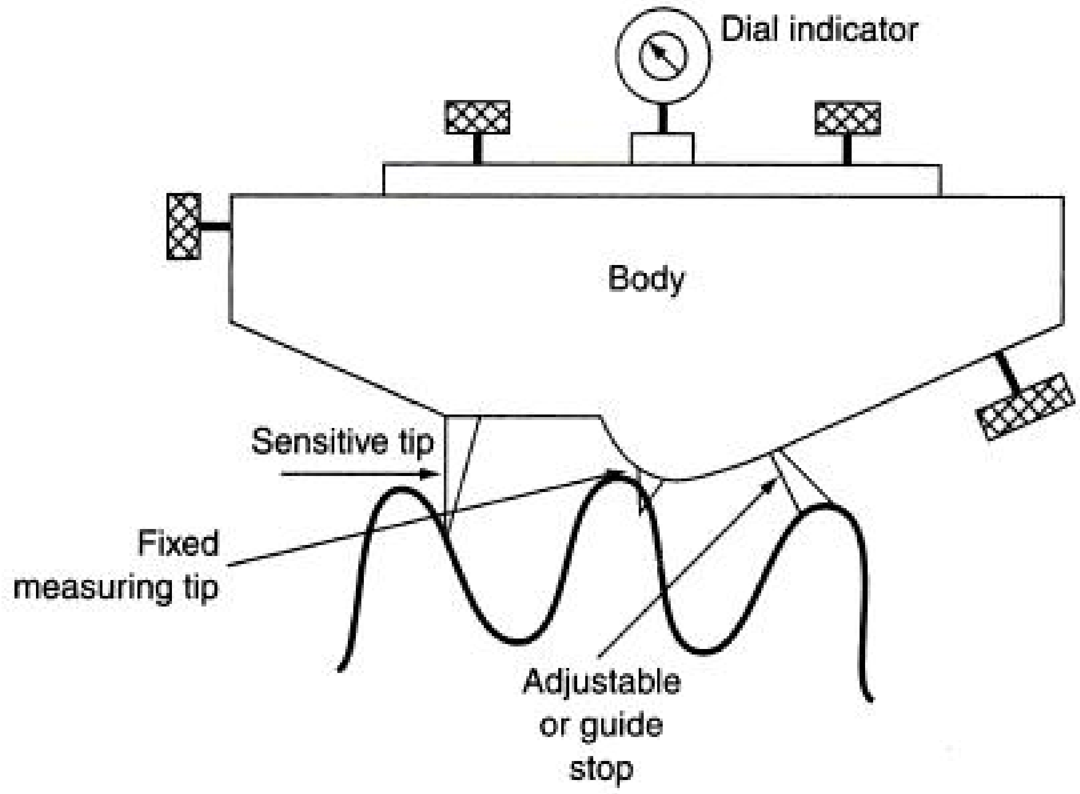
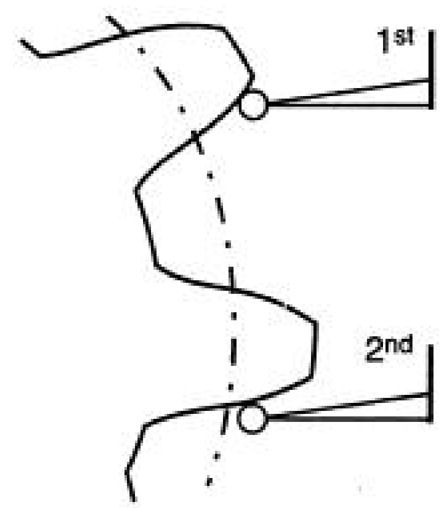


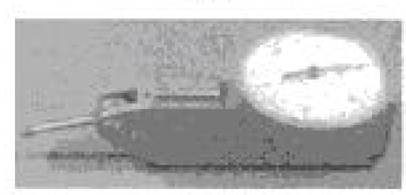
Fig. 12.6 *Portable base pitch-measuring instrument*

support. The distance the between the fixed and sensitive tip is set to be equivalent to the base pitch of the gear with the help of slip gauges. This properly set instrument is applied to the gear so that all three tips make contact with the tooth profile. The reading on the dial indicator is the pitch error.

b. Two-Dial Gauge Method for Pitch Measurement In this method, two lever-type dial gauges, as shown in Fig. 12.7 (b), are used on two adjucent teeth of a gear mounted in centres as shown in Fig. 12.7 (a). The gear under test is indexed through successive pitches to give constant reading on the first indicator, and any change in the reading on the second dial indicates pitch error.



