شـــرکت پترو پولاد پارس

((سازنده سازه های سبک و سنگین فلزی))

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Dimensional test

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Inspection

Inspection is an essential procedure carried on in connection with all manufacturing processes by which usable goods are produced. Inspection work, however, differs from that of all the processes discussed to this point. Unlike them, it does not change the individual product, but instead, by elimination of bad parts improves the average quality of those that remain for distribution and use.

In general terms, inspection can be defined as an examination to determine the conformance of parts or assemblies to their specifications. The information gathered from such an examination may be used for several purposes. Because it is frequently impossible to manufacture articles within close enough limits that all can be used interchangeably, the inspection information is frequently used to sort products into groups. The information gathered from inspection is also used as an indication of need for adjustment of equipment or processes. A third objective of inspection procedures is to provide data for control of quality.

Quality Control Uses Inspection Data for Process Improvement. Although the term *quality control* is occasionally used synonymously with inspection, its meaning is sometimes different. The association between quality control and inspection is close. Quality control is often a second step, making use of inspection data for analysis and decision making for achieving, maintaining, and improving quality of products. In some manufacturing plants, both inspection and quality control are performed by the same department and personnel. In others, they are completely separated and may even have separate data collecting facilities.

INSPECTION PROCEDURES

Because of their effects on the product function, the selection of dimensions, qualities, and appearance factors for any product is primarily a design problem. In many cases the choices are empirical in nature, being based on past experiences, and in some cases are even arbitrary because of the lack of real information on which to base the kind of choice. Most dimensions and qualities are subject to wide variability in the manufacturing process and, in some cases, may also be very difficult to measure.

The desired life expectancy for a product also will usually play an important part in the consideration given to dimensions and qualities needed for satisfactory manufacturing. Because of these factors and the close association between processing and quality control, both the manufacturing and inspection divisions of a manufacturing plant are often consulted before a final determination of quality tolerances. In addition, they are usually the principal decision makers for setting the inspection qualities, quantities, and standards.

Inspection Varies with Quality Desired. The difference in the amount and kind of inspection necessary for a machine tool as compared to a piece of farm equipment is considerable. In the first case, a machine tool would be expected to be rigid, to be free working with a minimum of friction loss, to have very accurate related surfaces for maintenance of accurate movement, to have long life, and, during that period, to be able to produce parts accurate within a few ten-thousandths of an inch of dimension. These requirements mean that most of the parts of which the machine is constructed must be held within extremely close accuracy limits, and large amounts of inspection are necessary.

In the case of the farm machinery, which may be no less important in its own area, the product must be strong, rugged, able to withstand exposure to the elements, and also to function over a long period of time, although the actual hours of use may be relatively few. The farm machinery, however, does not require the relationship accuracies that must exist in the machine tool, so that both the quality and quantity of inspection can be reduced. These differences naturally show up in the cost of the completed equipment.

Inspection Benefits Management and Customer. The meeting of specifications set by the designer is primarily a manufacturing problem. Whether or not the specifications are met is determined by inspection, which may be performed by either operating or specialized personnel. Regardless of his other duties, an inspector at the time he is performing this function may be considered to represent both management and the customer.

Processing Closely Related to Quality. Any product is always subject to quality variation, the degree of which will vary in wide ranges dependin largely upon the relationship between the product design and the process chosen for its manufactur. The materials of the product, the equipment use the personnel operating the equipment, and the planned steps by which the manufacturing is carrie on are all influencing factors on the quality variatior Inspection is for the purpose of finding these variations and, in many cases, aiding in assigning th causes for their existence.

ORGANIZATION OF INSPECTION

Inspection Always Present. Although certain kinds of inspection are limited to certain phases du ing the manufacturing processes, inspection of so type, sometimes as simple as casual observation, needed in every stage of manufacturing of every kin of product. It is, however, customary in many plant to label in general terms the inspection procedures according to the state of the product being examined, as receiving inspection, in-process inspection, an final inspection.

Receiving Inspection. The term *receiving inspection* denotes all the inspections, regardless of type that are given to incoming material, including such things as raw materials, speciality items, and subassemblies manufactured under subcontract. To cu down transportation and handling, companies making use of large quantities of speciality items or subcontract work frequently perform this kind of inspectior in the supplier's plant.

In-Process Inspection. Inspection that is conducted during the time raw material is being converte into a finished product is called *in-process inspecti* The place of inspection is dependent largely upon the degree of examination and the kind of equipment needed. When only a percentage of the parts produced are inspected, either periodically or in spot checks, the work is usually carried on at the machine. Particularly in small plants, this inspection may be performed by the machine operator himself. When large quantities of product are to be inspected, and when the inspection procedures require specialized equipment, the work is most often done in centralized areas.

First-Piece Inspection Part of In-Process Inspection. Regardless of the amount of other inspection that might be necessary, *first-piece* inspection is common practice. After any equipment setup, tool change, or any action that may influence the quality of the product, the first piece is examined to determine its conformance to specification. This is sometimes a very formal procedure, and in many cases in pressworking where the effect of wear and other factors is small, this may be the only inspection required.

Final Inspection. Inspection performed at *final* inspection may include a great variety of work. Visual inspection for appearance (paint, labels, cleanliness) and completeness (all parts, instruction books, parts list) is nearly always part of the job. Tests for function, which are sometimes necessary on mechanical goods, may involve elaborate testing procedures requiring much time and adding considerable cost to the overall manufacturing operation. Testing of most aircraft in the final stages would fall in this category.

When the amount of final inspection is large, reduced in-process inspection may be permitted, although this will depend on a number of factors, including the relation of inspection cost to processing cost and the cost of replacing bad parts in the final assembly.

Nondestructive Testing. The vast majority of inspection performed on manufactured goods is nondestructive in nature but most measurements of dimensions, geometry, appearance, completeness, and the like do not fit the usual concept of NDT. NDT usually involves indirect tests that are in some way related to qualities and characteristics that cannot be checked directly without destruction. This kind of testing not only fits into all of the described areas of inspection, but is essential if there is to be assurance of good quality product.

QUANTITY OF INSPECTION

The percentage of inspection at any phase of manufacturing will vary widely. When lowest inspection cost is the principal interest, the variation can be from 0% to 100%. When greatest reliability is of interest, 0% would be unlikely, but 100% may also be unlikely because 100% inspection does not always mean 100% reliability due to the effects of fatigue and monotony as well as the psychological and hypnotic effects of continuous detailed work.

Desired and Experienced Quality Determine Quantity Inspected. With a large portion of manufactured goods, the quantity to be inspected is determined by the use of various sampling plans. These may be used only in those cases where something less than 100% perfect quality will be accepted. In general, the lot size being inspected must be large because of the assumption that the inspected quality will vary according to known statistical laws. Mathematical methods are available for designing a number of sampling plans that take into account the product quality level and the willingness to accept a certain defective part. The necessary sample size is affected by these factors.

Randomness of Sample Important. For any sampling plan to be effective the sample inspected must be random and truly represent the overall quality of the lot. Before a complete sampling plan can be devised, a decision must be made as to the percentage of defective parts in a lot that would be willingly accepted. Ideally, a sampling plan would accept all good lots and reject all bad lots of parts.

