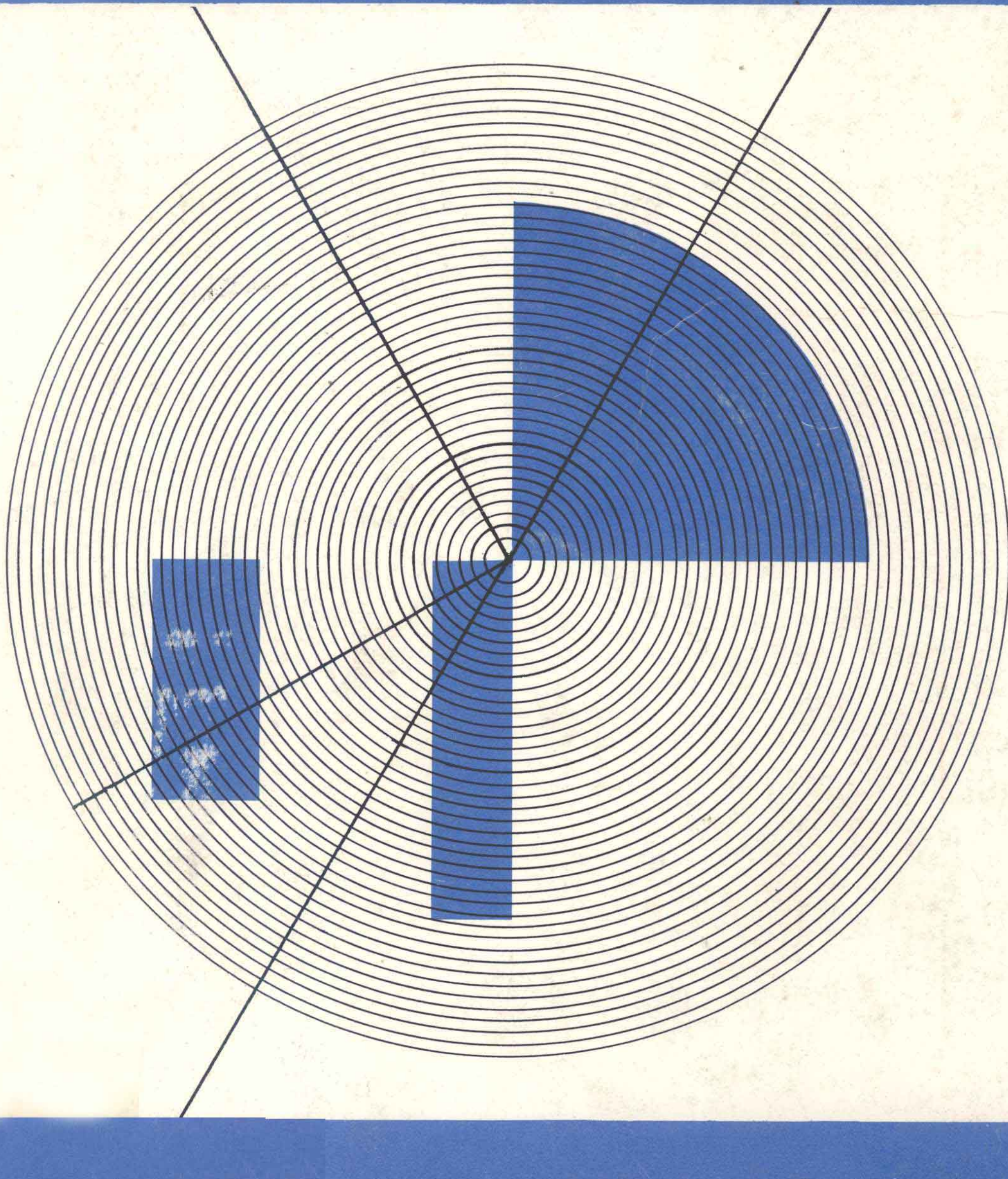
PRECISION MEASUREMENT in the METAL WORKING INDUSTRY



PREPARED BY THE DEPARTMENT OF EDUCATION OF
INTERNATIONAL BUSINESS MACHINES CORPORATION

Precision Measurement in the Metal Working Industry

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PRECISION MEASUREMENT IN THE METAL WORKING INDUSTRY, prepared by the International Business Machines Corporation as a text to train workers for the war effort, first appeared in 1939, in two volumes. Reissued in 1943, it became the first book to bear the imprint of the newly founded Syracuse University Press. A one-volume revised edition, published in 1952, has been continuously in demand since then. Now available in paper binding, this edition is dedicated, with appreciation, to the founder of Syracuse University Press: Chancellor Emeritus William Pearson Tolley.

