Engineering Metrology

As per AICTE Curriculum for Diploma in Mechanical Engineering

R. K. Jain

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Engineering Metrology

(for Diploma Course)

Er. R. K. Jain
(Author of Engineering Metrology for Degree Courses)

KHANNA PUBLISHERS®
Investing in Learning®
Operational Office :
4575/15, Onkar House, Opp. Happy School,
Ground Floor, Daryaganj, New Delhi 110 002
Phones : 011-45033819 • *Mob*. 09811541460
email : contactus@khannapublishers.in

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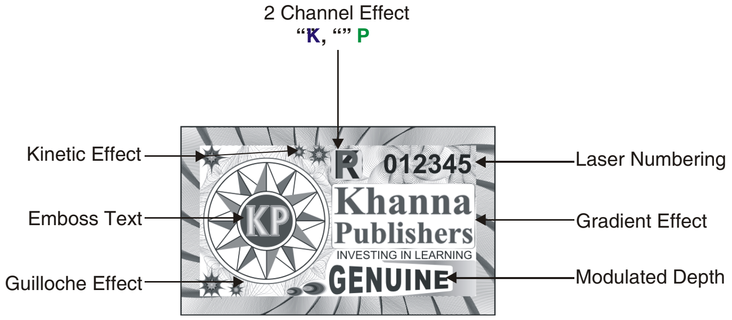

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Preface

Metrology deals with the science and technology of measurements and the measuring instruments. Measurements are necessary to increase our understanding of the world with a view to lead a better life. Measurements are essential to control processes, plants and industries to produce quality products. The advancements in industries depend on the quality and reliability of dimensional accuracy and the precision of measurement.

Metrology is mainly concerned with (*i*) establishing the units of measurements, reproducing these units in the form of standards, and ensuring the uniformity of measurements, (*ii*) developing methods of measurement, (*iii*) analysing the accuracy of methods of measurement, (*iv*) establishing uncertainty of measurement, (*v*) researching into the causes of measuring errors, and eliminating these, (*vi*) to minimise the cost of inspection by effective and efficient use of available facilities, and to reduce the cost of rejects and rework through application of Statistical Quality Control Techniques, (*vii*) standardisation of measuring methods, (*viii*) maintenance of the accuracies of measurement by periodical calibration of the metrological instruments.

In Metrology, study of errors, their sources and control, to ensure precision and accuracy of measurements is essential. Measurements of linear dimensions and circular measurements, surface finish measurement form basic back-ground. Study of tolerances, fits and gauges is also important. Comparators also play strong role in field of inspection.

The purpose of dimensional control is not to strive for the exact size as it is impossible to produce all the parts of exactly same size due to so many inherent and random sources of errors in machines and men. The principal aim is to control and restrict the variations within the prescribed limits. Since we are interested in producing the parts such that assembly meets the prescribed work standard, we must not aim at accuracy beyond the set limits which, otherwise is likely to lead to wastage of time and uneconomical results.

All these aspects, as designed for students appearing for diploma courses in Mechanical Engineering, have been thoroughly covered in this book in a systematic manner. Each chapter contains a lot of solved problems and numericals alongwith objective type questions to ensure that students have understood the basis of this subject and can face their examination confidentiality.

My sincere thanks to the Kratu Khanna and Ms. Akshita Khanna for taking keen interest in preparation and promoting of this book. Any suggestion for improvement shall be welcome.

1st January, 2021 —R.K. Jain

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Chapter 1

Introduction

1.1. DEFINITION OF METROLOGY

Metrology is concerned with science of measurements. In general, measurements are made to increase our knowledge and understanding of the world with a view to lead a better life. Measurement science is vital for trade and commerce and is the basis of modern science and technology. Measurements play a vital role in every field of investigation and present day scientific and technological progress has resulted from progress in the field of measurements. It is well-known saying that the knowledge about anything is complete only when it can be expressed in numbers and something is known about it. In order that the unit of measurement is followed by all and not one who is taking the measurements, there must be a universal standard and the various units for various parameters of importance must be standardised.

In metrology, the science of measurements, we go one step ahead and bother about the correctness of measurement also. We have to see whether the result is given with the sufficient correctness and accuracy for the particular need or not. Thus we are primarily concerned with methods of measurement based on agreed units and standards. Metrology is thus concerned with the establishment, reproduction, conservation and transfer of units of measurements and their standards. The practice of metrology involves precise measurements requiring the use of apparatus and equipments (instruments and necessary adjuncts) to permit the degree of accuracy required to be obtained.