Most Economical Sample Size a Compromise. The ideal, however, can be reached only when the sample size becomes 100% and is, in addition, performed without fault. As shown in Figure -1, ideal results are approached when the sample size is increased; consequently the best sample size is always a compromise based on the relative values of improved reliability versus greater inspection costs. Acceptance sampling plans are essential when inspection cost is high and the cost for replacing defectives is low, when the sampling plan is more efficient than 100% inspection, and in every case when the inspection procedure is destructive.

Always Some Risk of Nonrepresentative Sample. The operating characteristic curve shown in Figure -2 is a single sampling plan requiring an attribute (quality that is either wholly present or absent) of

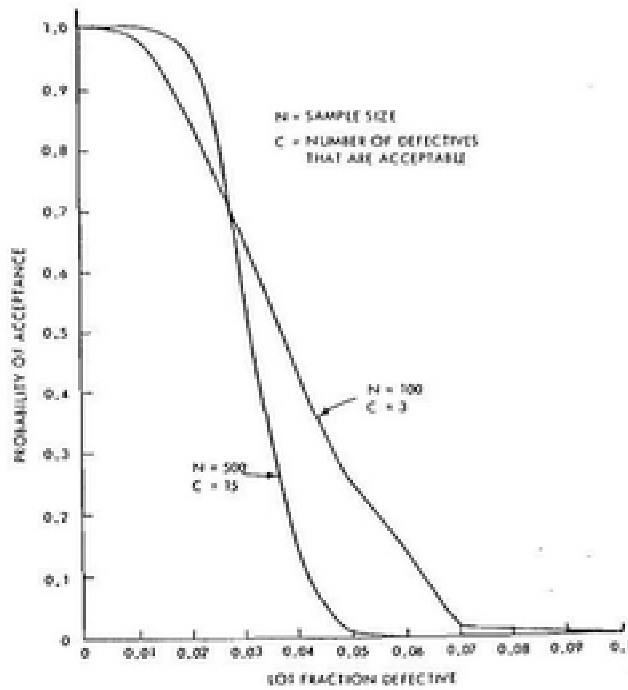

Figure -1
Operating characteristic curves for different sample sizes

200 randomly selected parts to be compared with its specification. If four or less defective parts are found in the sample, the entire lot from which it came will be accepted. If more than four defectives are found, the lot will be rejected and likely be sorted for removal of the defectives. In the plan shown, the dotted line marked P_1 indicates the so-called producers risk. If the lot being inspected had only 1% defectives, there would be a 6% chance that this plan would reject the material. The dotted line marked P_2 indicates the *consumer's risk*, which in this case is a 10%

chance that a lot with 4% defectives might be accepted. Sampling plans of this type therefore must be designed to be acceptable to both the producer and the consumer.

PROCESS CONTROL CHARTS

Need Variables Instead of Attributes. Another valuable use of statistical mathematics in inspection is for the construction of control charts with limit lines. Inspection values plotted on the chart will rarely fall outside these lines except when an assignable cause exists. In other words, the variation of points inside the control limits can be from chance causes alone. The data collected for construction of process control charts is in the form of variables rather than attributes. Data collection is therefore more costly, but in most cases considerably more information can be made available from analysis of the data.

Assumptions Do Not Destroy Value. In the making of control charts, some assumptions are made, which, although they may not be entirely true, can usually be approximated closely enough that the system will work. One of the important assumptions is that variation of the quality being inspected will follow a known frequency distribution. Most often it is assumed that the frequency distribution follows a normal curve, as shown in Figure -3. In a normal distribution, 99.73% of the measured values from an entire population will probably fall within the limits of $\pm 3\sigma$ from the arithmetical mean. (Sigma is the symbol for *standard deviation*, which is a measure of the dispersion of the measured values.) Similarly, 95.46% of measured values would be expected to fall within $\pm 2\sigma$ limits, and 68.26% within $\pm 1\sigma$.

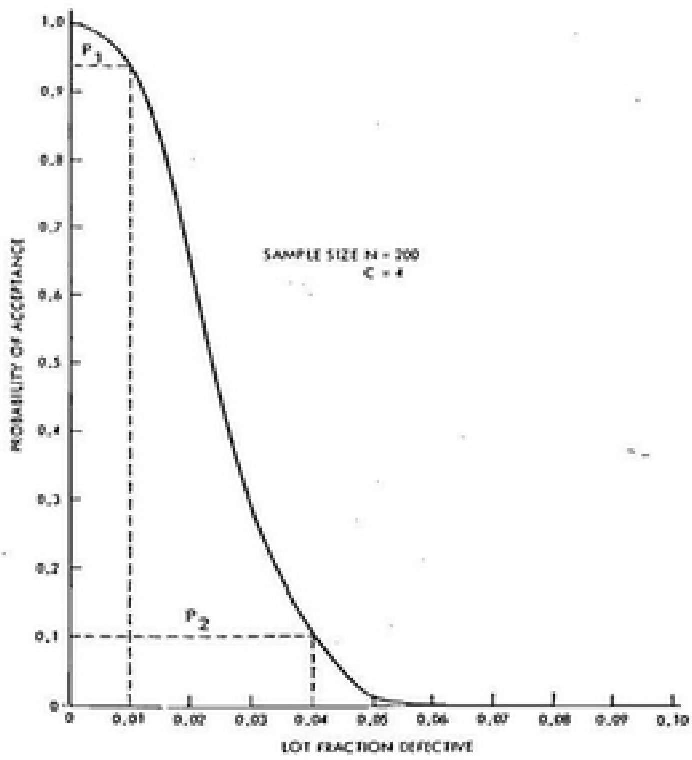

Figure -2
Operating characteristic curve

Chart Constructed from Process History. The construction of a quality control chart usually follows the following kind of procedure. First, the process is examined to ascertain that it is normal and that all assignable causes have been eliminated so that its operation is stable within the limits of chance variation. Next, an historical record is made by plotting, the mean values of a number of samples, the size frequency, and selection of which have been carefully predetermined after consideration of the process characteristics. These values are placed on two charts, one for averages and one for ranges, and limits calculated for each (Figure -4). If the limits used are $\pm 3\sigma$, not more than 0.2% of any plotted points would be expected to fall outside these lines. Therefore whenever a point does fall outside, the process is critically examined for an assignable cause.