THE PUBLISHER

PREFACE

MODERN PRODUCTION depends on interchangeability and uniform accuracy of parts. In America a century ago, Eli Whitney first demonstrated the value of parts that could be interchanged; more recently American industry proved both for all time by pioneering the mass production of automobiles and, later, a great variety of other products--from home appliances to computing machines.

Today, in countless laboratories and factories, the search goes on for answers to the problems of production: better materials, more practical design, improved machines, better ways of making and assembling parts. Many of these answers are provided by precision measurement--through accuracy in production, high standards of inspection, new and improved instruments, uniform measuring practices. Here is a fast-growing, changing, and increasingly significant field.

This book deals with the fundamentals of precision measurement. In the early 1940's "Precision Measurement in the Metal Working Industry" was published in two volumes, based on previous informal publications bearing similar names. As the IBM Department of Education continued to work on problems of training in inspection and the use of new instruments and methods, technological advances called for revised and additional instructional material. Much of that information became the basis for this completely revised edition in a new single-volume format.

The new edition remains a practical description of actual shop experience. All pertinent material in former editions has been retained; new text has been added to bring the information up to date; new illustrations show important changes in instruments. The result is a modern version of a book that has long been a leader in its field.

IBM engineering and manufacturing personnel have collaborated actively in the preparation of this material. Manufacturers of precision instruments, representatives of standards organizations, and others--named in the Acknowledgements section--have contributed information, counsel, and illustrations. Usefulness of the book is enhanced by the experience and constructive criticism of both military and civilian instructors who have used the previous editions as a working textbook in government arsenals, Army, Navy, and Air Force schools, industrial training classes, and technological and vocational classes.

Syracuse, New York
September 17, 1952

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MANY persons and organizations, as well as various members of the IBM Corporation, have made significant contributions to the revision of this edition.

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Chapter I

HISTORY AND BASIC PRINCIPLES

THE term "precision measurement" is applied to the field of measurement beyond the scope of non-precision line-graduated measuring instruments, such as the rule and scale. It refers to the art of reproducing and controlling dimensions expressed in thousandths of an inch or smaller. The instruments used to accomplish this purpose are known as precision measuring instruments.

In an essay published by the Ford Motor Company, "He Measured in Millionths," James Sweinhart tells how man has again and again devised means outside his physical self to help him extend his native abilities: the sound; the plumb; the prism and lens; the square, the angle and the triangle; the telescope. "But always, eventually," he continues, "their limit of use was reached. Always came a question of extension or refinement. Always, confronting, arose the inescapable problem of smaller and more accurate measurement. In many different branches of his explorations and investigations there came into being an unwritten but undeviating law that man's knowledge advances to the degree that he can measure precisely."

In the world's research and engineering laboratories this never-ending struggle to solve and measure the vast and mysterious phenomena of nature goes on. The achievements of these men of science read almost as fiction.

BRIEF HISTORY OF LINEAR MEASUREMENT

Evidences of linear measurement can be definitely traced back to the third century B.C., but there is reason to believe a system of measurement existed prior to this time. For example, the great pyramid of Khufu at Gizeh in Egypt was built about 4750 B.C. Although this edifice covers an area of 13 acres, the mean error in length of the sides of the base is about 6/10 of an inch, and the angles are not in error more than 12 seconds from a perfect square. The workmanship of these Egyptian artisans is remarkable even today. They finished the immense blocks of stone so accurately that the pyramids could be constructed without mortar. These men not only had an amazing amount of skill, but they also must have had an accurate system of linear and angular measurement.

The earliest known unit of measure is called the cubit. It was based on the length of the forearm from the elbow to the tip of the middle finger. Of several standard cubits discovered, two were outstanding: the Olympic cubit which averaged 18.24 inches, and the Royal Egyptian cubit which averaged 20.62 inches.

At later dates, various units, sub-units, and names were developed. Among these were:

Span -- One-half of the Olympic cubit, or about 9 inches.

Palm -- One-sixth of the Olympic cubit, or about 3 inches.

Digit -- One twenty-fourth of the Olympic cubit or about 3/4 of an inch.

Subsequently the cubit became known as a foot and was the equivalent of 12 thumbnail breadths or "unciae," which in Anglo-Saxon countries later became inches.