Metrology, the science of measurements, is also associated with the evaluation of its uncertainty. It is important to understand that only to measure is not the speciality of metrology but the core of metrology lies in the validation of the result, particularly by specifying its actual limitations. Metrology apart from standards of length and mass is also concerned with parameters in sectors of social concern, such as health, safety, and environment protection. Making mastery of the science of measurement is a prerequisite for progress in science itself. Industrial manufacturing and many fields of life call for activity at a high scientific and technical level at which any progress achieved has to be accomplished by progress in metrology. The increasing automation of manufacture requires the highest level of accuracy. One must remember the famous saying that man's knowledge of nature, the universe, and how to adapt nature to his purpose, advances in step with his ability to measure precisely.

The metrologist has to understand the underlying principles to be able to design and develop new instruments and also to use the available instruments in the best way. Metrology is therefore also concerned with the methods, execution and estimation of accuracy of measurements; the measuring instruments and the inspectors. Today's standard of precision and reliability are so high that man's basic instincts and senses are inadequate to cope with them. To this end, use has to be made of precision measuring instruments and various types of conventional and sophisticated gauges and comparators.

Thus, it can be said that metrology is mainly concerned with (*i*) establishing the units of measurements, reproducing these units in the form of standards, and ensuring the uniformity of measurements, (*ii*) developing methods of measurement, (*iii*) analysing the accuracy of methods of measurement, (*iv*) establishing uncertainty of measurement, (*v*) researching into the causes of measuring errors, and eliminating these.

In the broader sense, metrology is not limited to length measurement but is also concerned with the industrial inspection and its various techniques. Due to big industrial revolution and great advancement, industrial inspection does not simply mean the fulfilling of the specifications laid down by the manufacturers. Rather inspection in real sense is concerned with the checking of a product at various stages in its manufacture right from the raw material form to the finished products and even assembled parts in the form of machine also. Inspection is carried out with gauges and the metrologist is intimately concerned with the design, manufacturing and testing of gauges of all kinds. Dynamic metrology is concerned with measuring small variations of continuous nature. The measurement science today has developed to electronically operated and controlled equipments, computer-aided systems for on-line monitoring, opto-mechanical, laser and fibre optics based instruments, etc.

Metrological activities start from establishment of measurement standards, appraisal of various physical parameters including dimensions, development of measuring instruments and techniques, and calibration of test and measurement equipments. All this is essential for correct operative measurement for quality and products and services delivered by the industry. Present day industry demands not only one time achievability, but aims for conformity involving such aspects as repeatability, reproducibility, interchangeability, of very many dimensions and characteristics and evidence thereof, for confidence of both producers and customers. This is possible by creation of standards and measurement techniques.

It may be emphasised here that man has to handle various instruments and sense of 'feel' plays very important role. In order that all people get same readings for a component by the same instrument, the instrument should be designed in such a way that always constant pressure is applied between the component and the instrument. Also instrument must be held such that the sense of 'feel' present in hand is free to give correct decision. However, in Universal Machines, an attempt is made to eliminate human errors due to different senses of touch and feel.

In broader sense, metrology (the science and art of precision measurement, testing and evaluation) is the mother science for technological development. The advancements in industry depend, to a great extent, on the quality and reliability of dimensional accuracy and precision measurement of other physical characteristics.

1.1.1. Legal Metrology

Legal Metrology is that part of metrology which treats units of measurement, methods of measurement and the measuring instruments, in relation to the statutory, technical and legal requirements. It assures security and appropriate accuracy of measurements. Lack of legislation regarding various measurements will lead to great uncertainty.

Legal metrology is directed by a national organisation, viz. National Service of Legal Metrology whose object is to resolve problems of legal metrology in a particular country. Its functions are to ensure the conservation of national standards and to guarantee their accuracy by comparison with international standards; and also to impart proper accuracy to the secondary standards of the country by comparison with international standards.

The contemporary organisation of metrology includes a number of international organisations viz. (*a*) The International Organisation of Weights and Measures: and (*b*) National Service of Legal Metrology whose ultimate object is to maintain uniformity of measurements throughout the world.

The activities of the service of Legal Metrology are: control (testing, verification, standardisation) of measuring instruments; testing of prototypes/models of measuring instruments; examination of a measuring instrument to verify its conformity to the statutory requirements, etc.