(a)



(b)

Fig. 12.7 *Two-dial gauge method for pitch measurement*

12.7.2 Gear Tooth Profile Measurement

Gear tooth profile measurement can be done by measuring the tooth profile of a spur, i.e., the involute profile accurately. All the tooth profile errors are measured in transverse plane of a spur gear. It can be done in several ways.

a. Optical Projection Method In this method an optical comparator and profile projector (as shown in Fig. 12.8) (Plate 12) are used to magnify the profile of the gear under test and then it is compared with the master profile. It enables quick checking of the profile, which is more useful in the case of small-sized and thin gears.

b. Involute Measuring Machine In case of a large-sized gear, the involute profile is checked using involute measuring machine. This gear under test is held on a mandrel. A ground circular disc

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Single Flank Testing (Single Contact Testing) In this test, the gear is mated with a master gear on a fixed centre distance and set in such a way that only one tooth side makes contact. The gears are rotated through this single flank contact action, and the angular transmission error of the driven gear is measured. This is a tedious testing method and is seldom used except for inspection of the very highest precision gears.

Gear roll testers come along with a frictionless measuring carriage, which rides on high-precision roller bearings and guarantees high measuring accuracy and repeatability of the results. The setting carriage is opposed to the measuring carriage so that tests can be performed with two production gears or one production gear meshed with a master gear. The measuring carriage transmits the centre distance deviations to a pick-up or simply a dial indicator.