In the 12th century, the yard was determined by Britain as being the distance from the point of the nose of King Henry I to the end of his thumb. In 1324 the inch was defined as the combined length of three barleycorns set end to end. In 1558 the length of a certain bronze bar was decreed to be the standard yard.

An attempt was made in the 16th century to standardize the foot, which up to that time ranged in length from 9-3/4 inches to 19 inches. The order defined the foot in terms of the rod as follows: "On a certain Sunday as they come out of church, 16 men shall stand in line with the left feet touching, one behind the other. This distance shall be the legal rod and one-sixteenth of it shall be the foot."

In 1824 the yard of 1558 (known as Queen Elizabeth's yard) was superseded by "Bird's standard yard," but it was lost by fire in 1834.

Nearly all of these efforts to set up standards or units of measure involved measurements that were not stable or constant, parts of the body such as feet, arms, hands, or fingers. Not one was considered absolute nor could any one be referred to as a really basic, unvarying standard.

The Weights and Measures Act of 1878 defined the British Standard Yard in use today. It was declared to be the distance at 62.00°F. between two fine lines engraved on gold studs in a bronze bar. This bar was cast in 1844.

In France, scientists determined to establish a unit of measure that had a permanent relationship with something more concrete. They carefully computed the earth's diameter and circumference and then divided the meridian quadrant into ten million parts. To the unit of length produced, the designation "meter" was given. It became the foundation for what is now known as the metric system of linear measure. Later the computation was discovered to be inaccurate, and in 1927 the meter was redefined and is no longer associated with the size of the earth. The most recent definition of the meter, adopted in 1927, is as follows:

"The unit of length is the meter, defined by the distance at the temperature of melting ice between the centers of two lines traced on the plantinum-iridium bar deposited at the International Bureau of Weights and Measures, and declared prototype of the meter by the First General Conference on Weights and Measures, this bar being subjected to normal atmospheric pressure and supported by two rollers at least one centimeter in diameter situated in the same horizontal plane and at a distance of 572 millimeters from each other."

As an alternative or provisional definition which refers to some natural standard, the length of the meter is defined in terms of the wave length of light, as 1,553,164.13 wave lengths of the red light emitted by a cadmium vapor lamp excited under specified conditions. The relative accuracy of the value of the meter in terms of light waves is one part in ten million.

The International Bureau of Weights and Measures at the Pavillon de Breteuil, near Severs, France, has been declared international property by the French government and generally is regarded by the principal nations as possessing the basic standard of linear measure.

METRIC SYSTEM OF LINEAR MEASURE

The metric system of linear measure is based on the meter as the unit. The meter is subdivided into tenths, hundredths, and thousandths, and similarly is increased in multiples of ten, as shown in Table I.

TABLE I

10 millimeters (mm) equal 1 centimeter (cm)
10 centimeters (cm) equal 1 decimeter (dm)
10 decimeters (dm) equal 1 meter (m)
10 meters (m) equal 1 dekameter (dkm)
10 dekameters (dkm) equal 1 hektometer (hm)
10 hektometers (hm) equal 1 kilometer (km)

The following prefixes are used with the metric system of weights and measures:

milli	1/1000	(one-thousandth)
centi	1/100	(one-hundredth)
deci	1/10	(one-tenth)
deka	10	(ten)
hekto	100	(hundred)
kilo	1000	(thousand)

The metric system is almost universally used in Europe (except Great Britain), and considerably in the United States, especially in scientific laboratories and some types of manufacturing. The ball bearing industry, for example, lists all sizes of bearings in even millimeters, whereas the corresponding American figures run to four and five decimals. Manufacturers building machines and instruments largely for export to foreign countries occasionally use the metric system to facilitate assembly, servicing, and replacement of standard parts.

BRITISH IMPERIAL SYSTEM OF LINEAR MEASURE

The British imperial system differs from the metric in the size of the unit and in the manner in which it is subdivided. The names applied to the various multiples of the unit are those handed down from the Egyptians, Greeks, and Anglo-Saxons. The standard measuring length in the British imperial system is the yard, and the smallest unit identified by name is the inch. The present legal equivalent of the British yard is approximately 0.9143992 of a meter, a value which makes 1 inch equal to 2.54 cm, correct to two parts in a million. The system includes the following units:

12 inches equal 1 foot
3 feet equal 1 yard
5-1/2 yards equal 1 rod
40 rods equal 1 furlong
8 furlongs equal 1 mile

AMERICAN STANDARD OF LINEAR MEASURE

In 1856 the British government presented the United States with two bars, each of them one yard in length. These bars were regarded for many years as the best representation of the yard in this country, but they are no longer officially considered as having anything except historical significance.