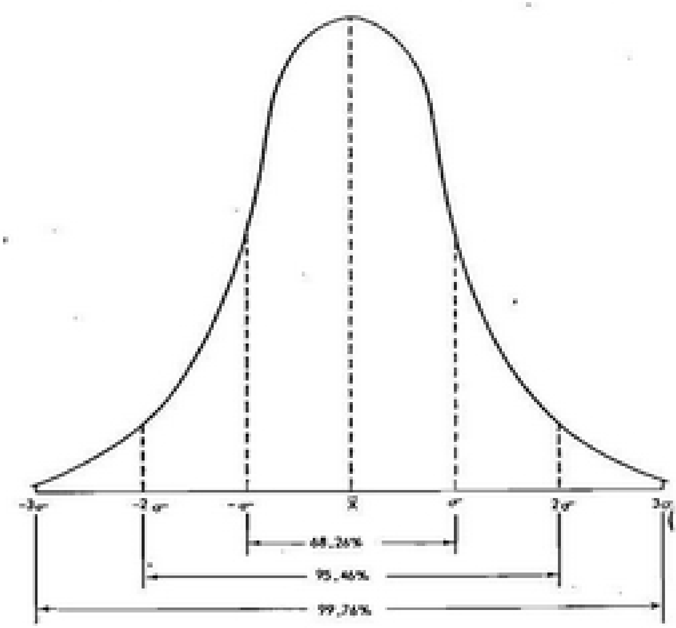

Figure -3
Distribution under a normal curve

As the process continues, current samples are plotted and compared with past history to determine that the process remains in control. In most processes, the mean is controllable by adjustment of the process, but the range can be changed only by finding and eliminating assignable causes.

Charts Best for Long Runs. Although process control charts can be useful for short-run operations under some conditions, their greatest value is in continuing operations in which a minimum number of changes may contribute to variability. The information that can be gathered from control charts can be useful for several purposes. It may be used for individual dimensions should receive first consideration regarding the holding of tolerances.

Drawings and Procedures Should Agree. Drawing dimensions should always agree as closely as possible with manufacturing and inspection procedures to minimize the need for calculations by machine operators and production personnel. When changes in a process cause changes in measurement procedures, action should be taken to correct the working drawings to fit the new methods.

TOLERANCES

Tolerances Should Fit Product and Process Need. Although it is possible by use of sufficient time and care to work as closely to a given dimension as is desired, it is impossible to manufacture to an exact size. Regardless of the accuracy displayed, it is always possible to choose a finer measuring method that can show discrepancies in the dimension. As working to higher accuracies costs more in money, time, and equipment, it is most economical and practical that dimensions should be permitted to vary within the widest limits for which they can still function properly. This variation is permitted by the use of *tolerances* added to dimensions in such a way that they indicate the permissible variation. Theoretically at least, the designer applies dimensional tolerances as wide as can be safely used. One of the inspector's jobs is to determine whether the product is made within these manufacturing limits.

Basic Dimensions Displayed as First Goal. Manufacturing tolerances may be shown in different ways, as indicated in Figure -6. If a dimension is approached in a definite direction by the manufacturing process used, and greater chance of error exists on one side of the basic dimension than on the other, unilateral tolerances are usually displayed, using the dimension that would be reached first as the basic dimension. When no reason exists for error on one side of the basic dimension more than on the other, bilateral tolerances permitting variation in both directions are used. The third method shows both limiting dimensions and thereby eliminates the need for calculation by production personnel. However, it tends to clutter up the drawings because of its sometimes greater space requirement and the increase of significant numbers.

Understood Tolerances — Local Agreements. The majority of dimensions on drawings are not critical and are usually shown without tolerances indicated. However, to prevent complete loss of control, these are usually treated to have *understood* tolerances that may vary in different plants but are usually in the range of ±0.010 to ±0.015 inch.

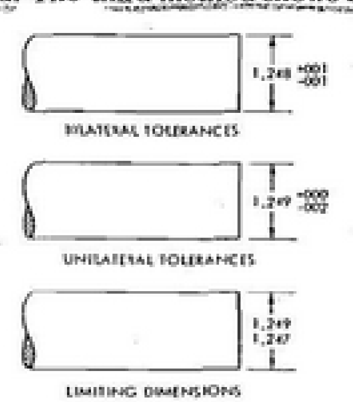

Figure -6
Methods of showing dimensional limits

SOURCES OF MEASUREMENT VARIATION

Variation in dimensional measurement comes from a number of sources. Some are common enough that they should be given consideration in the majority of measuring and inspection procedures. Among these are parallax, temperature effects, pressure effects, and human error.

Parallax Is an Apparent Displacement. The illusion created by parallax is shown in Figure -7. If the hand swinging over the scale is viewed from Point A, directly in front, measurement 5 would be observed. If, however, the eye were moved to position B, the hand in the same position would indicate a reading of 6. This is the illusion that makes it difficult to read a clock correctly when viewing it from an angle.

Any measuring or indicating device that has a finite thickness between the indicating member and the reading scale or the work will display an error caused by parallax if used incorrectly. Many meters are constructed with mirrors underneath the indicating hand so that, to obtain a single view of the hand, the eye must be positioned in the only spot where a correct reading can be directly read. Many meters and instruments used for NDT are so equipped.

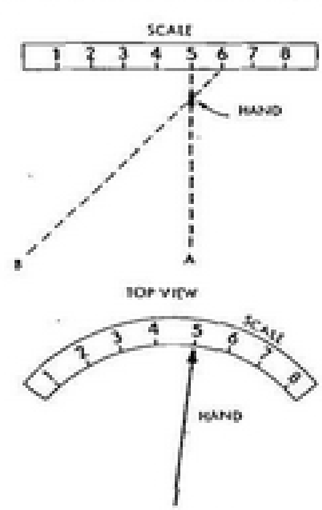

Figure -7
Parallax

Temperature Effects Often Present. It is well known that temperature variation causes changes of dimension in materials, causing them to grow larger with increased temperature and smaller with decreased temperature. Different materials are affected to different degrees by temperature changes or in other words, have different coefficients of thermal expansion. Many of the manufacturing processes cause temperature changes in the work and in the gaging and measuring equipment or are concerned with different materials such that measurement problems caused by temperature are significant.

The coefficient of thermal expansion for steel is approximately 0.0000117 unit per unit per ° C (0.0000065 unit per unit per ° F). It would not be unusual for a steel disc being machined to 150 millimeter (6-inch) diameter to have its temperature increased during the machining work to 120° C (200° F) above standard temperature of 20° C (68° F). If measured while still hot with a gage calibrated for use at standard temperature, an error of about 0.21 millimeter (0.008 inch) would be measurable on the disc when cooled to standard temperature.

$120 \times 1.17 \times 10^{-5} \times 150 = 0.21$ mm
$(200 \times 6.5 \times 10^{-6} \times 6 = 0.0078$ in.)

Aluminum, for which the coefficient of expansion is approximately 0.0000216 unit per unit per ° C (0.000012 unit per unit per° F), would under the same conditions be expanded almost twice as much and upon cooling would show an error of more than 0.38 millimeter (0.014 inch).

$120 \times 21.6 \times 10^{-6} \times 150 = 0.389$ mm
$(200° \times 12 \times 10^{-6} \times 6 = 0.0144$ in.)

When using a steel measure or gage on a steel workpiece, little error would be caused if both were at the same temperature (dependent somewhat upon the gage design). However, in the case of the gage and the work being of different materials, such as a steel gage on an aluminum part, exact measurement can be made only when both are at standard temperature. For example, if the above aluminum disc and steel gage were both at only 20° C (36° F) above standard temperature, the error in measurement would be almost 0.03 millimeter or more than 0.001 inch.