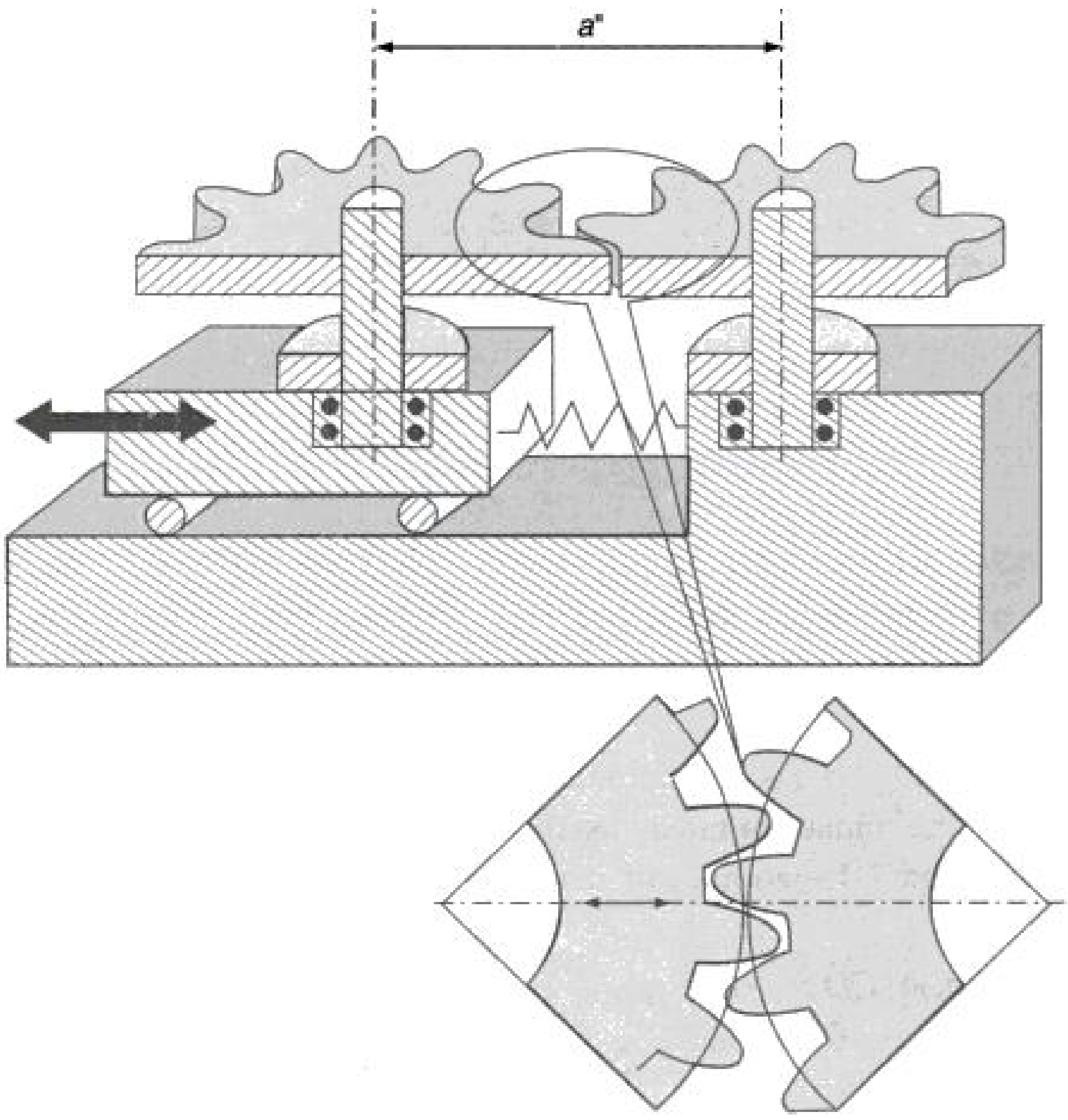

Fig. 12.23 *Cross-sectional view of gear rolling tester*

Double Flank Gear Roll Testing (Double Contact Testing) Two gears are rotated in tight mesh without play against each other. Under the influence of a pressure that is applied in the direction of the radial centre distance, at least one left and one right gear flank are meshed (double flank meshing). This causes variations in the radial centre distance. As always, two tooth flanks are in mesh, the measurement result represents the sum of the variations of both tooth flanks. For quality assessment, measuring results are defined as total radial composite deviation F_i'', tooth-to-tooth radial composite

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> More recently, however, these technological needs are being considered alongside other needs such as cost, ease of use, maintenance, up time and speed. Thus, in many regards, the instrument drivers have historically been technological in nature whereas in today's marketplace, technology is only one of the elements.

14.1 CONCEPT OF INSTRUMENT OVERLAPPING

Historically, an instrument served one basic purpose—length-measuring instruments measured length, roughness instruments measured roughness, and so on. However, advances in instrument technology have increased the bandwidths of most of today's metrology equipment. This has resulted in significant overlaps between the technologies.

As an example of these overlaps, consider the measurement of straightness. There are many measurement approaches—ranging from small stylus roughness instruments to large-scale interferometry that will yield some kind of straightness. In many cases, these different measurement approaches have followed very different development and standardization paths, but they are, nonetheless, reporting the same measurand: 'straightness'.

Metrology is, in many regards, a 'customer led' field as it can only provide data that is used for some subsequent application. As a result, advances in metrology are mostly provoked by the culture of the metrology customers. Today's manufacturing and product development environment continues to be one of ever-shrinking tolerances. Thus, there is a corresponding push in the metrology field for lower and lower measuring uncertainties. Furthermore, the design community has continued to move dimensional tolerancing schemes into smaller and smaller features (for example, micro-electronics and semiconductors) and surface-tolerancing schemes into larger and larger applications (for example, boat hulls and airplane wings).

In addition to these technological issues, metrology faces another (perhaps new) major challenge in the current environment—that being one of 'economics'. In considering today's metrology user-base, we find many companies that are built upon manufacturing or producing some kind of 'physical' good or product. However, the current economic trends indicate that this type of company (in very broad, general terms) is not receiving the attention of the fast-moving internet-based or 'dot-com' companies. This has driven the management of many metrology users to more carefully scrutinize the purchase of metrology equipment and the time spent using such equipment. After all, many business models consider activities such as measurement to be 'non-value added'!

