Metrology.

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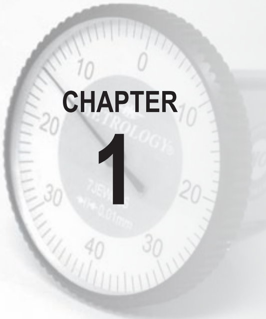


CHAPTER 1

Basic Principles of Engineering Metrology

After studying this chapter, the reader will be able to

- understand the importance of metrology
- appreciate the significance of inspection
- appreciate the concepts of accuracy and precision
- explain the objectives of metrology and measurements
- understand the general measurement concepts
- elucidate the different sources and types of errors
- compare the different types of measurements

1.1 INTRODUCTION

The importance of metrology as a scientific discipline gained momentum during the industrial revolution. Continuing technological advancement further necessitated refinement in this segment. Metrology is practised almost every day, often unknowingly, in our day-to-day tasks. Measurement is closely associated with all the activities pertaining to scientific, industrial, commercial, and human aspects. Its role is ever increasing and encompasses different fields such as communications, energy, medical sciences, food sciences, environment, trade, transportation, and military applications. Metrology concerns itself with the study of measurements. It is of utmost importance to measure different types of parameters or physical variables and quantify each of them with a specific unit. Thus, measurement is an act of assigning an accurate and precise value to a physical variable. The physical variable then gets transformed into a measured variable. Meaningful measurements require common measurement standards and must be performed using them. The common methods of measurement are based on the development of international specification standards. These provide appropriate definitions of parameters and protocols that enable standard measurements to be made and also establish a common basis for comparing measured values. In addition, metrology is also concerned with the reproduction, conservation, and transfer of units of measurements and their standards. Measurements provide a basis for judgements about process information, quality assurance, and process control.

according to the true value

Less variability

Design is one of the major aspects of all branches of engineering. A product/system comprising several elements has to be properly designed to perform the required (desired) function. In order to test whether functioning of the elements constituting the product/system meets the design expectation, and to finally assess the functioning of the whole system, measurements are inevitable. Another associated aspect is to provide proper operation and maintenance of such a product/system. Measurement is a significant source for acquiring very important and necessary data about both these aspects of engineering, without which the function or analysis cannot be performed properly.

Hence, measurements are required for assessing the performance of a product/system, performing analysis to ascertain the response to a specific input function, studying some fundamental principle or law of nature, etc. Measurements contribute to a great extent to the design of a product or process to be operated with maximum efficiency at minimum cost and with desired maintainability and reliability.

Metrology helps extract high-quality information regarding the completion of products, working condition, and status of processes in an operational and industrial environment. A high product quality along with effectiveness and productivity is a must, in order to survive economically in this competitive global market. The task of attaining workpiece accuracy in modern industrial production techniques has gained much significance through constantly increasing demands on the quality of the parts produced. In order to achieve high product quality, metrology has to be firmly integrated into the production activity. Hence, metrology forms an inseparable key element in the process of manufacturing. This needs focus on the additional expense caused throughout the whole manufacturing process, due to worldwide competition. The quality of the products influences various production attributes such as continuity, production volume and costs, productivity, reliability, and efficiency of these products with respect to their application or their consumption in a diverse manner. Thus, it is desirable to use the resources in an optimal manner and strive to achieve cost reduction in manufacturing.

1.2 METROLOGY

Metrology literally means science of measurements. In practical applications, it is the enforcement, verification, and validation of predefined standards. Although metrology, for engineering purposes, is constrained to measurements of length, angles, and other quantities that are expressed in linear and angular terms, in a broader sense, it is also concerned with industrial inspection and its various techniques. Metrology also deals with establishing the units of measurements and their reproduction in the form of standards, ascertaining the uniformity of measurements, developing methods of measurement, analysing the accuracy of methods of measurement, establishing uncertainty of measurement, and investigating the causes of measuring errors and subsequently eliminating them.

not all
measurement
can be eliminated
Ex: (Random error).

The word metrology is derived from the Greek word 'metrologia', which means measure. Metrology has existed in some form or other since ancient times. In the earliest forms of metrology, standards used were either arbitrary or subjective, which were set up by regional or local authorities, often based on practical measures like the length of an arm.

It is pertinent to mention here the classic statement made by Lord Kelvin (1824–1907), an eminent scientist, highlighting the importance of metrology: '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 of it 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.'

Another scientist Galileo (1564–1642) has clearly formulated the comprehensive goal of metrology with the following statement: 'Measure everything that is measurable and make measurable what is not so.'

Metrology is an indispensable part of the modern day infrastructure. In fact, it plays an important role in our lives, either directly or indirectly, in various ways. In this competitive world, economic success of most of the manufacturing industries critically depends on the quality and reliability of the products manufactured—requirements in which measurement plays a key role. It has become increasingly essential to conform to the written standards and specifications and mutual recognition of measurements and tests, to trade in national and international markets. This can be achieved by the proper application of measurement methods that enhance the quality of products and the productive power of plants.

Metrology not only deals with the establishment, reproduction, protection, maintenance, and transfer or conversion of units of measurements and their standards, but is also concerned with the correctness of measurement. In addition to encompassing different industrial sectors, it also plays a vital role in establishing standards in different fields that affect human beings, such as health sciences, safety, and environment. Hence, one of the major functions of metrology is to establish international standards for measurements used by all the countries in the world in both science and industry.

Modern manufacturing technology is based on precise reliable dimensional measurements. The term 'legal metrology' applies to any application of metrology that is subjected to national laws or regulations. There will be mandatory and legal bindings on the units and methods of measurements and measuring instruments. The scope of legal metrology may vary considerably from one country to another. The main objective is to maintain uniformity of measurement in a particular country. Legal metrology ensures the conservation of national standards and guarantees their accuracy in comparison with the international standards, thereby imparting proper accuracy to the secondary standards of the country. Some of the applications of legal metrology are industrial measurement, commercial transactions, and public health and human safety aspects.

A group of techniques employed for measuring small variations that are of a continuous nature is termed as 'dynamic metrology'. These techniques find application in recording continuous measurements over a surface and have obvious advantages over individual measurements of a distinctive character.

The metrology in which part measurement is substituted by process measurement is known as 'deterministic metrology'. An example of deterministic metrology is a new technique known as 3D error compensation by computer numerical control (CNC) systems and expert systems, leading to fully adaptive control. This technology is adopted in high-precision manufacturing machinery and control systems to accomplish micro and nanotechnology accuracies.

1.3 NEED FOR INSPECTION

Industrial inspection has acquired significance in recent times and has a systematic and scientific approach. Prior to the industrial revolution, craftsmen used to assemble the different parts by hand and, in the process, consumed a lot of time. They were entirely responsible for the quality of their products. Inspection was an integral function of production. Since the industrial revolution, many new manufacturing techniques have been developed to facilitate mass production of components.

In modern manufacturing techniques, a product has to be disintegrated into different components. Manufacture of each of these components is then treated as an independent process.

F.W. Taylor, who has been acknowledged as the father of scientific management of manufacturing industry, created the modern philosophy of production and also the philosophy of production metrology and inspection. He decomposed a job into multiple tasks, thereby isolating the tasks involved in inspection from the production tasks. This culminated in the creation of a separate quality assurance department in manufacturing industries, which is assigned the task of inspection and quality control.

Inspection is defined as a procedure in which a part or product characteristic, such as a dimension, is examined to determine whether it conforms to the design specification. Basically, inspection is carried out to isolate and evaluate a specific design or quality attribute of a component or product. Industrial inspection assumed importance because of mass production, which involved interchangeability of parts. The various components that come from different locations or industries are then assembled at another place. This necessitates that parts must be so assembled that satisfactory mating of any pair chosen at random is possible. In order to achieve this, dimensions of the components must be well within the permissible limits to obtain the required assemblies with a predetermined fit. Measurement is an integral part of inspection. Many inspection methods rely on measurement techniques, that is, measuring the actual dimension of a part, while others employ the gauging method. The gauging method does not provide any information about the actual value of the characteristic but is faster when compared to the measurement technique. It determines only whether a particular dimension of interest is well within the permissible limits or not. If the part is found to be within the permissible limits, it is accepted; otherwise it is rejected. The gauging method determines the dimensional accuracy of a feature, without making any reference to its actual size, which saves time. In inspection, the part either passes or fails. Thus, industrial inspection has become a very important aspect of quality control.

Inspection essentially encompasses the following:

1. Ascertain that the part, material, or component conforms to the established or desired standard.
2. Accomplish interchangeability of manufacture.
3. Sustain customer goodwill by ensuring that no defective product reaches the customers.
4. Provide the means of finding out inadequacies in manufacture. The results of inspection are recorded and reported to the manufacturing department for further action to ensure production of acceptable parts and reduction in scrap.
5. Purchase good-quality raw materials, tools, and equipment that govern the quality of the finished products.
6. Coordinate the functions of quality control, production, purchasing, and other departments of the organizations.
7. Take the decision to perform rework on defective parts, that is, to assess the possibility of making some of these parts acceptable after minor repairs.
8. Promote the spirit of competition, which leads to the manufacture of quality products in bulk by eliminating bottlenecks and adopting better production techniques.

not made
for certain
product

depends on the
product ability to
be reworked.

1.4 ACCURACY AND PRECISION

How much the Reading are close to the true value.

if it's unknown but if it's known, will be no need.

We know that accuracy of measurement is very important for manufacturing a quality product. *Accuracy* is the degree of agreement of the measured dimension with its true magnitude. It can also be defined as the maximum amount by which the result differs from the true value or as the nearness of the measured value to its true value, often expressed as a percentage. True value may be defined as the mean of the infinite number of measured values when the average deviation due to the various contributing factors tends to zero. In practice, realization of the true value is not possible due to uncertainties of the measuring process and hence cannot be determined experimentally. Positive and negative deviations from the true value are not equal and will not cancel each other. One would never know whether the quantity being measured is the true value of the quantity or not.

بغض النظر عن true value

could not be accurate.

Precision is the degree of repetitiveness of the measuring process. It is the degree of agreement of the repeated measurements of a quantity made by using the same method, under similar conditions. In other words, precision is the repeatability of the measuring process. The ability of the measuring instrument to repeat the same results during the act of measurements for the same quantity is known as *repeatability*. Repeatability is random in nature and, by itself, does not assure accuracy, though it is a desirable characteristic. Precision refers to the consistent reproducibility of a measurement. Reproducibility is normally specified in terms of a scale reading over a given period of time. If an instrument is not precise, it would give different results for the same dimension for repeated readings. In most measurements, precision assumes more significance than accuracy. It is important to note that the scale used for the measurement must be appropriate and conform to an internationally accepted standard.

It is essential to know the difference between precision and accuracy. Accuracy gives information regarding how far the measured value is with respect to the true value, whereas precision indicates quality of measurement, without giving any assurance that the measurement is correct. These concepts are directly related to random and systematic measurement errors.

Figure 1.1 also clearly depicts the difference between precision and accuracy, wherein several measurements are made on a component using different types of instruments and the results plotted.

It can clearly be seen from Fig. 1.1 that precision is not a single measurement but is associated with a process or set of measurements. Normally, in any set of measurements performed by the same instrument on the same component, individual measurements are distributed around the mean value and precision is the agreement of these values with each other. The difference

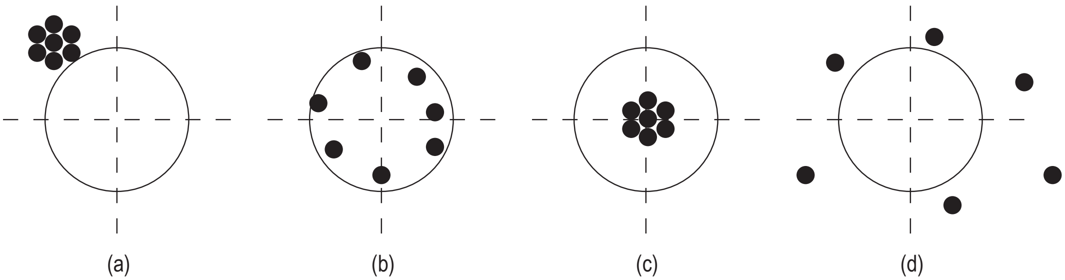


Fig. 1.1 Accuracy and precision (a) Precise but not accurate (b) Accurate but not precise (c) Precise and accurate (d) Not precise and not accurate

between the true value and the mean value of the set of readings on the same component is termed as an *error*. Error can also be defined as the difference between the indicated value and the true value of the quantity measured.

$$\boxed{E = V_m - V_t} = \left(\begin{array}{c}\text{measured}\\\text{value}\end{array}\right) - \left(\begin{array}{c}\text{true}\\\text{value}\end{array}\right).$$

where E is the error, V_m the measured value, and V_t the true value.

The value of E is also known as the absolute error. For example, when the weight being measured is of the order of 1 kg, an error of ±2 g can be neglected, but the same error of ±2 g becomes very significant while measuring a weight of 10 g. Thus, it can be mentioned here that for the same value of error, its distribution becomes significant when the quantity being measured is small. Hence, % error is sometimes known as relative error. Relative error is expressed as the ratio of the error to the true value of the quantity to be measured. Accuracy of an instrument can also be expressed as % error. If an instrument measures V_m instead of V_t, then,

$$\% \text{ error} = \frac{\text{Error}}{\text{True value}} \times 100$$

Or $$\% \text{ error} = \frac{V_m - V_t}{V_t} \times 100$$

accuracy.

Accuracy of an instrument is always assessed in terms of error. The instrument is more accurate if the magnitude of error is low. It is essential to evaluate the magnitude of error by other means as the true value of the quantity being measured is seldom known, because of the uncertainty associated with the measuring process. In order to estimate the uncertainty of the measuring process, one needs to consider the systematic and constant errors along with other factors that contribute to the uncertainty due to scatter of results about the mean. Consequently, when precision is an important criterion, mating components are manufactured in a single plant and measurements are obtained with the same standards and internal measuring precision, to accomplish interchangeability of manufacture. If mating components are manufactured at different plants and assembled elsewhere, the accuracy of the measurement of two plants with true standard value becomes significant.

In order to maintain the quality of manufactured components, accuracy of measurement is an important characteristic. Therefore, it becomes essential to know the different factors that affect accuracy. Sense factor affects accuracy of measurement, be it the sense of feel or sight. In instruments having a scale and a pointer, the accuracy of measurement depends upon the threshold effect, that is, the pointer is either just moving or just not moving. Since accuracy of measurement is always associated with some error, it is essential to design the measuring equipment and methods used for measurement in such a way that the error of measurement is minimized.

Two terms are associated with accuracy, especially when one strives for higher accuracy in measuring equipment: sensitivity and consistency. The ratio of the change of instrument indication to the change of quantity being measured is termed as *sensitivity*. In other words, it is the ability of the measuring equipment to detect small variations in the quantity being measured. When efforts are made to incorporate higher accuracy in measuring equipment, its sensitivity increases. The permitted degree of sensitivity determines the accuracy of the instrument. An instrument cannot be more accurate than the permitted degree of sensitivity. It is very pertinent to mention here that unnecessary use of a more sensitive instrument for measurement than required is a disadvantage. When successive readings of the measured quantity obtained from the measuring instrument are same all the time, the equipment is said to be *consistent*. A highly accurate instrument possesses both sensitivity and consistency. A highly sensitive instrument need not be consistent, and the degree of consistency determines the accuracy of the instrument. An instrument that is both consistent and sensitive need not be accurate, because its scale may have been calibrated with a wrong standard. Errors of measurement will be constant in such instruments, which can be taken care of by calibration. It is also important to note that as the magnification increases, the range of measurement decreases and, at the same time, sensitivity increases. Temperature variations affect an instrument and more skill is required to handle it. *Range* is defined as the difference between the lower and higher values that an instrument is able to measure. If an instrument has a scale reading of 0.01–100 mm, then the range of the instrument is 0.01–100 mm, that is, the difference between the maximum and the minimum value.

1.4.1 Accuracy and Cost

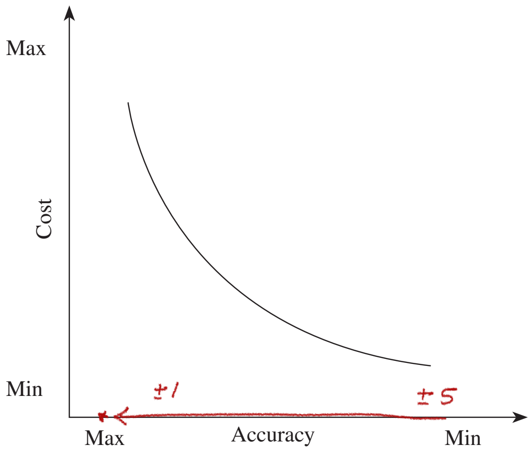


Fig. 1.2 Relationship of accuracy with cost

It can be observed from Fig. 1.2 that as the requirement of accuracy increases, the cost increases exponentially. If the tolerance of a component is to be measured, then the accuracy requirement will normally be 10% of the tolerance values. Demanding high accuracy unless it is absolutely required is not viable, as it increases the cost of the measuring equipment and hence the inspection cost. In addition, it makes the measuring equipment unreliable, because, as discussed in Section 1.4, higher accuracy increases sensitivity. Therefore, in practice, while designing the measuring equipment, the desired/required accuracy to cost considerations depends on the quality and reliability of the component/product and inspection cost.

1.5 OBJECTIVES OF METROLOGY AND MEASUREMENTS

From the preceding discussions, we know that accuracy of measurement is very important for the production of a quality product, and hence it is imperative to mention here that the basic objective of any measurement system is to provide the required accuracy at minimum cost. In addition, metrology is an integral part of modern engineering industry consisting of various departments, namely design, manufacturing, assembly, research and development, and engineering departments. The objectives of metrology and measurements include the following:

1. To ascertain that the newly developed components are comprehensively evaluated and designed within the process, and that facilities possessing measuring capabilities are available in the plant

2. To ensure uniformity of measurements
3. To carry out process capability studies to achieve better component tolerances
4. To assess the adequacy of measuring instrument capabilities to carry out their respective measurements
5. To ensure cost-effective inspection and optimal use of available facilities
6. To adopt quality control techniques to minimize scrap rate and rework
7. To establish inspection procedures from the design stage itself, so that the measuring methods are standardized
8. To calibrate measuring instruments regularly in order to maintain accuracy in measurement
9. To resolve the measurement problems that might arise in the shop floor
10. To design gauges and special fixtures required to carry out inspection
11. To investigate and eliminate different sources of measuring errors

1.6 GENERAL MEASUREMENT CONCEPTS

We know that the primary objective of measurement in industrial inspection is to determine the quality of the component manufactured. Different quality requirements, such as permissible tolerance limits, form, surface finish, size, and flatness, have to be considered to check the conformity of the component to the quality specifications. In order to realize this, quantitative information of a physical object or process has to be acquired by comparison with a reference. The three basic elements of measurements (schematically shown in Fig. 1.3), which are of significance, are the following:

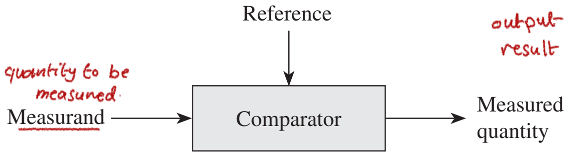


Fig. 1.3 Elements of measurement

1. *Measurand*, a physical quantity such as length, weight, and angle to be measured
2. *Comparator*, to compare the measurand (physical quantity) with a known standard (reference) for evaluation
3. *Reference*, the physical quantity or property to which quantitative comparisons are to be made, which is internationally accepted

All these three elements would be considered to explain the direct measurement using a calibrated fixed reference. In order to determine the length (a physical quantity called measurand) of the component, measurement is carried out by comparing it with a steel scale (a known standard).

1.6.1 Calibration of Measuring Instruments

It is essential that the equipment/instrument used to measure a given physical quantity is validated. The process of validation of the measurements to ascertain whether the given physical quantity conforms to the original/national standard of measurement is known as *traceability* of the standard. One of the principal objectives of metrology and measurements is to analyse the uncertainty of individual measurements, the efforts made to validate each measurement with a given equipment/instrument, and the data obtained from it. It is essential that traceability (which is often performed by a calibration laboratory having conformity with a proven quality system with such standards) should disseminate to the consumers. Calibration is a means of achieving traceability. One of the essential aspects of metrology is that the results of measurements obtained should be meaningful. To accomplish this, calibration of any measuring system/instrument is very essential. Calibration is the procedure used to establish a relationship between the values of the quantities indicated by the measuring instrument and the corresponding values realized by standards under specified conditions. It refers to the process of establishing the characteristic relationship between the values of the physical quantity applied to the instrument and the corresponding positions of the index, or creating a chart of quantities being measured versus readings of the instrument. If the instrument has an arbitrary scale, the indication has to be multiplied by a factor to obtain the nominal value of the quantity measured, which is referred to as *scale factor*. If the values of the variable involved remain constant (not time dependent) while calibrating a given instrument, this type of calibration is known as *static calibration*, whereas if the value is time dependent or time-based information is required, it is called *dynamic calibration*. The relationship between an input of known dynamic behaviour and the measurement system output is determined by dynamic calibration.

The main objective of all calibration activities is to ensure that the measuring instrument will function to realize its accuracy objectives. General calibration requirements of the measuring systems are as follows: (a) accepting calibration of the new system, (b) ensuring traceability of standards for the unit of measurement under consideration, and (c) carrying out calibration of measurement periodically, depending on the usage or when it is used after storage.

Calibration is achieved by comparing the measuring instrument with the following: (a) a primary standard, (b) a known source of input, and (c) a secondary standard that possesses a higher accuracy than the instrument to be calibrated. During calibration, the dimensions and tolerances of the gauge or accuracy of the measuring instrument is checked by comparing it with a standard instrument or gauge of known accuracy. If deviations are detected, suitable adjustments are made in the instrument to ensure an acceptable level of accuracy. The limiting factor of the calibration process is repeatability, because it is the only characteristic error that cannot be calibrated out of the measuring system and hence the overall measurement accuracy is curtailed. Thus, repeatability could also be termed as the minimum uncertainty that exists between a measurand and a standard. Conditions that exist during calibration of the instrument should be similar to the conditions under which actual measurements are made. The standard that is used for calibration purpose should normally be one order of magnitude more accurate than the instrument to be calibrated. When it is intended to achieve greater accuracy, it becomes imperative to know all the sources of errors so that they can be evaluated and controlled.

1.7 ERRORS IN MEASUREMENTS

While performing physical measurements, it is important to note that the measurements obtained are not completely accurate, as they are associated with uncertainty. Thus, in order to analyse the measurement data, we need to understand the nature of errors associated with the measurements.

Therefore, it is imperative to investigate the causes or sources of these errors in measurement systems and find out ways for their subsequent elimination. Two broad categories of errors in measurement have been identified: systematic and random errors.

1.7.1 Systematic or Controllable Errors

A systematic error is a type of error that deviates by a fixed amount from the true value of measurement. These types of errors are controllable in both their magnitude and their direction, and can be assessed and minimized if efforts are made to analyse them. In order to assess them, it is important to know all the sources of such errors, and if their algebraic sum is significant with respect to the manufacturing tolerance, necessary allowance should be provided to the measured size of the workpiece. Examples of such errors include measurement of length using a metre scale, measurement of current with inaccurately calibrated ammeters, etc. When the systematic errors obtained are minimum, the measurement is said to be extremely accurate. It is difficult to identify systematic errors, and statistical analysis cannot be performed. In addition, systematic errors cannot be eliminated by taking a large number of readings and then averaging them out. These errors are reproducible inaccuracies that are consistently in the same direction. Minimization of systematic errors increases the accuracy of measurement. The following are the reasons for their occurrence:

1. Calibration errors
2. Ambient conditions المحيط بالعينة
3. Deformation of workpiece
4. Avoidable errors

Ex: Standard temp.
Ambient cond. at internationally
accpted value of Standard
temp = 20 C°

Calibration Errors

A small amount of variation from the nominal value will be present in the actual length standards, as in slip gauges and engraved scales. Inertia of the instrument and its hysteresis effects do not allow the instrument to translate with true fidelity. Hysteresis is defined as the difference between the indications of the measuring instrument when the value of the quantity is measured in both the ascending and descending orders. These variations have positive significance for higher-order accuracy achievement. Calibration curves are used to minimize such variations. Inadequate amplification of the instrument also affects the accuracy.

Ambient Conditions

It is essential to maintain the ambient conditions at internationally accepted values of standard temperature (20 ºC) and pressure (760 mmHg) conditions. A small difference of 10 mmHg can cause errors in the measured size of the component. The most significant ambient condition affecting the accuracy of measurement is temperature. An increase in temperature of 1 ºC results in an increase in the length of C25 steel by 0.3 μm, and this is substantial when precision measurement is required. In order to obtain error-free results, a correction factor for temperature has to be provided. Therefore, in case of measurements using strain gauges, temperature compensation is provided to obtain accurate results. Relative humidity, thermal gradients, vibrations, and CO_2 content of the air affect the refractive index of the atmosphere. Thermal expansion occurs due to heat radiation from different sources such as lights, sunlight, and body temperature of operators.

reasons of error:

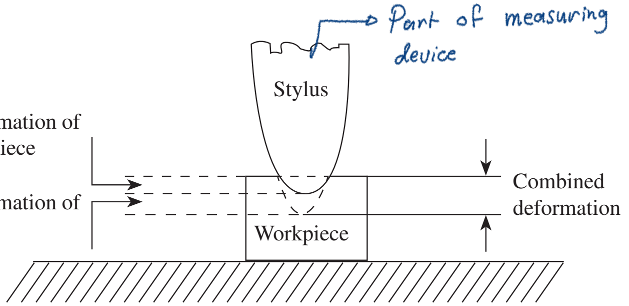


Fig. 1.4 Elastic deformation due to stylus pressure

Deformation of Workpiece

Any elastic body, when subjected to a load, undergoes elastic deformation. The stylus pressure applied during measurement affects the accuracy of measurement. Due to a definite stylus pressure, elastic deformation of the workpiece and deflection of the workpiece shape may occur, as shown in Fig. 1.4. The magnitude of deformation depends on the applied load, area of contact, and mechanical properties of the material of the given workpiece. Therefore, during comparative measurement, one has to ensure that the applied measuring loads are same.

Avoidable Errors

These include the following:

Datum errors Datum error is the difference between the true value of the quantity being measured and the indicated value, with due regard to the sign of each. When the instrument is used under specified conditions and a physical quantity is presented to it for the purpose of verifying the setting, the indication error is referred to as the datum error.

Reading errors These errors occur due to the mistakes committed by the observer while noting down the values of the quantity being measured. Digital readout devices, which are increasingly being used for display purposes, eliminate or minimize most of the reading errors usually made by the observer.

اختلاف بزوايا القراءة

* not existing in the Digital display.

Errors due to parallax effect Parallax errors occur when the sight is not perpendicular to the instrument scale or the observer reads the instrument from an angle. Instruments having a scale and a pointer are normally associated with this type of error. The presence of a mirror behind the pointer or indicator virtually eliminates the occurrence of this type of error.

زي مثلاً يكون جهاز اله طرفيه قياس . وما يكونو parallel.

Effect of misalignment These occur due to the inherent inaccuracies present in the measuring instruments. These errors may also be due to improper use, handling, or selection of the instrument. Wear on the micrometer anvils or anvil faces not being perpendicular to the axis results in misalignment, leading to inaccurate measurements. If the alignment is not proper, sometimes sine and cosine errors also contribute to the inaccuracies of the measurement.

اذا القراءة ما كانت Zero

Zero errors When no measurement is being carried out, the reading on the scale of the instrument should be zero. A zero error is defined as that value when the initial value of a physical quantity indicated by the measuring instrument is a non-zero value when it should have actually been zero. For example, a voltmeter might read 1 V even when it is not under any electromagnetic influence. This voltmeter indicates 1 V more than the true value for all subsequent measurements made. This error is constant for all the values measured using the same instrument. A *constant error* affects all measurements in a measuring process by the same amount or by an amount proportional to the magnitude of the quantity being measured. For example, in a planimeter, which is used to measure irregular areas, a constant error might occur because of an error in the scale used in the construction of standard or, sometimes, when an incorrect conversion factor is used in conversion between the units embodied by the scale and those in which the results of the measurements are expressed.

Therefore, in order to find out and eliminate any systematic error, it is required to calibrate the measuring instrument before conducting an experiment. Calibration reveals the presence of any systematic error in the measuring instrument.

1.7.2 Random Errors

Uncontrollable errors.

Random errors provide a measure of random deviations when measurements of a physical quantity are carried out repeatedly. When a series of repeated measurements are made on a component under similar conditions, the values or results of measurements vary. Specific causes for these variations cannot be determined, since these variations are unpredictable and uncontrollable by the experimenter and are random in nature. They are of variable magnitude and may be either positive or negative. When these repeated measurements are plotted, they follow a normal or Gaussian distribution. Random errors can be statistically evaluated, and their mean value and standard deviation can be determined. These errors scatter around a mean value. If n measurements are made using an instrument, denoted by $v_1, v_2, v_3, \ldots, v_n$, then arithmetic mean is given as

$$\bar{v} = \frac{v_1 + v_2 + v_3 \ldots \ldots \ldots v_n}{n}$$

and standard deviation σ is given by the following equation:

$$\sigma = \pm\sqrt{\sum \frac{\left(v - \bar{v}\right)^2}{n}}$$

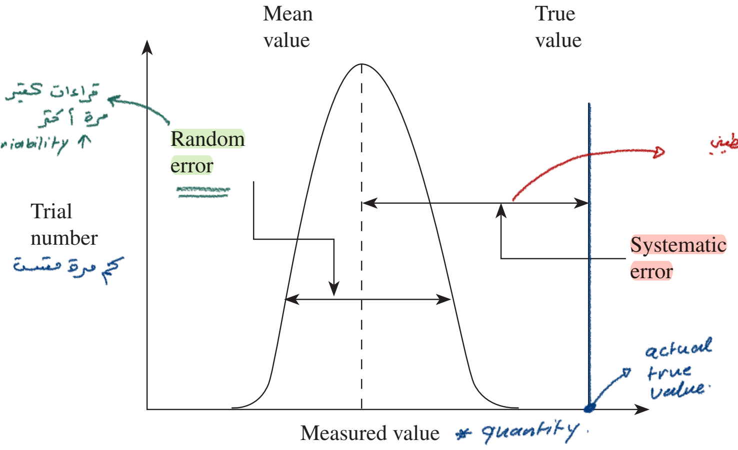
Standard deviation is a measure of dispersion of a set of readings. It can be determined by taking the root mean square deviation of the readings from their observed numbers, which is given by the following equation:

$$\sigma = \pm\sqrt{\sum \frac{\left(v_1 - \bar{v}\right)^2 + \left(v_2 - \bar{v}\right)^2 + \ldots + \left(v_n - \bar{v}\right)^2}{n}}$$

Random errors can be minimized by calculating the average of a large number of observations. Since precision is closely associated with the repeatability of the measuring process, a precise instrument will have very few random errors and better repeatability. Hence, random errors limit the precision of the instrument. The following are the likely sources of random errors:

1. Presence of transient fluctuations in friction in the measuring instrument
2. Play in the linkages of the measuring instruments
3. Error in operator's judgement in reading the fractional part of engraved scale divisions — not in the digital display
4. Operator's inability to note the readings because of fluctuations during measurement
5. Positional errors associated with the measured object and standard, arising due to small variations in setting

Figure 1.5 clearly depicts the relationship between systematic and random errors with respect to the measured value. The measure of a system's accuracy is altered by both systematic and random errors. Table 1.1 gives the differences between systematic and random errors.