In 1866 Congress legalized the use of the metric system. As a result of its participation in the metric convention, the United States government in 1889 was presented with a platinum-iridium meter which is an exact prototype of the International Standard Meter owned by France. This meter is called Meter No. 27, and since 1893 has been used as the standard in this country for all length measurements. It is the only standard of length authorized in the United States.

By law, the meter is declared equal to 39.37 inches, which makes the American legal yard 3600/3937 of a meter and the United States inch equal to 2.540005 + cm.

The following tables give the relationships between the American and metric systems, which permit conversion from one to the other. In calculating the figures, 1 inch is considered equal to 2.54 cm. This is an approximation to 2 parts in a million, as previously stated, making most of the relationships approximate:

- 1 millimeter equals .03937 inches exactly, or approximately 1/25 inch.
- 1 centimeter equals exactly .3937 inches.
- 1 meter equals 3.28083 feet or 1.09361 yards (approximately).
- 1 kilometer equals .62137 miles (approximately).

and conversely:

- 1 inch equals 25.4 millimeters or 2.54 centimeters (approximately).
- 1 foot equals .3048 meters (approximately).
- 1 yard equals .9144 meters (approximately).
- 1 mile equals 1.60934 kilometers.

The subdivisions or units of measure in the two systems have no uniform relation, and the only use for them is in the conversion from one system to the other.

INTERCHANGEABILITY OF PARTS

Eli Whitney, while known as the inventor of the cotton gin, is better remembered for his work as the forerunner of our modern mass production system, the manufacture of interchangeable parts.

Early craftsmanship failed during the 18th century when large armies demanded muskets. Each gun was individually made, each part fitted to each musket. Whitney recognized the deficiencies of such a system and decided to build a gun factory in which machinery would be used wherever possible to produce parts that were interchangeable. In order to produce parts usable on any gun he manufactured, he established measurement standards. By strict adherence to the gage standards set up, any part of a Whitney musket would fit any other Whitney musket, but the same muskets manufactured by others from identical drawings and dimensions were radically different, because of a lack of common standards.

Prior to World War I, interchangeable parts manufacture was confined largely to the products of a single plant. The sudden demand for war material and the inadequacy of the equipment in any one place for producing a complete unit made it necessary to delegate the manufacture of a machine to a number of plants. A great many difficulties arose from the fact that there were no universal standards of length and the parts from one plant would not fit those made in another.

The National Bureau of Standards undertook to calibrate and check all master industrial gages used in the manufacture of war material. Their efforts led to the subsequent use of gage blocks certified by the Bureau of Standards in controlling the accuracy of measuring instruments and gages in large industrial plants.

Rapid industrial development through mass production of popular-priced, high-quality machines required more exacting methods of manufacture and finer instruments to control them. The recognition of the value of precision gage blocks grew until today they are used by nearly every industrial concern making a product whose quality depends on the accuracy of its parts.

As faster and better-performing machines are developed, parts more accurate than ever before must be produced in great quantities. This means further use of precision gage blocks and further development in instruments capable of controlling smaller and smaller dimensional tolerances.

As plants continue to decentralize, as so many of the large automobile companies have done, universal standards of measure become increasingly important. In the assembly of the automobile, the component parts may come from hundreds of different points scattered over the country. To have these parts fit means that tolerances must be maintained and that all contributors to the final assembly must operate from a universal standard.

Products in the possession of customers must have interchangeable working parts throughout so that they may be properly serviced. This is possible only by using precision measurements based on universal standards.

STANDARD MEASURING TEMPERATURES

Until a few years ago there was no single method of converting the American inch accurately into the metric values of other countries. The standard measuring temperature in the United States and Canada was 68°F., and at this temperature one inch equals 25.40005 millimeters. The standard British equivalent was 25.39998 millimeters at 62°F., while the meter was defined at a measuring temperature of 0° C. (or 32° F.). Similar variations also existed among other countries. To overcome difficulties resulting from these different national standards, a group of large industrial concerns and standards organizations undertook the creation of a universal standard for conversion between the British imperial system and the French metric system. Many obstacles had to be overcome, including international prejudice or preference, but the largest of all was the revision of established standards and recalibrating industrial gages. Despite the difficulties involved, industrial nations of the world recognized the wisdom of having a universal standard based on a universal conversion factor between the imperial and metric systems, and a universal measuring temperature.