14.2 METROLOGY INTEGRATION

As the size of the part under inspection increases, and the required measurement resolution shrinks, both data volumes and data rates will increase dramatically. This raw data must be converted into useful information to facilitate process control and defect reduction. To accomplish this, metrology data must be integrated into factory and enterprise-level information systems so that it may be associated

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- Computer support is provided for acquiring, processing, logging, and transmitting measurement data
- Operating reliability and comfort by linking both measuring systems so as to make all information available on a single screen
- Reliability in complying with documentation requirements through the automatic adoption, storage, and ISO-compliant printout/logging of all relevant measurement data
- Universal application through a generous selection of accessories
- Form stability through a sturdy machine base of hard granite
- Adjustable measuring force for matching to the size and shape of the test-piece—measuring results are thus unaffected by subjective influences
- Easy change of measuring direction
- High resistance to wear through carbide-reinforced measuring surfaces

14.4 USE OF NUMERICAL CONTROL FOR MEASUREMENT

The terms 'numerical control' and 'digital readout' have been applied to the many devices developed for measuring coordinate dimensions on a workpiece. The workpiece is held in a fixture and a probe is brought in contact with the work surface to be measured. Either the workpiece or the probe is held on a movable table or arm and the reading is recorded in the readout section of the control device. Two and three-axis machines are available. A two-axis machine usually registers the vertical displacement of the probe. A three-axis machine records both of these as well as transverse horizontal motion.

Numerical control inspection is most commonly applied to the inspection of odd-shaped contoures, which cannot be easily measured by other means. Since it is a relatively slow process, it is not competitive with automatic gauging devices or other conventional methods for the inspection of easily measured dimensions.

14.4.1 Coordinate Measuring Machines (CMM)

These are mechanical systems designed to move a measuring probe to determine coordinates of points on a workpiece surface. CMMs are comprised of four main components: the machine itself, the measuring probe, the control or computing system, and the measuring software. Machines are available in a wide range of sizes and designs with a variety of different probe technologies.

Important specifications for coordinate measuring machines are the measuring lengths along the x, y and z-axes as well as resolution and workpiece weight. The x-axis measuring length is the total travel, or measuring length, that can be performed in the x-direction. The y-axis measuring length is the total travel, or measuring length, that can be performed in the y-direction. The z-axis measuring length is the total travel, or measuring length, that can be performed in the z-direction. These are not necessarily the same as the measuring capacity, which is the maximum size of the object in the x, y or z-direction that the machine can accommodate. The resolution is the least increment of a measuring device; on digital

- If the NC program is partially corrected prior to processing, there is no need to make a correction during processing. Accordingly, Correct Plus promises worry-free operation.
- Two types of systems are available, according to the type of production system:

1. Manual Feedback System The operator decides whether or not to give feedback on correction data.

2. Automatic Feedback System Correction data feedback is completely automatic, according to the setting.

- It can support multiple machining centres.
- Allows measurement results to be stored, output to a chart, and used for statistical data processing.

Wide varieties of CMM specifications for inspection of small-sized components to complete car body profile measurement are commercially available in the market. Figure 14.9 (Plate 15) shows a new, horizontal arm-type CMM inspecting the profile of the car body, and Fig. 14.10 (Plate 15) shows a CNC CMM, which provides a huge measuring range.

Common applications for coordinate measuring machines include dimensional measurement, profile measurement, angularity or orientation, depth mapping, digitizing or imaging, and shaft measurement. Features common to CMMs include crash protection, offline programming, reverse engineering, shop-floor suitability, SPC software and temperature compensation.

14.4.3 CMM Probes

CMM probes (Coordinate Measuring Machine) are transducers that convert physical measurements into electrical signals, using various measuring systems within the probe structure. CMM probes have a wide classification including instruments using diverse technologies for direct and comparative measurements.

CMM probes are available in three main probe forms:

i. Touch-trigger or discrete point,
ii. Displacement measuring, and
iii. Proximity or non-contact probes.