قراءات كتير مرة أقل مرة أكتر
variability ↑

كم مرة قستة

ممكن الجهاز دايما بيعطيني قراءة أقل بسبب
* between the average and the true value.

actual true value.

* quantity.

Fig. 1.5 Relationship between systematic and random errors with measured value

Table 1.1 Differences between systematic and random errors

* * *

Systematic error	Random error
Not easy to detect not calibrated	Easy to detect because of the var.
Cannot be eliminated by repeated measurements	Can be minimized by repeated measurements
Can be assessed easily يمكن تقييمه	Statistical analysis required
Minimization of systematic errors increases the accuracy of measurement accuracy مقياس	Minimization of random errors increases repeatability and hence precision of the measurement precision precision مقياس
Calibration helps reduce systematic errors	Calibration has no effect on random errors
Characterization not necessary	Characterized by mean, standard deviation, and variance
Reproducible inaccuracies that are consistently in the same direction	Random in nature and can be both positive and negative (±) uncontrollable factors.

1.8 METHODS OF MEASUREMENT

When precision measurements are made to determine the values of a physical variable, different methods of measurements are employed. Measurements are performed to determine the magnitude of the value and the unit of the quantity under consideration. For instance, the length of a rod is 3 m, where the number, 3, indicates the magnitude and the unit of measurement is metre. The choice of the method of measurement depends on the required accuracy and the amount of permissible error. Irrespective of the method used, the primary objective is to minimize the uncertainty associated with measurement. The common methods employed for making measurements are as follows:

Direct method In this method, the quantity to be measured is directly compared with the primary or secondary standard. Scales, vernier callipers, micrometers, bevel protractors, etc., are used in the direct method. This method is widely employed in the production field. In the direct method, a very slight difference exists between the actual and the measured values of the quantity. This difference occurs because of the limitation of the human being performing the measurement.

Indirect method In this method, the value of a quantity is obtained by measuring other quantities that are functionally related to the required value. Measurement of the quantity is carried out directly and then the value is determined by using a mathematical relationship. Some examples of indirect measurement are angle measurement using sine bar, measurement of strain induced in a bar due to the applied force, determination of effective diameter of a screw thread, etc.

Fundamental or absolute method In this case, the measurement is based on the measurements of base quantities used to define the quantity. The quantity under consideration is directly measured, and is then linked with the definition of that quantity.

Comparative method In this method, as the name suggests, the quantity to be measured is compared with the known value of the same quantity or any other quantity practically related to it. The quantity is compared with the master gauge and only the deviations from the master gauge are recorded after comparison. The most common examples are comparators, dial indicators, etc.

Transposition method This method involves making the measurement by direct comparison, wherein the quantity to be measured (V) is initially balanced by a known value (X) of the same quantity; next, X is replaced by the quantity to be measured and balanced again by another known value (Y). If the quantity to be measured is equal to both X and Y, then it is equal to

$$V = \sqrt{XY}$$

An example of this method is the determination of mass by balancing methods and known weights.

Coincidence method This is a differential method of measurement wherein a very minute difference between the quantity to be measured and the reference is determined by careful observation of the coincidence of certain lines and signals. Measurements on vernier calliper and micrometer are examples of this method.

Deflection method This method involves the indication of the value of the quantity to be measured directly by deflection of a pointer on a calibrated scale. Pressure measurement is an example of this method.

Complementary method The value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to the predetermined comparison value. An example of this method is determination of the volume of a solid by liquid displacement.

Null measurement method In this method, the difference between the value of the quantity to be measured and the known value of the same quantity with which comparison is to be made is brought to zero.

Substitution method It is a direct comparison method. This method involves the replacement of the value of the quantity to be measured with a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same. The Borda method of determining mass is an example of this method.

Contact method In this method, the surface to be measured is touched by the sensor or measuring tip of the instrument. Care needs to be taken to provide constant contact pressure in order to avoid errors due to excess constant pressure. Examples of this method include measurements using micrometer, vernier calliper, and dial indicator.

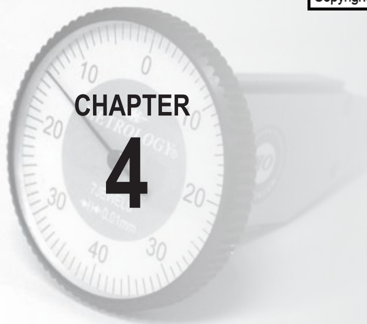
Contactless method As the name indicates, there is no direct contact with the surface to be measured. Examples of this method include the use of optical instruments, tool maker's microscope, and profile projector.

Composite method The actual contour of a component to be checked is compared with its maximum and minimum tolerance limits. Cumulative errors of the interconnected elements of the component, which are controlled through a combined tolerance, can be checked by this method. This method is very reliable to ensure interchangeability and is usually effected through the use of composite GO gauges. The use of a GO screw plug gauge to check the thread of a nut is an example of this method.

A QUICK OVERVIEW

- The importance and necessity of metrology have greatly increased with the industrial revolution, which emphasizes the importance of metrology in industries.
- Inspection is defined as a procedure in which a part or product characteristic, for example a dimension, is examined to determine whether it conforms to the design specification. Basically, inspection is carried out to isolate and evaluate a specific design or to measure the quality attribute of a component or product.
- We know that accuracy of measurement is very important in order to manufacture a quality product. *Accuracy* is the degree of agreement of the measured dimension with its true magnitude. It can also be defined as the maximum amount by which the result differs from true value.
- *Precision* is the degree of repetitiveness of the measuring process. It is the degree of agreement of the repeated measurements of a quantity made by using the same method, under similar conditions.
- The ability of the measuring instrument to repeat the same results during the act of measurements for the same quantity is known as *repeatability*.
- The difference between the true value and the mean value of the set of readings on the same component is termed as an *error*. Error can also

*linear measurement devices: devices used to measure linear distances



CHAPTER

4

Linear Measurement

After studying this chapter, the reader will be able to

- understand the basic principles of design of linear measuring instruments
- explain the use of 'datum planes' in dimensional measurement
- appreciate the advantages offered by scaled instruments in contrast to a simple steel rule, and discuss the various applications and limitations of their variants
- elucidate the vernier family of instruments for linear measurement and read vernier instruments
- describe how Abbe's law applies to micrometer measurement
- explain how the micrometer principle has developed into a family of diverse instruments
- utilize the digital electronic instruments in linear measurement
- explain the use of slip gauges, and their manufacture and calibration

4.1 INTRODUCTION

In Chapter 2, the methods by which engineering standards of length are established were discussed. Both direct and indirect linear measuring instruments conform to these established standards of length and provide convenient means for making accurate and precise linear measurements. Vernier calliper and vernier micrometer are the most widely used linear measuring instruments in machine shops and tool rooms. Measuring instruments are designed either for line measurements (e.g., steel rule or vernier calliper) or for end measurements in order to measure the distance between two surfaces using an instrument (e.g., screw gauge). Callipers and dividers, which are also linear measurement devices, are basically *dimension transfer instruments*. They will not directly provide the measurement of length on a scale. Quality of measurement not only depends on the accuracy of these instruments, but also calls for application of certain simple principles to be followed during measurements. Illustrations are given throughout this chapter, especially on the latter issue, to highlight that care should be exercised for the proper use of linear measuring instruments.

Most people's first contact with linear measurement is with a steel rule or a tape measure. However, today's engineer has a choice of a wide range of instruments—from purely

* better devices in the accuracy

easier to read but more cost.

more accurate

How much accuracy needed? & How much cost ?

mechanically operated instruments to digital electronics instruments. One has to consider only the nature of application and cost of measurement to decide which instrument is the best for an application. This chapter covers a broad range of linear measurement instruments, from a simple steel rule to digital callipers and micrometers. However, many of these instruments, such as depth gauge and height gauge, need to be used with a datum to ensure accuracy of measurements. The foundation for all dimensional measurements is the 'datum plane', the most important ones being the surface plate and the V-block. Constructions of the surface plate and V-block are also explained with illustrations.

4.2 DESIGN OF LINEAR MEASUREMENT INSTRUMENTS

The modern industry demands manufacture of components and products to a high degree of dimensional accuracy and surface quality. Linear measurement instruments have to be designed to meet stringent demands of accuracy and precision. At the same time, the instruments should be simple to operate and low priced to make economic sense for the user. Proper attachments need to be provided to make the instrument versatile to capture dimensions from a wide range of components, irrespective of the variations in cross-sections and shapes. The following points highlight important considerations that have to be addressed in the design of linear measurement instruments:

① For Example : steel rule with thin & bold lines more accuracy.

1. The measuring accuracy of line-graduated instruments depends on the original accuracy of the line graduations. Excessive thickness or poor definition of graduated lines affects the accuracy of readings captured from the instrument.
2. Any instrument incorporating a scale is a suspect unless it provides compensation against wear.
3. Attachments can enhance the versatility of instruments. However, every attachment used along with an instrument, unless properly deployed, may contribute to accumulated error. Wear and tear of attachments can also contribute to errors. Use attachments when their presence improves reliability more than their added chance for errors decreasing it.
4. Instruments such as callipers depend on the feel of the user for their precision. Good quality of the instrument promotes reliability, but it is ultimately the skill of the user that ensures accuracy. Therefore, it is needless to say that proper training should be imparted to the user to ensure accurate measurements.
5. The principle of alignment states that the line of measurement and the line of dimension being measured should be coincident. This principle is fundamental to good design and ensures accuracy and reliability of measurements.
6. Dial versions of instruments add convenience to reading. Electronic versions provide digital readouts that are even easier to read. However, neither of these guarantees accuracy and reliability of measurements unless basic principles are adhered to.
7. One important element of reliability of an instrument is its *readability*. For instance, the smallest division on a micrometer is several times larger than that on a steel rule of say 0.1 mm resolution, which is difficult to read. However, the micrometer provides better least count, say up to 0.01 mm, compared to the same steel rule. Therefore, all other things being equal, a micrometer is more reliable than even a vernier scale. However, micrometers have a lesser range than verniers.

more cost

8. If cost is not an issue, digital instruments may be preferred. The chief advantage of the electronic method is the ease of signal processing. Readings may be directly expressed in the required form without additional arithmetic. For example, they may be expressed in either metric or British units, and can also be stored on a memory device for further use and analysis.
9. Whenever a contact between the instrument and the surface of the job being measured is inevitable, the contact force should be optimum to avoid distortion. The designer cannot leave the fate of the instrument on the skill of the user alone. A proper device like a *ratchet stop* can limit the contact force applied on the job during measurements, thereby avoiding stress on the instrument as well as distortion of the job.

4.3 SURFACE PLATE

* اشي بستخدمه عشان اعمل القياس عليه

* used in the linear & the angular measurments

In Section 4.2, we understood that every linear measurement starts at a reference point and ends at a measured point. This is true when our basic interest is in measuring a single dimension, length in this case. However, the foundation for all dimensional measurements is the 'datum plane', the most important one being the surface plate. A surface plate is a hard, solid, and horizontal flat plate, which is used as the reference plane for precision inspection, marking out, and precision tooling set-up (Fig. 4.1). Since a surface plate is used as the datum for all measurements on a job, it should be finished to a high degree of accuracy. It should also be robust to withstand repeated contacts with metallic workpieces and not be vulnerable to wear and tear.

workpiece.

The history of surface plates can be traced to the early 19th century when Richard Robert invented the planer in 1817, which was presumably the first machine tool that used a flat surface. He showed a way of duplicating flat surfaces with a high degree of accuracy, and the world of sliding motions and flat surfaces was born. However, the surface plates used by Roberts were of quite low accuracy compared to today's standards. One should credit the contribution of Sir Joseph Whitworth, a leading name in metrology, who recognized the lack of understanding of the concept of flatness at that time and devised a methodology in the year 1840 for generating a flat surface by the 'three-plate method'. This method is being used even today to manufacture surface plates, although better and modern methods of fabricating surface plates are becoming increasingly popular. In this method, three cast iron plates with ribbed construction (for rigidity) are rough machined along their edges and top surfaces. The plates are kept in the open for normalizing for about a year. Natural changes in temperature relieve the internal stresses. The plates are then finish-machined to a high degree of accuracy and are marked #1, #2, and #3, and applied with a coating of Prussian blue. In a six-step process, the surfaces of two of the plates are placed in contact in a particular order and the blued portions are scraped. The pairing of the plates is varied in a preplanned sequence, which ensures that all three surfaces match to a high degree, thereby ensuring accurate flat surfaces.

* flat surface
* with angles
(to make sure it horizontal).

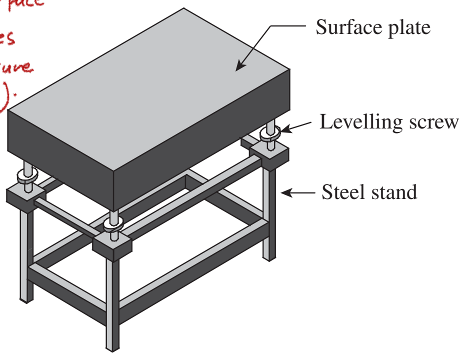


Fig. 4.1 Surface plate

The surface plates are made either from cast iron or from granite. Even though granite surface plates are perceived to be superior, cast iron surface plates are still in wide use. In fact, a cast iron surface plates is used as a tool for lapping granite surface plates to the required degree of accuracy. Cast iron allows itself to be impregnated with the lapping media over a large flat surface. In the following paragraphs, we will look into the construction and use of cast iron and granite surface plates in greater detail.

مش مهمين
كتير

Cast Iron Surface Plates

Despite a drop in their usage, cast iron surface plates still retain popularity as surface masters. They are made of either plain or alloyed close-grained cast iron, reinforced with ribs to provide strength against bending or buckling. IS2285-1991 specifies the composition, size, and cross-sectional details of ribs and thickness of plates. The plates are manufactured in three grades, namely grade 0, grade I, and grade II. While grade 0 and grade I plates are hand scraped to achieve the required degree of flatness, grade II plates are precision machined to the required degree of accuracy. Table 4.1 illustrates some of the standard sizes of surface plates as per IS 2285-1991.

Table 4.1 Cast iron surface plate specifications as per IS 2285-1991

Size (mm)	Maximum deviation from flatness in microns			Approximate weight (kg)
	Grade 0	Grade I	Grade II	
300 × 300	4	7	15	21
400 × 400	4.5	9	17	50
450 × 300	4	8	16	39
450 × 450	4.5	9	18	62
600 × 450	5	10	20	79
630 × 400	5	10	20	96
600 × 600	5	10	20	128
630 × 630	5	10	21	156
900 × 600	6	12	23	204
1500 × 1200	8	16	33	986

Smaller-size plates are usually provided with a handle. All surface plates need to be provided with protective covers when not in use. Fabricated heavy angle iron stands with levelling screws provide convenient working height for surface plates. As per the proven practice devised by Sir Whitworth, surface plates are fabricated in sets of three. Cast iron is dimensionally more stable over time compared to granite plates. Unlike granite, it also has uniform optical properties with very small light penetration depth, which makes it a favourable material for certain optical applications. One significant drawback of cast iron is its higher coefficient of thermal expansion, which makes it unsuitable for applications involving large variations in temperature.

لما يكون في حرارة بيعمل expansion
بشكل سريع

مش منيح للاستخدام عشان درجات الحرارة

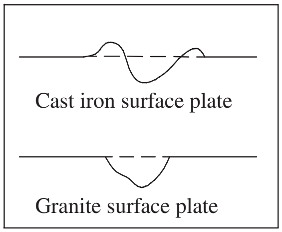


Fig. 4.2 Comparison between CI and granite surfaces

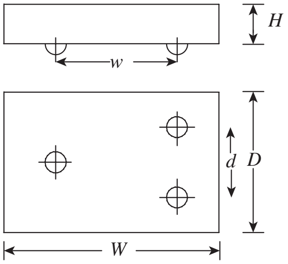


Fig. 4.3 Dimension parameters used in Table 4.2

Granite Surface Plates

In recent times, granite has replaced cast iron as the preferred material for surface plates. Most surface plates are made of black granite, while pink granite is the next preferred choice. Granite has many advantages over cast iron. Natural granite that is seasoned in the open for thousands of years is free from warp age or deterioration. It is twice as hard as cast iron and not affected by temperature changes. It is not vulnerable to rusting and is non-magnetic. As shown in Fig. 4.2, it is free from burrs or protrusions because of its very fine grain structure.

Table 4.2 lists some of the standard sizes of surface plates as per IS 2285-1991. Figure 4.3 illustrates the meaning of dimension parameters used in Table 4.2. The plates are manufactured in three grades, namely grade 00, grade 0, and grade 1. Flatness for grade 00 surface plates range from 0.002 to 0.007 mm, whereas that for grade 0 plates varies from 0.003 to 0.014 mm. Grade 1 plate is the coarsest, with flatness ranging from 0.005 to 0.027 mm.

Table 4.2 Sizes of granite surface plates as per IS 2285-1991

Grade	S. no.	Dimensions *W* × *D* × *H* (mm)	Flatness (mm)	*w* (mm)	*d* (mm)	Mass (kg)
00	1	300 × 300 × 100	0.002	240	240	27
	2	450 × 300 × 100	0.002	390	240	40
	3	750 × 500 × 130	0.003	630	420	146
	4	1500 × 1000 × 200	0.004	1100	700	900
	5	3000 × 2000 × 500	0.007	2000	1500	9000
0	1	300 × 300 × 100	0.003	240	240	27
	2	450 × 300 × 100	0.003	390	240	40
	3	750 × 500 × 130	0.005	630	420	146
	4	1500 × 1000 × 200	0.008	1100	700	900
	5	3000 × 2000 × 500	0.014	2000	1500	9000
1	1	300 × 300 × 100	0.005	240	240	27
	2	450 × 300 × 100	0.006	390	240	40
	3	750 × 500 × 130	0.009	630	420	146
	4	1500 × 1000 × 200	0.016	1100	700	900
	5	3000 × 2000 × 500	0.027	2000	1500	9000

Glass Surface Plates

Glass is an alternative material for surface plates. It was used during World War II when material and manufacturing capacity were in short supply. Glass can be ground suitably and has the benefit that it chips rather than raising a burr, which is a problem in cast iron surface plates.

→ while the former is convenient for clamping the job onto the V-block, so that measurements can be made accurately, the latter has a magnetic base.

4.4 V-BLOCKS

used in the linear & angular measurements

V-blocks are extensively used for inspection of jobs with a circular cross section. The major purpose of a V-block is to hold cylindrical workpieces to enable measurement. The cylindrical surface rests firmly on the sides of the 'V', and the axis of the job will be parallel to both the base and the sides of the V-block. Generally, the angle of the V is 90°, though an angle of 120° is preferred in some cases. It is made of high-grade steel, hardened above 60 Rc, and ground to a high degree of precision. V-blocks are manufactured in various sizes ranging from 50 to 200 mm. The accuracy of flatness, squareness, and parallelism is within 0.005 mm for V-blocks of up to 150 mm length, and 0.01 mm for those of length between 150 and 200 mm (Fig. 4.4).

V-blocks are classified into two grades, grade A and grade B, according to IS: 2949-1964, based on accuracy. Grade A V-blocks have minimum departure from flatness (up to 5 µm for 150 mm length) compared to grade B V-blocks.

There are many variants of V-blocks, such as V-blocks with clamp, magnetic V-block, and cast iron V-block. Figure 4.5 illustrates a V-block with a stirrup clamp. It is convenient for clamping the job onto the V-block, so that measurements can be made accurately. Another popular type of V-block is the magnetic V-block, shown in Fig. 4.6. The magnetic base sits on a flat surface, preferably on a surface plate. The base and two sides are energized for gripping onto a flat surface and a 'vee'slot enables the device to grip the job firmly with a circular cross section. A push-button control turns the permanent magnetic field on and off, thereby enabling the attachment or detachment of the V-block to a flat surface. All three magnetic surfaces are carefully ground and, when switched on, all three magnetic surfaces are activated simultaneously. Magnetic V-blocks are used in tool rooms for drilling and grinding round jobs.

4.5 GRADUATED SCALES

only linear measurement device.

accuracy ↑ ⇒ cost ↑

We often use the words 'rule' and 'scale' to mean the simple devices that we have been using since primary-school geometry class. However, there is a clear difference in the actual meaning of these two familiar words. A scale is graduated in *proportion* to a unit of length. For example,

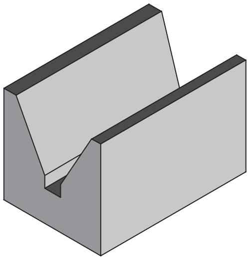
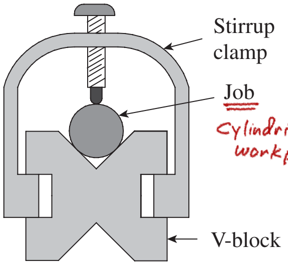
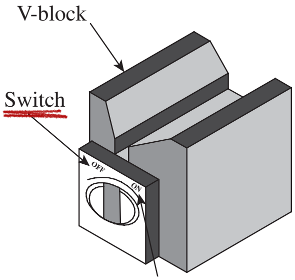


Fig. 4.4 V-block



Cylindrical workpiece.

Fig. 4.5 V-block with a stirrup clamp

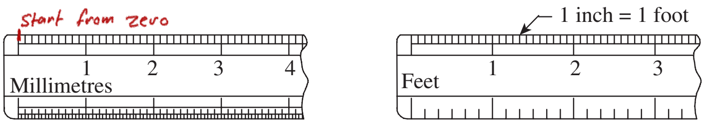


بشغل المغناطيس
لما بدي اشبكه على
surface plate.

Fig. 4.6 Magnetic V-block

* V-block could be used to find the center of cylindrical workpiece

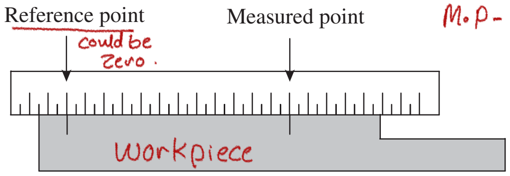
the divisions in an architect's scale, illustrated in Fig. 4.7, represent feet and inches, while the plumber's scale would have divisions in terms of 1/32th or 1/64th of an inch. The divisions of a rule, on the other hand, are the unit of length, its divisions, and its multiples. Typically, the rules with which we are familiar have graduations (in centimetres, millimetres, or inches) and their decimal divisions throughout the length.



Steel rule Architect's scale

Fig. 4.7 Illustration of the difference between a rule and a scale

Steel rules are most popular in metrology applications since they are more accurate and durable compared to rules made from other materials such as wood or plastic. While rigid rules can be used for laying out lines on a job, flexible steel rules can also be used to measure surfaces with circular profiles. Steel rules are either stamped or cut from a roll of spring steel. The graduations are photo-engraved and tempered with satin chrome finish for good readability. The ruler can be 150, 300, 500, or 1000 mm long; 19 or 25 mm wide; and 1. mm thick. The finer sub-divisions may be marked either throughout the length of the scale or in only a part of its length.



M.P - R.P = dim.

Fig. 4.8 Illustration of reference and measured points

The use of steel rule requires consideration of the relationship between the reference point and the measured point. Figure 4.8 illustrates the preferred way of choosing the reference point for making a measurement. A graduated line on the rule, rather than an edge of the rule, is selected as the reference point. This method improves the accuracy of measurement considerably, even though a little effort is required to align carefully, the reference and measured points. It is recommended not to use the edge of the rule as the reference point, as the edge is subjected to wear and tear and worn-out corners may contribute to error in measurements. Sometimes an attachment such as a hook or a knee is used to facilitate measurement, as shown in Fig. 4.9.

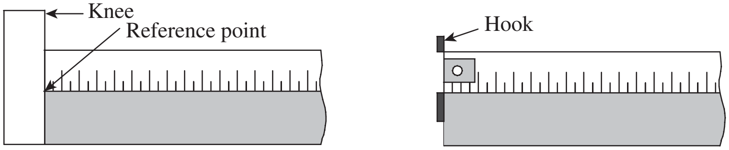


Fig 4.9 Correct ways of using a rule with attachments

4.5.1 Errors in Measurements

Steel rules are often used on the manufacturing shop floors for making measurements. Even though the least count of rules is limited to 1 mm or at the most to 0.5 mm, the user should never be lax in the usage of any measuring device, however simple or trivial it may be. Therefore, one should be aware of the two common errors that can creep up in measurements involving rules. The first one is an inherent error because of poor quality of the rule. This can be attributed to either poor quality of the material of the rule or poor workmanship in the manufacture of the rule. One can avoid this by purchasing a good-quality rule from a standard vendor.

The second error may creep up because of wrong usage of a rule and the observational error. The rule should be properly aligned with the job being measured, ensuring that the reference and measured points are set accurately. The rule should not be twisted or bent in the process of measurement. The major observational error occurs because of parallax error. This is illustrated in Fig. 4.10. Parallax is the apparent shift in the position of an object caused by the change of position of the observer. If an observer views the scale along the direction B or C, the line of sight would be such that there is an apparent shift in the recorded reading by a division or two, as apparent from Fig. 4.10. The more the shift of the eye, from a vertical position right above the measured point, the more pronounced the error. It is needless to say that parallax error can be avoided if the observer recognizes this typical error and takes care to align his/her eyesight in the direction A, shown in Fig. 4.10.

Steel rules come in various sizes and shapes, depending upon the requirements of the component being measured. Accordingly, there are narrow rules, flexible fillet rules, short rules with holders, angle rules, measuring tapes, pocket tapes, and so on (Fig. 4.11). Narrow rules, fillet rules, and angle rules are used for measuring the inside of small holes, narrow slots, and grooves. Short rules with holders are convenient for measuring within recesses. Short rule is an extension of steel rule and obeys the same principle For very precise measurements, temperature expansion and contraction must be considered.

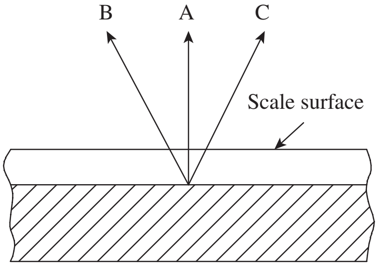
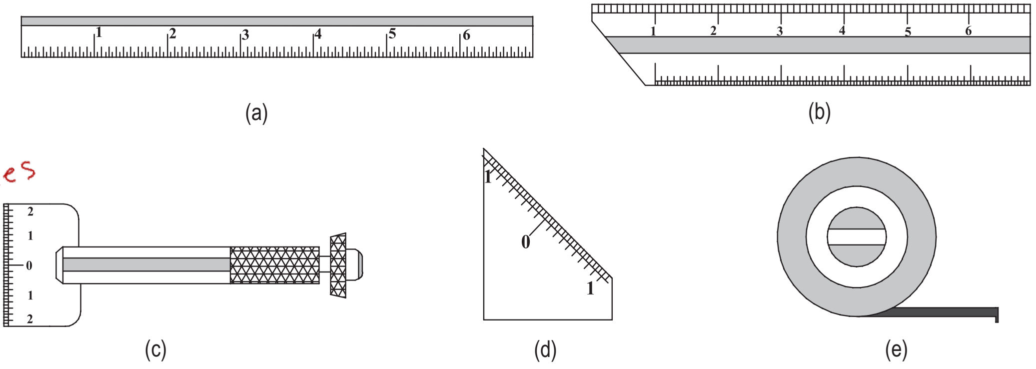


Fig. 4.10 Parallax error that can be minimized by direct eye measurements



Examples of the steel rule.

Fig. 4.11 Types of steel rules (a) Narrow tempered steel rule (b) Flexible fillet rule (c) Short rule with holder (d) Angle rule (e) Steel measuring tape

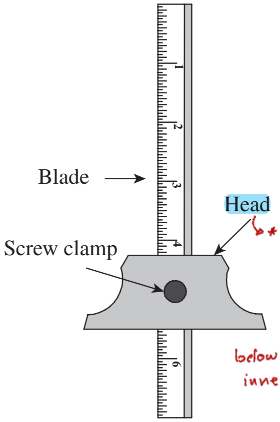
للمناطق الصغيرة صعب نوصلها

4.6 SCALED INSTRUMENTS

Rules are useful for many shop floor measurements. However, measurements of certain components require some mechanical means to either hold the measuring device steadily against the component being measured or capture the reading, which can be read at leisure. Another important advantage of a scaled instrument is that the least count of measurement can be improved greatly compared to an ordinary steel rule. Most of the modern scaled instruments provide digital display, which comes with a high degree of magnification. Measurements can be made up to micron accuracy. This section presents three scaled instruments, namely depth 1.) * gauge, combination set 2.), and callipers 3.), which are necessary accessories in a modern metrology laboratory.

4.6.1 Depth Gauge

Depth gauge is the preferred instrument for measuring holes, grooves, and recesses. It basically consists of a graduated rod or rule, which can slide in a T-head (simply called the head) or stock. The rod or rule can be locked into position by operating a screw clamp, which facilitates accurate reading of the scale. Figure 4.12 illustrates a depth gauge, which has a graduated rule to read the measurement directly. The head is used to span the shoulder of a recess, thereby providing the reference point for measurement. The rod or rule is pushed into the recess until it bottoms. The screw clamp helps in locking the rod or rule in the head. The depth gauge is then withdrawn, and reading is recorded in a more convenient position. Thus, depth gauge is useful for measuring inaccessible points in a simple and convenient manner.



↳* moveable part

below the head for inner dim.

Fig. 4.12 Depth gauge

As already pointed out, either rods or rules can be used in depth gauges for the purpose of measurement. Although a slender rod can easily transfer measurements from narrow and inaccessible holes and recesses, the instrument cannot directly display the reading. One has to use another rule to measure the length of the protruded rod and record the measurement. This may lead to errors in measurements and reduce the reliability of the instrument. To overcome this problem, a graduated rod can be used, which can indicate the measurement directly. However, it is somewhat difficult to read graduations from a slender rod. Therefore, a narrow flat scale is the preferred choice for depth gauges. The rule is often referred to as the blade and is usually 150 mm long. The blade can accurately read up to 1 or ½ mm.

As already pointed out, the head is used to span the shoulder of a recess, thereby providing the reference point for measurement. This is illustrated in the rod-type depth gauge shown in Fig. 4.13. The end of the rod butts against the end surface to provide the measured point. Whenever depth needs to be measured, the projected length of the rod from the head is made very less. The lower surface of the head is firmly held against the job to ensure accurate location of the measured point. Now the rod is lowered until it butts against the surface of the job, thereby marking the measured point. The screw clamp is tightened, the instrument is slowly taken out, and the depth of the hole is read in a convenient position. This method is preferred for narrow recesses and holes. To summarize, the depth gauge is first positioned against the reference point, followed by the capture of the measured point in order to complete the measurement process.