In 1929, at one of the sessions of the International Commission of Weights and Measures, the measuring temperature of 20° C., which is equivalent to 68° F., was established as standard for the metric system. In 1930, the British Standards Association adopted 68° F. as standard for the British imperial system and also adopted the conversion factor of 25.4 millimeters for one inch. In 1932, the American Standards Association submitted the standard measuring temperature (68° F.) and the fixed conversion factor (2.54), and they were approved by the American industries. However, this conversion factor is not yet legal so far as the United States government is concerned.

During the latter part of 1934, the Deutscher

Normenausshuss (German Standards Association) announced that it, too, had adopted these standards. Sweden, Finland, Denmark, Japan, and several other countries have cooperated with the International Standards Association (I. S. A.) and likewise have adopted the 2.54 conversion factor and the 68°F. or 20°C. measuring temperature.

Now that an international standard has been established, 2.54 is a fixed conversion factor and not a long irrational number having different values in different countries. The universally used measuring temperature is 68°F. or 20°C. and the centimeter and the inch are each the same all over the world.

AMERICAN STANDARDS ASSOCIATION

The American Standards Association is a clearing house for voluntary development of standards for all interested persons. It was organized in 1918 by five engineering societies as the American Engineering Standards Committee. Its purpose was to serve as a coordinating body, eliminating duplication and overlapping of their standardization activities.

As the work of the committee grew and its activities extended into new industrial fields, reorganization became necessary along broader, more flexible lines to meet the growing need and demand for adequate national standards. In 1928, the name was changed to American Standards Association. Today the membership of the Association includes some 100 national trade associations, technical societies and consumer organizations, and more than 2000 companies. Membership is open to any industrial, commercial, technical, or governmental group interested in standardization work.

The methods used by the Association have been developed through more than 32 years of experience in dealing with difficult inter-group problems. Based as they are on the assent of all groups having a substantial interest in the completed work, American standards are today becoming a positive force in American business. Eleven hundred standards and safety codes have thus far been approved.

The American Standards Association is the United States member of the International Organization for Standardization (I.S.O.) through which the national standardizing bodies of 30 countries carry on their general cooperative activities. Through this and other means, the A.S.A. makes available to American industry direct and authoritative contact with standardization developments in other countries.

The broad range of projects undertaken by the A.S.A. includes dimensional standards to allow for interchangeability of supplies or to secure the interworking of parts or interrelated apparatus; specifications for materials and methods of test; definitions of technical terms used in industry, industrial safety codes to make possible uniform requirements in safety devices for machines and other equipment in the fields of both public and industrial safety, industrial health codes for the prevention of occupational diseases, development of a national building code; specifications for consumer goods sold in retail trade.

NATIONAL BUREAU OF STANDARDS

Established by act of Congress in 1901, the National Bureau of Standards is the principal agency of the federal government for fundamental research in physics, mathematics, chemistry, and engineering. It has custody of the national standards of physical measurement, in terms of which all working standards in research laboratories and industry are calibrated, and carries on research leading to improvement in such standards and measurement methods. In addition to basic and applied research, the bureau determines physical constants and properties of materials and develops improved methods for testing materials and equipment.

The Bureau is authorized to make tests and calibrations for American industry, on a fee basis, when devices or materials must be checked with the Bureau's standards or when sufficient accuracy cannot be obtained elsewhere than at the Bureau. The Bureau assists industries in maintaining accurate standards of linear measurement by certifying master gage blocks to the American standard inch when this service is requested. General information on the testing program and the fees required is given in National Bureau of Standards Circular 483, "Testing by the National Bureau of Standards," available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

An important phase of the Bureau's work consists in cooperation with technical and trade associations, both in this country and abroad, on problems of concern to the Government and the nation, particularly those relating to the determination and establishment of scientific quantities and standards. In this way, organizations such as the American Society for Testing Materials and the American Standards Association are assisted in the development of specifications and industrial standards. As a large part of the research and testing has direct bearing on technical requirements for safe working and living conditions, the Bureau provides a central source of information to which federal, state, and municipal authorities, as well as industrial and trade associations, can turn when dealing with problems of safety or with building or plumbing codes. The Bureau also plays an important part in the development and establishment of federal specifications; these specifications insure quality and economy in federal purchase while providing an equal opportunity to all suppliers to compete for federal purchases.