$20 \times 21.6 \times 10^{-6} \times 150 = 0.0648$ mm
$20 \times 11.7 \times 10^{-6} \times 150 = 0.0351$ mm
$0.0648 - 0.0351 = 0.0297$ mm

$(36 \times 12 \times 10^{-6} \times 6 = 0.00259$ in.)
$(36 \times 6.5 \times 10^{-6} \times 6 = 0.00140$ in.)
$(0.00259 - 0.00140 = 0.00119$ in.)

Temperature also affects resistivity of material and changes flow of electric current. Therefore, eddy current results may be affected to the point that temperature readings should also be recorded when temperatures are different from normal. Non-uniform temperatures over a part being checked may also cause readings to vary in different locations when no difference in the tested attribute really exists.

For critical dimensions, particularly those of small size when the percent error will be large, care should be taken to see that the product being tested and any comparison standards are at the same temperature level.

Pressure Springs or Deforms Work and Equipment. For most dimensional measurement, some element of the measuring device must make contact with the work surfaces. The effect of the contact pressure depends on the strength and rigidity of both the work and the measuring tool and on the loads applied. Most measuring devices are constructed to use light pressures that only break through oil and dirt films on the surfaces, as contact is often only at a point or along a line until deformation causes sufficient bearing area to carry the applied load. It must be remembered that load can be carried only by a reaction of bending or deformation; consequently, light and repeatable contact pressures are a necessity to accurate dimensional measurement.

Human Element a Large Variable. One of the most difficult problems to deal with in inspection, as well as in all the other phases of manufacturing, is error caused by the human element. Inspection procedures making use of any of the human senses (sight, hearing, smell, taste, or touch) are subject to some variation with any individual and usually to large variation between individuals. Sight and touch in particular are frequently used as part of a measuring system. At any time great reliability is required, the procedure should be designed to minimize the effects of the human element.

BASIS FOR MEASUREMENT

Measurement of various attributes may be either comparative or absolute. In many cases knowledge of the value of a dimension or other quality is unimportant, and interest is focused on measurement of the difference from some standard.

Many kinds of gaging apparatus are designed to show only the nearness or farness of a measurement from a predetermined standard.

Other gaging equipment sets the limits within which a dimension must fall to be acceptable and also does not assign any real value to the measurement.

A third type of measurement provides knowledge regarding the real or absolute value of a measurement by comparing the measurement with a known standard.

Comparison with Standards May Be Converted to Absolute. The differential measurements described in the preceding paragraphs can be converted to absolute values by addition or subtraction of the reading with the standard if its absolute value is known. All absolute measurements use zero as a reference point.

Metric and English Measuring Systems. Two measuring systems are commonly used throughout the world. These are the metric and the English systems, with the metric being more widespread but the English being more important to manufacturing in the United States until the current time. The metric system is universally used in most scientific applications but, for manufacturing in the United States, has been limited to a few specialities, mostly items that are related in some way to products manufactured abroad.

The Metric System Soon to Be Worldwide. England is currently in the middle of an official change from the old system to a metric system similar to that used in most of the world. The United States is not as far along in a similar change to the international system of units, which is a simplified form of the metric system, but there is little doubt the change will continue and accelerate.

United States Changeover Beginning. Some primary schools in the United States are introducing the new system to students. A few factories have already changed to metric units, and others are studying the problems, both functional and economic, connected with the change. There are some incompatibilities to be ironed out, and there are bound to be difficulties for those familiar with the English system becoming comfortable with a replacement.

New System to Be Simpler to Use. The international system of units (SI) simplifies calculations because of the multiple of ten relationship. Although some measurements will eventually be performed completely with the new units, some will require a long period for the change, and all during the transition will require conversion at times. This text has been written with dual units to help with familiarization of the relationship, but an attempt has been made to emphasize the new system to encourage its use. As an aid to conversion, some tables showing the relationships between the two systems are available in the appendix.

Length Standard Definitions. Length measurement standards are essential in order that units of measure have any meaning. All length measurements are related to the standard meter, which at one time was the distance between two marks on gold buttons placed on a platinum-irridium bar stored in Paris, France. Since the year 1960, a standard meter has been defined as being 1,650,763.73 wavelengths of light emitted from krypton-86. In 1866, the Congress of the United States defined a legal yard as being 3600/3937 of the length of a meter. From this definition, 1 inch turns out to be slightly more than 25.4 millimeters. More recently, the inch has been defined as exactly 25.4 millimeters. The meter and the inch are therefore primary measurement standards to which all length measurements are related.

Length Measurement Standardized by Gage Blocks. The use of uniform length measurement throughout the country is made possible by the use of secondary standards in the form of gage blocks that are used in three ways. Master gage blocks, the most accurate obtainable (guaranteed to be accurate within ±0.000002 inch per inch of length), are used only for checking other gage block sets so that their accuracy may be retained. Other sets of gage blocks, which may be of less original accuracy, are used as references and inspection blocks for the manufacture, calibration, and setting of various measuring devices. A third use applies blocks directly to precision measuring work in shop operations. The more gage blocks are used, the more important it becomes that they be frequently checked against other blocks to detect inaccuracies from wear and abuse.

Various Size and Quality Sets. Gage blocks may be obtained in sets containing as few as five to more than one hundred individual blocks. They are used by selecting blocks of such size as needed and wrung together to make up a desired dimension. Wringing in this case implies the use of a twisting sliding motion between the blocks that places their extremely flat and smooth faces so close together that they adhere to each other and can be built up to larger dimensions without inaccuracy caused by added space between the contacts.

Special Gages and Masters for Production Control. A tertiary measuring standard is used in manufacturing in the form of gages and measuring devices designed for specific purposes, and in the form of master work parts that can be used for comparative measurements.

INSPECTION EQUIPMENT

The equipment to be described in this section is primarily for dimensional measurement. It employs some type of comparison, with the principal difference being in the degree of reference to an absolute standard. The steel rule, for example, has a built-in reference to zero. A dial indicator has no built-in reference and is used mostly for differential measurements, but it can be used for absolute measurement by establishing proper reference. The spring caliper may be used as a gage to establish a dimensional limit, or it can be used to transfer a dimension from a work surface to some measuring device. Measuring tools may be classified as direct-reading devices, comparators, or limit gages.