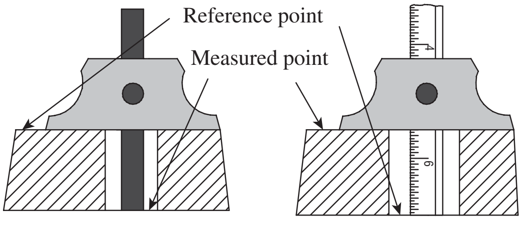


Fig. 4.13 Measured and reference points in depth gauges

Sometimes, it becomes necessary to alter the reference and measured points to suit the requirement, as illustrated by the blade-type depth gauge in Fig. 4.13. If the hole is large enough for visually positioning the blade of the depth gauge, the preferred method is to first locate the end of the blade against the lower surface of the hole. The blade is extended from the head, the instrument is brought close to the job, and the end of the blade is butted against the lower surface of the hole. This establishes the reference point for measurement. Now, the head is lowered and the lower surface of the head is made to butt against the top of the job, as shown in Fig. 4.10. The surface of the head provides the measured point. The screw clamp is now tightened and the measurement recorded.

Although depth gauge provides an easy and convenient method for measuring depths of holes and recesses, it has the following limitations:

1. The job size is limited by the width of the head of the depth gauge. Usually, the maximum width of the hole that can be spanned is about 50 mm.
2. The base of the head should be perpendicular to the line of measurement. Otherwise, the line of measurement will be skewed, resulting in erroneous readings.
3. The end of the blade must butt against the desired reference. This will be rather difficult to achieve, especially in blind holes.
4. The end of the blade and the lower surface of the head are always in contact with the job being measured. Therefore, these surfaces will undergo wear and tear. The instrument should be periodically checked for accuracy and replaced if the wear amounts to one graduation line of the instrument.

لما نكون بنستخدمها فنكون مركبين عليها قطعة
من ضمن الـ(٣) قطع.

4.6.2 Combination Set

A combination set has three devices built into it: a combination square comprising a square head and a steel rule, a protractor head, and a centre head. While the combination square can be used as a depth or height gauge, the protractor head can measure the angles of jobs. The centre head comes in handy for measuring diameters of jobs having a circular cross section. The combination set is a useful extension of steel rule. This non-precision instrument is rarely used in any kind of production inspection. However, it is frequently used in tool rooms for tool and die making, pattern making, and fabrication of prototypes. It is a versatile and interesting instrument that has evolved from a try-square, which is used for checking squareness between two surfaces.

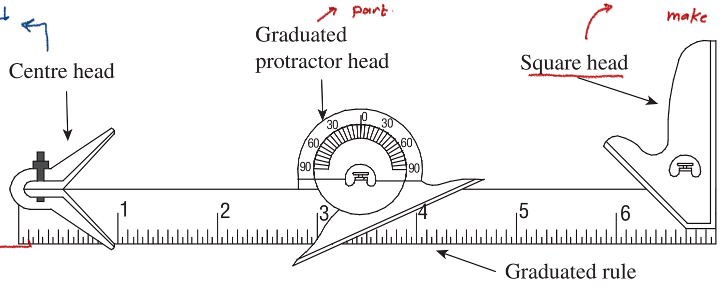
The graduated steel rule is grooved all along its length. The groove enables the square head to be moved along the length of the rule and fixed at a position by tightening the clamp screw provided on the square head. The square head along with the rule can be used for measuring heights and depths, as well as inside and outside squaring operations. The blade of the graduated circular cross-section

لما يكون عندي مثلا

moveable part

T-square. بحسير نفس فكرة

make right angle.



steel rule

Fig. 4.14 Combination set

protractor head can be swivelled to any angle, which enables the measurement of angles on jobs. The protractor can also be moved along the scale and fixed at a convenient point. Protractors of some combination sets are provided with a spirit level for the purpose of levelling a surface. The centre head attachment is used with the rule to locate the centre of bar stocks. The illustration in Fig. 4.14 shows how each of these attachments are integrated in the combination set.

* Spirit Levels
tube inside the device
فيه سائل عشان يتأكد
مدا استقامة سطح معين
* نفس فكرة ميزان المي

Square Head

The square head along with the graduated rule on the combination set provides an easy way of measuring heights and depths. While the square head provides a right angle reference, the rule provides a means for directly taking the readings. However, a primary requirement is that the square head can be used only against a flat reference surface. Figure 4.15 illustrates a typical method of measuring height using the combination set. The square head is firmly held against a flat surface of the job, and the rule is lowered until it touches the reference point at the bottom of the job, as shown in the figure. The rule can be locked in this position, and the reading noted down in a convenient position. Attachments are available to mark the measured point with reference to the end of the steel rule. The range of measurement can also be extended by using attachments. In some instruments, the square head is provided with a spirit level, which can be used to test the surfaces for parallelism. A scribing point is provided at the rear of the base in some instruments for scribing purposes.

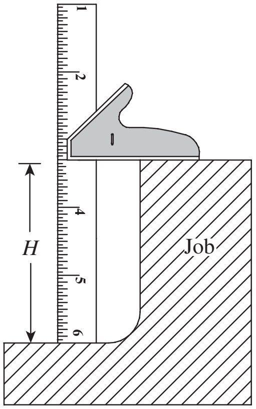


Fig. 4.15 Combination square as a height gauge

Protractor Head

Figure 4.16 illustrates the use of the protractor head on the combination set. This head comprises a rotatable turret within a stock. The turret has an angular scale graduated in degrees. Similar to the square head, the protractor head can also slide along the rule. The blade of the protractor is held firmly against the job and the angle can be directly read from the scale. A spirit level provided on the protractor head can be used for the purpose of levelling a surface. The protractor can also be used to determine the deviation of angle on the job from the desired one. The protractor is first set to the correct angle and locked in position. Now it is held against

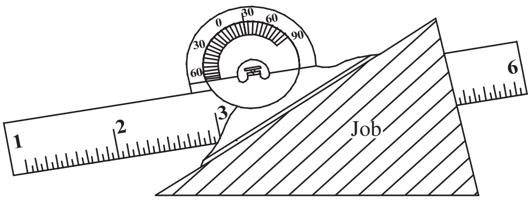


Fig. 4.16 Use of a protractor head for angle measurement

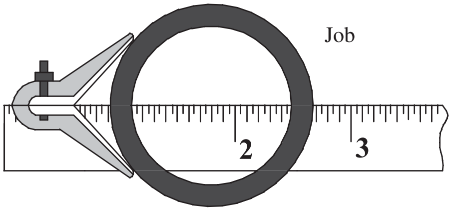


Fig. 4.17 Use of a centre head for the measurement of diameter

the surface of the job for which angle is to be measured. Any deviation from the desired angle can be checked by inserting angle gauges (feeler gauges) in the gap between the blade of the protractor and the job.

Centre Head

The centre head attachment is used along with the steel rule to locate the centre of a bar stock or a circular job. It can be seen from Fig. 4.17 that one edge of the steel rule bisects the V-angle of the centre head. Therefore, it lies on the centre line of any circular job held against the centre head. The diameter of the job can be directly read on the graduated scale, which is useful for marking the centre of the job by using a scriber. The V between the two blades of the centre head facilitates accurate positioning of circular jobs, which greatly improves measurement accuracy when compared to taking readings directly using a rule held against the job. The latter method is completely manual and depends on the skill of the person taking the reading, and therefore is highly prone to error.

Combination sets are available in various sizes. The length of the steel rule ranges from 150 to 600 mm. The scales are graduated in mm and 0.5 mm, and the graduations are available on both sides of the scale. Considering two sets of graduations on one side of the rule, it is possible to have four scales with different graduation schemes and least count. This enhances the versatility of the instrument considerably.

4.6.3 Callipers

(transfer)

* indirect

not graduated.

- will use another measuring device.

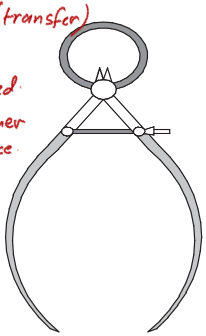


Fig. 4.18 Callipers, the original transfer instruments

There are many jobs whose dimensions cannot be accurately measured with a steel rule alone. A typical case in point is a job with a circular cross section. An attempt to take measurement using a steel rule alone will lead to error, since the steel rule cannot be positioned diametrically across the job with the required degree of accuracy. One option is to use the combination set. However, callipers are the original transfer instruments to transfer such measurements on to a rule (Fig. 4.18). They can easily capture the diameter of a job, which can be manually (identified as the maximum distance between the legs of the calliper) that can just slide over the diameter of the job. Even though callipers are rarely used in production inspection, they are widely used in tool room and related work. *

↳ production line لاين قطعة

Busch defines *callipers as instruments that physically duplicate the separation between the reference point and measured point of any dimension*

* outside Calipers : measure external dim. for workpiece

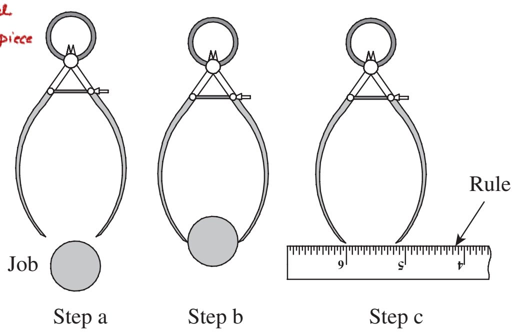


Fig. 4.19 Calliper being used to transfer a dimension from a job to a rule

within their range. Thus, callipers do only the job of transferring a dimension, but not of measuring instruments on their own. This is illustrated in Fig. 4.19, where a calliper is shown transferring the outer diameter of a job on to a graduated steel rule, to read the dimension accurately and conveniently. The outer diameter of a job is to be measured (Step a). Aligning the ends of the two legs of the calliper to a feature of the part being measured, like the one shown in Fig. 4.19, is accomplished quite easily (Step b) because the calliper provides for easy flexing of the two legs and a means of locking them into position whenever required. Now, simply laying the ends of the calliper on a steel rule facilitates easy measurement of the dimension in question (Step c). Thus, as the definition stated earlier mentions, physical duplication of the separation of reference and measured points is accomplished with a high degree of accuracy.

Callipers are available in various types and sizes. The two major types are the *firm joint calliper* and the *spring calliper*. A firm joint calliper, as the name itself suggests, can hold the position of two legs opened out to a particular degree unless moved by a certain force. This is possible because of higher friction developed at the joint between the two legs of the calliper. They are adjusted closely for size by gentle tapping of a leg. A locknut is needed to lock the calliper in a particular position. On the other hand, a spring calliper can hold a particular position due to the spring pressure acting against an adjusting nut. This permits a very careful control, and no lock is needed. Figure 4.20 illustrates the classification of callipers. Callipers are manufactured in a large number of sizes. They are designated not by their measurement ranges, but by the length of their legs,which range from 50 to 500 mm.

Figure 4.21 illustrates the different types of callipers. These are all simple callipers, whose ends are adjustable to transfer a measurement from the job to a steel rule. Although a member of the calliper family, a divider classified under callipers is simply referred to as a divider.

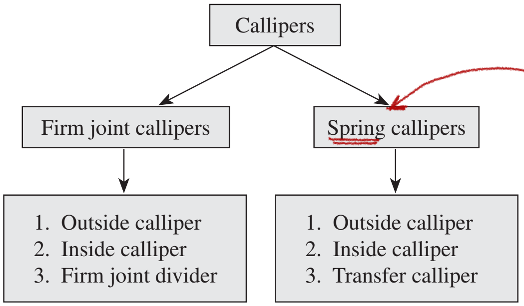


Fig. 4.20 Classification of callipers

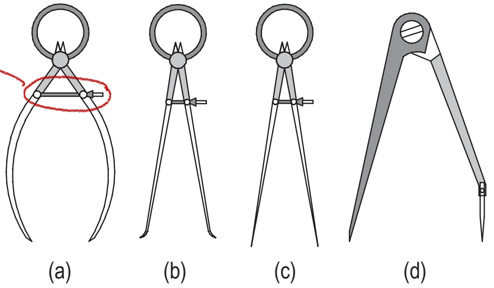


Fig. 4.21 Types of callipers (a) Outside calliper (b) Inside calliper (c) Divider (d) Hermaphrodite calliper

↳ to measure the inside dim. of the workp.

Outside calliper As the name suggests, an outside calliper is used to measure the outside or external dimensions. While taking measurements, the legs of the calliper should be set gently against the job either by a small physical force in case of a firm joint calliper or by an adjustment of the nut in case of a spring calliper. The user should ensure that a firm contact is established between the calliper and the job before transferring the measurement to a rule. One leg of the calliper is firmly held against a graduation on the steel rule to establish the reference point. The other leg is now gently transferred on to the rule to capture the measured point. The legs of callipers are made of alloy steel, with the measuring points being heat treated to withstand wear and tear. The legs are of a rectangular cross section, and should be free from cracks and any other type of flaw for longevity. The springs in spring callipers are made of spring steel, which is hardened and tempered. The spring force is adjusted by a knurled nut operating on a precision machined screw.

Inside calliper As illustrated in Fig. 4.21, the measuring ends of the legs of an inside calliper are shaped in the form of a hook. While taking measurements, the calliper legs are initially in a folded condition, which are inserted into the component. Now, the legs are stretched out to butt against the surface of the job. The calliper is carefully rocked over the centre. The feel provided as they pass the centre is the limit of their sensitivity.

Divider As with callipers, the primary use of dividers is to transfer measurements. However, they are used with line references rather than with surface references. Dividers are used for the following tasks: (a) transferring a dimension of a job to a rule for measurement, (b) transferring a dimension from one part to another part, and (c) transferring a dimension from a rule to a job for layout of the part. Scribing arcs during layout work is another chief use of dividers.

Hermaphrodite calliper It is essentially a scribing tool comprising one divider leg and one calliper leg. The scriber can be mounted by means of a locknut, as shown in Fig. 4.21. The chief advantage of a hermaphrodite calliper is that a scriber of any required shape and size can be fitted to it and used.

The proper use of the inside and outside callipers depends to a large extent on the skill of the person taking measurements. Measuring with a calliper consists of adjusting the opening so that its reference points duplicate the features of the job being measured. In other words, there is no other provision in a calliper that helps in its alignment than the reference points. As illustrated in Fig. 4.22, the greatest accuracy is achieved in case of callipers when the line of measurement coincides with a plane perpendicular to the job. The divider provides the best accuracy when the measurements are taken from well-marked lines, as shown in Fig. 4.22. Many a time measurements need to be taken between edges, in which case care must be exercised in ascertaining the proper way of taking measurements.

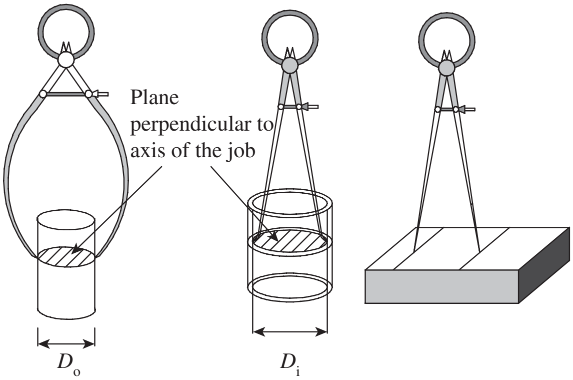


Fig. 4.22 Measurement using callipers (a) Outside calliper (b) Inside calliper (c) Divider

4.7 VERNIER INSTRUMENTS

main scale
+ vernier scale

The instruments discussed in this chapter until now can be branded 'non-precision' instruments, not for their lack of precision but for their lack of amplification. A steel rule can measure accurately up to 1 mm or at best up to 0.5 mm. It is not sensitive to variations in dimensions at much finer levels because of the inherent limitation in its design. On the other hand, vernier instruments based on the vernier scale principle can measure up to a much finer degree of accuracy. In other words, they can amplify finer variations in dimensions and can be branded as 'precision' instruments.

The vernier scale was invented in its modern form in 1631 by the French mathematician Pierre Vernier (1580–1637). Vernier instruments are being used for more than two centuries. The American, Joseph Brown, is credited with the invention of the vernier calliper. As is perhaps known to a student, a vernier scale provides a least count of up to 0.01 mm or less, which remarkably improves the measurement accuracy of an instrument. It has become quite common in the modern industry to specify dimensional accuracy up to 1 μm or less. It is the responsibility of an engineer to design and develop measuring instruments that can accurately measure up to such levels.

It will not be out of place here to briefly brush up our memory of the basic principles of a vernier scale. A vernier scale comprises two scales: the main scale and the vernier scale. Consider the scale shown in Fig. 4.23. Let us say that the main scale has graduations in millimetres up to a minimum division of 1 mm. The vernier scale also has graduations, having 10 equal divisions. In this example, 10 vernier scale divisions (VSDs) equal nine main scale divisions (MSDs). Obviously, the value of one VSD is less than one MSD. Such a vernier scale is called a *forward vernier*. On the other hand, suppose 10 VSDs equal 11 MSDs, the value of one VSD is more than that of one MSD. Such a vernier scale is called the *backward vernier*.

Calculation of least count The minimum length or thickness that can be measured with a vernier scale is called the *least count*. For a forward vernier shown in Fig. 4.23,

$$N \text{ VSD} = (N-1) \text{ MSD}$$

$$1 \text{ VSD} = (N-1)/N \text{ MSD}$$

$$\text{Least count} = 1 \text{ MSD} - 1 \text{ VSD}$$

Therefore, $\text{Least count} = 1 \text{ MSD} - (N-1)/N \text{ MSD}$

$$\text{Least count} = [1-(N-1)/N] \text{ MSD}$$

$$\text{Least count} = 1 \text{ MSD}/N$$

Total reading = MSR + (VC × LC), where MSR is the main scale reading, LC is the least count, and VC is the vernier coinciding division. Refer to Fig. 4.24 where the fourth division of the vernier coincides with a division on the main scale.

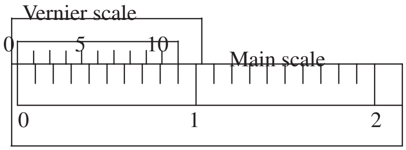


Fig. 4.23 Principle of a vernier scale

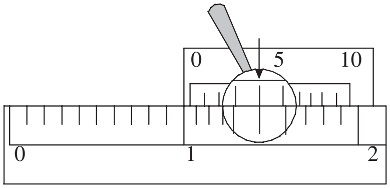


Fig. 4.24 Fourth division of vernier coinciding with a division on the main scale

Least count = 1 MSD/N = 1 mm/10 = 0.1 mm

Therefore, total reading = 1 + (4 × 0.1) = 1.4 mm

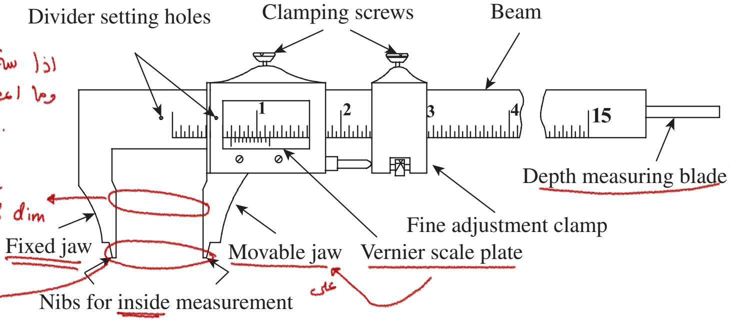
Digital read-out instruments and dial callipers are rapidly replacing vernier instruments. However, the principle of vernier measurement is basic to metrology, and the use of vernier instruments comprising vernier calliper, vernier depth gauge, vernier height gauge, vernier micrometers, etc., is still widespread in the industry. One can argue that anyone who can measure reliably with the vernier instruments can use the digital versions with equal reliability without any additional training. Even though the use of vernier instruments is not frequent for production inspection, they continue to play an important role in tool room and laboratory work. Production inspectors prefer limit gauges and comparators, which can speed up the inspection process considerably.

4.7.1 Vernier Calliper

used in:
→ outside dim.
inside dim.
Depth.

A vernier calliper consists of two main parts: the main scale engraved on a solid L-shaped frame and the vernier scale that can slide along the main scale. The sliding nature of the vernier has given it another name—*sliding calliper*. The main scale is graduated in millimetres, up to a least count of 1 mm. The vernier also has engraved graduations, which is either a forward vernier or a backward vernier. The vernier calliper is made of either stainless steel or tool steel, depending on the nature and severity of application.

Figure 4.25 illustrates the main parts of a vernier calliper. The L-shaped main frame also serves as the fixed jaw at its end. The movable jaw, which also has a vernier scale plate, can slide over the entire length of the main scale, which is engraved on the main frame or the beam. A clamping screw enables clamping of the movable jaw in a particular position after the jaws have been set accurately over the job being measured. This arrests further motion of the movable jaw, so that the operator can note down the reading in a convenient position. In order to capture a dimension, the operator has to open out the two jaws, hold the instrument over the job, and slide the movable jaw inwards, until the two jaws are in firm contact with the job. A fine adjustment screw enables the operator to accurately enclose the portion of the job where measurement is required by applying optimum clamping pressure. In the absence of the fine adjustment screw, the operator has to rely on his careful judgement to apply the minimum force that is required to close the two jaws firmly over the job. This is easier said than done, since any excessive application of pressure increases wear and tear of the instrument and may also cause damage to delicate or fragile jobs. The two jaws are shaped in such a manner that



اذا سكرت ال(movable) على ال (fixed)
وما اعطاني (zero) فالجهاز محتاج
caliperation.

between 2 parallel
surfaces ⇒ External dim

used in the inner
(inside) measurements.

usually in inner dim.
بنقيس بالعادة عمق ثقوب
depth.

على

Fig. 4.25 Main parts of a vernier calliper

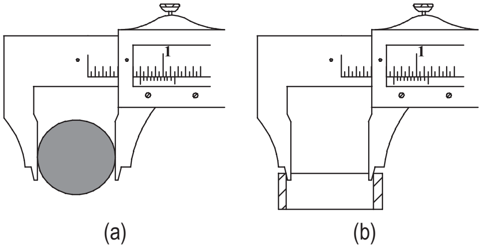


Fig. 4.26 Measurement of dimensions (a) Outside dimension (b) Inside dimension

they can be used to measure both inside and outside dimensions. Notice the nibs in Fig. 4.25, which can be used to measure inside dimension. Figure 4.26 illustrates the method of measuring inside and outside dimensions using a vernier calliper. Whenever the vernier slides over the main frame, a depth-measuring blade also slides in and out of the beam of the calliper. This is a useful attachment for measuring depths to a high degree of accuracy. Divider setting holes are provided, which enable the use of a divider to aid the measurement process.

Measuring a diameter is easier than measuring between flat surfaces, because the diameter is the greatest distance separating the reference and the measured points. Compared to the measurement between flat surfaces, the area of contact between the calliper and the job is much lesser in diameter measurement. Therefore, the resultant force acting either on the job or on the jaws of the calliper is lesser, with the result that there is no deformation or buckling of the jaws. This not only improves the accuracy of measurement, but also reduces the wear and tear of the instrument. Whether the measurement is done for the inside diameter or outside diameter, the operator has to rely on his/her feel to judge if proper contact is made between the measured surfaces and also that excessive force is not exerted on the instrument or the job. Continued closing of the calliper will increase the springing. High gauging pressure causes rapid wear of the jaws, burnishes the part (localized hardening of metal), and may cause damage to the calliper. The following guidelines are useful for the proper use of a vernier calliper:

1. Clean the vernier calliper and the job being measured thoroughly. Ensure that there are no burrs attached to the job, which could have resulted from a previous machining operation.
2. When a calliper's jaws are fully closed, it should indicate zero. If it does not, it must be recalibrated or repaired.
3. Loosen the clamping screw and slide the movable jaw until the opening between the jaws is slightly more than the feature to be measured.
4. Place the fixed jaw in contact with the reference point of the feature being measured and align the beam of the calliper approximately with the line of measurement.
5. Slide the movable jaw closer to the feature and operate the fine adjustment screw to establish a light contact between the jaws and the job.
6. Tighten the clamp screw on the movable jaw without disturbing the light contact between the calliper and the job.
7. Remove the calliper and note down the reading in a comfortable position, holding the graduations on the scale perpendicular to the line of sight.
8. Repeat the measurement a couple of times to ensure an accurate measurement.
9. After completing the reading, loosen the clamping screw, open out the jaws, and clean and lubricate them.
10. Always store the calliper in the instrument box provided by the supplier. Avoid keeping the vernier calliper in the open for long durations, since it may get damaged by other objects or contaminants.
11. Strictly adhere to the schedule of periodic calibration of the vernier calliper.

According to IS: 3651-1974,vernier callipers are of three types: type A, type B, and type C. While all the three types have the scale on the front of the beam, type A vernier scale has jaws on both sides for external and internal measurements, along with a blade for depth measurement. Type B, shown in Fig. 4.25, is provided with jaws on one side only for both external and internal measurements. Type C has jaws on both sides for making the measurements. However, the jaws have knife edge faces for marking purpose. The recommended measuring ranges for vernier callipers are 0–125, 0–200, 0–250, 0–300, 0–500, 0–750, 0–1000, 750–1500, and 750–2000 mm.

Dial Calliper

A vernier calliper is useful for accurate linear measurements. However, it demands basic mathematical skill on the part of the user. One should be able to do simple calculations involving MSD, vernier coinciding division, and least count, in order to compute the measured value of a dimension. In addition, considerable care should be exercised in identifying the coinciding vernier division. These problems can be offset by using a dial calliper (Fig. 4.27).

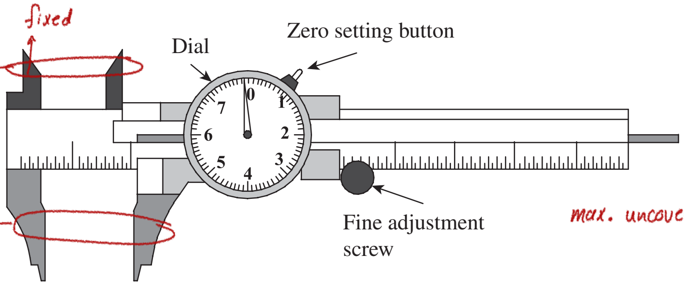


Fig. 4.27 Dial calliper

In a dial calliper, the reading can be directly taken from a dial gauge that is attached to the calliper. The dial gauge has its own least count, which is clearly indicated on the face of the dial. By multiplying the value of the reading indicated by the least count, one can calculate the measured value easily. A small but precise pair of rack and pinion drives a pointer on a circular scale. This facilitates direct reading without the need to read a vernier scale. Typically, the pointer undergoes one complete rotation per centimetre or per millimetre of linear measurement. This measurement should be added to the main scale reading to get the actual reading. A dial calliper also eliminates parallax error, which is associated with a conventional vernier calliper.

سلايدات

A dial calliper is more expensive than the vernier calliper. In addition, the accuracy of the reading mechanism of the dial calliper is a function of length of travel, unlike the vernier calliper that has the same accuracy throughout its length. A dial calliper is also subject to malfunctioning because of the delicate nature of the dial mechanism.

Electronic Digital Calliper

An electronic digital calliper is a battery-operated instrument that displays the reading on a liquid crystal display (LCD) screen. The digital display eliminates the need for calculations and provides an easier way of taking readings. Figure 4.28 illustrates the main parts of an electronic digital calliper.

more cost

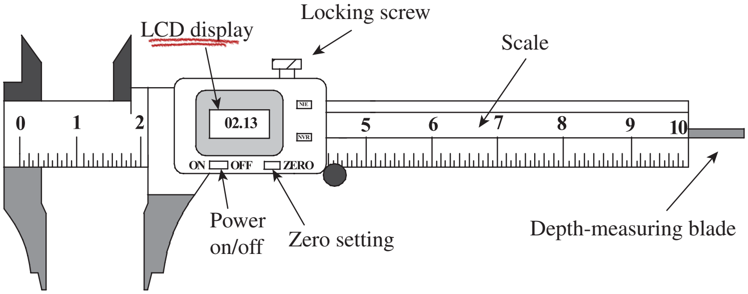


Fig. 4.28 Electronic digital calliper

The LCD display is turned on or off with a button. In order to initialize the instrument, the external jaws are brought together until they touch and the 'zero button' is pressed to set the reading to zero. The digital calliper can now be used to measure a linear dimension. Some digital callipers can be switched between centimetres or millimetres, and inches. Digital callipers are made of stainless steel and are generally available in three sizes: 150, 200, and 300 mm.

The two greatest advantages of an electronic digital calliper are its electronic calculator functions and capability to be interfaced with a computer. It can be set to either metric or British system of units. The 'floating zero' option allows any place within the scale range to be set to zero. The digital display will then exhibit either plus or minus deviations of the jaw from a reference value. This enables the instrument to be also used as a limit gauge. More importantly, a digital calliper can be interfaced with a dedicated recorder or personal computer through a serial data cable. The digital interface provides secured storage for a series of readings, thereby improving the reliability of the records. It can be connected to a printer to provide a printed record or can be directly interfaced with a computer of a statistical control system.

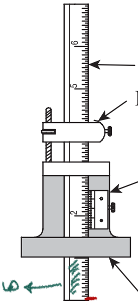
شوفي السلايدات

4.7.2 Vernier Depth Gauge

Section 4.7.1 already highlighted the construction and working principle of a depth gauge. However, even though it is simple to operate, it cannot take measurements finer than 1 mm accuracy. A vernier depth gauge is a more versatile instrument, which can measure up to 0.01 mm or even finer accuracy. Figure 4.29 illustrates the constructional features of a vernier depth gauge. The lower surface of the base has to butt firmly against the upper surface of the hole or recess whose depth is to be measured. The vernier scale is stationary and screwed onto the slide, whereas the main scale can slide up and down. The nut on the slide has to be loosened to move the main scale. The main scale is lowered into the hole or recess, which is being measured. One should avoid exerting force while pushing the scale against the surface of the job being measured, because this will not only result in the deformation of the scale resulting in erroneous measurements, but also accelerate the wear and tear of the instrument. This problem is eliminated thanks to the fine adjustment clamp provided with the instrument. A fine adjustment wheel will rotate the fine adjustment screw, which in turn will cause finer movement of the slide. This ensures firm but delicate contact with the surface of the job.

Vernier depth gauges can have an accuracy of up to 0.01 mm. Periodic cleaning and lubrication are mandatory, as the main scale and fine adjustment mechanism are always in motion in the process of taking measurements.

* طريقة قرائتهم نفس طريقة (Vernier calipar)

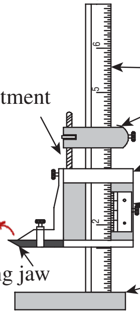


Base:
بترتكز على السطح العلوي
للي بدي اقيس عليه

هاد بدخلوجوا القطعة باخد (max. covered Reading)
على (main) وبضيفلها (vernier)

Fig. 4.29 Vernier depth gauge

inner dimension.