Legal metrology has application in :

(*i*) Commercial transactions (net quantity)

(*ii*) Industrial measurements (proper control on accuracy of measurement, so as to ensure interchangeability with a view to promoting mass production.

(*iii*) Measurements needed for ensuring public health and human safety.

A national law relating to legal metrology covers the following points:

(*i*) Legal units of measurements. In 1976, Parliament enacted comprehensive law, the Standards of Weights and Measures Act 1976, to establish the International System of Units (S1), to regulate inter-State trade or commerce in weights and measures, and to provide for other matters important from the view-point of consumer protection.

(*ii*) Physical presentation of legal units;

(*iii*) Hierarchy of standards-their maintenance and custody;

National Standards (Echelon-I)

Reference Standards (Echelon-II)

Secondary Standards (Echelon-III A)

Working Standards (Echelon-III B)

(*iv*) Specifications or technical regulations of measuring instruments as regards their metrological and technical requirements;

(*v*) Metrological control on measuring instruments; (approval of model, initial verification, periodical verification; verification after repairs, inspection of the use of measuring instruments)

(*vi*) Metrological control on pre-packed goods;

(*vii*) Control on manufacture, repair and sale of measuring instruments;

(*viii*) Organisation/service concerned with legal metrology ;

(*ix*) Levy and collection of fees ;

(*x*) Penalties for contraventions;

(*xi*) Training of personnel.

1.1.2. Deterministic Metrology

This is a new philosophy in which part measurement is replaced by process measurement. In the deterministic metrology, full advantage is taken of the deterministic nature of production machines (machines under automatic control are totally deterministic in performance) and all of the manufacturing sub-systems are optimised to maintain deterministic performance within acceptable quality levels. In this science, the system processes are monitored by temperature, pressure, flow, force, vibration, accoustic "finger printing" sensors, these sensors being fast and non-intrusive. The new technique such as 3D error compensation by CNC (Computer Numerical Control) systems and expert systems are applied, leading to fully adaptive control. This technology is used for very high precision manufacturing machinery and control systems to achieve microtechnology and nanotechnology accuracies.

1.1.3. Need of Inspection

In order to determine the fitness of anything made, man has always used inspection. But industrial inspection is of recent origin and has scientific approach behind it. It came into being because of mass production which involved interchangeability of parts. In old craft, same craftsman used to be producer as well as assembler. Separate inspections were not required. If any component part did not fit properly at the time of assembly, the craftsman would make the necessary adjustments in either of the mating parts so that each assembly functioned properly. So actually speaking, no two parts will be alike and there was practically no reason why they should be.

Now new production techniques have been developed and parts are being manufactured in large scale due to low-cost methods of mass production. So hand-fit methods cannot serve the purpose any more. When large number of components of same part are being produced, then any part would be required to fit properly into any other mating component part. This required specialisation of men and machines for the performance of certain operations. It has, therefore, been considered necessary to divorce the worker from all round crafts work and to supplant hand-fit methods with interchangeable manufacture.

The modern production techniques require that production of complete article be broken up into various component parts so that the production of each component part becomes an independent process. The various parts to be assembled together in assembly shop come from various shops. Rather some parts are manufactured in other factories also and then assembled at one place. So it is very essential that parts must be so fabricated that the satisfactory mating of any pair chosen at random is possible. In order that this may be possible, the dimensions of the component part must be confined within the prescribed limits which are such as to permit the assembly with a predetermined fit. Thus industrial inspection assumed its importance due to necessity of suitable mating of various components manufactured separately. It may be appreciated that when large quantities of work-pieces are manufactured on the basis of interchangeability, it is not necessary to actually measure the important features and much time could be saved by using gauges which determine whether or not a particular feature is within the prescribed limits. The methods of gauging, therefore, determine the dimensional accuracy of a feature, without reference to its actual size.

The purpose of dimensional control is however not to strive for the exact size as it is impossible to produce all the parts of exactly same size due to so many inherent and random sources of errors in machines and men. The principal aim is to control and restrict the variations within the prescribed limits. Since we are interested in producing the parts such that assembly meets the prescribed work standard, we must not aim at accuracy beyond the set limits which, otherwise is likely to lead to wastage of time and uneconomical results.