Direct-reading devices provide the widest range of measurement of any of the measuring tools but are slower to use than the other types. In general, they

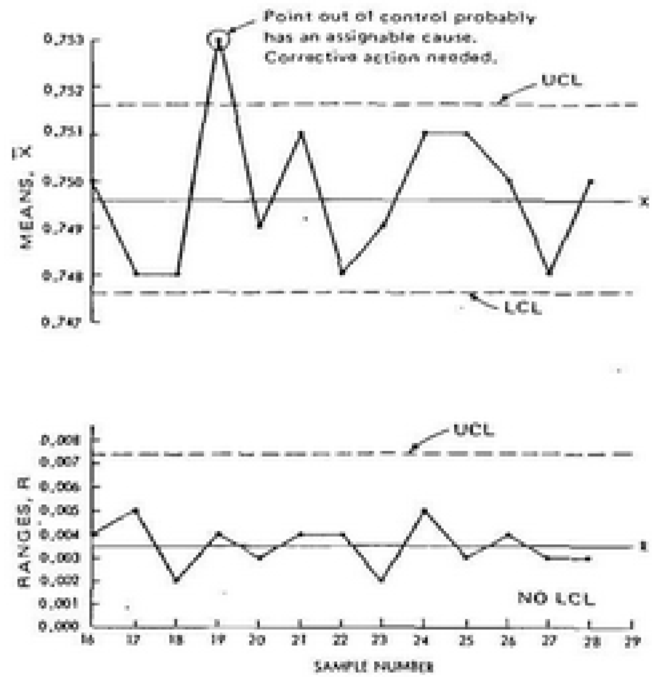

Figure 4
Quality control process chart

determining the overall quality of a product. The data can be useful for matching mating part dimensions with a minimum of waste. Understanding of the statistical variation in a product usually will permit wider tolerance use. Although all the points within the control limits on the mean chart could be in these positions by chance variation, a gradual shift toward one or the other limit can often be interpreted as a trend caused by an assignable reason. For example, gradual tool wear in a cutting operation would cause the average mean value to change gradually.

Process Improved by Identification of Causes. Frequently, the use of process control charts will cause improvement in the processes on which they are used by pointing out possibly correctable variation causes. Analysis of the process itself and correction of faults as they are found will produce gradual improvement in the process history and tend to tighten down on the control limits as they are recalculated. The presence of regularly kept charts in the process area tends to have a rather large psychological effect on the operators. Frequently they do a better job merely because the chart is before them. The data that are collected for construction of the control chart are, of course, useful also for inspection acceptance, and often provide more information than would be available from data collected for inspection alone.

PRINCIPLES OF MEASUREMENT

This section of inspection is concerned primarily with dimensions, shapes, finishes, dimensional tolerances, and the dimensional relationships, together with geometric relationships existing between surfaces. Any quality desired in a manufactured product may require inspection to assure its meeting specifications. In the manufacture of hard goods, the greatest amount of inspection time is spent checking those qualities mentioned in this paragraph. Some important properties such as hardness and strength, together with their testing procedures, have been discussed in earlier chapters.

DIMENSIONAL REFERENCES

Use of Common Reference Points Valuable. When dimensional measurements are being made, a reference point and a measured point always exist. In the case of single dimensions, it usually makes no difference which is which, except in those cases in which one surface is more rigid or more easily accessible and will serve better as a reference point. When a number of dimensions originate from the same point or can be measured from a common point, that point should be used as a reference point. All measurements should be made from it to reduce the possibilities of accumulation of error. When a series of dimensions are measured, each dependent upon the previous one, the total possible error is the accumulation of all the individual errors. But if, as shown in Figure 17-5, each measurement is made to a common reference point, the maximum total error can be only twc individual errors for any of the dimensions measured

In those cases where the only practical dimensioning method requires a sequential group of measurements, it is good practice to leave the least importan dimension off the drawing and thereby eliminate th argument as to whether the overall dimension o

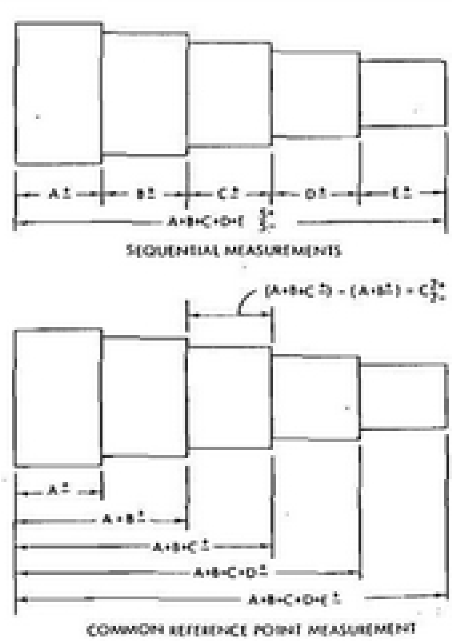

Figure 5
Accumulation of dimensional error

require greater skill from the user and are therefore more subject to human error.

Steel Rules for Relatively Rough Measurement. Among the most common of the direct-reading inspection devices are steel rules and their variations. Steel rules are made in all sizes, from ones a fraction of an inch long that must be held in special holders, up to those several feet in length. They may be calibrated in different ways, depending on the use for which they were intended, and sometimes are calibrated with four different scales on the same rule. Most common for use in the United States are calibrations showing 1/64, 1/32, 1/16, and 1/8 inch, although in some applications, divisions in hundredths are of value. Steel rules showing combinations of English and metric units or all metric units are also available.

Good quality steel rules are machine divided with the calibration marks accurately placed, but ordinarily cannot be expected to be used with accuracies closer than about ±0.5 millimeter or ±1/64 inch.

Variations of the Steel Rule for Improved Accuracy. The steel rule has a number of variations, including the hooked rule that can be held over a corner, caliper rules that have a fixed and a sliding jaw to permit setting and easier reading, and depth rules that can reach into recesses. Some of these rules are shown in Figure -8.

Vernier Caliper and Height Gage Similar. Vernier calipers are variations of the steel rule that can be

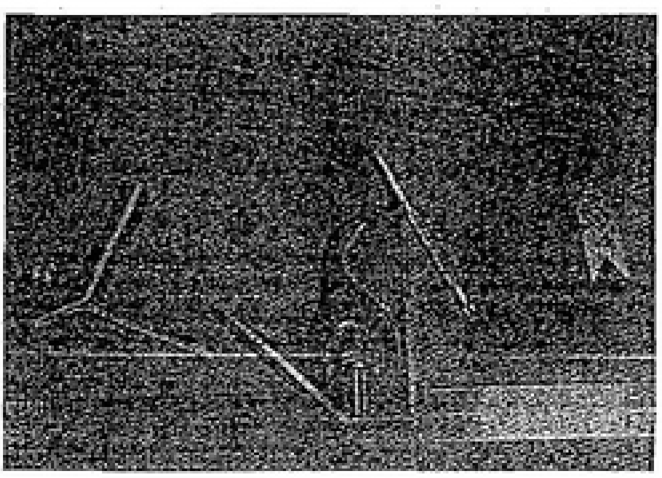

Figure -8
Steel rules

read to thousandths of an inch by use of a vernier scale built as part of the instrument. The height gage is similar to the vernier caliper with the exception that it is mounted on a base to hold it in a position suitable for vertical measurement.

Vernier Scales Are All Similar in Principle. Both instruments are calibrated as shown in the insert of Figure 9, with the main scale divided into inches and subdivided into 1/10 and 1/40 (0.025) inch. The vernier scale, which slides along adjacent to the main scale, has twenty-five divisions in the length equal to twenty-four divisions of the main scale and furnishes the witness line for reading a measurement. Each division on the vernier scale is 0.001 inch shorter than the similar divisions on the main scale, so that for each 0.001 inch of movement between the two, a different line on the vernier scale will line up with one of the marks on the main scale. A measurement reading is accomplished by first reading the full inches, adding tenths of an inch exposed before the zero of the vernier scale, adding 0.025 inch for each exposed subdivision, and finally adding the number indicated by the mark on the vernier that is in closest alignment with one of the marks on the main scale.