بثبت عليها ال w/p

Fig. 4.30 Vernier height gauge

to measure Height of the workpiece

4.7.3 Vernier Height Gauge

In a vernier height gauge, as illustrated in Fig. 4.30, the graduated scale or bar is held in a vertical position by a finely ground and lapped base. A precision ground surface plate is mandatory while using a height gauge. The feature of the job to be measured is held between the base and the measuring jaw. The measuring jaw is mounted on a slider that moves up and down, but can be held in place by tightening of a nut. A fine adjustment clamp is provided to ensure very fine movement of the slide in order to make a delicate contact with the job. Unlike in depth gauge, the main scale in a height gauge is stationary while the slider moves up and down. The vernier scale mounted on the slider gives readings up to an accuracy of 0.01 mm.

Vernier height gauges are available in sizes ranging from 150 to 500 mm for precision tool room applications. Some models have quick adjustment screw release on the movable jaw, making it possible to directly move to any point within the approximate range, which can then be properly set using the fine adjustment mechanism. Vernier height gauges find applications in tool rooms and inspection departments. Modern variants of height gauges such as optical and electronic height gauges are also becoming increasingly popular.

4.8 MICROMETER INSTRUMENTS

The word 'micrometer' is known by two different meanings. The first is as a unit of measure, being one thousandth of a millimetre. The second meaning is a hand-held measuring instrument using a screw-based mechanism. The word *micrometer* is believed to have originated in Greece, the Greek meaning for this word being *small*. The first ever micrometer screw was invented by William Gascoigne of Yorkshire, England, in the 17th century and was used in telescopes to measure angular distances between stars. The commercial version of the micrometer was released by the Browne & Sharpe Company in the year 1867. Obviously, micrometer as an instrument has a long and cherished history in metrological applications. There have been many variants of the instrument, and modern industry makes use of highly sophisticated micrometers, such as digital micrometers and laser scan micrometers. A micrometer can provide better least counts and accuracy than a vernier calliper. Better accuracy results because of the fact that the line of measurement is in line with the axis of the instrument, unlike the vernier calliper that does not conform to this condition. This fact is best explained by *Abbe's principle*, which states that *'maximum accuracy may be obtained only when the standard is in line with the axis of the*

reading scale
* كل ما كان (line of meas.) البعيد عنه ال
line of devisions
* اذا (wp) بعيدة عنه (axis of instrument) ممكن يكون ال movable j.
مائل بزاوية بسيطة

part being measured'. Figure 4.31 illustrates the relevance of Abbe's law for micrometers and vernier callipers.

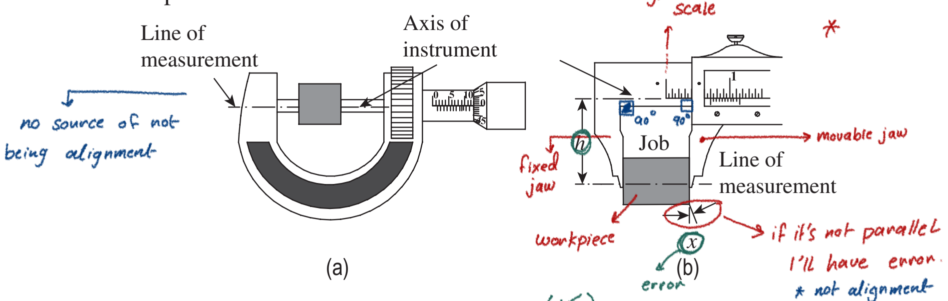


Fig. 4.31 Conformity to Abbe's law (a) Micrometer (b) Vernier calliper

In case of a micrometer, the axis of the job being measured is in line with the line of measurement of the instrument, as illustrated in Fig. 4.31(a). In case of a vernier calliper, for the reading to be accurate, the beam would have to be perfectly straight and the two jaws perfectly at 90° to it. However, this is rarely the case. There is always some lack of straightness of the beam, and the jaws may not be perfectly square with the beam. With continuous usage and wear and tear, the jaws will develop more and more play (Play refers to uncontrolled movements due to slip of one part over the other.) because of repeated sliding movements. Therefore, a certain amount of angular error, marked as x in Fig. 4.31(b), will always be present. This angular error also depends on how far the line of measurement is from the axis of the instrument. The higher the value of this separation h, the greater will be the angular error. We can therefore conclude that *the degree to which an instrument conforms to Abbe's law determines its inherent accuracy.*

$h\uparrow = \text{error}\uparrow$

4.8.1 Outside Micrometer

Figure 4.32 illustrates the details of an outside micrometer. It consists of a C-shaped frame with a stationary anvil and a movable spindle. The spindle movement is controlled by a precision ground screw. The spindle moves as it is rotated in a stationary spindle nut. A graduated scale is engraved on the stationary sleeve and the rotating thimble. The zeroth mark on the thimble will coincide with the zeroth division on the sleeve when the anvil and spindle faces are brought together. The movement of the screw conforms to the sets

يعني لما اسكره
لازم يعطينا قراءة
Zero in the main scale
وكمان
zero in the
Thimble scale

* كل ما الف ال Thimble بمقدار لفه كاملة
رح ينكشف عندي one devision
من ال (main scale)

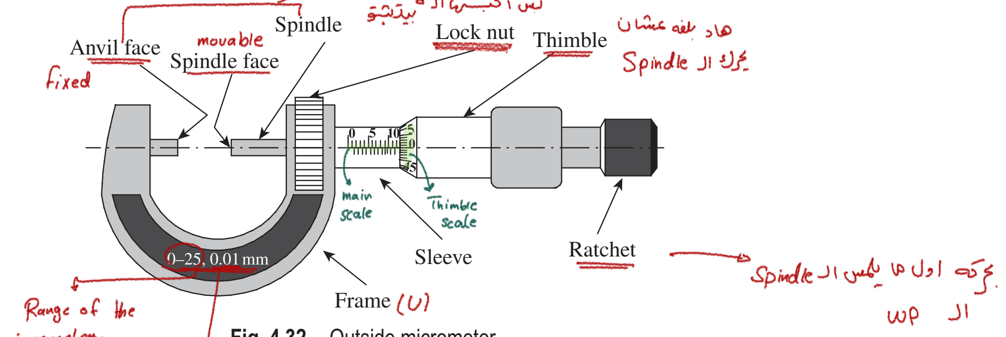
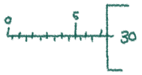


Fig. 4.32 Outside micrometer

accuracy.

How to read micrometers :

main scale smallest dev. = 0.05



7.30 mm

on the Thimble = 0.01 mm
with 50 graduation

$\left(\frac{1}{2}\text{ mm per revolution}\right)$

$\frac{0.5}{50} = 0.01$

of graduations. The locknut enables the locking of the spindle while taking a reading. The ratchet ensures a 'feel' while taking a reading and prevents application of excessive force on the job. The ranges of micrometers are normally 0–25, 25–50, or 0–50 mm. The maximum range of micrometers is limited to 500 mm.

A micrometer is made of steel or cast steel. The measuring faces are hardened to about 60–65 HRC since they are in constant touch with metallic jobs being measured. If warranted, the faces are also tipped with tungsten carbide or a similar material to prevent rapid wear. The anvil is ground and lapped to a high degree of accuracy. The material used for thimble and ratchet should be wear-resistant steel.

Micrometers with metric scales are prevalent in India. The graduations on the sleeve are in millimetres and can be referred to as the main scale. If the smallest division on this scale reads 0.5 mm, each revolution of the thimble advances the spindle face by 0.5 mm. The thimble, in turn, will have a number of divisions. Suppose the number of divisions on the thimble is 50, then the least count of the micrometer is 0.5/50, that is, 0.01 mm. Figure 4.33 illustrates how the micrometer scale is read when a job is held between the anvil face and the spindle face.

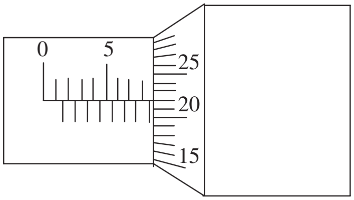


Fig. 4.33 Reading an outside micrometer

In this example, the main scale reading is 8.5 mm, which is the division immediately preceding the position of the thimble on the main scale. As already pointed out, let us assume the least count of the instrument to be 0.01 mm. The 22nd division on the thimble is coinciding with the reference line of the main scale. Therefore, the reading is as follows:

$$8.5 + 22\,(0.01)\,\text{mm} = 8.72\,\text{mm}$$

Thus, a micrometer is a simple instrument to use. However, there are two precautions to be observed while reading a micrometer. The thimble must be read in the correct direction. The other precaution concerns the zero position on the thimble. When passing the index line on the main scale, there is a chance to read an extra 0.5 mm. This is caused by the fact that the next main scale graduation has begun to show but has not yet fully appeared. This is avoided by being careful to read only full divisions on the barrel. Assuming that these simple precautions are adhered to, a micrometer has many advantages over other linear measurement instruments. It has better readability than a vernier scale and there is no parallax error. It is small, lightweight, and portable. It retains accuracy over a longer period than a vernier calliper and is less expensive. On the flip side, it has a shorter measuring range and can only be used for end measurement.

Types of Micrometers

A micrometer is a versatile measuring instrument and can be used for various applications by simply changing the anvil and the spindle face. For example, the anvil may be shaped in the form of a V-block or a large disk. Figure 4.34 shows a few variants, namely the disk micrometer, screw thread micrometer, dial micrometer, and blade micrometer. The following paragraphs briefly highlight the use of each type of micrometer in metrology applications:

Disk micrometer It is used for measuring the distance between two features with curvature. A tooth span micrometer is one such device that is used for measuring the span between the two teeth of a gear. Although it provides a convenient means for linear measurement, it is prone to error in measurement when the curvature of the feature does not closely match the curvature of the disk.

Screw thread micrometer It measures pitch diameters directly. The anvil has an internal '*vee*', which fits over the thread. Since the anvil is free to rotate, it can accommodate any rake range of thread. However, interchangeable anvils need to be used to cover a wide range of thread pitches. The spindle has a conical shape and is ground to a precise dimension.

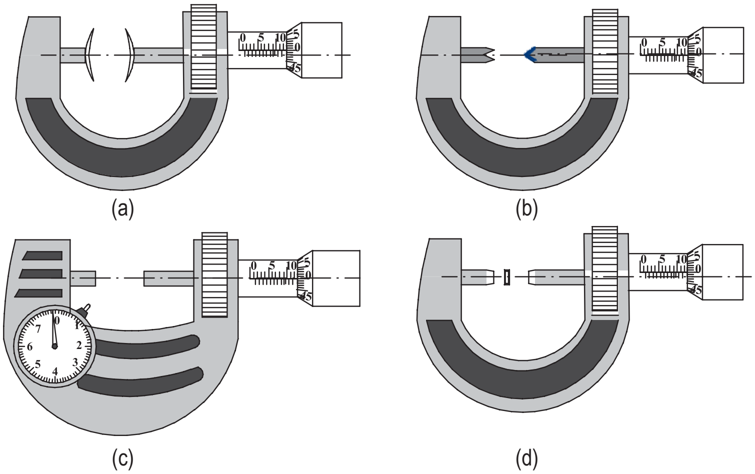


Fig. 4.34 Types of micrometers (a) Disk type (b) Screw thread type (c) Dial type (d) Blade type

Dial micrometer The dial indicator fixed to the frame indicates the linear displacement of a movable anvil with a high degree of precision. It is especially useful as a comparator for GO/NO-GO judgement in mass production. The dial micrometer normally has an accuracy of 1 µm and repeatability of 0.5 µm. Instruments are available up to 50 mm measuring distance, with a maximum measuring force of 10 N. The dial tip is provided with a carbide face for a longer life.

بشيك اذا القطعة
منيحة او لا .

Blade micrometer The anvil and spindle faces are in the form of narrow blades and useful for measuring narrow grooves, slots, keyways, and recesses. The blade thickness is around 0.75–1 mm. The spindle does not rotate when the movable blade is moving along the measuring axis. Due to the slender nature of the instrument and non-turning spindle working against a rotating screw, it is vulnerable to rapid wear and tear and needs careful use and maintenance.

inner dim.

Universal micrometer It has interchangeable anvils such as flat, spherical, spline, disk, or knife edge. It is called universal because of its modular design. The micrometer fitted with the required accessories can function as an outside micrometer, a depth micrometer, a step micrometer, etc.

4.8.2 Vernier Micrometer

A micrometer that we considered hitherto can provide an accuracy of at best 0.01 mm or 10 μm. Placing a vernier scale on the micrometer permits us to take readings up to the next decimal place. In other words, one can accurately measure up to 1 μm or 0.001 mm, which is an excellent proposition for any precision workmanship. As illustrated in Fig. 4.35, in addition to the barrel and thimble scales, a vernier scale is provided next to the barrel scale. Divisions on this vernier scale have to be read in conjunction with the barrel scale to provide the next level of discrimination in readings. The vernier scale consists of a number of equally spaced lines, which are numbered from 0 to 5 or 10, depending on the scale.

main scale

The principle of measurement of a vernier micrometer is very similar to that of a vernier calliper. If a division on the thimble is exactly coinciding with the reference line (line marked 0 in the vernier scale in Fig. 4.35) of the vernier scale, the reading is taken in a way similar to an ordinary micrometer explained earlier. However, if none of the divisions on the thimble coincide with the reference line, we need to examine which division on the thimble coincides with one of the divisions on the vernier scale. Hence, an additional step is involved in the calculation since the vernier reading should be taken into account.

Refer to Fig. 4.36, which shows a sample reading. In this case, the thimble has crossed the 12.5 mm mark on the barrel scale. None of the divisions on the thimble coincides with the zeroth line on the vernier scale, that is, the reference line on the barrel. However, the reference line is between the 24th and 25th divisions on the thimble. Suppose the thimble has 50 divisions, and five divisions on the vernier scale correspond to six divisions on the thimble, we can calculate the least count of the instrument as follows.

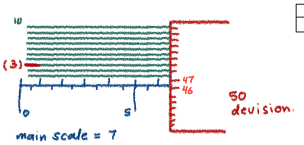
If one complete rotation of the thimble moves it by 0.5 mm on the barrel scale, the least count of the micrometer scale is 0.5/50 = 0.01 mm.

Since five divisions on the vernier scale correspond to six divisions on the thimble, the least count of the vernier scale is equal to 0.01/5 = 0.002 mm. In Fig. 4.36, the fourth division on the vernier scale is coinciding with a division on the thimble.

Therefore, the reading is 12.5 + 24 (0.01) + 4 (0.002) = 12.748 mm.

Guidelines for Use of Micrometers

1. Before placing the micrometer on the job being measured, bring it near the desired opening. Do this by rolling the thimble along the hand but not by twirling. Hold the micrometer



main scale = 7

Thimble ⇒ $\frac{0.5}{50} = 0.01$

⇒ 0.46

* Vernier : $\frac{0.01}{10} = 0.001$

counter clock wise.

تكبير القراءة

$= 7 + 0.46 + 0.003$

$= 7.463$

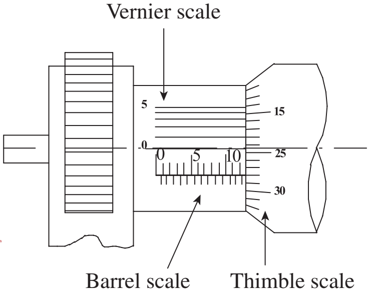


Fig. 4.35 Vernier micrometer

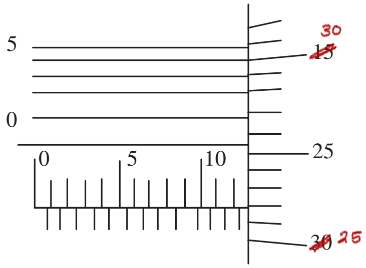


Fig. 4.36 Reading a vernier scale

Mistakes :
- direction. (counter c.w)
- values.

firmly with one hand, and use the feel of the hand to ensure that the axis of the micrometer is perpendicular to the reference plane of the job. Close the micrometer using the ratchet stop until it disengages with a click.

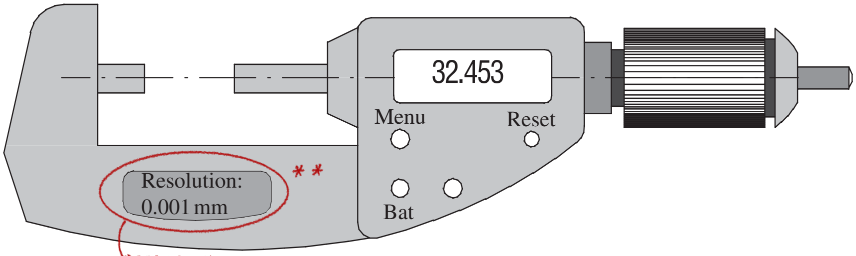
2. Even though a micrometer can be locked in position by tightening the clamp ring (locknut) and used as a snap gauge for inspection purposes, it is not basically designed for this role. Locking the spindle movement and forcing the measuring faces over the job result in sliding friction, which accelerates wear on the contact surfaces as well as on the micrometer screw.
3. The locknut is a memory device. It retains the reading so that it can be read in a convenient position. However, avoid tightening the locknut when the spindle is withdrawn. Doing so will injure the clamping mechanism.
4. It is not wise to buy a micrometer that does not have a controlled force feature. Excessive force while closing the measuring faces over the job will result in rapid wear and tear of the instrument. A ratchet stop acts as an overriding clutch that holds the gauging force at the same amount for each measurement regardless of the differences in manual application of force.
5. While measuring the diameter of a cylindrical part, rock the cylinder to find the maximum opening that provides the desired feel.
6. Do not expect the micrometer to guarantee reliable measurement if it is (a) dirty; (b) poorly lubricated; (c) poorly adjusted; or (d) closed too rapidly.
7. At the end of each day, the micrometer should be wiped clean, visually inspected, oiled, and replaced in its case to await the next use.

4.8.3 Digital Micrometer

The 'multifunction' digital micrometer is becoming very popular in recent times. The readings may be processed with ease. The push of a button can convert a reading from decimal to inch and vice versa. Any position of the spindle can be set to zero and the instrument can be used to * inspect a job within a specified tolerance. The instrument can be connected to a computer or a printer. Most instruments can record a series of data and calculate statistical information such as mean, standard deviation, and range (Fig. 4.37).

digital type of memore.

to make inspection
use a standard wp.
* if the zero of the
device is a standard
value
error = reading.



**
accuracy.

Fig. 4.37 Digital micrometer

The instrument is recommended to be used along with a stand for ease of measurement. The spindle is made of stainless steel and measuring faces are carbide tipped for a longer life. A locking clamp ensures locking of spindle at any desired setting. A constant and low measuring force is ensured by the thimble mechanism. Most of the instruments have a least count of

0.001 mm. An LCD screen displays the reading with absolute linear scale with simple digimatic data collection for personal computer (SPC) data output. An easy push button control is provided to choose the various functions of the instrument. The push buttons controlling the various functions are as follows:

1. ON/OFF: To power the instrument on or off
2. IN/MM: To select either inch or metric system of measurement
3. ZERO: To set the screen display to zero at any desired position
4. HOLD: To hold the measurement taken until the push button is operated again
5. ORIGIN: To set the minimum value for the micrometer depending upon its size; micrometer count commences from this value
6. Alarm indicator: To indicate low voltage and counting value composition error

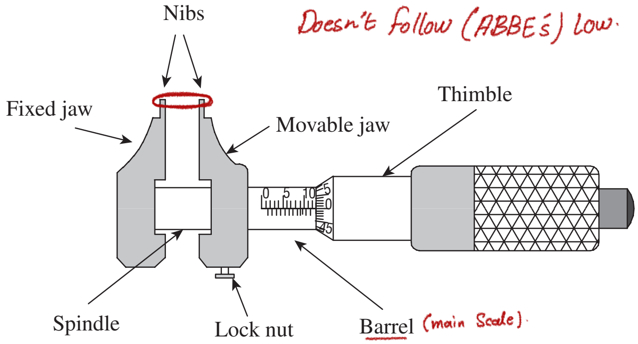
4.8.4 Inside Micrometer Calliper

Thickness of Nibs

The inside micrometer calliper is useful for making small measurements from 5 to 25 mm. In this instrument, unlike a regular micrometer, the axis of the instrument does not coincide with the line of measurement. In addition, unlike the outside micrometer where there is a surface contact between the job and the instrument, the contact between the job and the instrument is line contact. The *nibs*, as the contacts are called, are ground to a small radius. As a necessity, this radius has to be smaller than the smallest radius the instrument can measure. Therefore, all measurements are made with line contacts.

Doesn't follow (ABBE's) Law.

As illustrated in Fig. 4.38, the movable jaw can be moved in and out by the rotation of the thimble. ✱✱ One complete rotation of the thimble moves it by one division on the barrel scale. A locknut can be operated to hold the position of the movable jaw for ease of noting down a reading. While taking measurements, it needs to be rocked and centralized to assure that the axis of the instrument is parallel to the line of measurement. This makes the instrument prone to rapid wear. It is therefore needless to say that the instrument needs to be checked and calibrated regularly.



(main Scale).

Fig. 4.38 Inside micrometer calliper

4.8.5 Inside Micrometer

This instrument perfectly complies with Abbe's law. The axis of an inside micrometer is also its line of measurement. It is useful for measuring the inside diameter of cylinders, rings, and other machine parts. The inside micrometer set has several accessories, which have to be assembled together for taking the readings. The main unit is the measuring head, which has a thimble that moves over a barrel, same as in the case of an outside micrometer. Graduated scales are provided on the barrel and thimble, which give readings up to an accuracy of 0.01 mm, but with a limited range. The rear end of the measuring head has a contact surface, whereas extension rods of various lengths can be fitted to the front end of the measuring head. A set of extension rods are provided with the instrument to cover a wide range of measurements. The rod ends are spherical and present nearly point contact to the job being measured. A chuck attached to the spindle facilitates the attachment of extension rods. Using a particular extension rod, the distance between contact surfaces can be varied by rotating the thimble up to the range of the micrometer screw. Higher diameters and distances can be measured using longer extension rods. Figure 4.39 illustrates the construction details of an inside micrometer.

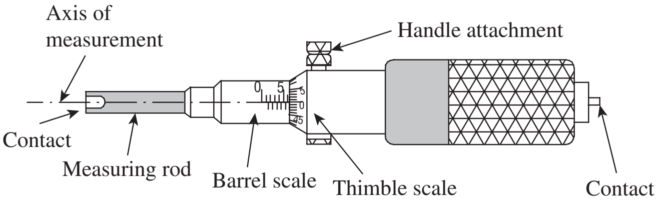


Fig. 4.39 Inside micrometer

The inside micrometer is more common than the inside micrometer calliper because of the flexibility it affords to measure a large range of dimensions. A range of 25 mm above the length of extension rods is commonly used in shops. A standard set will have five extension rods of ranges 50–75, 75–100, 100–125, 125–150, 150–175, and 175–200 mm. In addition to extension rods, a spacing collar (usually 12.5 mm in length) is provided for smaller adjustments in the range of measurements. The micrometer is also provided with a detachable handle for easier handling of the instrument.

The best practice for using an inside micrometer is to first measure the dimension approximately by using a steel rule. Then select a suitable extension rod that can adequately cover the range of measurements. Insert the extension rod into the chuck and set the instrument to read zero. Now fix the handle and lower the instrument into the gap where the dimension is to be measured. Operate the thimble until the two contact surfaces establish a firm contact with the surfaces of the job. While measuring diameters, it is always recommended to lightly move the instrument to and fro so that the actual diameter is sensed by the person taking measurements. Now, operate the locknut and take out the instrument. The micrometer reading has to be added to the length of the extension rod to get the actual reading.

4.8.6 Depth Micrometer

An alternative to vernier depth gauge is the depth micrometer. In fact, most shop floor engineers vouch for its superiority over vernier depth gauges because of its greater measuring range, better reliability, and easier usability. One peculiarity of this instrument is that it reads in reverse from other micrometers. Looking from the ratchet side, a clockwise rotation moves the spindle downwards, that is, into the depth of the job being measured. Therefore, the entire barrel scale is visible when the tip of the measuring rod is in line with the bottom surface of the base. As the measuring rod advances into the depths, the thimble will move over the barrel scale. Reliable measurements of up to 0.01 mm are possible with this instrument. Figure 4.40 illustrates the parts of a depth micrometer. The bottom flat surface of the base butts over the reference plane on the job, and the micrometer scale directly gives the depth of the measuring rod tip from the reference plane.

* Reading from Max. covered reading.

The head movement of the depth micrometer is usually 25 mm. Inter-changeable measuring rods, similar to an inside micrometer discussed in the previous section, provide the required measuring range for the instrument. Measuring rods of up to 250 mm length are used in a standard set.

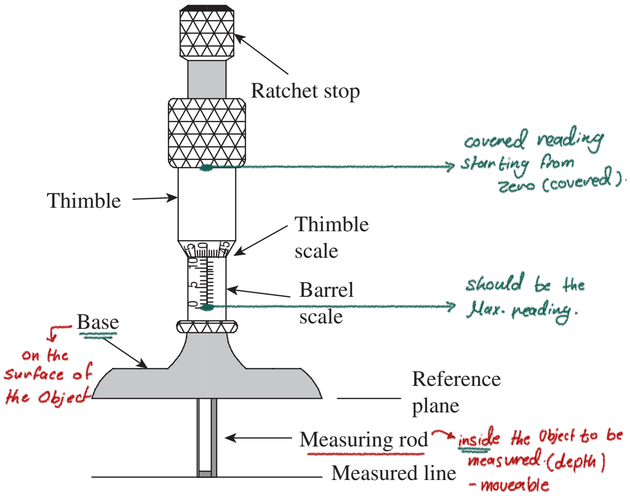


Fig. 4.40 Depth micrometer

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4.8.7 Floating Carriage Micrometer

A floating carriage micrometer, sometimes referred to as an effective diameter-measuring micrometer, is an instrument that is used for accurate measurement of 'thread plug gauges'. Gauge dimensions such as outside diameter, pitch diameter, and root diameter are measured with the help of this instrument. All these dimensions have a vital role in thread plug gauges, since the accuracy and interchangeability of the component depend on the gauges used. To reduce the effect of slight errors in the micrometer screws and measuring faces, this micrometer is basically used as a comparator. Figure 4.41 illustrates a floating carriage micrometer.

The carriage has a micrometer with a fixed spindle on one side and a movable spindle with the micrometer on the other side. The carriage moves on a finely ground 'V' guide way or an antifriction guide way to facilitate movement in a direction parallel to the axis of the plug gauge mounted between the centres. The micrometer has a non-rotary spindle with a least count of up to 0.001 or 0.002 mm. The instrument is very useful for thread plug gauge manufacturers, in gauge calibration laboratories (established under NABL accreditation), and in standard rooms where in-house gauge calibration is carried out.

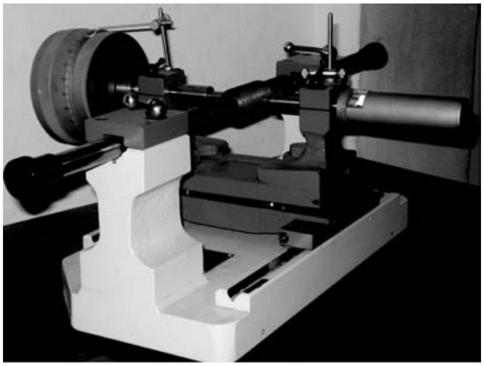


Fig. 4.41 Floating carriage micrometer

4.9 SLIP GAUGES

Hitherto we have seen instruments such as vernier calliper, depth gauge, and micrometer, which can facilitate measurement to a fairly high degree of accuracy and precision. All these measurements involve line standards. The accuracy of these instruments depends on the accuracy of the workmanship involved in their manufacture. Any minor misalignment or error in a screw can lead to errors in measurement. Repetitive use of a screw or joint results in rapid wear and tear, which can lead to accumulation of errors in measurement within a short time. Slip gauges, also called gauge blocks, can counter some of these limitations and provide a high degree of accuracy as *end standards*. In fact, slip gauges are a direct link between the measurer and the international length standards.

The origin of gauge blocks can be traced to the 18th century Sweden, where 'gauge sticks' were known to have been used in machine shops. However, the modern-day slip gauges or gauge blocks owe their existence to the pioneering work done by C.E. Johansson, a Swedish armoury inspector. Therefore, gauge blocks are also known as *Johansson gauges*. He devised a set of slip gauges manufactured to specific heights with a very high degree of accuracy and surface finish. He also proposed the method of 'wringing' slip gauges to the required height to facilitate measurements. He also emphasized that the resulting slip gauges, to be of universal value, must be calibrated to the international standard. Johansson was granted a patent for his invention in the year 1901 and formed the Swedish company CE Johansson AB in the year 1917. He started manufacturing and marketing his gauge blocks to the industry, and found major success in distant America. One of his customers was Henry Ford with whom he signed a cooperative agreement to establish a gauge making shop at his Cadillac automobile company. The development of 'GO' and 'NO-GO' gauges also took place during this time.

Figure 4.42 illustrates the functional features of a slip gauge. It is made of hardened alloy steel having a 30 mm × 10 mm cross section. Steel is the preferred material since it is economical and has the same coefficient of thermal expansion as a majority of steel components used in production. Hardening is required to make the slip gauge resistant to wear. Hardening is followed by stabilizing at a sub-zero temperature to relieve stresses developed during heat treatment. This is followed by finishing the measuring faces to a high degree of accuracy, flatness, and surface finish. The height of a slip gauge is engraved on one of the rectangular faces, which also features a symbol to indicate the two measured planes. The length between the measuring surfaces, flatness, and surface conditions of measuring faces are the most important requirements of slip gauges.

Carbide gauge blocks are used for their superior wear resistance and longer life. They also have low coefficient of thermal expansion. However, they are quite expensive and used when rapid wear of gauges is to be avoided.

Several slip gauges are combined together temporarily to provide the end standard of a specific length. A set of slip gauges should enable the user to stack them together to provide an accuracy of up to one-thousandth of a millimetre or better. In order to achieve this, individual gauges must be available in dimensions needed to achieve any combination within the available number of gauges. The surfaces of neighbouring slip gauges should stick so close together that there should not be any scope for even a layer of air to be trapped between them, which can add error to the final reading. For this to happen, there should be absolute control over the form, flatness, parallelism, surface finish, dimensional stability of material, and homogeneity of gauging surfaces. While building slip gauges to the required height, the surfaces of slip gauges are pressed

more accuracy

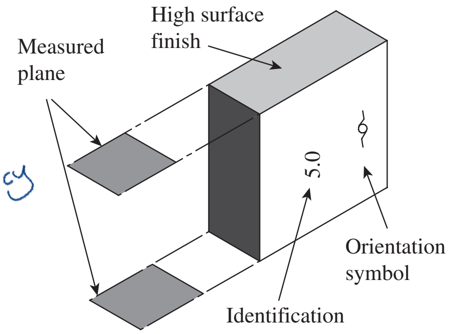


Fig. 4.42 Functional features of a slip gauge

* made from hardening steel
with dimension.

* can be used to check
calibration.

*smoth surface
finish.

into contact by imparting a small twisting motion while maintaining the contact pressure. The slip gauges are held together due to molecular adhesion between a liquid film and the mating surfaces. This phenomenon is known as 'wringing'.