The result of much of the Bureau's research and development are of direct interest to industry. These contributions are made available to the scientific and engineering world through publication in the "Journal of Research" of the National Bureau of Standards, and the National Bureau of Standards' "Technical News Bulletin," both of which are available from the Superintendent of Documents on a subscription basis.

The National Bureau of Standards now employs over 3,000 people, of whom approximately three-fourths are technically trained. Scientific and technical activities are carried out in 15 divisions concerned with electricity, optics and metrology, heat and power, atomic and radiation physics, chemistry, mechanics, organic and fibrous materials, metallurgy, mineral products, building technology, applied mathematics, electronics, ordnance development, and so on.

INDUSTRIAL STANDARDS OF LINEAR MEASURE

Manufacturing industries throughout the world have been instrumental in the establishment of basic standards of measurement. Through control of the accuracy of measuring instruments used to check vital dimensions of machine parts, manufacturers are able to guarantee high standards of quality and performance. By establishment of linear standards of measure and development of ways to bring them down to the bench, interchangeable part manufacture has been made possible. Universal standards enable manufacturers to secure standard parts, such as screws, nuts, and pins, made by many different concerns and to know those parts will fit into their proper places. These developments enable a manufacturer to order by blueprint, from a vendor in a distant city, parts to his specifications and receive them ready for use.

Modern production methods of manufacture require the assembly of machines with a minimum of fitting. Back of this mass production of interchangeable parts must be a set of universal standards or master gages with which the instruments employed to control accuracy may be calibrated. These instruments have gone through a long process of development. In 1851, the vernier caliper, the most accurate instrument of its time, was invented. It was capable of measuring to one thousandth of an inch. In 1867, the Systѐme Palmer appeared; this became the micrometer caliper. In 1896, the metric gage block, the first of the precision gage blocks, was developed.

During the last 35 years greater accomplishments have been made. Measurements in terms of millionths of an inch are now possible by machines and instruments. Many modern industrial plants have master sets of gage blocks with a guaranteed accuracy of two and a half millionths of an inch (.0000025). Such measurement is difficult for the layman to visualize, but it is illustrated in Figure 1; one millionth of an inch has the same relationship to one inch as 1/16 of an inch has to one mile.

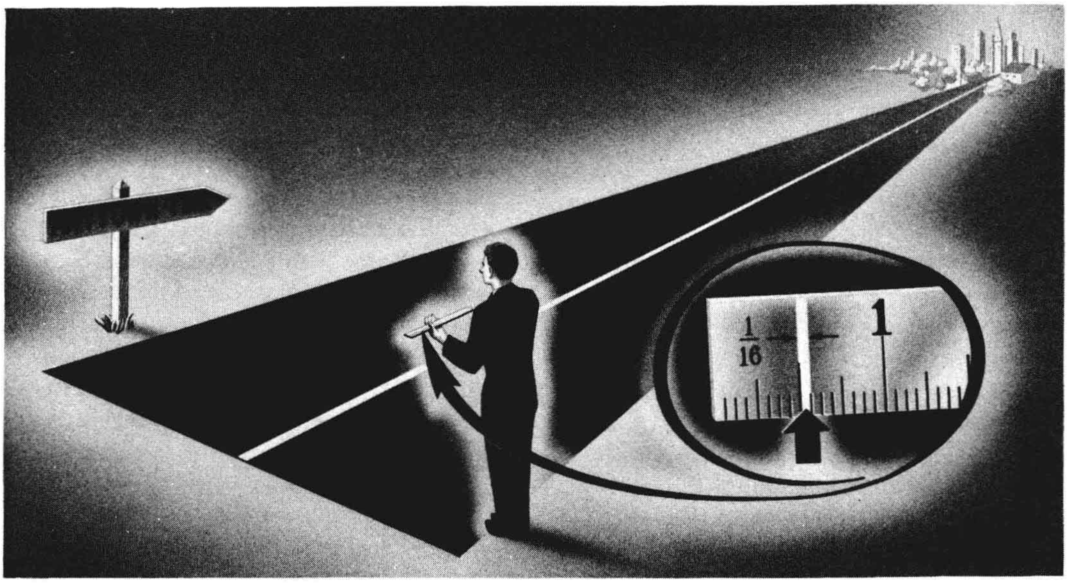

Figure 1

INTERCHANGEABILITY AND SELECTIVE ASSEMBLY

Interchangeability of parts is essential to mass production and in the large majority of manufactured products this objective is easily obtained with the standard gages commercially available.