MICROMETER CALIPER

Micrometer Nomenclature. The micrometer caliper, or "mike," shown in Figure -10 is one of the most common measuring instruments used in the manufacturing field. For a precision tool, its construction is relatively simple. A U-shaped frame supports a hardened steel button called an *anvil* on the inside of one end and a *sleeve, barrel* or *hub* containing a threaded nut on the opposite end. The threaded nut supports threads on a spindle that extends through the sleeve and frame so that its flat end can be paired with the anvil to serve as the measuring element. The opposite end of the spindle is

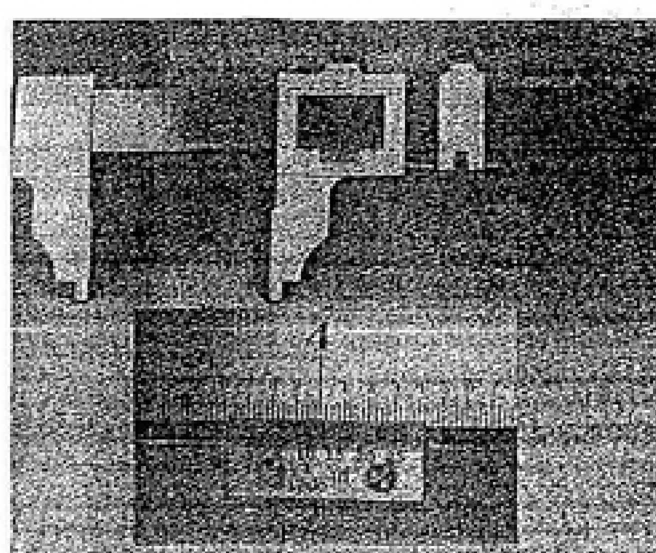

Figure 9
Vernier caliper

attached to a tubular *thimble* that rides over the outside of the sleeve so that when the thimble is turned, the spindle thread rotates in the fixed nut and structed with accurately ground round buttons either 5 or 10 inches apart. The bar can be positioned with an angular position to match a workpiece. The difference in button heights from the base plane, divided by five for the 5-inch bar and by ten for the 10-inch bar, provides a number that is the sine of the angle of the bar's position in relation to the base. Accurate measurement of the button height is frequently performed by use of gage blocks.

INDICATING GAGES AND COMPARATORS

A second type of inspection device is the indicating gage or comparator, which is used for showing deviation from a dimension. By relating the reading to a suitable reference, these gages can provide absolute measure values. These devices require more skill than the direct-reading instruments for setup. Once set up, they may be used faster, easier, and frequently with greater accuracy than the direct type. Many also have the advantage of being combinable for multiple measurements and thus provide even greater time-savings. Most do, however, have a narrow measuring range for any single setup.

Most indicating gages and comparators are quite sensitive, with high amplification characteristics that may be provided by mechanical, electrical, pneumatic, or optical systems. They are used for comparing with known dimensions and with master workpieces and for checking parallelism, concentricity, and general conformance to shape.

Dial Indicators Have Many Applications. The majority of mechanical-type comparators are of th dial indicator style shown in Figure -12. These are constructed with a spindle that operates a rack gear in contact with a system of gears which turn the indicating hand over a calibrated dial. The use of light return springs to keep backlash from contributing error and of high quality bearing supports provide sensitivity permitting the indicator to be read accurately to within 1/10,000 inch. The majority of dial indicators are calibrated in thousandths of inches, but many, particularly in the larger diameters where the calibration marks can be better separated, are calibrated in 1/10,000 inch. The majority of dial indicators operate over ranges from about 1/16 to 1/8 inch, but some long range types have been designed to cover as much as 1 inch. These are constructed with an additional hand to count the multiple revolutions of the main indicating hand.

The majority of dial indicators are used for measuring dimension differences without regard to absolute values. Many special-purpose structures have been designed for supporting dial indicators for different kinds of uses. Some are special attachments designed to permit contact to be made with a surface difficult to reach. Some support a dial indicator in such a way that it may be used for work that would ordinarily be done with a fixed gage. Others hold the indicator so that it can be adjusted over a table where it can be used for making accurate comparison measurement.

No Joint Losses in Reed Mechanisms. The *reed* mechanism shown in Figure -13 is another method for amplifying small motions. One make of comparator gage uses this type of mechanism to move a small mirror. A light beam reflected by this mirror to a calibrated scale is in effect a weightless lever that increases the amplification of motion and provides extremely high sensitivity and response, permitting accurate readings in the range of 0.25 micron (1/100,000 inch).

Electrical Gages Permit Close Measurement. Electrical power is used for operation of both compara-

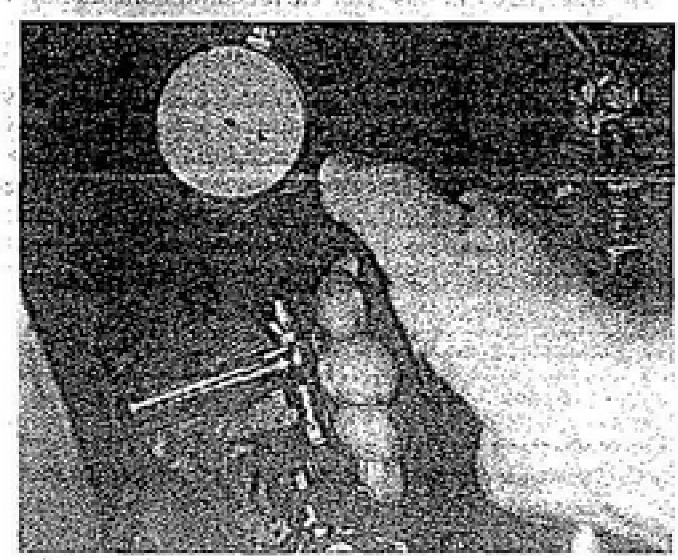

Figure -12
Dial indicator type of snap gage

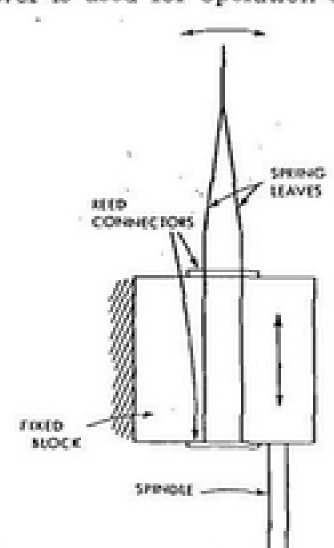

Figure -13
Reed mechanism for movement application

causes the distance between the spindle and the anvil to decrease or increase.