4.9.1 Gauge Block Shapes, Grades, and Sizes

linear

Slip gauges are available in three basic shapes: rectangular, square with a central hole, and square without a central hole. Rectangular blocks are the most commonly used since they can be used conveniently where space is restricted and excess weight is to be avoided. Square slip gauges have larger surface area and lesser wear rate because of uniform distribution of stresses during measurements. They also adhere better to each other when wrung together. Square gauge blocks with central holes permit the use of tie rods, which ensure that the built-up slip gauges do not fall apart.

Slip gauges are classified into grades depending on their *guaranteed* accuracy. The grade defines the type of application for which a slip gauge is suited, such as inspection, reference, or calibration. Accordingly, slip gauges are designated into five grades, namely grade 2, grade 1, grade 0, grade 00, and inspection grade.

Grade 2 This is the workshop-grade slip gauge. Typical uses include setting up machine tools, milling cutters, etc., on the shop floor.

Grade 1 This grade is used for tool room applications for setting up sine bars, dial indicators, calibration of vernier, micrometer instruments, and so on.

more accuracy
↳ more cost

Grade 0 This is an inspection-grade slip gauge. Limited people will have access to this slip gauge and extreme care is taken to guard it against rough usage.

Grade 00 This set is kept in the standards room and is used for inspection/calibration of high precision only. It is also used to check the accuracy of the workshop and grade 1 slip gauges.

Calibration grade This is a special grade, with the actual sizes of slip gauges stated on a special chart supplied with the set of slip gauges. This chart gives the exact dimension of the slip gauge, unlike the previous grades, which are presumed to have been manufactured to a set tolerance. They are the best-grade slip gauges because even though slip gauges are manufactured using precision manufacturing methods, it is difficult to achieve 100% dimensional accuracy. Calibration-grade slip gauges are not necessarily available in a set of preferred sizes, but their sizes are explicitly specified up to the third or fourth decimal place of a millimetre.

Many other grading standards are followed for slip gauges, such as JIS B 7506-1997 (Japan), DIN 861-1980 (Germany), ASME (USA), and BS 4311:Part 1:1993 (UK). Most of these standards assign grades such as A, AA, AAA, and B. While a grade B may conform to the workshop-grade slip gauge, grades AA and AAA are calibration and reference grades, respectively.

Slip gauges are available in standard sets in both metric and inch units. In metric units, sets of 31, 48, 56, and 103 pieces are available. For instance, the set of 103 pieces consists of the following:

*

31
48
56
88
103

1. One piece of 1.005 mm
2. 49 pieces ranging from 1.01 to 1.49 mm in steps of 0.01 mm

↳ because there is no
dim. starts from
0.01.

first & Last blocks should be protectors.

3. 49 pieces ranging from 0.5 to 24.5 mm in steps of 0.5 mm
4. Four pieces ranging from 25 to 100 mm in steps of 25 mm

A set of 56 slip gauges consists of the following:

1. One piece of 1.0005 mm
2. Nine pieces ranging from 1.001 to 1.009 mm in steps of 0.001 mm
3. Nine pieces ranging from 1.01 to 1.09 mm in steps of 0.01 mm
4. Nine pieces ranging from 1.0 to 1.9 mm in steps of 0.1 mm
5. 25 pieces ranging from 1 to 25 mm in steps of 1.0 mm
6. Three pieces ranging from 25 to 75 mm in steps of 25 mm

Ex: List the min. # of block to get 92.357.
Solve it in (88 pieces).
(we should find the min. # of blocks).
1.] Wearing blocks with 2mm
92.357 − (2×2) = 88.357.
2.] using (1.007) → 88.357 − 1.007
= 87.35.
3.] (1.35) ⇒ 87.35 − 1.35 = 86.
4.] (6) ⇒ 86 − 6 = 80
5.] (80) ⇒ 80 − 80 = 0
*4 blocks : min.
↳ but total = 6 blocks.
↳ to get less error.

Generally, the set of slip gauges will also include a pair of tungsten carbide protection gauges. These are marked with letter ‘P’, are 1 or 1.5 mm thick, and are wrung to the end of the slip gauge combination. They are used whenever slip gauges are used along with instruments like sine bars, which are made of metallic surfaces that may accelerate the wear of regular slip gauges. Wear blocks are also recommended when gauge block holders are used to hold a set of wrung gauges together. The purpose of using a pair of wear blocks, one at the top and the other at the bottom of the stack, is to ensure that major wear is concentrated over the two wear gauges, which can be economically replaced when worn out. This will extend the useful life of the set of slip gauges.

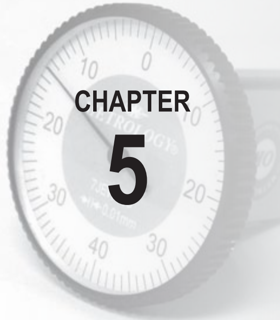
4.9.2 Wringing of Slip Gauges

Wringing is the phenomenon of adhesion of two flat and smooth surfaces when they are brought into close contact with each other. The force of adhesion is such that the stack of a set of blocks will almost serve as a single block, and can be handled and moved around without disturbing the position of individual blocks. More importantly, if the surfaces are clean and flat, the thin layer of film separating the blocks will also have negligible thickness. This means that stacking of multiple blocks of known dimensions will give the overall dimension with minimum error.

Wringing Phenomenon

When two surfaces are brought into contact, some amount of space exists between them. This is because of surface irregularities and presence of dirt, oil, grease, or air pockets. Let us assume that the two surfaces are perfectly flat with highly finished surfaces, free from dirt and oil, and firmly pressed together. Now the air gap becomes so small that it acts in the same way as a liquid film. The thickness of this film can be as low as 0.00001 mm. Now a question arises as to why the blocks stick together so firmly that even a high magnitude of force acting perpendicular to their surfaces will not be able to separate them. A combination of two factors appears to ensure this high adhesion force. First, as shown in Fig. 4.43, an atmospheric force of 1 bar is acting in the direction shown by the two arrows. This is contributing to the adhesion of the surfaces of the two slip gauges.

Secondly, the surfaces are in such close proximity that there is molecular adhesion of high magnitude that creates a high adhesion force. Since the slip gauge surfaces undergo lapping as a super finishing operation, material removal takes place at the molecular level. Since some molecules are lost during the lapping operation, the material is receptive to molecules of the mating surface, which creates high molecular adhesion.



CHAPTER 5

Angular Measurement

After studying this chapter, the reader will be able to

- understand the basic requirements of angular measurement in the industry and the variety of instruments available at our disposal
- elucidate the basic principle of a protractor and its extension as the universal bevel protractor, which is an indispensable part of a metrology laboratory
- measure angles using the sine principle and explain the use of sine bar, sine block, sine plate, and sine centre
- use angle gauges to set them accurately to the required angle
- appreciate the importance of ‘bubble instruments’ such as the conventional spirit level and clinometers in angular measurement
- explain the principles of optical measurement instruments, the most popular ones being the autocollimator and the angle dekkor

5.1 INTRODUCTION

Length standards such as foot and metre are arbitrary inventions of man. This has necessitated the use of wavelength of light as a reference standard of length because of the difficulty in accurately replicating the earlier standards. On the other hand, the standard for angle, which is derived with relation to a circle, is not man-made but exists in nature. One may call it degree or radian, but the fact remains that it has a direct relation to a circle, which is an envelope of a line moving about one of its ends. Whether one defines a circle as the circumference of a planet or path of an electron around the nucleus of an atom, its parts always bear a unique relationship.

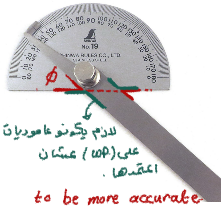
The precise measurement of angles is an important requirement in workshops and tool rooms. We need to measure angles of interchangeable parts, gears, jigs, fixtures, etc. Some of the typical measurements are tapers of bores, flank angle and included angle of a gear, angle made by a seating surface of a jig with respect to a reference surface, and taper angle of a jib. Sometimes, the primary objective of angle measurement is not to measure angles. This may sound rather strange, but this is the case in the assessment of alignment of machine parts. Measurement of straightness, parallelism, and flatness of machine parts requires highly

قياس من خلال الزوايا
(indirect measuring device).

sensitive instruments like autocollimators. The angle reading from such an instrument is a measure of the error of alignment.

There are a wide range of instruments, starting from simple scaled instruments to sophisticated types that use laser interferometry techniques. The basic types are simple improvisations of a protractor, but with better discrimination (least count), for example, a vernier protractor. These instruments are provided with a mechanical support or a simple mechanism to position them accurately against the given workpiece and lock the reading. A spirit level has universal applications, not only in mechanical engineering but also in civil engineering construction for aligning structural members such as beams and columns. Instruments employing the basic principle of a spirit level but with higher resolution, such as conventional or electronic clinometers, are popular in metrology applications. By far, the most precise instruments are collimators and angle dekkors, which belong to the family of instruments referred to as *optical tooling*. This chapter deals with some of the popular angle measurement devices that are widely used in the industry.

5.2 PROTRACTOR



لازم يكونو عاموديات
على (wp) عشان
اعتمدها .

to be more accurate

accuracy to 1°

not much accurate.

A simple protractor is a basic device used for measuring angles. At best, it can provide a least * count of 1° for smaller protractors and ½° for large ones. However, simple though it may be, the user should follow the basic principles of its usage to measure angles accurately. For instance, the surface of the instrument should be parallel to the surface of the object, and the reference line of the protractor should coincide perfectly with the reference line of the angle being measured. Positioning of the protractor and observation of readings should be performed with care to avoid parallax error.

not accurate

Similar to a steel rule, a simple protractor has limited usage in engineering metrology. However, a few additions and a simple mechanism, which can hold a main scale, a vernier scale, and a rotatable blade, can make it very versatile. A universal bevel protractor is one such instrument that has a mechanism that enables easy measurement and retention of a reading. A vernier scale improves the least count substantially. Additional attachments enable the measurement of acute and obtuse angles with ease and thereby justify its name as the universal bevel protractor. It can measure the angle enclosed by bevelled surfaces with ease and hence the name.

In fact, if one traces the history of development of angle-measuring devices, the bevel protractor preceded the universal bevel protractor. The earliest bevel protractor had a simple mechanism that facilitated rotation of measuring blades and locked them in place. It had a scale graduated in degrees on which the measurements could be directly read. However, these instruments have largely been replaced by universal bevel protractors and the older types are not being used in metrology applications now. Therefore, we shall directly go to a discussion on the universal bevel protractor.

5.2.1 Universal Bevel Protractor

with vernier scale.

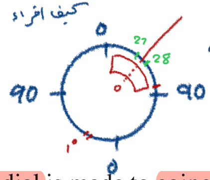
The universal bevel protractor with a 5' accuracy is commonly found in all tool rooms and metrology laboratories. Figure 5.1 illustrates the construction of a universal bevel protractor. It has a base plate or stock whose surface has a high degree of flatness and surface finish. The stock is placed on the workpiece whose angle is to be measured. An adjustable blade attached

(13-1) angular M. موضوع مهم

* varnien هنوخذ الي بتفقد مع mainscale بالاتجاه.

27° 10'.

vernier scale.



main scale

vernien.

accuracy.

$1^{\circ} = \frac{60'}{12} = 5'$

12

12

moveable-

accuracy = 5'

θ ⇒ base & plate

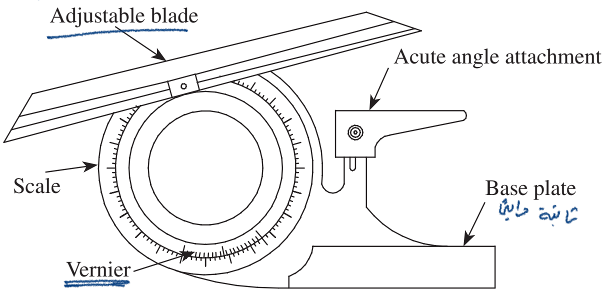


Fig. 5.1 Universal bevel protractor

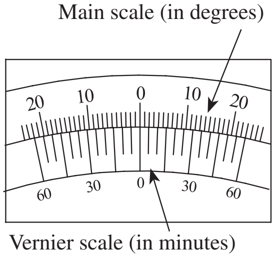


Fig. 5.2 Divisions on the vernier scale

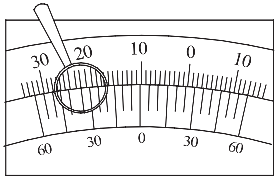


Fig. 5.3 Reading the vernier scale

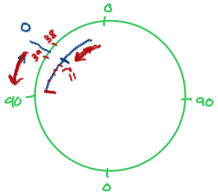
to a circular dial is made to coincide with the angular surface. It can be swivelled to the required angle and locked into position to facilitate accurate reading of the circular scale that is mounted on the dial. The main scale on the dial is graduated in degrees and rotates with the rotation of the adjustable blade. A stationary vernier scale mounted close to the dial, as shown in Fig. 5.1, enables measurements to a least count of 5' or less. An acute angle attachment is provided for the measurement of acute angles.

The main scale on the dial is divided into four quadrants, each measuring 90°. Each division on this scale reads 1°. The degrees are numbered from 0 to 90 on either side of the zeroth division. The vernier scale has 24 divisions, which correspond to 46 divisions on the main scale. However, the divisions on the vernier scale are numbered from 0 to 60 on either side of the zeroth division, as shown in Fig. 5.2.

Calculation of Least Count

Value of one main scale division = 1°

24 vernier divisions correspond to 46 main scale divisions. From Fig. 5.2, it is clear that one vernier division equals 1/12th of 23°. Let us assume that the zeroth division on both the main and the vernier scales are lined up to coincide with each other. Now, as the dial rotates, a vernier division, starting from the fifth minute up to the 60th minute, progressively coincides with a main scale division until the zeroth division on the vernier scale moves over the main scale by 2°.



38° + 55'.

Therefore, the least count is the difference between one vernier division and two main scale divisions, which is 1/12° or 5'.

Reading Vernier Scales

Consider the situation shown in Fig. 5.3. The zeroth division of the vernier scale is just past the 10° division on the main scale. The seventh division, marked as the 35' division, on the left-hand side of the vernier scale coincides with a division on the main scale. Therefore, the reading in this case is 10°35'.

Sometimes, confusion arises regarding the direction in which the vernier has to be read. This confusion may crop up for the aforementioned example also. It is possible that a division on the right side of zero on the vernier scale may be coinciding with a division on the main scale (dial scale). In order to eliminate this confusion, we follow a simple rule. *Always read the*

دايماً بتعطين الزاوية الحادة الي
بين blade وال Base

$\theta > 90$
$180 - \alpha$

$\alpha = 15^\circ\ 45'$

$\theta = 180 - \alpha$

$= 164\ 15'$

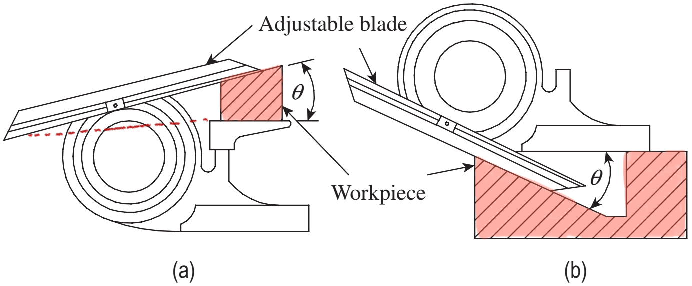


Fig. 5.4 Measurement of angles using bevel protractor (a) Acute angle attachment (b) Inside bevelled face angle measurement

vernier from zero in the same direction that you read the dial scale. In the given example, the 10th division on the dial, which is close to the zeroth division on the vernier, is to the left of the zeroth division on the dial scale. In other words, the dial scale is being read in the leftward or anticlockwise direction. Therefore, the vernier should also be read towards the left of the vernier zero division. Figure 5.4 illustrates the use of a bevel protractor for measurement of angles. While Fig. 5.4(a) illustrates the use of acute angle attachment, Fig. 5.4(b) shows how the angle of an inside bevelled face can be measured.

Angles and their Supplements

Since a universal bevel protractor can measure both acute and obtuse angles, care should be exercised to clearly differentiate between the angle being indicated on the scale and its supplement. The dial gauge is graduated from 0° to 90° in four quadrants, as shown in Fig. 5.5. Figure 5.5(a) illustrates the orientation of the blade with respect to the base when the protractor is set to 90°. The zeroth division on the vernier coincides with the 90° division on the dial scale.

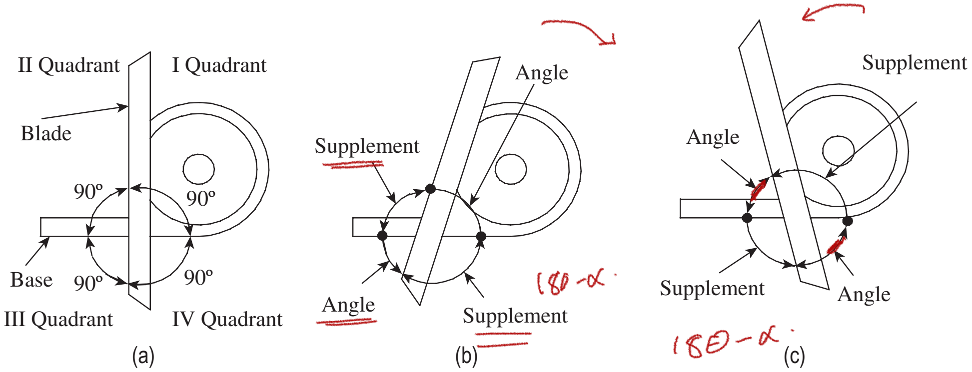


Fig. 5.5 Angles and their supplements (a) Blade oriented with base (b) Blade turned clockwise (c) Blade turned counterclockwise

Suppose the blade is turned clockwise, as in Fig. 5.5(b), the angles read directly are those that are formed from the blade to the base counterclockwise. Thus, if the angles of a work part are being measured in quadrant I or III, the angles can be read directly from the scale. On the other hand, if the angles of a work part are being measured in quadrant II or IV, the actual angles are given by their supplements. In other words, the value of the angle is obtained by subtracting the angle indicated by the scale from 180°. Both these angles, obviously, are obtuse angles.

Further, Fig. 5.5(c) illustrates a situation when the blade is turned counterclockwise. Here also, angles can be directly read only in two quadrants, namely the second and the fourth. These angles are formed in the clockwise direction from the blade to the base, and are acute angles. The supplements in I and III quadrants give the obtuse angles of the work parts, which are held in these quadrants.

Bevel protractors in general are classified into four types: A, B, C, and D. Types C and D are the basic types, with the dial scale graduated in degrees. They are neither provided with a vernier scale nor a fine adjustment device. Types A and B are provided with a vernier scale, which can accurately read up to 5'. While type A has both an acute angle attachment and a fine adjustment device, type B does not have either of them.

A bevel protractor is a precision angle-measuring instrument. To ensure an accurate measurement, one should follow these guidelines:

1. The instrument should be thoroughly cleaned before use. It is not recommended to use compressed air for cleaning, as it can drive particles into the instrument.
2. It is important to understand that the universal bevel protractor does not essentially measure the angle on the work part. It measures the angle between its own parts, that is, the angle between the base plate and the adjustable blade. Therefore, one should ensure proper and intimate contact between the protractor and the features of the part.
3. An easy method to determine if the blade is in contact with the work part is to place a light behind it and adjust the blade so that no light leaks between the two.
4. It should always be ensured that the instrument is in a plane parallel to the plane of the angle. In the absence of this condition, the angle measured will be erroneous.
5. The accuracy of measurement also depends on the surface quality of the work part. Burrs and excessive surface roughness interfere with the intimate contact between the bevel protractor and the work part, leading to erroneous measurements.
6. One should be careful to not slide the instrument over hard or abrasive surfaces, and not over-tighten clamps.
7. Before replacing the instrument in its case, it has to be wiped with a clean and dry cloth, a thin rust-preventing coating has to be applied, and moving parts need to be lubricated.

5.2.2 Optical Bevel Protractor

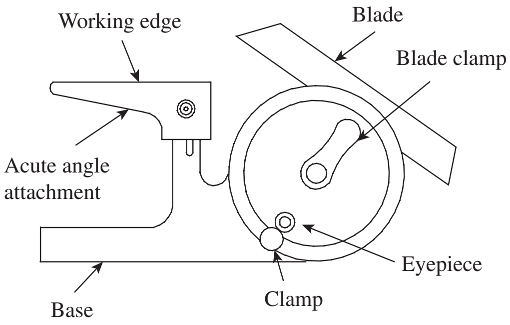


Fig. 5.6 Optical bevel protractor

An optical protractor is a simple extension of the universal bevel protractor. A lens in the form of an eyepiece is provided to facilitate easy reading of the protractor scale. Figure 5.6 illustrates the construction details of an optical bevel protractor. The blade is clamped to the dial by means of a blade clamp. This enables fitting of blades of different lengths, depending on the work part being measured. In a protractor without a vernier, the dial scale reading can be directly read through the eyepiece. In vernier protractors, the eyepiece is attached on top of the vernier scale itself, which together move as a single unit over the stationary dial scale. The eyepiece provides a magnified view of the reading for the convenience of the user.

Most of the universal protractors in use are of this type. An acute angle attachment is provided to facilitate measurement of acute angles on work parts. A clamp is provided to lock the reading, so that it can be read and recorded at a convenient position by the user.

5.3 SINE BAR

to get more accuracy of the reading.

We start with initial Reading, measured from other devices.

A sine bar is used to measure angles based on the sine principle. Its upper surface forms the hypotenuse of a triangle formed by a steel bar terminating in a cylinder near each end. When one of the cylinders, called a roller, is resting on a flat surface, the bar can be set at any desired angle by simply raising the second cylinder. The required angle is obtained when the difference in height between the two rollers is equal to the sine of the angle multiplied by the distance between the centres of the rollers. Figure 5.7 illustrates the construction details of a sine bar.

$\sin\theta = \frac{h}{L}$

Sine bars are made of corrosion-resistant steel, and are hardened, ground, and stabilized. The size is specified by the distance between the centres of the cylinders, which is 100, 200, or 300 mm. The upper surface has a high degree of flatness of up to 0.001 mm for a 100 mm length and is perfectly parallel to the axis joining the centres of the two cylinders. The parallelism of upper surface with the datum line is of the order of 0.001 mm for a 100 mm length. Relief holes are sometimes provided to reduce the weight of the sine bar. This by itself is not a complete measuring instrument. Accessories such as a surface plate and slip gauges are needed to perform the measurement process. Figure 5.8 illustrates the application of a sine rule for angle measurement.

indirect meas. device.

The sine of angle θ formed between the upper surface of a sine bar and the surface plate (datum) is given by

$$\text{Sin}\,(\theta) = h/L$$

where h is the height difference between the two rollers and L is the distance between the centres of the rollers.

Therefore, $h = L\,\text{Sin}\,(\theta)$

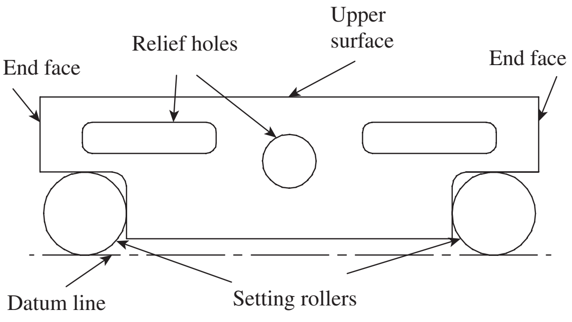
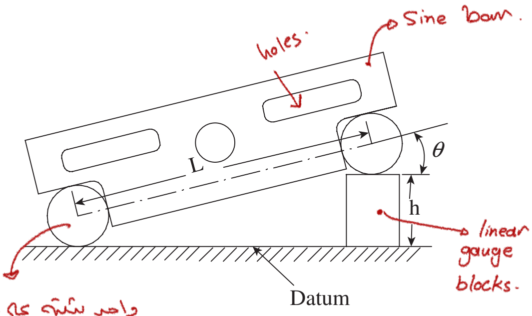


Fig. 5.7 Sine bar



واحد بيثبت على surface plate.

Fig. 5.8 Sine rule

holes : (Sine Bar) تخفف وزن ال

5.3.1 Setting Sine Bars to Desired Angles

By building slip gauges to height *h* and placing the sine bar on a surface plate with one roller on top of the slip gauges, the upper surface can be set to a desired angle with respect to the surface plate. The set-up is easier because the cylinders are integral parts of the sine bar and no separate clamping is required. No measurement is required between the cylinders since this is a known length. It is preferable to use the sine bar on a grade A surface plate. In addition, it is desirable to support both rollers on gauge blocks so that the minute irregularities of the surface plate may be eliminated.

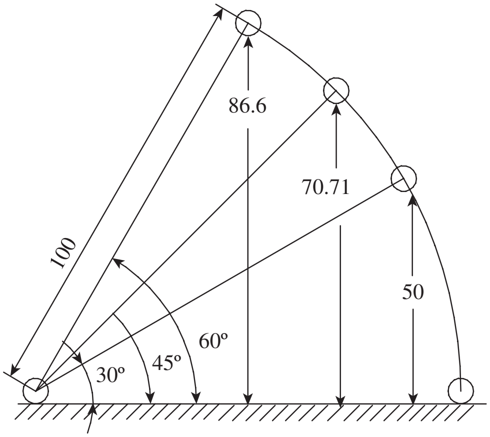


Fig. 5.9 Change in sine value with change in angle

The question often asked is about the maximum angle that can be set using a sine bar. The standard response is 45°. At higher angles, errors due to the distance between the centres of the rollers and gauge blocks get magnified. This is explained in the following example.

Let us assume a 100 mm-long sine bar and calculate the heights to set it at 30°, 45°, and 60°, as shown in Fig. 5.9. The heights are respectively 53, 73.71, and 89.6 mm for angles 30°, 60°, and 90°.

Assume there is an error of +0.1 mm in the height, *h*. Table 5.1 illustrates the error in the measured angles. The actual angle in 'degrees' is given by sine^{-1} (h/L).

Table 5.1 Relationship between error and angle being set

Angle to be set (degrees)	Length of sine bar (mm)	Height of slip gauges (mm)	Actual angle (degrees)	Error in measurement (degrees)
30	100.0	50	30	0.066
		50.1	30.066	
45	100.0	70.71	45	0.080
		70.81	45.080	
60	100.0	86.6	60	0.112
		86.7	60.112	

Accounting for an error of 0.1 mm in height *h*, the angular error for 30° is 0.066 mm. This error increases to 0.08 mm for 45° and jumps to 0.112 mm for 60°. A similar increase in error is observed if the distance between the centres of the rollers of the sine bar has an error. This is the primary reason why metrologists avoid using sine bars for angles greater than 45°.

need more time to set-up

L: always standard & known.

5.3.2 Measuring Unknown Angles with Sine Bar

A sine bar can also be used to measure unknown angles with a high degree of precision. The angle of the work part is first measured using an instrument like a bevel protractor. Then, the work part is clamped to the sine bar and set on top of a surface plate to that angle using slip gauges, as shown in Fig. 5.10 (clamping details are not shown in the figure).

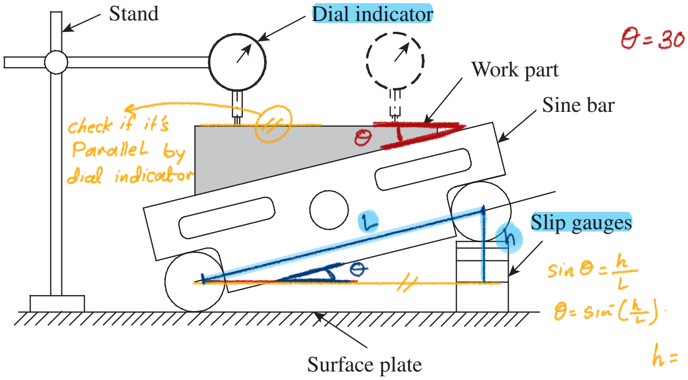


Fig. 5.10 Measurement of unknown angles

h = length of the gauges blocks

A dial gauge fixed to a stand is brought in contact with the top surface of the work part at one end and set to zero. Now, the dial indicator is moved to the other end of the work part in a straight line. A zero reading on the dial indicator indicates that the work part surface is perfectly horizontal and the set angle is the right one. On the other hand, if the dial indicator shows any deviations, adjustments in the height of slip gauges is necessary to ensure that the work part surface is horizontal. The difference in height corresponding to the dial gauge reading is incorporated in the slip gauges, and the procedure is repeated until the dial indicators show zero deviation. The actual angle is calculated using the total height of the slip gauges.

Instead of a dial gauge, a high-amplification comparator can be used for better accuracy. Whether setting a sine bar to a known angle or for measuring unknown angles, a few guidelines should be followed to ensure proper usage of the instrument:

1. It is not recommended to use sine bars for angles greater than 45° because any error in the sine bar or height of slip gauges gets accentuated.
2. Sine bars provide the most reliable measurements for angles less than 15°.
3. The longer the sine bar, the better the measurement accuracy.
4. It is preferable to use the sine bar at a temperature recommended by the supplier. The accuracy of measurement is influenced by the ambient temperature.
5. It is recommended to clamp the sine bar and the work part against an angle plate. This prevents misalignment of the workpiece with the sine bar while making measurements.
6. One should always keep in mind that the sine principle can be put to use provided the sine bar is used along with a high-quality surface plate and set of slip gauges.

5.3.3 Sine Blocks, Sine Plates, and Sine Tables

A *sine block* is a sine bar that is wide enough to stand unsupported (Fig. 5.11). If it rests on an integral base, it becomes a *sine plate* (Fig. 5.12). A sine plate is wider than a sine block. A heavy-duty sine plate is rugged enough to hold work parts for machining or inspection of angles. If a sine plate is an integral part of another device, for example, a machine tool, it is called a *sine table*. However, there is no exact dividing line between the three.

للاشياء الي شكلها مخروطي.

Fig. 5.11 Sine block

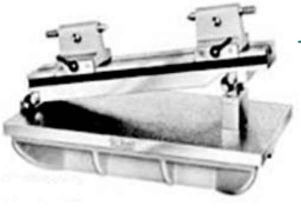


Fig. 5.12 Sine plate

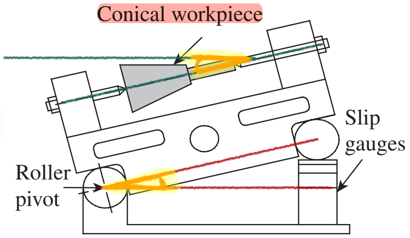


Fig. 5.13 Sine centre

In all these three devices, the work part rests on them. They are often used like a fixture to keep the work part at a particular orientation, so that the required angle is machined. The instruments have attachments to raise and lock the block to the required angle, and to also fasten work parts. The sine table is the most rugged device, which may be swung to any angle from 0° to 90° by pivoting about the hinged end.

There are many instances where compound angles need to be machined or inspected. While simple angles lie on one plane, compound angles of a surface lie on more than one plane. In a surface formed by the intersections of planes, the angles on the surface planes are called *face angles*. A compound sine plate can conveniently measure or set itself to this face angle. In a typical compound sine plate, there are two sine plates: a base plate creates one plane, while the top plate creates the second plane. Compound sine plates are usually used for finishing operations, for example, a finish grinding operation.