Lastly, inspection led to development of precision inspection instruments which caused the transition from crude machines to better designed and precision machines. It had also led to improvements in metallurgy and raw material manufacturing due to demands of high accuracy and precision. Inspection has also introduced a spirit of competition and led to production of quality products in volume by eliminating tooling bottle-necks and better processing techniques.

1.1.4. Measuring Means

The means of measurements could be classified as follows:

(*i*) Standards (Reference masters or setting standards). These are used to reproduce one or several definite values of a given quantity.

(*ii*) Fixed gauges. These are used to check the dimensions, form, and position of product features.

(*iii*) Measuring instruments-These are used to determine the values of the measured quantity.

1.1.5. The Measurement Problem

In practice, we come across four basic conditions to be controlled by tolerances, viz, (*a*) size, (*b*) form, (*c*) location and (*d*) conditions of assembly, operation, or function. Fig. 1.1 illustrates these.

The difference between sizes *X* and *Y* determines the assembly condition. Size conditions are generally simple to specify and control; the form and location conditions are more complex, especially where composite surfaces and cumulative tolerances are involved. It will be appreciated that all these four conditions inter-relate to define quality characteristics, and the problem of measuring quality characteristics to evaluate conformance to specifications becomes complex. Lack of true geometric perfection makes it difficult to define and control product quality characteristics. It may be noted that it is easy to define geometric form but difficult to produce. However, to maintain specific quality, the variation from perfect form must be defined and controlled. The geometric variations known as macro-errors concern straightness, flatness, parallelism, squareness, angular displacement, symmetry, concentricity, eccentricity, roundness. Lack of perfect rigidity caused due to material properties like expansion, stretching, springing, warping etc., also affect geometric form, size and location conditions.

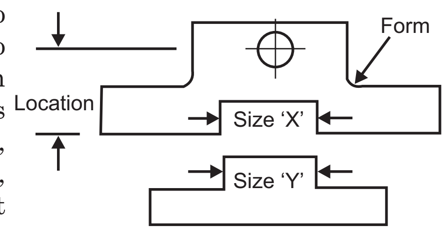

Fig. 1.1. Product conditions.

The inter-relationships of size, form and location conditions required to define quality characteristics, coupled with production variations due to geometric form and rigidity errors, lead to a variety of complex measurement problems involving sophisticated gauging method.

In some cases the configuration of parts is such that accurate measurement becomes difficult. In some cases, it is not possible for the standard gauge or tool to span the component. Such cases are: parts having not even a single common plane, irregular curved surfaces, odd number spline or gear, parts with phantom dimensions (*i.e.*, dimensions to be gauged have to be calculated or their dimensions are w.r.t. points in space) etc.

The measurement must be correct to a degree commensurate with the specified tolerances and the required functional service of the product. Following two factors need to be considered when evaluating the correctness of dimensional measurements : (*i*) gauging accuracy, (*ii*) the proper location of the measured dimension on the physical part. It must be remembered that the improperly located dimensions, can often have a greater effect on correctness of dimensional measurements than errors due to insufficient indicating accuracy.

The precision of the measurement can be affected by limitations in either of the basic requirements, viz. the accuracy of the instrument at the proper location of the gauging points which determine the dimension being measured on the physical part.

1.1.6. General Care of Metrological Equipment

The equipment (apparatus) used for precision measurements is designed to fine limits of accuracy and is easily liable to be damaged by even slight mishandling and such damage may not be noticeable. A great deal of careful handling is, therefore, required. As far as possible, the highly finished surfaces should not be touched by hand because the natural acids on the skin are likely to corrode the finished surface and also the temperature of body may upset the dimensions of the precision instruments. In order to overcome this many standard metrology laboratories recommend washing of hands thoroughly and coating them with a thin film of pure petroleum jelly before handling the instruments. Further very precise equipment like slip gauges is allowed to be handled only by using a piece of chamois leather or tongs made from a strip of "Perspex".

When the equipment is not in use, it should be protected from atmospheric corrosion. For this purpose, the highly finished surfaces are first wiped with a solvent to remove any finger marks and then coated with mixture of heated petroleum jelly and petrol. This mixture spreads much more easily and is applied with cloth or with fingers. Brushing is not recommended as it is liable to trap air which, with the moisture it contains, may cause rusting.

As the standard temperature for measurement is 20°C, for very precise measurements the instruments and workpieces should be allowed to attain this temperature before use and the handling should be as little as possible.