Reading Is a Systematic Procedure. The threads of micrometers are the real measuring elements and are precision made, usually being ground in hardened materials. Forty threads per inch cause the thread lead to be 1/40, or 0.025 inch. A witness line along the side of the micrometer sleeve is divided into ten numbered divisions, each representing four full turns of the micrometer thread, a distance of 0.100 inch. Each 1/10-inch division is subdivided into four smaller divisions, each representing one full turn, or 0.025 inch. The bevel of the micrometer thimble is divided into twenty-five equal spaces to enable the user to read fractional turns with the accuracy permitted by 0.001-inch calibration.

Vernier Use Requires Careful Setting. Some micrometers also carry a vernier calibration consisting of ten marked spaces on the sleeve of the micrometer in a space equal to nine 0.001-inch divisions on the thimble. The principle of the vernier is the same as that on the vernier caliper and, with proper use, allows the micrometer to be read accurately to the nearest 0.0001 inch. Vernier micrometers calibrated to this accuracy are not too commonly used, however, because variations in temperature, pressure, and the human element frequently cause errors large enough to make this kind of accuracy impractical.

Frame Sizes Varied to Cover Large Range. Most micrometer heads are substantially the same in design and cover a 1-inch range. To permit wide range measurement, the heads are fitted to frames different in size by 1-inch increments. The tool is in common enough use in small sizes that the 1-, 2- and 3-inch micrometers (maximum limits) are usually personal tools of machine operators and mechanics.

Large Mikes Difficult to Use. Larger sizes, usually up to 24 inches, although larger than this have been built, are normally supplied from a company tool crib when their use is required. The larger sizes are naturally more difficult to position on work and to adjust with the correct "feel." Thus, frequently, some other device will be used when long dimensions must be accurately measured.

Mikes are rugged tools and can stand some abuse but should be accorded the careful treatment due a precision instrument. With relative ease, they can be used for measuring to accuracies of 0.001 inch; in the case of vernier mikes, they approach 0.0001 inch if proper consideration is given to temperature and pressure effects.

Other Applications. In addition to the outside micrometer described, the same principles are applied in the making of inside micrometers and depth micrometers for measurements and of various types of positioning screws for accurate locating-type applications. A bench-type *supermicrometer* is sometimes

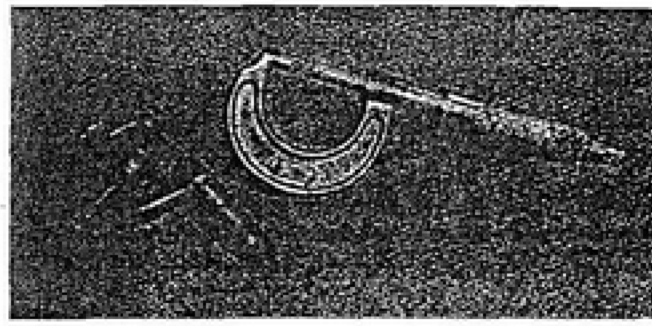

Figure 10
Micrometer

used in laboratories and tool rooms for accurate length measurements. This instrument also uses a screw thread for measurement but is constructed with a heavy frame consisting of a steel bar more than 3.5 inches in diameter, and incorporating spring loading on the workpiece so that very accurate measuring or contact pressure can be duplicated. The design eliminates practically all effects of the human element.

OTHER ADJUSTABLE TOOLS

Some commonly used adjustable inspection tools can be set to be used as limit gages but are more commonly used as dimension transfer devices. Inside calipers have turned-out legs to make contact with inside shoulders and holes. Outside calipers have turned-in legs for checking across the outside of shoulders or diameters of bar material. Hermaphrodite calipers, consisting of an inside caliper leg combined with a pointed divider leg, are primarily layout tools rather than measuring devices. Telescoping gages are made up of sleeves that can be locked in position to carry an inside dimension such as a hole diameter to a measuring device such as a micrometer.

Sine Bars or Tables for Accurate Angle Measurement. Angles may be measured in a number of ways, but one of the more precise methods used primarily in the laboratory and tool room is by use of a *sine bar*, illustrated in Figure 11. Sine bars are con-

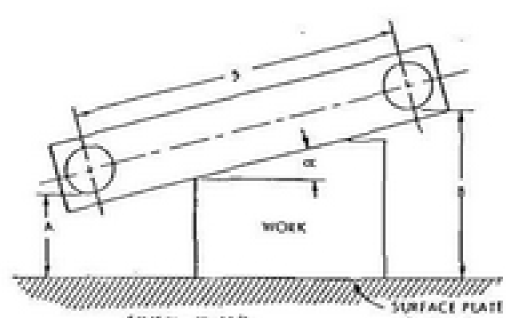

Figure 11
Sine bar

tor-type gages and limit gages. In the comparator type, movement of the work contact point of the gage from its zero or set position produces unbalance in the electrical system that causes current flow which can be read on a meter calibrated as finely as 0.025 micron (1/1,000,000 inch).

The electrical limit type of gage operates by the action of extremely sensitive switches that may be preset to definite dimensions. The switches may then be connected to operate signal lights, buzzers, or controls of gates in high speed sorting operations.

Pneumatic Gages Allow Noncontact Measurement. Air gages for making comparative dimensional measurements are of two types. In the pressure type, a pressure sensing element indicates a dimensional value on a calibrated scale as a result of back pressure built up from restriction of air flow through the gaging head. In the flow type, an indicator button floats on a column of air in a tapered glass tube, as air at constant pressure flows through a flexible tube and out orifices in the gage head. The gages are usually set with master workpieces or with limit gages that determine the limiting acceptance points.

Air gages are made with different degrees of amplification and sensitivity. Although they are used primarily as limit gages, a strong indication of absolute value is provided by the position of the indicator. Because air gage heads have some clearance with the surfaces they are designed to measure, their life is quite long. They are especially satisfactory for measuring materials that have abrasive characteristics or for use around abrasive processes such as grinding, honing, and lapping.

Optical Comparators Provide Enlarged View of Work. Optical comparators are designed to show a reflected surface picture, or a profile image, of a workpiece on a frosted glass screen. This is accomplished by casting light against the surface of the specimen and projecting its reflection through a magnifying lens system onto a mirror, which in turn reflects the image to the glass screen, or by passing light past the edge of the work to show its silhouette or contour (Figure -14). Most comparators permit lens changing to vary the magnification from 10 power to 100 power.

The enlarged image on the screen can be measured, observed visually for defects, or compared with enlarged drawings, frequently complete with limiting outlines, for inspection purposes. The equipment is especially useful for inspection of small, complicated shapes that would be difficult to examine carefully or measure by other means. Multiple dimensions and complex shapes can be quickly checked with this device.

Optical Flats Used for Flatness or Length Measurement. Another method of optical inspection involves the use of optical flats. These are flat, clear discs, usually made of fused quartz, constructed with the two sides as parallel as possible. The principle upon which use of the optical flat is based is interferometry, a word used to indicate light wave interference to produce identifiable light and dark bands, as illustrated in Figure -15. Light waves from a monochromatic (single wavelength) light source are transmitted through the optical flat, which is set at a slight angle on the work surface. Part of the light will be reflected from the lower surface of the optical flat. Another part will pass this surface and continue on to be reflected from the work surface to rejoin the first part as both are reflected toward the observer's eye.