5.3.4 Sine Centre

A sine centre provides a convenient means of measuring angles of conical workpieces that are held between centres, as shown in Fig. 5.13. One of the rollers is pivoted about its axis, thereby allowing the sine bar to be set to an angle by lifting the other roller. The base of the sine centre has a high degree of flatness, and slip gauges are wrung and placed on it to set the sine bar at the required angle.

Conical workpieces that need to be inspected are placed between the centres. The sine centre is used for measuring angles up to 60°. The procedure for measuring angles is very similar to the one described in Section 5.3.2. A dial gauge clamped to a stand is set against the conical workpiece. The sine bar is set to an angle such that the dial gauge registers no deviation when moved from one end of the workpiece to the other. The angle is determined by applying the sine rule.

5.4 ANGLE GAUGES *

Angle gauges, which are made of high-grade wear-resistant steel, work on a principle similar to slip gauges. While slip gauges can be built to give linear dimensions, angle gauges can be built to give the required angle. The gauges come in a standard set of angle blocks that can be wrung together in a suitable combination to build an angle. C.E. Johansson, who developed slip gauges, is also credited with the invention of angle gauge blocks. However, the first set of a combination of angle gauges was devised by Dr G.A. Tomlinson of the National Physical

Laboratory, UK, in the year 1939, which provided the highest number of angle combinations. His set of 10 blocks can be used to set any angle between 0° and 180° in increments of 5'.

At the outset, it seems improbable that a set of 10 gauges is sufficient to build so many angles. However, angle blocks have a special feature that is impossible in slip gauges—the former can be subtracted as well as added. This fact is illustrated in Fig. 5.14.

This illustration shows the way in which two gauge blocks can be used in combination to generate two different angles. If a 5° angle block is used along with a 30° angle block, as shown in Fig. 5.14(a), the resulting angle is 35°. If the 5° angle block is reversed and combined with the 30° angle block, as shown in Fig. 5.14(b), the resulting angle is 25°. Reversal of an angle block subtracts itself from the total angle generated by combining other angle blocks. This provides the scope for creating various combinations of angle gauges in order to generate angles that are spread over a wide range by using a minimum number of gauges.

Angle gauges are made of hardened steel, which is lapped and polished to a high degree of accuracy and flatness. The gauges are about 75 mm long and 15 mm wide, and the two surfaces that generate the angles are accurate up to ±2". The gauges are available in sets of 6, 11, or 16. Table 5.2 provides the details of individual blocks in these sets.

Most angles can be combined in several ways. However, in order to minimize error, which gets compounded if the number of gauges used is increased, it is preferable to use the least number of angle gauge blocks. The set of 16 gauges forms all the angles between 0° and 99° in 1" steps—a total of 3,56,400 combinations! The laboratory master-grade set has an accuracy of one-fourth of a second. While the inspection-grade set has an accuracy of ½", the tool room-grade set has an accuracy of 1".

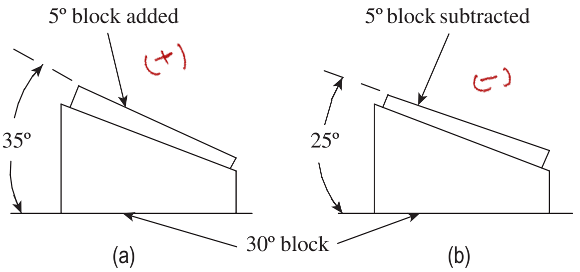


Fig. 5.14 Angle gauge block (a) Addition (b) Subtraction

Table 5.2 Angle gauge block sets

Smallest increment by which any angle can be produced	Number of individual blocks contained in the set	Detailed listing of the blocks composing the set
1°	6	Six blocks of 1°, 3°, 5°, 15°, 30°, and 45°
1′	11	Six blocks of 1°, 3°, 5°, 15°, 30°, and 45° Five blocks of 1', 3', 5', 20', and 30′
1″	16	Six blocks of 1°, 3°, 5°, 15°, 30°, and 45° Five blocks of 1', 3', 5', 20', and 30' Five blocks of 1", 3", 5", 20", and 30"

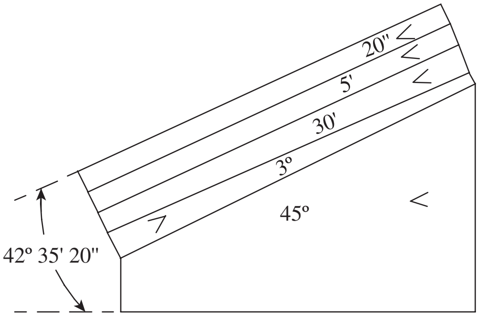


Fig. 5.15 Combination of angle gauges for 42°35'20"

The illustrations in Fig. 5.15 show how angle gauges can be combined to provide the required angles. It may be noted that each angle gauge is engraved with the symbol '<', which indicates the direction of the included angle. Obviously, when the angles of the gauges need to be added up, the symbol < of all gauges should be in line. On the other hand, whenever an angle gauge is required to be subtracted from the combination, the gauge should be wrung such that the symbol < is in the other direction.

Let us consider an angle 42°35′20", which is to be built using the 16-gauge set. Starting from degrees, the angle of 42° can be built by subtracting a 3° block from a 45° block. The angle of 35' can be obtained by combining a 30' gauge with a 5' gauge. A 20" gauge is readily available. The resulting combination is shown in Fig. 5.15.

It can be noticed in this combination that except for the 3° angle gauge, all other gauges are added. Accordingly, the 3° gauge is reversed and wrung with the other gauges, as shown in the figure. The 'wringing' method is the same as that of slip gauges explained in Chapter 4. After wringing, the entire combination is placed on a surface plate and the edges are properly aligned to facilitate measurement.

From the calibration point of view, it is much easier to calibrate angle gauge blocks compared to slip gauges. This is due to the fact that an angle being measured is a portion of a full circle and is, therefore, self-proving. For instance, each of three exactly equal portions of 90° must equal 30°. Thus, the breakdown system can be used to create masters of angle measuring, and each combination can be proved by the same method. In addition, the accuracy of angle gauges is not as sensitive to temperature changes as that of slip gauges. For example, a gauge block manufactured at, say, 30 °C will retain the same angle when used at 40 °C, assuming that the readings are taken some time after the temperature has stabilized and the whole body of the gauge is exposed to the same temperature.

5.4.1 Uses

Angle gauges are used for measurement and calibration purposes in tool rooms. It can be used for measuring the angle of a die insert or for inspecting compound angles of tools and dies. They are also used in machine shops for either setting up a machine (e.g., the revolving centre of a magnetic chuck) or for grinding notches on a cylindrical grinding machine. The illustration in Fig. 5.16 highlights the inspection of a compound angle by using angle gauge blocks. In this case, a surface is inclined in two planes at an angle of 90° to each other. Angle gauges offer a simple means for inspecting such a compound angle by using a dial gauge mounted on a stand.

Figure 5.16 shows a workpiece with a compound angle. Let us assume that the back angle (α) is 15°20' and the side angle (β) is 5°. In order to set the workpiece to 15°20', two angle gauge blocks of 15° and 20' are selected and wrung together. This combination is placed on a surface plate, and the workpiece is positioned on top of the angle gauges. Now, the dial indicator

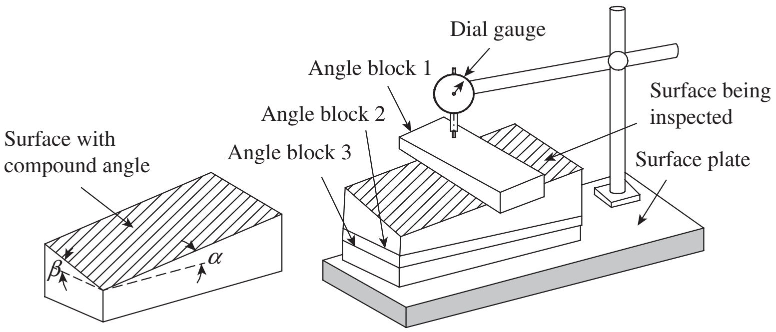


Fig. 5.16 Inspection of a compound angle using angle gauges

reading is taken along a longitudinal direction. If the reading remains zero, it indicates a conformance of the angle α; in this case, the back angle is 15°20'. Then, a 5° angle block is selected and is positioned across the workpiece in the transverse direction, as shown in the figure. Correctness of the compound angle is then easily determined by running the dial indictor across the top surface of the 5° gauge in the transverse direction. A zero reading on the dial gauge indicates the conformance of angle β, that is, 5°. Thus, in a single setting, the compound angles can be inspected using simple devices.

5.4.2 Manufacture and Calibration

Angle gauges are quite often used as the standard for calibration purpose, and therefore, should be manufactured with a high degree of accuracy and precision. Steel blanks are cut to the required shape and machined to the nearest size and shape. Before subjecting them to finish machining, the blanks are heat treated to impart the required hardness. The heat treatment process involves quenching and tempering, followed by a stabilizing process. Now, the gauges are ground and lapped using a sine table. The advantage of using a sine table is that it can ensure that a precise angle is generated without needing to use a custom-made jig or fixture. The non-gauging sides of an angle block are ground and lapped to uniform thickness. This is followed by lapping of the gauging faces. It is important to ensure that the gauging faces are perfectly square to the non-gauging sides. The gauges are then inspected using an autocollimator or interferometry technique to ensure that they meet the accuracy requirements.

The newly manufactured or in-use angle gauges are subjected to calibration to ensure accuracy. One of the popular calibration methods for angle gauges is the interferometry method, which is quite a simple and accurate way of calibrating angle gauges.

The angle gauge, which needs to be calibrated, is carefully placed on a steel platen. The platen is nothing but a surface plate with a degree of flatness. An optical flat is positioned above the angle gauge at some angle, as shown in Fig. 5.17. A monochromatic light source is provided for the optical flat, so that fringe patterns are seen on both the platen and the angle gauge. Assuming that the angle gauge and the platen surfaces are inclined in one plane only, the fringes are straight, parallel, and equally spaced. However, the pitch of the two sets of fringes is different; those on the angle gauge have a lesser pitch. For a distance 'l' measured across the fringes, if 'p' is the number of fringes on the platen and 'q' the number of fringes on the angle gauge, then,

$$\theta = \theta_1 + \theta_2 = \lambda (p - q)/2l$$

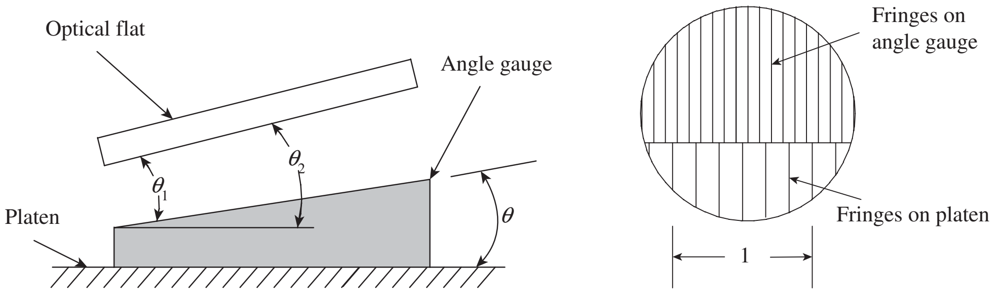


Fig. 5.17 Calibration of angle gauges by interferometry

where λ is the wavelength of light. In this method, it is possible to calibrate angle gauges up to 0.1" of an arc.

5.4.3 True Square

A true square is used as a companion tool along with an angle gauge block set. It is available for both tool room and laboratory master sets. As the name itself suggests, it is a square piece made of hardened and wear-resistant steel. All faces of the true square are precisely at a 90° angle to adjacent gauging surfaces. It has a high degree of optical flatness and parallelism to be used with autocollimators. The main advantage of a true square is that it extends the range of the angle block set to 360°, be it in degree, minute, or second steps. Figure 5.18 illustrates the shape of a true square.

5.5 SPIRIT LEVEL

A spirit level is a basic 'bubble instrument', which is widely used in engineering metrology. It is derived from the practice in cold western countries. To combat freezing, the tubes were filled with 'spirits of wine', hence the general term spirit level. Spirit level, as you are aware, is an angular measuring device in which the bubble always moves to the highest point of a glass vial. The details of a typical spirit level are shown in Fig. 5.19. The base, called the reference plane, is seated on the machine part for which straightness or flatness is to be determined. When the base is horizontal, the bubble rests at the centre of the graduated scale, which is engraved on the glass. When the base of the spirit level moves out of the horizontal, the bubble shifts to the highest point of the tube. The position of the bubble with reference to the scale is a measure of the angularity of the machine part. This scale is calibrated to directly provide the reading in minutes or seconds. A cross test level provided at a right angle to the main bubble scale indicates the inclination in the other plane. A screw adjustment is provided to set the bubble to zero by referencing with a surface plate.

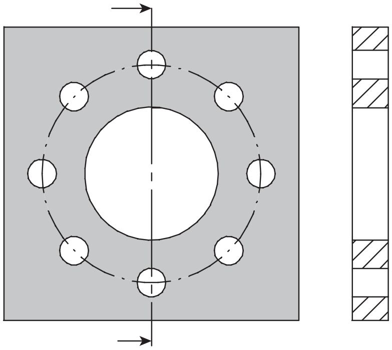


Fig. 5.18 True square

The performance of the spirit level is governed by the

more accurate
(1')

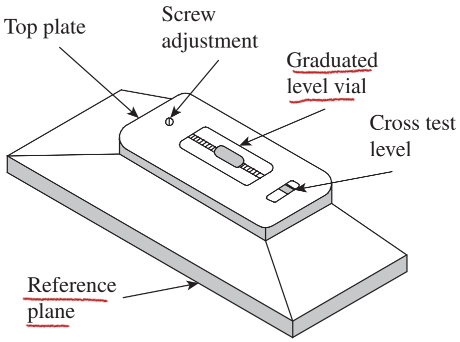


Fig. 5.19 Spirit level

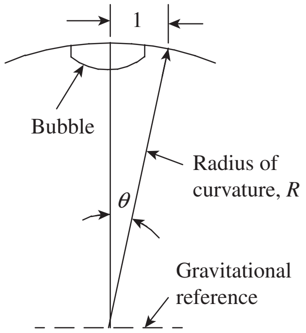


Fig. 5.20 Relationship between radius of curvature and bubble scale reading

geometrical relationship between the bubble and the two references. The first reference is the effect of gravity acting at the centre of the bubble. The second is the scale against which the bubble position is read. The sensitivity of the spirit level depends on the radius of curvature of the bubble, which is formed against the inside surface of the glass vial, and the base length of its mount.

Assuming that a level has graduations on the vial with a least count of 1mm and a radius of curvature, R, as shown in Fig. 5.20, the angle $\theta = l/R$ (since θ is very small).

If the graduations are at a 2 mm interval and represent a tilt of 10", then the following can be concluded:

$$\theta^c = 10 \times \pi/(180 \times 3600)$$

Therefore, $R = 41{,}273.89$ mm or 41.274 m approximately.

If the base length is 250 mm, the height h, to which one end must be raised for a 2 mm bubble movement, is given by the following relation:

$$\theta^c = h/250$$

Therefore, $h = 0.012$ mm.

It is obvious from these computations that sensitivity of the instrument depends on the radius of curvature of the bubble tube and the base length. Sensitivity can be increased by either increasing the radius of curvature or reducing the base length. The most useful sensitivity for precision measurement is 10" per division.

The main use of a spirit level is not for measuring angles, but for measuring alignment of machine parts and determining flatness and straightness. Typically, the level is stepped along the surface in intervals of its own base length, the first position being taken as the datum. The heights of all other points are determined relative to this datum. One should always keep in mind that the accuracy of a given spirit level depends on the setting of the vial relative to the base. There is bound to be a certain amount of error in the setting of the vial. In order to minimize this error, the following procedure is recommended while using a spirit level for precision measurement:

1. Take readings from both ends of the vial.
2. Reverse the base of the spirit level.
3. Repeat readings from both ends.

4. Average the four readings.
5. Repeat all steps for critical cases.

more accurate than the Spirit level.

5.5.1 Clinometer

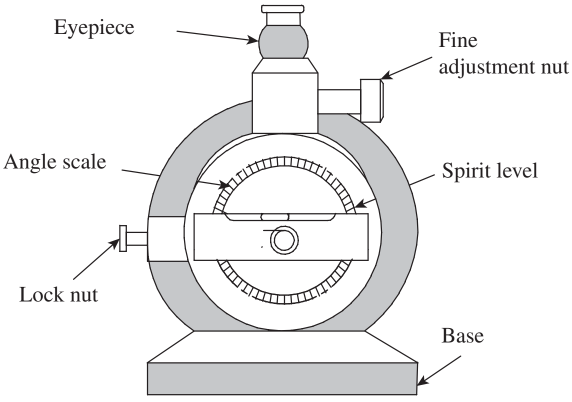


Fig. 5.21 Clinometer

A clinometer (Fig. 5.21) is a special case of a spirit level. While the spirit level is restricted to relatively small angles, clinometers can be used for much larger angles. It comprises a level mounted on a frame so that the frame may be turned to any desired angle with respect to a horizontal reference. Clinometers are used to determine straightness and flatness of surfaces. They are also used for setting inclinable tables on jig boring machines and angular jobs on surface grinding machines. They provide superior accuracy compared to ordinary spirit levels.

To measure with clinometers, the base is kept on the surface of the workpiece. The lock nut is loosened, and the dial comprising the circular scale is gently rotated until the bubble in the spirit level is approximately at the centre. Now, the lock nut is tightened and the fine adjustment nut is operated until the bubble is exactly at the centre of the vial scale. The reading is then viewed through the eyepiece. Most clinometers in a metrology laboratory provide readings up to an accuracy of 1'. Precision clinometers can be used if the accuracy requirement is up to 1".

A recent advancement in clinometers is the electronic clinometer. It consists of a pendulum whose displacement is converted into electrical signals by a linear voltage differential transformer. This provides the advantage of electronic amplification. It is powered by an electronic chip that has a provision for recording and data analysis. Electronic clinometers have a sensitivity of 1". A major advantage of these clinometers is that the readings settle down within 1 second in contrast to the mechanical type, which requires a couple of seconds for the reading to settle down.

5.6 OPTICAL INSTRUMENTS FOR ANGULAR MEASUREMENT

لبعدين

Chapter 7 is devoted to the discussion of optical measurements. Nevertheless, it would be appropriate to highlight the four principles that govern the application of optics in metrology here. The most vital one is *magnification*, which provides visual enlargement of the object. Magnification enables easy and accurate measurement of the attributes of an object. The second one is *accuracy*. A monochromatic light source provides the absolute standard of length, and therefore, ensures a high degree of accuracy. The third principle is one of *alignment*. It uses light rays to establish references such as lines and planes. The fourth, and a significant one, is the principle of *interferometry*, which is a unique phenomenon associated with light. These principles have driven the development of a large number of measuring instruments and comparators. This section is devoted to two such instruments, which are most popular in angular measurement, namely the autocollimator and the angle dekkor.

An autocollimator is an optical instrument that is used to measure small angles with very

Chapter (5) : Angular measurement.

* primary objective → measure the straightness, parallelism, & Flatness → require sensitive instruments as autocollimators

the angle reading = measure of the error.

(5.2) Protractor : Least count 1° in small protractor & $\frac{1}{2}$° " Large "

→ parallel to the object

* Limited usage → not accurate

→ Universal Bevel protractor : → accuracy = 5′

with base plate, high degree of Flatness ... ①

② Blade, swivelled to required angles → rotate with the main scale.

③ Main Scale : 4 quardants 1° from (0° – 90°)

④ Vernier Scale : 24 divisions (1′ – 60′)

→ رح يعطينا قراءة الزاوية الحادة between base & blade.

→ Angles & their Supplements :

α : Acute angle → between base & blade

θ : Supplements → $180 - \alpha$

$\alpha = 15° 45'$

the supplements

$\theta = 164° 15'$

** Optical bevel protractor

(5.3) Sine bars : ① more accurate reading → required angle → diff erence between the two rollers = $\sin\theta * L$.

→ made of corrosion resistance steel → with holes = Less weight

$\rightarrow \sin\theta = \frac{h}{L} \rightarrow \theta = \sin^{-1}\left(\frac{h}{L}\right)$

→ Between the upper surface & the Surface plate (Datum)

* not complete measuring → indirect.

② measuring unknow angles

→ first measured could be with bevel protractor, then sine bar with dial gauge → check if the surface is perfectly horizontal. (parallel)

+ h : hight using slip gauges.

→ Sine block : Sine bar wide enough to stand unsupported → sine plate if it rest on integral base (wider)

→ heavy-duty, rugged enough to hold work parts

Sine table : if sine plate is an integral part of other devices

*** Sine Center for Conical workpieces

(5.4) Angular gauges

made of high grade wear resistance steel

* two gauge blocks can generate two different angles

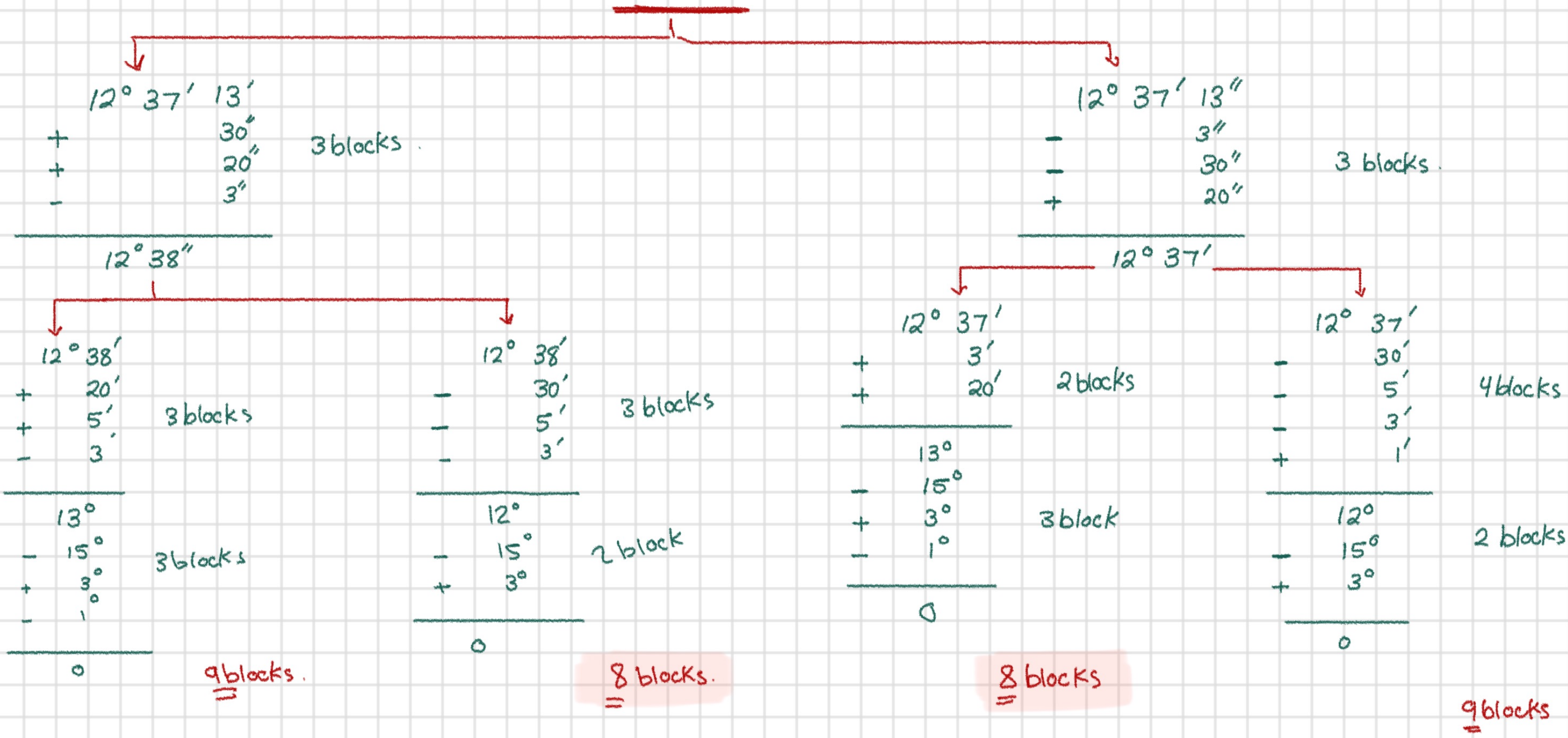
5′ along 30′ ⟹ 35′
5′ reversed 30′ ⟹ 25′

** True Square : compainion tool along angle gauge block

↳ made of hardened & wear resistant steel ⟶ All faces at 90°

⟶ main advantage : extends the range of the angle block set to 360°

Example : 16 pieces set to form 12° 37′ 13″



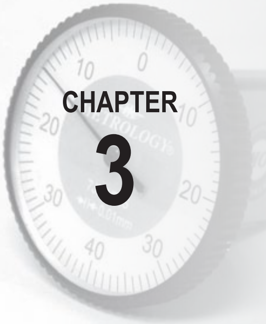
(5.5) Spirit Level :

* base (reference) seated on the machine part ⟶ (Straightness or flatness is to be determined).

↳ horizontal ⟹ bubble rests at the center ⟶ position of the bubble measure the angularity.

accuracy = 1′

** Clinometer case of a spirit level ⟶ used for larger angles



CHAPTER 3

Limits, Fits, and Tolerances

After studying this chapter, the reader will be able to

- understand the importance of manufacturing components to specified sizes
- elucidate the different approaches of interchangeable and selective assembly
- appreciate the significance of different types of limits, fits, and tolerances in design and manufacturing fields, which are required for efficient and effective performance of components/products
- utilize the principle of limit gauging and its importance in inspection in industries
- design simple GO and NOT gauges used in workshops/ inspection

3.1 INTRODUCTION

Although any two things found in nature are seldom identical, they may be quite similar. This is also true in the case of manufacturing of different components for engineering applications. No two parts can be produced with identical measurements by any manufacturing process. A manufacturing process essentially comprises five m's—man, machine, materials, money, and management.

Variations in any of the first three elements induce a change in the manufacturing process. All the three elements are subjected to natural and characteristic variations. In any production process, regardless of how well it is designed or how carefully it is maintained, a certain amount of natural variability will always exist. These natural variations are random in nature and are the cumulative effect of many small, essentially uncontrollable causes. When these natural variations in a process are relatively small, we usually consider this to be an acceptable level of process performance.

Usually, variability arises from improperly adjusted machines, operator error, tool wear, and/or defective raw materials. Such characteristic variability is generally large when compared to the natural variability. This variability, which is not a part of random or chance cause pattern, is referred to as 'assignable causes'. Characteristic variations can be attributed to assignable causes that can easily be identified and controlled. However, this has to be assignable causes

Large variability between the Samples

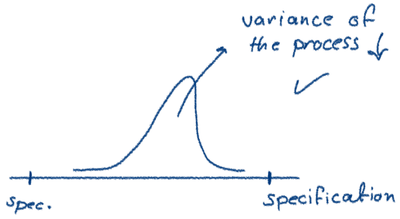
random causes:

acceptable variability

achieved economically, which brings in the fourth element. Characteristic variability causes variations in the size of components. If the process can be kept under control, that is, all the assignable and controllable causes of variations have been eliminated or controlled, the size variations will be well within the prescribed limits. These variations can be modified through operator or management action.

Production processes must perform consistently to meet the production and design requirements. In order to achieve this, it is essential to keep the process under control. Thus, when the process is under control, distribution of most of the measured values will be around the mean value in a more or less symmetrical way, when plotted on a chart. It is therefore impossible to produce a part to an exact size or basic size and some variations, known as tolerances, need to be allowed. Some variability in dimension within certain limits must be tolerated during manufacture, however precise the process may be. The permissible level of tolerance depends on the functional requirements, which cannot be compromised.

No component can be manufactured precisely to a given dimension; it can only be made to lie between two limits, upper (maximum) and lower (minimum). The designer has to suggest these tolerance limits, which are acceptable for each of the dimensions used to define shape and form, and ensure satisfactory operation in service. When the tolerance allowed is sufficiently greater than the process variation, no difficulty arises. The difference between the upper and lower limits is termed *permissive tolerance*.



Shaft with dia.
= 40 ± 0.02

For example, a shaft has to be manufactured to a diameter of 40 ± 0.02 mm. This means that the shaft, which has a basic size of 40 mm, will be acceptable if its diameter lies anywhere between the limits of sizes, that is, an upper limit of 40.02 mm and a lower limit of 39.98 mm. Then permissive tolerance is equal to 40.02 – 39.98 = 0.04. *Basic* or *nominal size* is defined as the size based on which the dimensional deviations are given.

In any industry, a manufactured product consists of many components. These components when assembled should have a proper fit, in order for the product to function properly and have an extended life. Fit depends on the correct size relationships between the two mating parts. Consider the example of rotation of a shaft in a hole. Enough clearance must be provided between the shaft and the hole to allow an oil film to be maintained for lubrication purpose. If the clearance is too small, excessive force would be required to rotate the shaft. On the other hand, if the clearance is too wide, there would be vibrations and rapid wear resulting in ultimate failure. Therefore, the desired clearance to meet the requirements has to be provided. Similarly, to hold the shaft tightly in the hole, there must be enough interference between the two so that forces of elastic compression grip them tightly and do not allow any relative movement between them.

An ideal condition would be to specify a definite size to the hole and vary the shaft size for a proper fit or vice versa. Unfortunately, in practice, particularly in mass production, it is not possible to manufacture a part to the exact size due to the inherent inaccuracy of manufacturing methods. Even if a part is manufactured to the exact size by chance, it is not possible to measure it accurately and economically during machining. In addition, attempts to manufacture to the exact size can increase the production cost.

Dimensional variations, although extremely small, do exist because of the inevitable inaccuracies in tooling, machining, raw material, and operators. If efforts are made to identify and reduce or eliminate common causes of variation, that is, if the process is kept under control, then the resultant frequency distribution of dimensions produced will have a normal

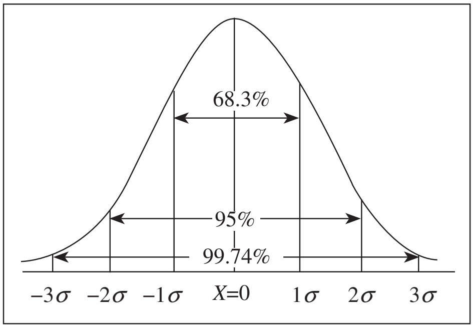


Fig. 3.1 Normal or Gaussian frequency distribution

or Gaussian distribution, that is, 99.74% parts will be well within $\pm 3\sigma$ limits of the mean value, as shown in Fig. 3.1. Thus, it is possible to express the uncertainty in measurement as a multiple of standard deviation. This value is determined by the probability that a measurement will fall outside the stated limits.