1.1.7. Objectives of Metrology

While the basic objective of a measurement is to provide the required accuracy at minimum cost, metrology would have further objective in a modern engineering plant with different shops like Tool Room, Machine Shop, Press Shop, Plastic Shop, Pressure Die Casting Shop, Electroplating and Painting Shop, and Assembly Shop, as also Research, Development and Engineering Department. In such an engineering organisation, the further objectives would be as follows:

(*a*) Thorough evaluation of newly developed products, to ensure that components designed are within the process and measuring instrument capabilities available in the plant.

(*b*) To determine the process capabilities and ensure that these are better than the relevant component tolerances.

(*c*) To determine the measuring instrument capabilities and ensure that these are adequate for their respective measurements.

(*d*) To minimise the cost of inspection by effective and efficient use of available facilities, and to reduce the cost of rejects and rework through application of *Statistical Quality Control Techniques.*

(*e*) Standardisation of measuring methods. This is achieved by laying down inspection methods for any product right at the time when production technology is prepared.

(*f*) Maintenance of the accuracies of measurement. This is achieved by periodical calibration of the metrological instruments used in the plant.

(*g*) Arbitration and solution of problems arising on the shop floor regarding methods of measurement.

(*h*) Preparation of designs for all gauges and special inspection fixtures.

1.1.8. Requirements of an Inspection Tool

The requirements of an ideal inspection tool are: It should be

(*a*) accurate
(*b*) require a minimum of operator skill
(*c*) inspect a specific type of error
(*d*) fast to use
(*e*) Self checking.

The degree of accuracy of calibration depends on the accuracy of the inspecting instruments. Devices which reduce dependence on operator skill contribute to both efficiency and accuracy. The requirement of speed is not for economic reasons but to avoid errors from changes in temperature where inspections become involved. A good inspection tool should be capable of being checked against itself. This feature increases the reliability.

1.1.9. Standardisation and Standardising Organisations

For overall higher economy, efficiency and productivity in a factory and country, it is essential that diversity be minimised and interchangeability among parts encouraged. All this is possible with standardisation. Standardisation is done at various levels, viz. International, National, Association, Company.

Realising the role of standardisation in the development of industry, organisations to handle the complexities of standardisation have been evolved in each of the chief industrial countries. In India, Bureau of Indian Standards (BIS) is responsible for evolving standards on metrological instruments, etc. There are several sectional committees, each dealing with various main branches of industry, in BIS. The detailed work of drawing up specifications is done by more specialised technical committees who prepare a draft standard based on practice in other countries and the needs of the country, and circulate it to relevant industries, government and service departments, research and teaching organisations, and others likely to be interested. Comments are invited both from producer and user to consider all aspects; meetings help to discuss the matters in depth and final standards issued. The technical committees also keep on revising the existing standards from time to time.

The Bureau of Indian Standards is the National body for standardisation in India.

The functions of the Bureau are:

(*a*) Formulation, publication and promotion of Indian Standards;

(*b*) Inspection of articles or process under Certification Scheme;

(*c*) Establishment, maintenance and recognition of laboratories ;

(*d*) Formulate, implement and coordinate activities relating to quality maintenance and improvement in products and processes;

(*e*) Promote harmonious development in standardization, quality systems and certification and matters connected therewith both within the country and at international level ;

(*f*) Provide information, documentation and other services t0 consumers and recognised consumer organisations on such terms and conditions as may be mutually agreed upon;

(*g*) Give recognition to quality assurance systems in manufacturing or processing units on such terms and conditions as mutually agreed upon;

(*h*) Bring out handbooks, guides and other special publications; and for conformity to any other standard if so authorized.

Thus, the main functions of the Bureau can be grouped under standards formulation, certification marking and laboratory testing, promotional and international activities.

Bureau of Indian Standards has under the Mechanical Engineering Division Council, EDC, a separate Engineering Metrology Sectional Committee. This Committee was set up in 1958 and its main task is to formulate standards for the various aspects of dimensional metrological measuring instruments and accessories used in the mechanical engineering field. A large number of Indian Standards in the field of engineering metrology have been formulated.