1. Touch-trigger Probes are the most common types of probe. They actually touch the surface of the workpiece, and upon contact, send a signal with the coordinates of that point to the CMM. The probe is then backed off and moved to the next location where the process is repeated.

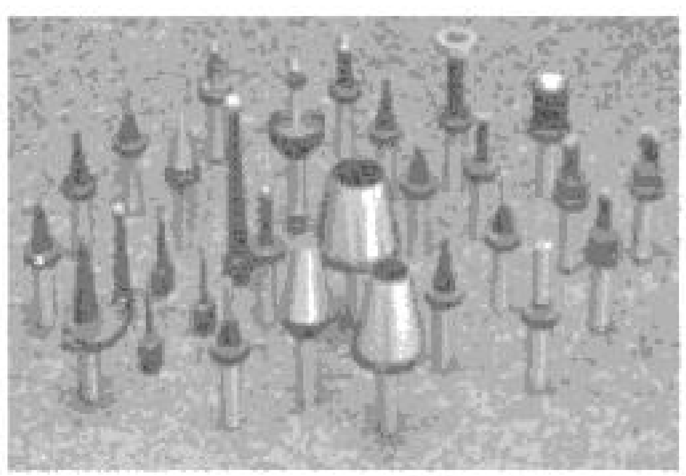

Fig. 14.11 *Types of hard probes*

2. Displacement Measuring CMM Probes are also referred as *scanning probes*. This method generally involves

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are called *static characteristics*. Normally, static characteristics at a measurement system are those that must be considered when the system or instrument is used to measure a condition not varying with respect to time.

1. Accuracy Accuracy of the instrument may be defined as its ability to respond to a true value of a measured variable under reference conditions. In other words, it can also be explained as the closeness with which an instrument reading approaches the true value of the quantity being measured. Moreover, the accuracy of measurement means conformity to the truth. The accuracy of an instrument may be expressed in different ways, viz., in terms of the measured variable itself, span of the instrument, upper-range value, per cent of scale length of actual output reading.

Overall Accuracy For the instruments composed of separate physical units like primary, secondary, manipulation, etc., overall accuracy is expressed by combining individual accuracies of different elements.

For pressure spring thermometer having accuracy of bulb-capillary system as ±0.5% and accuracy of Bourdon pressure gauge as ±1 %, the overall accuracy can be expressed as

a. least accuracy is within ± (0.5 + I), i.e., within ±1.5

b. root square accuracy is within $\pm\sqrt{0.5^2} + \sqrt{1^2} = \pm\sqrt{1.25}$

2. Precision It is a measure of reproducibility of the measurements, given a fixed value of a quantity or the degree of exactness for which an instrument is designed or intended to perform. In other words, precision is a measure of the degree of agreement within the group of measurements. It is expressed in terms of conformity of the instrument, which is nothing but maximum deviation of an instrument's actual calibration curve as compared to its specified characteristic curve. In general, the distinction between the words 'accuracy' and 'precision' is usual1y very vague. But as far

Table 15.1 *Differences between accuracy and precision*

Sl. No.	*Accuracy*	*Precision*
1.	It is closeness with the true value of the quantity being measured.	It is a measure of the reproducibility of the measurement.
2.	The accuracy of measurement means conformity to truth.	The term *precise* means clearly or sharply defined.
3.	Accuracy can be improved.	Precision cannot be improved.
4.	Accuracy depends upon simple techniques of analysis.	Precision depends upon many factors and requires many sophisticated techniques of analysis.
5.	Accuracy is necessary but not sufficient condition for precision.	Precision is necessary but not a sufficient condition for accuracy.

6. Discuss the performance characteristics of measuring devices.
7. Differentiate between
   a. Static and dynamic characteristics
   b. Accuracy and precision
   c. Repeatability and reproducibility
   d. Random and systemic error
8. Define sensitivity, drift, dead zone, resolution or discrimination and threshold.
9. Define drift and explain its types.
10. Explain what you mean by hysteresis and its effect in the measurement process.
11. Explain the following dynamic characteristics: speed of response, measuring lag, fidelity.
12. Explain the different types of errors in measurement.

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