3.2 PRINCIPLE OF INTERCHANGEABILITY

For manufacturing a large number of components, it is not economical to produce both the mating parts (components) using the same operator. Further, such parts need to be manufactured within minimum possible time without compromising on quality. To enable the manufacture of identical parts, mass production, an idea of the last industrial revolution that has become very popular and synonymous with the present manufacturing industry, becomes inevitable.

Modern production techniques require that a complete product be broken into various component parts so that the production of each part becomes an independent process, leading to specialization. The various components are manufactured in one or more batches by different persons on different machines at different locations and are then assembled at one place.

To achieve this, it is essential that the parts are manufactured in bulk to the desired accuracy and, at the same time, adhere to the limits of accuracy specified. Manufacture of components under such conditions is called *interchangeable manufacture*.

When interchangeable manufacture is adopted, any one component selected at random should assemble with any other arbitrarily chosen mating component. In order to assemble with a predetermined fit, the dimensions of the components must be confined within the permissible tolerance limits. By *interchangeable assembly*, we mean that identical components, manufactured by different operators, using different machine tools and under different environmental conditions, can be assembled and replaced without any further modification during the assembly stage and without affecting the functioning of the component when assembled. Production on an interchangeable basis results in an increased productivity with a corresponding reduction in manufacturing cost. Modern manufacturing techniques that complement mass production of identical parts facilitating interchangeability of components have been developed. When components are produced in bulk, unless they are interchangeable, the purpose of mass production is not fulfilled.

For example, consider the assembly of a shaft and a part with a hole. The two mating parts are produced in bulk, say 1000 each. By interchangeable assembly any shaft chosen randomly should assemble with any part with a hole selected at random, providing the desired fit.

Another major advantage of interchangeability is the ease with which replacement of defective or worn-out parts is carried out, resulting in reduced maintenance cost. In addition, the operator, by performing the same limited number of operations, becomes a specialist in that work. By achieving specialization in labour, there will be a considerable reduction in manufacturing and assembly time and enhancement in quality. Interchangeable manufacture increases productivity and reduces production and time costs.

In order to achieve interchangeability, certain standards need to be followed, based on which interchangeability can be categorized into two types—universal interchangeability and local interchangeability.

When the parts that are manufactured at different locations are randomly chosen for assembly, it is known as universal interchangeability. To achieve universal interchangeability, it is desirable that common standards be followed by all and the standards used at various manufacturing locations be traceable to international standards.

When the parts that are manufactured at the same manufacturing unit are randomly drawn for assembly, it is referred to as local interchangeability. In this case, local standards are followed, which in turn should be traceable to international standards, as this becomes necessary to obtain the spares from any other source.

3.2.1 Selective Assembly Approach

Today's consumers desire products that are of good quality and, at the same time, reliable and available at attractive prices. Further, in order to achieve interchangeability, it is not economical to manufacture parts to a high degree of accuracy. It is equally important to produce the part economically and, at the same time, maintain the quality of the product for trouble-free operation. Sometimes, for instance, if a part of minimum limit is assembled with a mating part of maximum limit, the fit obtained may not fully satisfy the functional requirements of the assembly. The reason may be attributed to the issues of accuracy and uniformity that may not be satisfied by the certainty of the fits given under a fully interchangeable system. It should be realized that, in practice, complete interchangeability is not always feasible; instead, selective assembly approach can be employed. Attaining complete interchangeability in these cases involves some extra cost in inspection and material handling, as selective assembly approach is employed wherein the parts are manufactured to wider tolerances. In selectively assembly, despite being manufactured to rather wide tolerances, the parts fit and function as if they were precisely manufactured in a precision laboratory to very close tolerances.

The issue of clearances and tolerances when manufacturing on an interchangeable basis is rather different from that when manufacturing on the basis of selective assembly. In interchangeability of manufacture, minimum clearance should be as small as possible as the assembling of the parts and their proper operating performance under allowable service conditions. Maximum clearance should be as great as the functioning of the mechanisms permits. The difference between maximum clearance and minimum clearance establishes the sum of the tolerances on companion parts. To manufacture the parts economically on interchangeable basis, this allowable difference must be smaller than the normal permissible manufacturing conditions. In such situations, selective assembly may be employed. This method enables economical manufacture of components as per the established tolerances. In selective assembly, the manufactured components are classified into groups according to their sizes. Automatic gauging is employed for this purpose. Both the mating parts are segregated according to their sizes, and only matched groups of mating parts are assembled. This ensures complete protection and elimination of defective assemblies, and the matching costs are reduced because the parts are produced with wider tolerances.

Selective assembly finds application in aerospace and automobile industries. A very pertinent and practical example is the manufacture and assembly of ball and bearing units, as the tolerances desired in such industries are very narrow and impossible to achieve economically by any sophisticated machine tools. Balls are segregated into different groups depending on their size to enable the assembly of any bearing with balls of uniform size. In a broader sense, a combination of both interchangeable and selective assemblies exists in modern-day manufacturing industries, which help to manufacture quality products.

3.3 TOLERANCES

To satisfy the ever-increasing demand for accuracy, the parts have to be produced with less dimensional variation. Hence, the labour and machinery required to manufacture a part has become more expensive. It is essential for the manufacturer to have an in-depth knowledge of the tolerances to manufacture parts economically but, at the same time, adhere to quality and reliability aspects. In fact, precision is engineered selectively in a product depending on the functional requirements and its application. To achieve an increased compatibility between mating parts to enable interchangeable assembly, the manufacturer needs to practise good tolerance principles. Therefore, it is necessary to discuss some important principles of tolerances that are usually employed for manufacturing products.

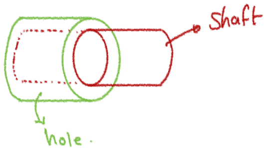
We know that it is not possible to precisely manufacture components to a given dimension because of the inherent inaccuracies of the manufacturing processes. The components are manufactured in accordance with the permissive tolerance limits, as suggested by the designer, to facilitate interchangeable manufacture. The permissible limits of variations in dimensions have to be specified by the designer in a logical manner, giving due consideration to the functional requirements. The choice of the tolerances is also governed by other factors such as manufacturing process, cost, and standardization.

Tolerance can be defined as the magnitude of permissible variation of a dimension or other measured value or control criterion from the specified value. It can also be defined as the total variation permitted in the size of a dimension, and is the algebraic difference between the upper and lower acceptable dimensions. It is an absolute value.

The basic purpose of providing tolerances is to permit dimensional variations in the manufacture of components, adhering to the performance criterion as established by the specification and design. If high performance is the sole criterion, then functional requirements dictate the specification of tolerance limits; otherwise, the choice of setting tolerance, to a limited extent, may be influenced and determined by factors such as methods of tooling and available manufacturing equipment. The industry follows certain approved accuracy standards, such as ANSI (American National Standards Institute) and ASME (American Society of Mechanical Engineers), to manufacture different parts.

3.3.1 Computer-aided Modelling

Nowadays, computers are widely being employed in the design and manufacture of parts. Most leading design tools such as AEROCADD, AUTOCAD, and Solid Works, which are currently being used in industries, are equipped with tolerance features. The algorithms and programming codes that are in existence today are aimed at enhancing the accuracy with minimum material wastage. These programs have the capability of allotting tolerance ranges for different miniature parts of complex mechanical systems.



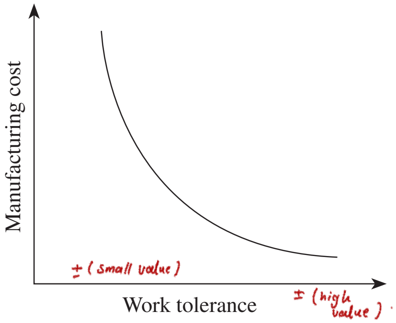


Fig. 3.2 Relationship between work tolerance and manufacturing cost

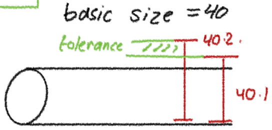
3.3.2 Manufacturing Cost and Work Tolerance

It is very pertinent to relate the production of components within the specified tolerance zone to its associated manufacturing cost. As the permissive tolerance goes on decreasing, the manufacturing cost incurred to achieve it goes on increasing exponentially. When the permissive tolerance limits are relaxed without degrading the functional requirements, the manufacturing cost decreases. This is clearly illustrated in Fig. 3.2.

Further, in order to maintain such close tolerance limits, manufacturing capabilities have to be enhanced, which certainly increases the manufacturing cost. The components manufactured have to undergo a closer scrutiny, which demands stringent inspection procedures and adequate instrumentation. This increases the cost of inspection. Hence, tolerance is a trade-off between the economical production and the accuracy required for proper functioning of the product. In fact, the tolerance limits specified for the components to be manufactured should be just sufficient to perform their intended functions.

$\boxed{40^{+0.2}_{+0.1}}$

40.1 lower limit
40.2 higher limit



unilateral

LLS = 19.5
HLS = 20
basic Size = 20
unilateral

$\boxed{20^{+0.0}_{-0.5}}$

LLS = 29.9
HLS = 30.2
basic = 30
Bilateral

$\boxed{30^{+0.2}_{-0.1}}$

3.3.3 Classification of Tolerance

Ex: basic = 40
lower limit = 39.5
upper " = 39.8
Unilateral
راجعيه با كتام واهد
diff = tolerance

Tolerance can be classified under the following categories:

1. Unilateral tolerance
2. Bilateral tolerance
3. Compound tolerance
4. Geometric tolerance

Unilateral Tolerance

When the tolerance distribution is only on one side of the basic size, it is known as unilateral tolerance. In other words, tolerance limits lie wholly on one side of the basic size, either above or below it. This is illustrated in Fig. 3.3(a). Unilateral tolerance is employed when precision fits are required during assembly. This type of tolerance is usually indicated when the mating parts are also machined by the same operator. In this system, the total tolerance as related to the basic size is in one direction only. Unilateral tolerance is employed in the drilling process wherein dimensions of the hole are most likely to deviate in one direction only, that is, the hole is always oversized rather than undersized. This system is preferred because the basic size is used for the GO limit gauge. This helps in standardization of the GO gauge, as holes and shafts of different grades will have the same lower and upper limits, respectively. Changes in the magnitude of the tolerance affect only the size of the other gauge dimension, the NOT GO gauge size.

Example

$$40^{+0.02}_{+0.01},\ 40^{+0.02}_{-0.00},\ 40^{-0.01}_{-0.02},\ 40^{+0.00}_{-0.02}$$

Bilateral Tolerance

When the tolerance distribution lies on either side of the basic size, it is known as bilateral tolerance. In other words, the dimension of the part is allowed to vary on both sides of the basic

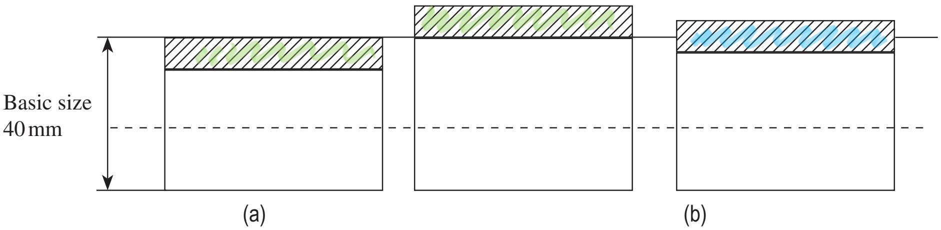


Fig. 3.3 Tolerances (a) Unilateral (b) Bilateral

size but may not be necessarily equally disposed about it. The operator can take full advantage of the limit system, especially in positioning a hole. This system is generally preferred in mass production where the machine is set for the basic size. This is depicted in Fig. 3.3(b). In case unilateral tolerance is specified in mass production, the basic size should be modified to suit bilateral tolerance.

Example

$(40 \pm 0.02)(40^{+0.02}_{-0.01})$

Compound Tolerance

When tolerance is determined by established tolerances on more than one dimension, it is known as compound tolerance For example, tolerance for the dimension *R* is determined by the combined effects of tolerance on 40 mm dimension, on 60º, and on 20 mm dimension. The tolerance obtained for dimension *R* is known as compound tolerance (Fig. 3.4). In practice, compound tolerance should be avoided as far as possible.

Geometric Tolerance

Normally, tolerances are specified to indicate the actual size or dimension of a feature such as a hole or a shaft. In order to manufacture components more accurately or with minimum dimensional variations, the manufacturing facilities and the labour required become more cost intensive. Hence, it is essential for the manufacturer to have an in-depth knowledge of tolerances, to manufacture quality and reliable components economically. In fact, depending on the application of the end product, precision is engineered selectively. Therefore, apart from considering the actual size, other geometric dimensions such as roundness and straightness of a shaft have to be considered while manufacturing components. The tolerances specified should also encompass such variations. However, it is difficult to combine all errors of roundness, straightness, and diameter within a single tolerance on diameter. Geometric tolerance is defined as the total amount that the dimension of a manufactured part can vary. Geometric tolerance underlines the importance of the shape of a feature as against its size. Geometric dimensioning and tolerancing is a method of defining parts based on how they function, using standard symbols. This method is frequently used in industries. Depending on the functional requirements, tolerance on

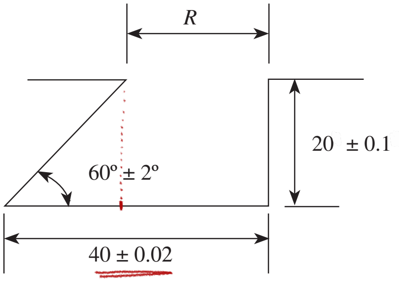


Fig. 3.4 Compound tolerance

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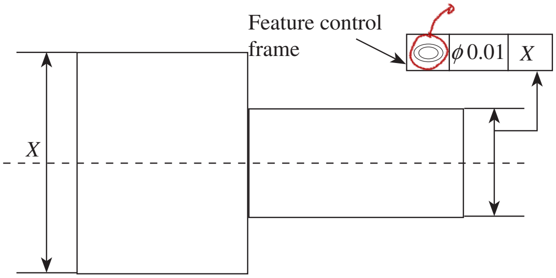


Fig. 3.5 Representation of geometric tolerance

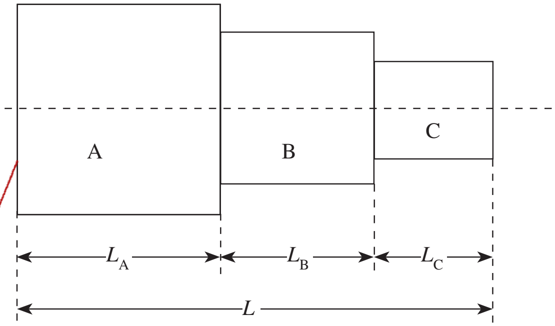


Fig. 3.6 Accumulation of tolerances

diameter, straightness, and roundness may be specified separately. Geometric tolerance can be classified as follows:

Form tolerances Form tolerances are a group of geometric tolerances applied to individual features. They limit the amount of error in the shape of a feature and are independent tolerances. Form tolerances as such do not require locating dimensions. These include straightness, circularity, flatness, and cylindricity.

Orientation tolerances Orientation tolerances are a type of geometric tolerances used to limit the direction or orientation of a feature in relation to other features. These are related tolerances. Perpendicularity, parallelism, and angularity fall into this category.

Positional tolerances Positional tolerances are a group of geometric tolerances that controls the extent of deviation of the location of a feature from its true position. This is a three-dimensional geometric tolerance comprising position, symmetry, and concentricity.

Geometric tolerances are used to indicate the relationship of one part of an object with another. Consider the example shown in Fig. 3.5. Both the smaller- and the larger-diameter cylinders need be concentric with each other. In order to obtain a proper fit between the two cylinders, both the centres have to be in line with each other. Further, perhaps both the cylinders are manufactured at different locations and need to be assembled on an interchangeable basis. It becomes imperative to indicate how much distance can be tolerated between the centres of these two cylinders. This information can be represented in the feature control frame that comprises three boxes. The first box on the left indicates the feature to be controlled, which is represented symbolically. In this example, it is concentricity. The box at the centre indicates the distance between the two cylinders that can be tolerated, that is, these two centres cannot be apart by more than 0.01 mm. The third box indicates that the datum is with X. The different types of geometric tolerances and their symbolic representation are given in Table 3.1.

Consider the example shown in Fig. 3.6.

0.3 tolerance

Let $L_A = 30^{+0.02}_{-0.01}$ mm, $L_B = 20^{+0.02}_{-0.01}$ mm, and $L_C = 10^{+0.02}_{-0.01}$ mm.

The overall length of the assembly is the sum of the individual length of components given as

$$L = L_A + L_B + L_C$$
$$L = 30 + 20 + 10 = 60\,\text{mm}$$

Table 3.1 Symbolic representation of geometric tolerances

Type of geometric tolerance	Feature	Geometric characteristic	Definition	Symbol
Form tolerance	Independent	Straightness (two-dimensional)	Controls the extent of deviation of a feature from a straight line	⏤
		Circularity (two-dimensional)	Exercises control on the extent of deviation of a feature from a perfect circle	○
		Flatness (three-dimensional)	Controls the extent of deviation of a feature from a flat plane	⏥
		Cylindricity (three-dimensional)	Controls the extent of deviation of a feature from a perfect cylinder	⌭
	Related or single	Profile of a line (two-dimensional)	Controls the extent of deviation of an outline of a feature from the true profile	⌒
		Profile of a surface (two-dimensional)	Exercises control on the extent of deviation of a surface from the true profile	⌓
Orientation tolerance	Related	Perpendicularity (three-dimensional)	Exercises control on the extent of deviation of a surface, axis, or plane from a 90° angle	⊥
		Parallelism (three-dimensional)	Controls the extent of deviation of a surface, axis, or plane from an orientation parallel to the specified datum	∥
		Angularity (three-dimensional)	Exercises controls on the deviation of a surface, axis, or plane from the angle described in the design specifications	∠
Position tolerance	Related	Position (three-dimensional)	Exercises control on the extent of deviation of location of a feature from its true position	⌖
		Symmetry (three-dimensional)	Exercises control on extent of deviation of the median points between two features from a specified axis or centre plane	⌯
		Concentricity (three-dimensional)	Exercises control on extent of deviation of the median points of multiple diameters from the specified datum axis	◎
Runout	Related	Circular runout (two-dimensional)	Exercises composite control on the form, orientation, and location of multiple cross-sections of a cylindrical part as it rotates	↗
		Total runout (three-dimensional)	Exercises simultaneous composite control on the form, orientation, and location of the entire length of a cylindrical part as it rotates	⌰

هاد المفروض
يكون الحل.

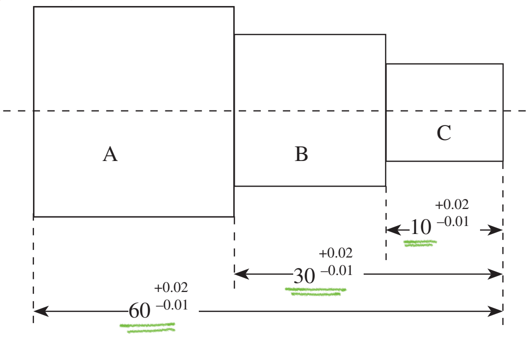


Fig. 3.7 Progressive dimensioning

Then, cumulative upper tolerance limit is 0.02 + 0.02 + 0.02 = 0.06 mm and cumulative lower limit = − 0.01 − 0.01 − 0.01 = −0.03 mm

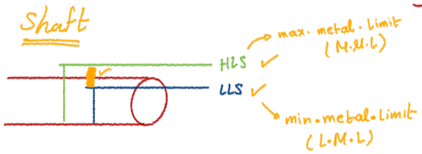
Therefore, dimension of the assembled length will be = $60^{+0.06}_{-0.03}$ mm

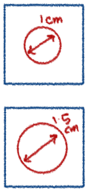
It is essential to avoid or minimize the cumulative effect of tolerance build-up, as it leads to a high tolerance on overall length, which is undesirable. If progressive dimensioning from a common reference line or a baseline dimensioning is adopted, then tolerance accumulation effect can be minimized. This is clearly illustrated in Fig. 3.7.

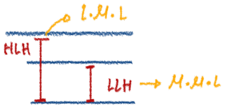
في ملف

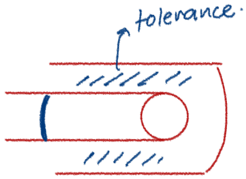
مهمة *

3.4 MAXIMUM AND MINIMUM METAL CONDITIONS









Let us consider a shaft having a dimension of 40 ± 0.05 mm.

The maximum metal limit (MML) of the shaft will have a dimension of 40.05 mm because at this higher limit, the shaft will have the maximum possible amount of metal.

The shaft will have the least possible amount of metal at a lower limit of 39.95 mm, and this limit of the shaft is known as minimum or least metal limit (LML).

Similarly, consider a hole having a dimension of 45 ± 0.05 mm.

The hole will have a maximum possible amount of metal at a lower limit of 44.95 mm and the lower limit of the hole is designated as MML. For example, when a hole is drilled in a component, minimum amount of material is removed at the lower limit size of the hole. This lower limit of the hole is known as MML. *

The higher limit of the hole will be the LML. At a high limit of 45.05 mm, the hole will have the least possible amount of metal. The maximum and minimum metal conditions are shown in Fig. 3.8.

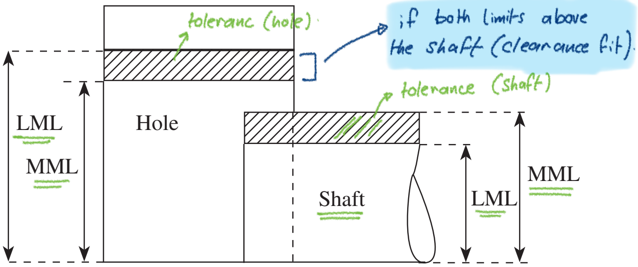


Fig. 3.8 MML and LML

3.5 FITS

⇒ 3 types,

Manufactured parts are required to mate with one another during assembly. The relationship between the two mating parts that are to be assembled, that is, the hole and the shaft, with respect to the difference in their dimensions before assembly is called a *fit*. An ideal fit is required for proper functioning of the mating parts. Three basic types of fits can be identified, depending on the actual limits of the hole or shaft:

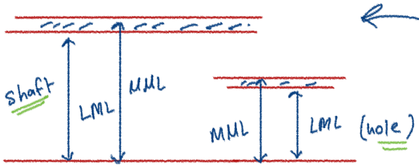
1. Clearance fit

is the min diameter (hole) > max diameter (Shaft).

2. Interference fit
3. Transition fit

Clearance fit The largest permissible diameter of the shaft is smaller than the diameter of the smallest hole. This type of fit always provides clearance. Small clearances are provided for a precise fit that can easily be assembled without the assistance of tools. When relative motions are required, large clearances can be provided, for example, a shaft rotating in a bush. In case of clearance fit, the difference between the sizes is always positive. The clearance fit is described in Fig. 3.9.

عكسه اعرضها للحرارة او (force).



is Min dia. (shaft) > max dia. (hole).

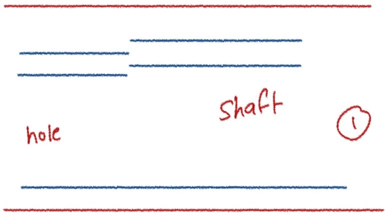
Interference fit The minimum permissible diameter of the shaft exceeds the maximum allowable diameter of the hole. This type of fit always provides interference. Interference fit is a form of a tight fit. Tools are required for the precise assembly of two parts with an interference fit. When two mating parts are assembled with an interference fit, it will be an almost permanent assembly, that is, the parts will not come apart or move during use. To assemble the parts with interference, heating or cooling may be required. In an interference fit, the difference between the sizes is always negative. Interference fits are used when accurate location is of utmost importance and also where such location relative to another part is critical, for example, alignment of dowel pins. The interference fit is illustrated in Fig. 3.10.

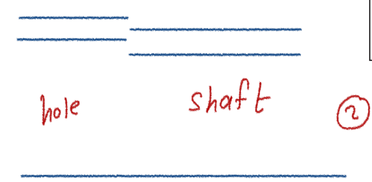
دائمة

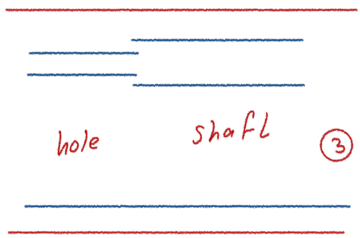
في صورة بالسلايدات

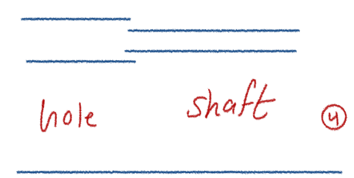
* transition fit

يعني انه من النوعين الي قبل









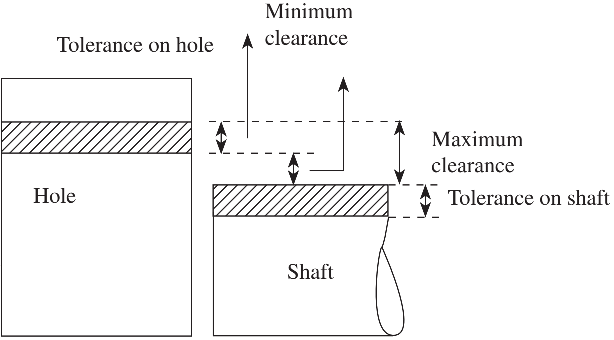


Fig. 3.9 Clearance fit

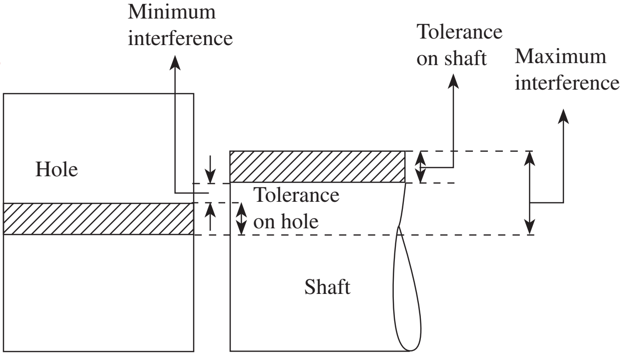
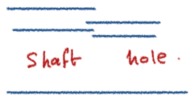


Fig. 3.10 Interference fit

Transition fit The diameter of the largest permissible hole is greater than the diameter of the smallest shaft and the diameter of the smallest hole is smaller than the diameter of the largest shaft. In other words, the combination of maximum diameter of the shaft and minimum diameter of the hole results in an interference fit, while that of minimum diameter of the shaft and maximum diameter of the hole yields a clearance fit. Since the tolerance zones overlap, this type of fit may sometimes provide clearance and sometimes interference, as depicted in Fig. 3.11. Precise assembly may be obtained with the assistance of tools, for example, dowel pins may be required in tooling to locate parts.

In a clearance fit, minimum clearance is the difference between minimum size of the hole, that is, low limit of the hole (LLH), and maximum size of the shaft, that is, high limit of the shaft (HLS), before assembly. In a transition or a



في اسئلة باختر ✱
الستابتر .

LML (hole) with LML shaft ⇒ clearance .
MML (hole) with MML shaft ⇒ interfernce

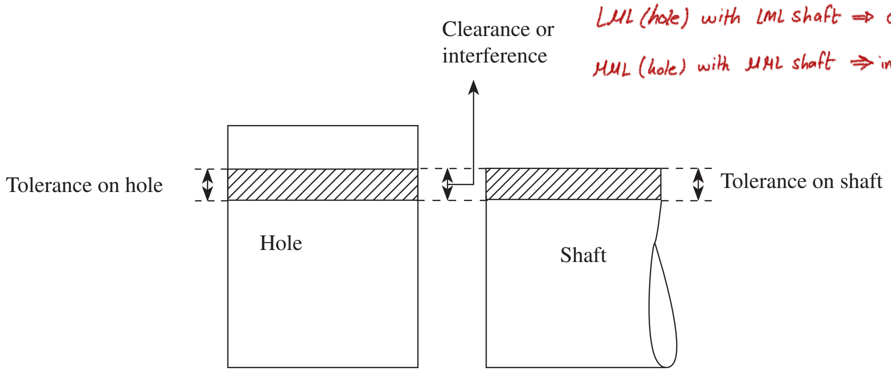


Fig. 3.11 Transition fit

clearance fit, maximum clearance is the arithmetical difference between the maximum size of the hole, that is, high limit of the hole (HLH), and the minimum size of the shaft, that is, low limit of the shaft (LLS), before assembly.

In an interference fit, minimum interference is the arithmetical difference between maximum size of the hole, that is, HLH, and minimum size of the shaft, that is, LLS, before assembly. In a transition or an interference fit, it is the arithmetical difference between minimum size of the hole, that is, LLH, and maximum size of the shaft, that is, HLS, before assembly.

Thus, in order to find out the type of fit, one needs to determine HLH – LLS and LLH – HLS. If both the differences are positive, the fit obtained is a clearance fit, and if negative, it is an interference fit. If one difference is positive and the other is negative, then it is a transition fit.

The three basic types of fits, clearance, transition, and interference, can be further classified, as shown in Fig. 3.12.

3.5.1 Allowance

An allowance is the intentional difference between the maximum material limits, that is, LLH and HLS (minimum clearance or maximum interference) of the two mating parts. It is the

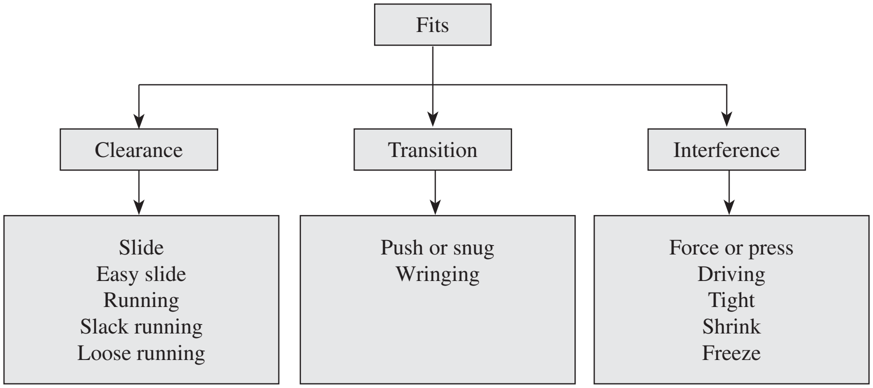


Fig. 3.12 Detailed classification of fits

H → most use.

Table 3.2 Examples of different types of fits

Description of fit	Class of fit	Application area
Clearance fit		
Slide	H7/h6	Sealing rings, bearing covers, movable gears in change gear trains, clutches, etc.
Easy slide	H7/g7	Lathe spindle, spigots, piston, and slide valves
Running	H8/f8	Lubricated bearings (with oil or grease), pumps and smaller motors, gear boxes, shaft pulleys, etc.
Slack running	H8/c11	Oil seals with metal housings, multi-spline shafts, etc.
Loose running	H8/d9	Loose pulleys, loose bearings with low revolution, etc.
Interference fit		
Force or press	H8/r6	Crankpins, car wheel axles, bearing bushes in castings, etc.
Driving	H7/s6	Plug or shaft slightly larger than the hole
Tight	H7/p6	Stepped pulleys on the drive shaft of a conveyor
Shrink	H7/u6, H8/u7	Bronze crowns on worm wheel hubs, couplings, gear wheels, and assembly of piston pin in IC engine piston
Freeze	H7/u6, H8/u7	Insertion of exhaust valve seat inserts in engine cylinder blocks and insertion of brass bushes in various assemblies
Transition fit		
Push or snug	H7/k6	Pulleys and inner ring of ball bearings on shafts
Wringing	H7/n6	Gears of machine tools

prescribed difference between the dimensions of the mating parts to obtain the desired type of fit. Allowance may be positive or negative. Positive allowance indicates a clearance fit, and an interference fit is indicated by a negative allowance.