In Europe, the International Federation of National Standardising Association, known as I.S.A., co-ordinates the work of the continental countries. Before Second World War, U.K. and U.S.A. did not take any part in it, but after war, the countries like U.K., U.S.A. and Russia have taken part in its works. In 1946, the I.S.A., was re-formed as the International Organisation for Standardisation, I.S.O. In fact, for engineering matters, the foremost standards organisation at international level is I.S.O. The national standards organisation of individual countries are the members of I.S.O. The I.S.O. recommendations are used as basis for national and company standards. Lot of co-operative discussions in the field of standardisation have also been carried out in three countries-America, Britain and Canada known was ABC conference. The International Electro-technical Commission (IEC) deals with electrical engineering standards. Both ISO and IEC have published recommendations on some aspects of engineering metrology.

National Physical Laboratories (NPL) carry out lot of research work in various fields ; responsible for defining standards, and also issue certification marks for quality instruments.

International Organisation of Weights and Measures. It was established in 1975 under the "International Metre Convention" in Paris with the object of maintaining uniformity of measurements throughout the world. It comprises of:

(*a*) The General Conference of Weights and Measures.

(*b*) The International Committee of Weights and Measures.

(*c*) The International Organisation of Legal Metrology.

General Conference of Weights and Measures. Its objects are:

(*i*) To draw up and promote the decisions necessary for the propagation and perfection of an international system of units and standards of measurement.

(*ii*) To approve the results of new fundamental metrological determinations and the various scientific resolutions in the field of metrology which are of international interest.

International Committee of Weights and Measures. This Committee is placed under the authority of the General Conference of Weights and Measures and is responsible for promoting the decisions taken by the latter. Its objects are:

(*i*) To direct and supervise the work of the International Bureau of Weights and Measures.

(*ii*) To establish co-operation among national laboratories of metrology for executing the metrological work which the General Conference of Weights and Measures decides to execute jointly by the member states of the organisation.

(*iii*) To direct such work and co-ordinate the results and to look after the conservation of the International Standards.

1.1.10. Principal Global Organisations involved in Metrology

(*i*) **BIPM (Bureau International des Poids et Mesures).** It is created under the Metre convention for measurement standard activities. It provides leadership in ensuring collaboration on metrological matters and the maintenance of an efficient worldwide measurement system. It serves as the technical focal point to guarantee the equivalence of national standards. BIPM with its laboratories and offices at Serves act as a permanent international centre for Metrology under the supervision of the CIPM.

(*ii*) **ILAC (International Laboratory Accreditation Conference).** It is engaged in international laboratory accreditation and the standards writing bodies. It has demonstrated competence in calibration and testing.

(*iii*) **IEC (International Electrotechnical Commission).** A voluntary sector to prescribe standards.

(*iv*) **CIPM (Comite International des Poids et Mesures).** Most of the activities of CIPM are performed under the supervision of CIPM. Several (CCs) consultative committees have been set up by the CIPM.

(*v*) **CGPM (Conference Generale des Poids et Mesures).**

(*vi*) **ISO (International Organisation for Standardisation).** A voluntary sector to specify standards.

(*vii*) **NMI (National Metrology Institute).** A national laboratory responsible for the development and maintenance of measurement standards for the dissemination of the SI units, their multiples and sub multiples, and capable of making accurate measurements available to all users.

(*viii*) **International Organisation of Legal Metrology (OIML).** It was established in 1955 under the "International Convention of Legal Metrology" Paris to unify the metrological practices.

1.2. STANDARD OF MEASUREMENT

In metrology, a standard is an object, system, or experiment that bears a defined relationship to a unit of measurement of a physical quantity. Inspectors all over the world can compare the results of experiments on a consistent basis only if certain standards of units of length, mass, time, temperature, etc. are established.

Metrology concerns itself with the science of measurements and nearly all measurements in workshop involve measurement of dimensions. Production engineer is specially concerned with the measurement of the length and angle. Length is of fundamental importance as even angles can be measured by combination of linear measurements. Thus it is very essential that some standards be prescribed for the length. The importance of study of length has been realised long back and man has always sought a fixed and unvarying natural standard of length (fundamental unit). It is well known fact that without standards of fundamental units (length, mass, time), it would have not been possible for civilization to exist.

Modern manufacturing technology is based on precise reliable dimensional measurements. Ultimately, all of these measurements are comparisons with standards developed and maintained by bureaus of standards throughout the world.

1.2.1. Standards

The standard system for linear measurement used throughout the world is Metric (metre). Length can be measured by using (*i*) line standard or (*ii*) end standard.