However, when the successful operation or the required performance of a product depends upon holding dimensions closer than is desirable from the standpoint of production, it is customary to resort to selective assembly. Selective assembly means classifying by size both of the parts to be joined, and selecting mating parts which will subsequently be assembled into the machine as a unit. For example, wrist pins are graded into a series of sizes to be fitted selectively to pistons, which are similarly graded. Ball bearings are another example of parts which must be assembled selectively.

Following is a quotation of the American Standards Association on the subject of interchangeability: "Applied to manufactured material, the result sought is sufficient uniformity in size and contour to adapt the material without further fitting to the requirements of the industries. The fundamental principle involved in interchangeable manufacture requires that a system of standardization and classification of fits shall establish a clearly defined line at which interference between parts begins."

MEASUREMENT TERMS

Consider now the meaning of some of the terms which will be needed throughout this book. Anyone familiar with production processes knows that the parts of a machine cannot be made to an absolute dimension; all have some variation. In the majority of industrial applications, the mechanic or the inspector is not so interested in the exact value of a dimension as in its variation from the basic size. The allowable variation is determined by the function and design of the part, and is expressed in terms of limits between which the dimensions may vary.

DIMENSION. The measure of width, height, depth, or length in units of length of any object, as shown in Figure 2. A unit of length, as distinguished from a standard of length, is a measure in space without considering any physical conditions, such as temperature and pressure, while a standard of length is the physical representation of a defined unit of length under definite physical conditions.

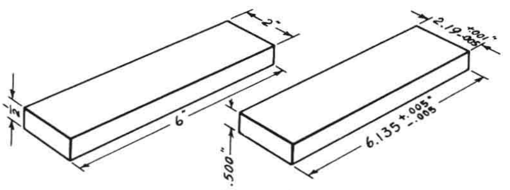

Figure 2

STANDARD SIZE. "A series of recognized or accepted sizes corresponding to various subdivisions of a recognized unit of length such as the yard or the meter. These are usually expressed in inches or in millimeters; sometimes by arbitrary numbers or letters" (American Standards Association). For example, cold-rolled bar stock may be obtained in standard sizes 1/64 inch, 1/32 inch, 3/64 inch and 1/16 inch, but if a bar between these sizes is desired, it is considered an odd size.

BASIC DIMENSION is the exact theoretical size from which all limiting variations are made. To illustrate: on a blueprint a dimension is given as 2.251 inch ± .001. The flat dimension (2.251) stripped of the allowable variation is the basic dimension.

Basic Dimension:

2.251" + .001 (plus tolerance)
- .001 (minus tolerance)

Upper Limit: 2.252

Lower Limit: 2.250

LIMITS are the maximum and minimum dimensions obtained by applying the tolerances to the basic dimensions and are the extreme dimensions beyond which the work cannot extend.

MEAN DIMENSION. The mean dimension is the average of the sum of the high and low limits. For example:

Basic Dimension:

.250" + .002
- .004

Upper Limit: .252"

Lower Limit: .246"

Mean Dimension: .249"

TOLERANCE. The permissible variation in the size of a part. The practice of showing the amount of permissible variation above and below the basic size is practically universal, because the tolerance on a dimension is the most pertinent information required in making the part. The meaning of the term "tolerance" is illustrated by the fact that dimensions such as $1.000'' \begin{smallmatrix} +.000 \\ -.004 \end{smallmatrix}$, $1.000'' \pm .002$, $1.000'' \begin{smallmatrix} +.001 \\ -.003 \end{smallmatrix}$, and $1.000'' \begin{smallmatrix} +.004 \\ -.000 \end{smallmatrix}$, all have a tolerance of .004.

If the permissible variation is both plus and minus, it is referred to as a bilateral tolerance. If the tolerance is in one direction only, plus or minus, it is referred to as unilateral.

ALLOWANCE. "An intentional difference in the dimensions of mating parts or the minimum clearance space which is intended between mating parts. It represents the condition of the tightest permissible fit, or the largest internal member mated with the smallest external member. It is to provide for different classes of fit" (American Standards Association). The terms "tolerance" and "allowance" are often considered as having the same meaning. They are not synonyms, however, and have two entirely different meanings. Tolerance is the total permissible variation in one basic dimension on a single part, whereas allowance is the difference between the two tightest dimensions on mating parts.