Allowance = LLH − HLS

Table 3.2 gives examples of the classification of fits.

3.5.2 Hole Basis and Shaft Basis Systems

To obtain the desired class of fits, either the size of the hole or the size of the shaft must vary. Two types of systems are used to represent the three basic types of fits, namely clearance, interference, and transition fits. They are (a) hole basis system and (b) shaft basis system.

Although both systems are the same, hole basis system is generally preferred in view of the functional properties.

Hole Basis System

In this system, the size of the hole is kept constant and the shaft size is varied to give various types of fits. In a hole basis system, the fundamental deviation or lower deviation of the hole is zero, that is, the lower limit of the hole is the same as the basic size. The two limits of the shaft and the higher dimension of the hole are then varied to obtain the desired type of fit, as illustrated in Fig. 3.13.

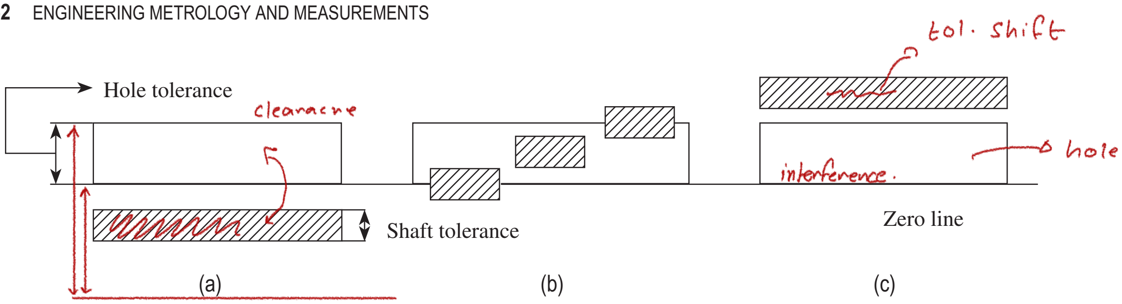


Fig. 3.13 Hole basis system (a) Clearance fit (b) Transition fit (c) Interference fit

This type of system is widely adopted in industries, as it is easier to manufacture shafts of varying sizes to the required tolerances. Standard size drills or reamers can be used to obtain a variety of fits by varying only the shaft limits, which leads to greater economy of production. The shaft can be accurately produced to the required size by standard manufacturing processes, and standard-size plug gauges are used to check hole sizes accurately and conveniently.

Shaft Basis System

The system in which the dimension of the shaft is kept constant and the hole size is varied to obtain various types of fits is referred to as shaft basis system. In this system, the fundamental deviation or the upper deviation of the shaft is zero, that is, the HLH equals the basic size. The desired class of fits is obtained by varying the lower limit of the shaft and both limits of the hole, as shown in Fig. 3.14.

This system is not preferred in industries, as it requires more number of standard-size tools such as reamers, broaches, and gauges, which increases manufacturing and inspection costs. It is normally preferred where the hole dimension is dependent on the shaft dimension and is used in situations where the standard shaft determines the dimensions of the mating parts such as couplings, bearings, collars, gears, and bushings.

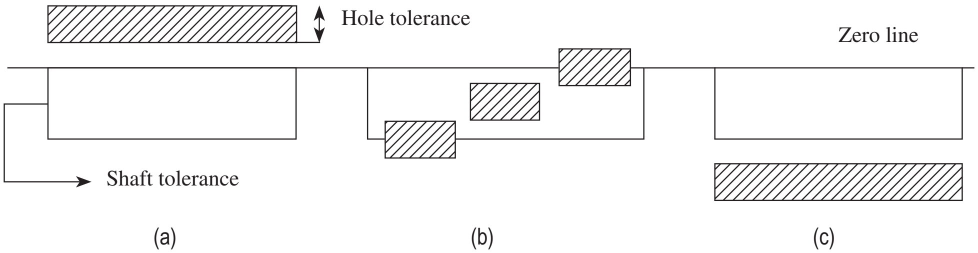


Fig. 3.14 Shaft basis system (a) Clearance fit (b) Transition fit (c) Interference fit

3.5.3 Numerical Examples

Example 3.1 In a limit system, the following limits are specified for a hole and shaft assembly:

Hole = $30^{+0.02}_{+0.00}$ mm and shaft = $30^{-0.02}_{-0.05}$ mm
Determine the (a) tolerance and (b) allowance.

Solution

(a) Determination of tolerance:

Tolerance on hole = HLH − LLH
= 30.02 − 30.00 = 0.02 mm
Tolerance on shaft = HLS − LLS
= [(30 − 0.02) − (30 − 0.05)] = 0.03 mm

(b) Determination of allowance:

Allowance = Maximum metal condition of hole – Maximum metal condition of shaft
= LLH − HLS
= 30.02 − 29.98 = 0.04 mm

Example 3.2 The following limits are specified in a limit system, to give a clearance fit between a hole and a shaft:

Hole = $25^{+0.03}_{-0.00}$ mm and shaft = $25^{-0.006}_{-0.020}$ mm

Determine the following:
(a) Basic size
(b) Tolerances on shaft and hole
(c) Maximum and minimum clearances

Solution

(a) Basic size is the same for both shaft and hole.

(b) Determination of tolerance:

Tolerance on hole = HLH − LLH
= 25.03 − 25.00 = 0.03 mm
Tolerance on shaft = HLS − LLS
= [(25 − 0.006) − (25 − 0.020)] = 0.014 mm

Determination of clearances:

Maximum clearance = HLH − LLS
= 25.03 − 24.98 = 0.05 mm
Minimum clearance = LLH − HLS
= 25.00 − (25 − 0.006) = 0.06 mm

Example 3.3 Tolerances for a hole and shaft assembly having a nominal size of 50 mm are as follows:

Hole = $50^{+0.02}_{+0.00}$ mm and shaft = $50^{-0.05}_{-0.08}$ mm

Determine the following:
(a) Maximum and minimum clearances
(b) Tolerances on shaft and hole
(c) Allowance
(d) MML of hole and shaft
(e) Type of fit

Solution

(a) Determination of clearances:
Maximum clearance = HLH − LLS
= 50.02 − (50 − 0.08) = 0.10 mm
Minimum clearance = LLH − HLS
= 50.00 − (50 − 0.005) = 0.05 mm

(b) Determination of tolerance:
Tolerance on hole = HLH − LLH
= 50.02 − 50.00 = 0.02 mm
Tolerance on shaft = HLS − LLS
= [(50 − 0.05) − (50 − 0.08)] = 0.03 mm

(c) Determination of allowance:
Allowance = Maximum metal condition of hole − Maximum metal condition of shaft
= LLH − HLS
= 50.00 − (50 − 0.05) = 0.05 mm

(d) Determination of MMLs:
MML of hole = Lower limit of hole = 50.00 mm
MML of shaft = Higher limit of shaft = 50.00 − 0.05 = 49.05 mm

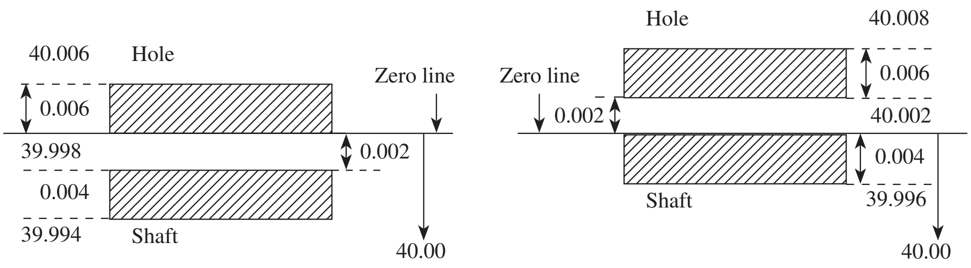
(e) Since both maximum and minimum clearances are positive, it can be conclude that the given pair has a clearance fit.

Example 3.4 A clearance fit has to be provided for a shaft and bearing assembly having a diameter of 40 mm. Tolerances on hole and shaft are 0.006 and 0.004 mm, respectively. The tolerances are disposed unilaterally. If an allowance of 0.002 mm is provided, find the limits of size for hole and shaft when (a) hole basis system and (b) shaft basis system are used.

Solution

(a) When hole basis system is used:
Hole size:
HLH = 40.006 mm
LLH = 40.000 mm
The allowance provided is +0.002 mm.
Therefore, HLS = LLH − Allowance
= 40.000 − 0.002 = 39.998 mm
LLS = HLS − Tolerance
= 39.998 − 0.004 = 39.994 mm

(b) When shaft basis system is used:
Shaft size:
HLS = 40.000 mm
LLS = 40.000 − 0.004 = 39.996 mm
The allowance provided is +0.002 mm.
Therefore, LLH = HLS + allowance
= 40.000 + 0.002 = 40.002 mm



(a) (b)

Fig. 3.15 Disposition of tolerances (a) Hole basis system (b) Shaft basis system

HLH = 40.002 + 0.006 = 40.008 mm

The disposition of tolerance for both hole basis and shaft basis systems are given in Fig. 3.15.

Example 3.5 For the following hole and shaft assembly, determine (a) hole and shaft tolerance and (b) type of fit.

Hole = $20^{+0.025}_{+0.000}$ mm and shaft = $20^{+0.080}_{+0.005}$ mm

Solution

(a) Determination of tolerance:

Tolerance on hole = HLH − LLH
= 20.025 − 20.00 = 0.025 mm
Tolerance on shaft = HLS − LLS
= 20.080 − 20.005 = 0.075 mm

(b) To determine the type of fit, calculate maximum and minimum clearances:

Maximum clearance = HLH − LLS
= 20.025 − 20.005 = 0.020 mm
(Clearance because the difference is positive)
Minimum clearance = LLH − HLS
= 20.00 − 20.080 = −0.08 mm
(Interference because the difference is negative)
Since one difference is positive and the other negative, it can be concluded that the given hole and shaft pair has a transition fit.

Example 3.6 For the following hole and shaft assembly, determine (a) hole and shaft tolerance and (b) type of fit

Hole = $20^{+0.05}_{+0.00}$ mm and shaft = $20^{+0.08}_{+0.06}$ mm

Solution

(a) Determination of tolerance:

Tolerance on hole = HLH − LLH
= 20.05 − 20.00 = 0.05 mm
Tolerance on shaft = HLS − LLS
= 20.08 − 20.06 = 0.02 mm

(b) To determine the type of fit, calculate maximum and minimum clearances:
Maximum clearance = HLH − LLS
= 20.05 − 20.06 = −0.01 mm
Minimum clearance = LLH − HLS
= 20.00 − 20.08 = −0.08 mm

Since both differences are negative, it can be concluded that the given hole and shaft pair has an interference fit.

3.6 SYSTEM OF LIMITS AND FITS

The rapid growth of national and international trade necessitates the developments of formal systems of limits and fits, at the national and international levels. Economic success of most manufacturing industries critically depends on the conformity of the specifications of the products to international standards. The International Organization for Standardization (ISO) specifies the internationally accepted system of limits and fits. Indian standards are in accordance with the ISO.

The ISO system of limits and fits comprises 18 grades of fundamental tolerances to indicate the level of accuracy of the manufacture. These fundamental tolerances are designated by the letters IT followed by a number. The ISO system provides tolerance grades from IT01, IT0, and IT1 to IT16 to realize the required accuracy. The greater the number, the higher the tolerance limit. The choice of tolerance is guided by the functional requirements of the product and economy of manufacture. The degree of accuracy attained depends on the type and condition of the machine tool used. Table 3.3 gives the fundamental tolerance values required for various applications.

Tolerance values corresponding to grades IT5–IT16 are determined using the standard tolerance unit (*i*, in µm), which is a function of basic size.

Tolerance = Max. dia − min. dia.
$= E_s - E_i$
$= e_s - e_i$

* **Table 3.3** Tolerances grades for different applications

Fundamental tolerance	Applications
IT01–IT4	For production of gauges, plug gauges, and measuring instruments
IT5–IT7	For fits in precision engineering applications such as ball bearings, grinding, fine boring, high-quality turning, and broaching
IT8–IT11	For general engineering, namely turning, boring, milling, planning, rolling, extrusion, drilling, and precision tube drawing
IT12–IT14	For sheet metal working or press working
IT15–IT16	For processes such as casting, stamping, rubber moulding, general cutting work, and flame cutting

not the Basic Size

$$i = 0.453\sqrt[3]{D} + 0.001D \text{ microns}$$

where D is the diameter of the part in mm. The linear factor $0.001D$ counteracts the effect of measuring inaccuracies that increase by increasing the measuring diameter. By using this formula, the value of tolerance unit 'i' is obtained for sizes up to 500 mm. D is the geometric mean of the lower and upper diameters of a particular diameter step within which the given or chosen diameter D lies and is calculated by using the following equation:

$$\sqrt{D_{\max} \times D_{\min}}$$

The various steps specified for the diameter steps are as follows:

1–3, 3–6, 6–10, 10–18, 18–30, 30–50, 50–80, 80–120, 120–180, 180–250, 250–315, 315–400, 400–500 500–630, 630–800, and 800–1000 mm.

Tolerances have a parabolic relationship with the size of the products. The tolerance within which a part can be manufactured also increases as the size increases. The standard tolerances corresponding to IT01, IT0, and IT1 are calculated using the following formulae:

IT01: $0.3 + 0.008D$
IT0: $0.5 + 0.012D$
IT1: $0.8 + 0.020D$

The values of tolerance grades IT2–IT4, which are placed between the tolerance grades of IT1 and IT5, follow a geometric progression to allow for the expansion and deformation affecting both the gauges and the workpieces as dimensions increase. For the tolerance grades IT6–IT16, each grade increases by about 60% from the previous one, as indicated in Table 3.4.

Table 3.4 Standard tolerance units

First find the value of (i)
Tolerance in (μm)

**

Tolerance grade	IT6	IT7	IT8	IT9	IT10	IT11	IT12	IT13	IT14	IT15	IT16
Standard tolerance unit (i)	10	16	25	40	64	100	160	250	400	640	1000

The tolerance zone is governed by two limits: the size of the component and its position related to the basic size. The position of the tolerance zone, from the zero line (basic size), is determined by fundamental deviation. The ISO system defines 28 classes of basic deviations for holes and shafts, which are marked by capital letters A, B, C, ..., ZC (with the exception of I, L, O, Q, and W) and small letters a, b, c, ..., zc (with the exception of i, l, o, q, and w), respectively, as depicted in Fig. 3.16. Different combinations of fundamental deviations and fundamental tolerances are used to obtain various types of fits.

The values of these tolerance grades or fundamental deviations depend on the basic size of the assembly. The different values of standard tolerances and fundamental deviations can be obtained by referring to the design handbook. The choice of the tolerance grade is governed by the type of manufacturing process and the cost associated with it. From Fig. 3.16, a typical case can be observed in which the fundamental deviation for both hole H and shaft h having a unilateral tolerance of a specified IT grade is zero. The first eight designations from A (a) to H (h) for holes (shafts) are intended to be used in clearance fit, whereas the remaining designations, JS (js) to ZC (zc) for holes (shafts), are used in interference or transition fits. For JS, the two deviations are equal and given by ±IT/2.

Consider the designation 40 H7/d9. In this example, the basic size of the hole and shaft is 40 mm. The nature of fit for the hole basis system is designated by H and the fundamental deviation of the hole is zero. The tolerance grade is indicated by IT7. The shaft has a d-type fit for which the fundamental deviation (upper deviation) has a negative value, that is, its dimension falls below the basic size having IT9 tolerance.

Depending on the application, numerous fits ranging from extreme clearance to extreme interference can be selected using a suitable combination of fundamental deviations and fundamental tolerances. From Fig. 3.16, it can be seen that the lower deviation for the holes 'A' to 'G' is above the zero line and that for 'K' to 'ZC' is below the zero line. In addition, it can be observed that for shafts 'a' to 'g', the upper deviation falls below the zero line, and for 'k' to 'zc' it is above the zero line.

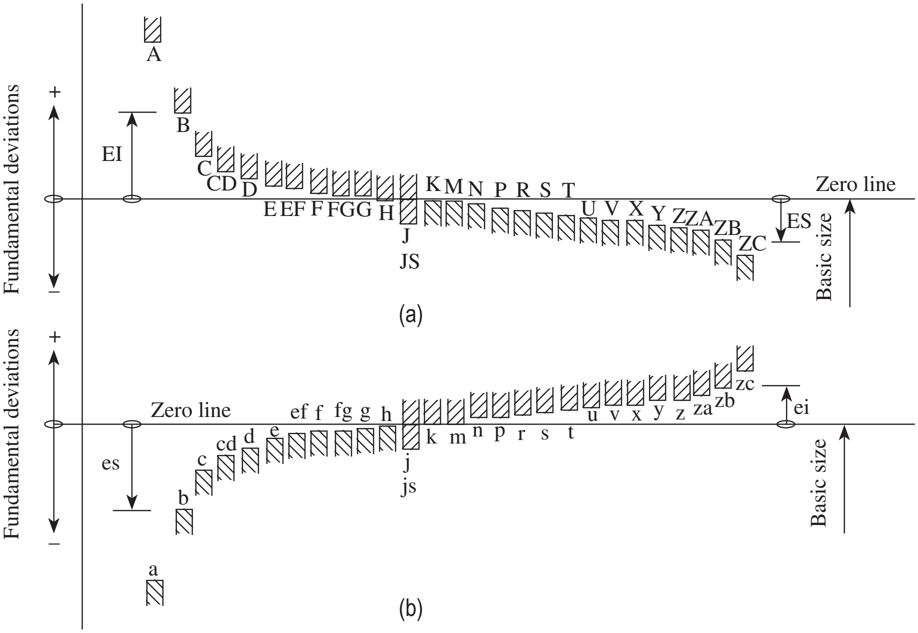
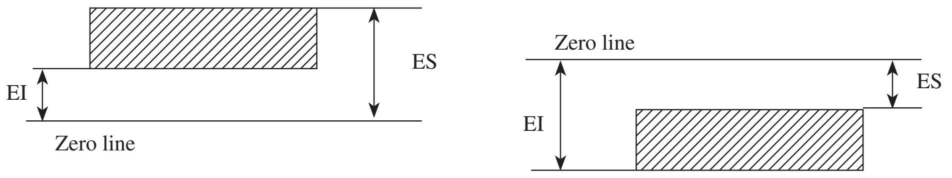


Fig. 3.16 Typical representation of different types of fundamental deviations (a) Holes (internal features) (b) Shafts (external features)

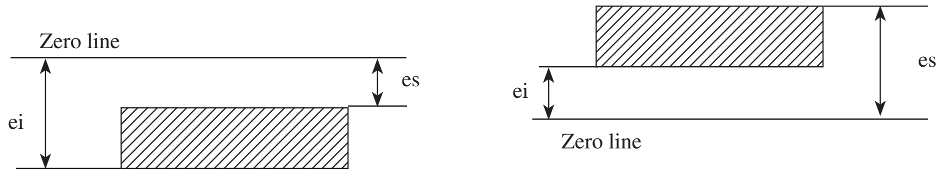
It can be seen from Fig. 3.17 that 'EI' is above the zero line for holes 'A' to 'G', indicating positive fundamental deviation. In contrast, Fig. 3.18 shows that 'ei' is below the zero line for the shafts 'a' to 'g' and therefore the fundamental deviation is negative. In addition, from Figs 3.17 and 3.18, it can be observed that for holes 'K' to 'ZC', the fundamental deviation is negative ('EI' below the zero line), whereas for shafts 'k' to 'zc', it is positive ('ei' above the zero line).

It follows from Figs 3.17 and 3.18 that the values of 'ES' and 'EI' for the holes and 'es' and 'ei' for the shafts can be determined by adding and subtracting the fundamental tolerances, respectively. Magnitude and sign of fundamental deviations for the shafts, either upper deviation 'es' or lower deviation 'ei' for each symbol, can be determined



(a) (b)

Fig. 3.17 Deviations for holes (a) Deviations for A to G (b) Deviations for K to Z_i



(a) (b)

Fig. 3.18 Deviations for shafts (a) Deviations for a to g (b) Deviations for k to Z_i

from the empirical relationships listed in Tables 3.5 and 3.6, except for shafts j and js for which there is no fundamental deviation. The values given in Tables 3.5 and 3.6 are as per IS: 919. The

Table 3.5 Fundamental deviation formulae for shafts of sizes up to 500 mm

Upper deviation (es) (—)		**Lower deviation (ei)** → when it's (+) ⇒ above the basic	
Shaft designation	In µm (for D in mm)	Shaft designation	In µm (for D in mm)
a	$= -(265 + 1.3D)$ for $D \le 120$	j5–j8	No formula
		(For js two deviations are equal to IT ± 2)	
	EI = 3.5 $= -3.5D$ for $D > 120$	k4–k7	$= +0.6\sqrt[3]{D}$
		For grades ≤k3 to ≥k8	= 0
b	$= -(140 + 0.85D)$ for $D \le 160$	m	= +(IT7 − IT6)
	$= -1.8D$ for $D > 160$	n	$= +5D^{0.34}$
		p	= + IT7 + 0 to 5
c	$= -52D^{0.2}$ for D + IT7 + 0 to 40	r	= Geometric mean of ei values for p and s
	$= -(95 + 0.8D)$ for $D > 40$		= +IT8 + 1 to 4 for $D \le 50$
d	$= -16D^{0.44}$	s	= +IT7 + $0.4D$ for $D > 50$
e	$= -11D^{0.41}$	t	= +IT7 + $0.63D$
f	$= -5.5D^{0.41}$	u	= +IT7 + D
g	$= -2.5D^{0.34}$	v	= +IT7 + $1.25D$

es(a) = EI (A)

es is the fundamental ←

max. − Basic = (−ve)

(Contd)

Table 3.5 (Contd)

h	Es = zero = 0	x	= +IT7 + 1.6D
		y	= +IT7 + 2D
		z	= +IT7 + 2.5D
		za	= +IT8 + 3.15D
		zb	= +IT9 + 4D
		zc	= +IT10 + 5D

Table 3.6 Fundamental deviation formulae for holes of sizes up to 500 mm

For all deviations except the following:			General rule: Hole limits are identical with the shaft limits of the same symbol (letter and grade) but disposed on the other side of the zero line EI = upper deviation es of shaft of the same letter symbol but of opposite sign
For sizes above 3 mm	N	9 and coarser grades	ES = 0
	J, K, M, and N	Up to grade 8 inclusive	Special rule: ES = lower deviation ei of the shaft of the same letter symbol but one grade finer and of opposite sign, increased by the difference between the tolerances of the two grades in question
	P to ZC	Up to grade 7 inclusive	

other deviations of the holes and shafts can be determined using the following relationships that can be derived from Figs 3.17 and 3.18:

1. For holes A to G, EI is a positive fundamental deviation and EI = ES – IT.
2. For holes K to Z*i*, the fundamental deviation ES is negative and ES = EI – IT.
3. For shafts 'a' to 'g', the fundamental deviation es is negative and es = ei – IT.
4. For shafts 'k' to 'Z*i*', the fundamental deviation ei is positive, and ei = es – IT.

Production of large-sized components is associated with problems pertaining to manufacture and measurement, which do not exist in the case of smaller-sized components. As the size of the components to be manufactured increases, the difficulty in making accurate measurements also increases. Variations in temperature also affect the quality of measurement.

When the size of the components to be manufactured exceeds 500 mm, the tolerance grades IT01–IT5 are not provided, as they are considered to be too small. The fundamental tolerance unit in case of sizes exceeding 500 and up to 3150 mm is determined as follows:

$i = 0.004D + 2.1D$, where D is 0.001 mm.

The fundamental deviations for holes and shafts are given in Table 3.7, which are as per IS: 2101.

Table 3.7 Fundamental deviation for shafts and holes of sizes from above 500 to 3150 mm

Shafts			Holes			Formula for deviations in μm
Type	Fundamental deviation	Sign	Type	Fundamental deviation	Sign	(for D in mm)
d	es	–	D	EI	+	$16D^{0.44}$
e	es	–	E	EI	+	$11D^{0.41}$
f	es	–	F	EI	+	$5.5D^{0.41}$
g	es	–	G	EI	+	$2.5D^{0.34}$
h	es	No sign	H	EI	No sign	0
js	ei	–	JS	ES	+	$0.5IT\pi$
k	ei	–	K	ES	–	0
m	ei	+	M	ES	–	$0.024D + 12.6$
n	ei	+	N	ES	–	$0.04D + 21$
P	ei	+	P	ES	–	$0.072D + 37.8$
r	ei	+	R	ES	–	Geometric mean of the values for p and s or P and S
s	ei	+	S	ES	–	$IT7 + 0.4D$
t	ei	+	T	ES	–	$IT7 + 0.63D$
u	ei	+	U	ES	–	$IT7 + D$

في شكل ملف تبع المرة الماضية.

* 3.6.1 General Terminology

The following are the commonly used terms in the system of limits and fits.

Basic size This is the size in relation to which all limits of size are derived. Basic or nominal size is defined as the size based on which the dimensional deviations are given. This is, in general, the same for both components.

Limits of size These are the maximum and minimum permissible sizes acceptable for a specific dimension. The operator is expected to manufacture the component within these limits. The maximum limit of size is the greater of the two limits of size, whereas the minimum limit of size is the smaller of the two.

Tolerance This is the total permissible variation in the size of a dimension, that is, the difference between the maximum and minimum limits of size. It is always positive.

Allowance It is the intentional difference between the LLH and HLS. An allowance may be either positive or negative.

Allowance = LLH − HLS

Grade This is an indication of the tolerance magnitude; the lower the grade, the finer the tolerance.

Deviation It is the algebraic difference between a size and its corresponding basic size. It may be positive, negative, or zero.

Upper deviation It is the algebraic difference between the maximum limit of size and its corresponding basic size. This is designated as 'ES' for a hole and as 'es' for a shaft.

Lower deviation It is the algebraic difference between the minimum limit of size and its corresponding basic size. This is designated as 'EI' for a hole and as 'ei' for a shaft.

Actual deviation It is the algebraic difference between the actual size and its corresponding basic size.

Fundamental deviation It is the *minimum* difference between the size of a component and its basic size. This is identical to the upper deviation for shafts and lower deviation for holes. It is the closest deviation to the basic size. The fundamental deviation for holes are designated by capital letters, that is, A, B, C, …, H, …, ZC, whereas those for shafts are designated by small letters, that is, a, b, c…, h…, zc. The relationship between fundamental, upper, and lower deviations is schematically represented in Fig. 3.19.

Zero line This line is also known as the line of zero deviation. The convention is to draw the zero line horizontally with positive deviations represented above and negative deviations indicated below. The zero line represents the basic size in the graphical representation.

Shaft and hole These terms are used to designate all the external and internal features of any shape and not necessarily cylindrical.

Fit It is the relationship that exists between two mating parts, a hole and a shaft, with respect to their dimensional difference before assembly.

Maximum metal condition This is the maximum limit of an external feature; for example, a shaft manufactured to its high limits will contain the maximum amount of metal. It is also the minimum limit of an internal feature; for example, a component that has a hole bored in it to its lower limit of size will have the minimum amount of metal removed and remain in its

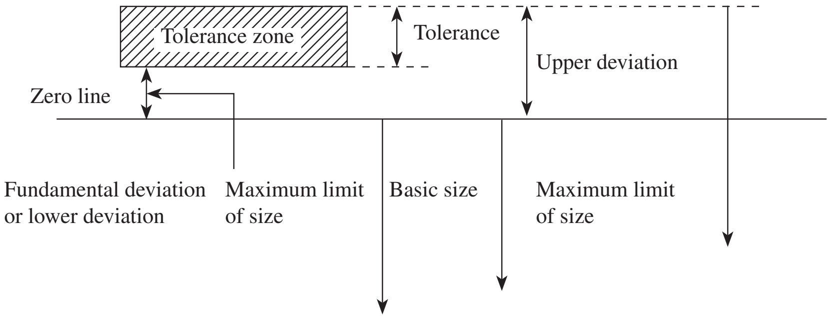


Fig. 3.19 Relationship between fundamental, upper, and lower deviations

maximum metal condition, (i.e., this condition corresponds to either the largest shaft or the smallest hole). This is also referred to as the GO limit.

Least metal condition This is the minimum limit of an external feature; for example, a shaft will contain minimum amount of material, when manufactured to its low limits. It is also the maximum limit of an internal feature; for example, a component will have the maximum amount of metal removed when a hole is bored in it to its higher limit of size, this condition corresponds to either the smallest shaft or the largest hole. This is also referred to as the NO GO limit.

Tolerance zone The tolerance that is bound by the two limits of size of the component is called the tolerance zone. It refers to the relationship of tolerance to basic size.

International tolerance grade (IT) Tolerance grades are an indication of the degree of accuracy of the manufacture. Standard tolerance grades are designated by the letter IT followed by a number, for example, IT7. These are a set of tolerances that varies according to the basic size and provides a uniform level of accuracy within the grade.

Tolerance class It is designated by the letter(s) representing the fundamental deviation followed by the number representing the standard tolerance grade. When the tolerance grade is associated with letter(s) representing a fundamental deviation to form a tolerance class, the letters IT are omitted and the class is represented as H8, f7, etc.

Tolerance symbols These are used to specify the tolerance and fits for mating components. For example, in 40 H8f7, the number 40 indicates the basic size in millimetres; capital letter H indicates the fundamental deviation for the hole; and lower-case letter f indicates the shaft. The numbers following the letters indicate corresponding IT grades.

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3.6.2 Limit Gauging

Eli Whitney, who is hailed as the father of the American system, won the first contract in 1798 for the production of muskets and developed the gauging system. Richard Roberts of the United Kingdom first used plug and collar gauges for dimensional control. In 1857, Joseph Whitworth demonstrated internal and external gauges for use with a shaft-based limit system.

As discussed in Section 3.1, in mass production, components are manufactured in accordance with the permissive tolerance limits, as suggested by the designer. Production of components within the permissive tolerance limits facilitates interchangeable manufacture. It is also essential to check whether the dimensions of the manufactured components are in accordance with the specifications or not. Therefore, it is required to control the dimensions of the components. Several methods are available to achieve the control on dimensions. Various precision measuring instruments can be used to measure the actual dimensions of the components, which can be compared with the standard specified dimensions to decide the acceptability of these components.

In mass production, where a large number of similar components are manufactured on an interchangeable basis, measuring the dimensions of each part will be a time-consuming and expensive exercise. In addition, the actual or absolute size of a component, provided that it is within the limits specified, is not of much importance because the permissible limits of