Search for a suitable unit of length has always been there and attempts made to keep that unit of length constant irrespective of the environmental conditions. Actually, previously the standards were made of materials which could change their size with temperature and other conditions. Thus a great care and attention was needed to maintain same conditions so that the fundamental unit remains same. Finally the natural and invariable unit of length was sought when it was found that the wavelength of mono choma tic light never changed with other conditions. Due to it, the previously defined yard and metre could be very easily expressed in terms of the wavelength of light.

The various standards now known for linear measurements are (*i*) Line standard, (*ii*) End standard, and (*iii*) Wavelength standard.

In line standard, metre is defined as the distance between scribed lines on a bar of metal under certain conditions of temperature and support. These are legal standards and Act of Parliament authorises their use.

1.2.2. Metre

Metre is the distance between the centre portions of two lines engraved on the polished surface of a bar of pure paltinum-iridium alloy (90% platinum and 10% iridium). It is inoxidisable and can have good polish required for ruling good quality of lines. The bar is kept at 0°C and under normal atmospheric pressure. It is supported by two rollers of at least 1 cm dia symmetrically situated in the same horizontal plane at a distance of 751 mm, so as to give minimum deflection (points of Bessel). It has a shape of winged section as shown in Fig. 1.2, having a web whose surface lines are on the neutral axis. The section chosen gives maximum rigidity and economy of costly material. Also the neutral axis lies at the top of the web and, therefore, whole of it can be graduated. Overall width and depth are 16 mm each. This reference is designated as International Prototype Metre—M in 1899. This standard is kept at BIPM at Sevres in Paris.

Earlier metre standard (before 1875 where the above described metre was adopted by International Bureau of Weights and Measures) used to be end standard which had great disadvantages associated with it and was found unsuitable. End standards are subjected to secular changes (*i.e.* changes in dimension over a period of time). Thus they are not suitable as fundamental standard. This is obvious from the fact that the standard yard described above was found to be decreasing in length when compared with metre line standard. The metre line being on platinum iridium alloy was quite stable. Therefore, yard's relationship had to be defined in terms of metre as 1 yard = 0.91439841 metre or 1 metre = 39.37014 inches.

On International basis, this relation was modified as the American yard was longer by four parts in one million. Thus for stability of standards, International yard was adopted as 1 yard = 0.914400 metre, or 1 inch = 25.4 millimetres.

Secondly, it is very difficult to transfer accurately the line standard to end standard which is generally used for practical measurement. Fig. 1.2.

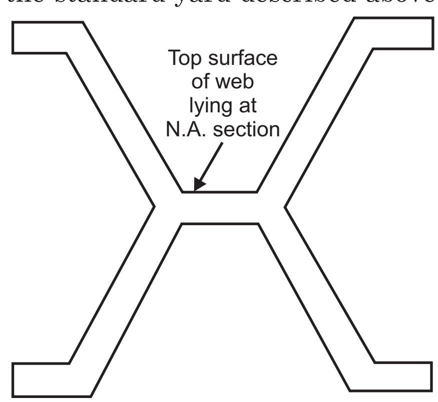

Fig. 1.2.

1.2.3. The precision scale

Inspite of a natural standard, the need for physical standard remains. The obvious advantage of line standard over end standard is that the bar can be subdivided into very small increments further in the greater lengths (over one meter), fabrication of the end standard becomes increasingly difficult. The precision scale of reference standard caliber is usually of a Tresca or *H* section, designed to be supported and used horizontally. Fine lines are engraved 90° to the longitudinal axis of the bar, on a highly polished, flat surface at the neutral bending plane of the bar. While it is the overall length between extreme end points, that is of interest to the bureaus, the precision scales are marked with lines at spacing of each 1 mm. The lines on scale are engraved by using a specially constructed ruling engine. The spacing of lines is governed by a precise, compensated lead screw, or alternately by reference to a master scale,

Engineering Metrology

About the book

The subject of Engineering Metrology is gaining lot of popularity and recognition in industry with the advent of automatic and precision machines which depend for their operation on sophisticated instruments capable of giving accurate measurements. The present day manufacturing industries demand engineers with sound background of metrology and statistical quality control techniques. It is hoped that this book will continue to serve as an inspiration to the engineers to take up the challenging jobs, the industries offer.

Numericals play an important role in clarifying the text and accordingly a large number of solved numericals have been added. In recent years Quality Management and Reliability Analysis have been gaining attention.

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4575/15, Onkar House, Opp. Happy School,
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