To illustrate allowance, consider that a shaft is dimensioned .999" (+ .000, .001). The shaft is to be assembled to a gear, which has a hole in the hub dimensioned 1.000" (+ .001, - .000). The tightest condition possible between these parts occurs when the shaft is largest and the hole is smallest. The largest shaft is .999, the smallest hole is 1.000 inch, and so the minimum clearance or allowance is .001.

If the shaft diameter was 1.001" (+ .0000, - .0005), and the hole diameter 1.000" (+ .000, - .0005), it would be necessary to force the shaft into the hole because the hole is smaller than the shaft. It would be possible for the shaft and hole to have all the following combinations:

	(1)	(2)	(3)	(4)
Shaft	1.001	1.0005	1.001	1.0005
Hole	.9995	.9995	1.000	1.000
Negative Clearance	-.0015	-.0010	-.001	-.0005

In this case the allowance is always negative, and since the American Standards Association defines the allowances as the tightest fit, the allowance is -.0015.

If the dimensions of the shaft and hole were reversed, the clearances above would be positive, and the allowance would be + .0005, the condition representing the tightest fit. See Figure 3.

CODE OF TOLERANCE

In setting up a system to control the accuracy to which a product is to be manufactured, tolerances are given on the principal dimensions of all parts, and a code of tolerances is established to control the accuracy of the measuring instruments and gages used in the shop.

In general, the allowable error in a measuring instrument or gage is a small fraction of the tolerance on the dimension it is to control. The following excerpts from a typical code of tolerances illustrates the type of standards set up in a manufacturing industry for measuring instruments.

EXCERPTS, TYPICAL CODE OF TOLERANCES

GAGE BLOCKS. The master set of precision gage blocks shall be used only as a reference and shall be considered the basic standards of linear measure for the plant.

The master set of precision gage blocks must check a total error of not more than .000002 per inch of length. The working sets of precision gage blocks may have a total error of .000005 to as much as .000040 per inch of length, depending on the degree of accuracy required by the job.

SURFACE PLATES. Surface plates shall be flat, smooth, and true. The error in flatness of an 18 x 24 inch surface plate shall not exceed .001 of an inch. That is, no appreciable area of the working surface shall differ from the remainder of the surface by more than .001 inch.

OUTSIDE MICROMETER CALIPERS. The faces of the anvil and spindle must be flat and parallel with each other. The measuring error must not exceed .0002 of an inch at any point in the entire range of the graduations. This applies to all ordinary micrometer calipers whether equipped with a vernier for reading ten-thousandths or not.

VERNIER CALIPERS. The total error must not exceed .002 inch up to 18 inches of length and not exceed .001 of an inch for additional 12-inch lengths.

VERNIER HEIGHT GAGES. The total error must not exceed .002 inch up to 18 inches of length and not exceed .001 inch for additional 12-inch lengths. The blade must be square with the base within .005 inch in its entire length and the measuring surface of the sliding jaw must be parallel with the base within .005 inch.

PLUG, RING, AND LIMIT GAGES. In general, the error in size due to wear should not exceed .0002 inch. When gages are used to check parts having either very close or very wide limits, the allowable limits of error in the gage should be adjusted accordingly.

SOLID SQUARES. Solid squares must not have a total error in the 90-degree angle of

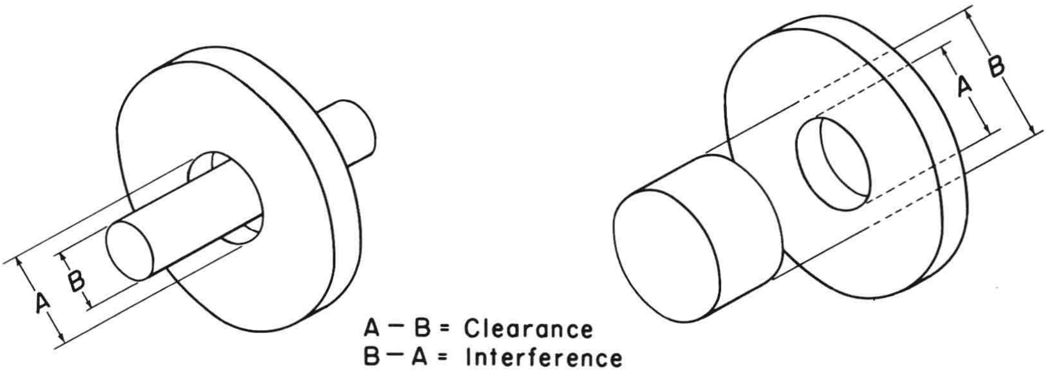

Figure 3