Depending on the distances each set of waves travel, some will be in phase and reinforce each other to form bright lines, while others will be out of phase, will interfere, and will cancel each other to produce

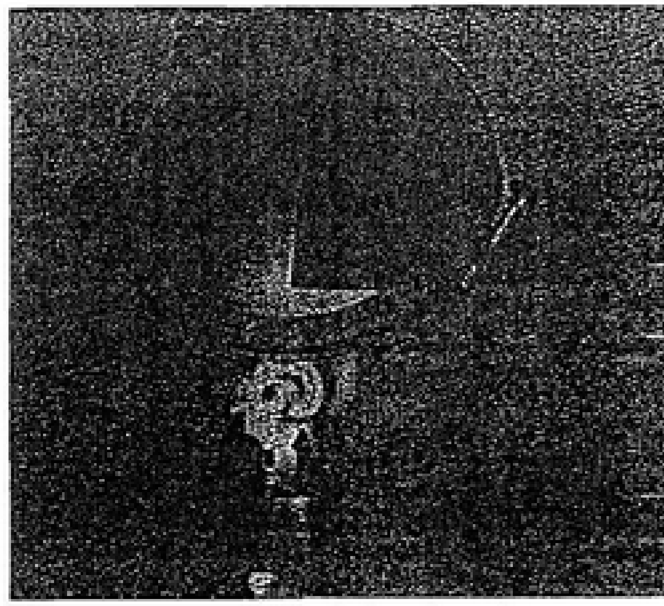

Figure -14
Optical comparator projecting a magnified view of the work silhouette on a ground glass screen. Suitable for dimensional measurement as well as for checking shapes and relationships

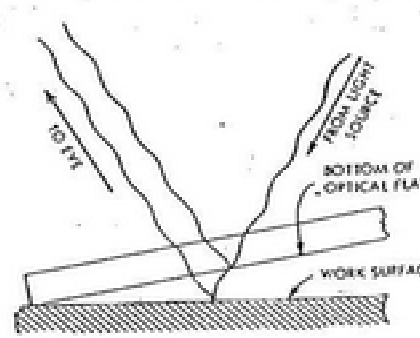

Figure -15
Light wave interference

dark bands or "fringes." Interference to form dark fringes will occur as the thickness of the air wedge between the optical flat and the work surface varies by one-half wavelengths. The frequency of bands will therefore depend upon the angle of the flat and the wavelengths of the light being used.

Optical flats may be used for checking flatness of surfaces because any deviation of the work surface being checked from the lower surface of the optical flat results in a pattern of fringe bands. The shape and spacing of the bands can be used to calculate accurately the degree of difference between the surfaces. Optical flats can also be used for making measurements as illustrated in Figure 7-16. In this case, 1-inch working gage block A is being compared with 1-inch master block B. Observation of the fringe bands of block A in the top view shows three complete bands indicating that if a monochromatic light source with a one-half wavelength of 11.6 microinches (0.0000116 inch) is being used, the optical flat is 3 x 11.6 or 34.8 microinches higher on one edge than on the other. By simple proportions, it can then be calculated that block A is shorter than block B by 3 x 34.8 or 104.4 microinches, and the height of block A is 1.000000 − 0.000104 or 0.999896 inch.

FIXED GAGES

A third type of inspection tool is the fixed gage,

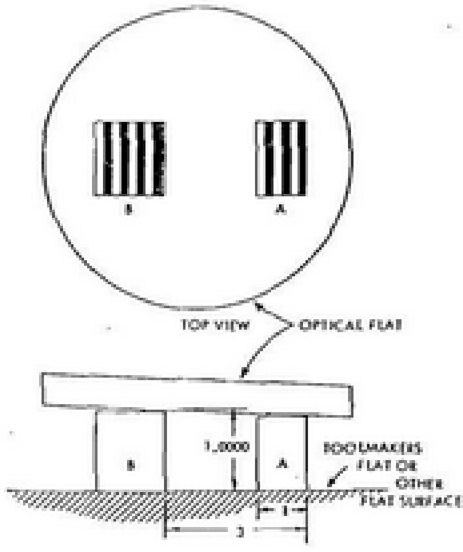

Figure -16
Work measurement with an optical flat

which is set to a limit of a dimension to establish a maximum or minimum value or to both limits to enclose the tolerance range. This type of gage measures attributes only and provides very little information regarding absolute measurement. Fixed gages are fast to use and require little skill to produce satisfactory results; consequently they are frequently used as production gages.

Most Are Special Production Gages. Most fixed gages are single-purpose tools, useful only for the dimension for which they have been set, although some of the standard types are adjustable and can be changed for other dimensions within a limited range. Fixed gages may be designed to check dimensions, shapes, relationships, or, in some cases, combinations of these qualtities.

Pictured in Figure -17 are some typical fixed gages. Some, such as the plug gages and ring gages, are *go-not go* gages that are made with the two tolerance limits. Others, such as profile gages, are a negative shape of the part to be checked and may or may not be made to both tolerance limits, depending mainly on the importance of the shape and size. Progressive gages, such as a sequential series of increasing diameter plugs, come close to providing an absolute measure by dividing the overall tolerance into a number of smaller increments, thus tying the dimension down to a small range.

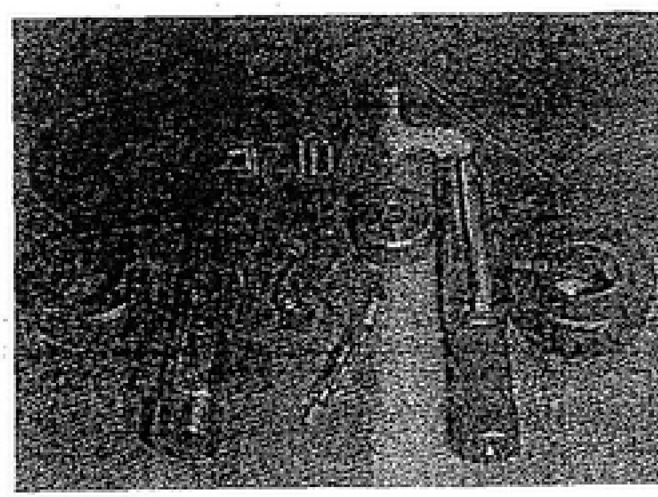

Figure -17
Fixed gages

Fixed Gage Tolerances Reduce Working Range. Gages, like any other manufactured articles, must be made to tolerances permitting some dimensional variation. These tolerances, naturally, must be smaller than the tolerances for the manufactured part on which the gage is to be used, and are usually held to between 10% and 20% of the part tolerance.

Gages must also be designed with some wear allowance so that they will not accept bad parts after a short period of use. The wear allowance used is variable, depending on the conditions of gage use, the precision of the product being inspected, and the gage life desired. In large operations, it is common for two sets of gages to be used. One set, called *working gages*, is made to the above tolerances and is used by the machine operators to check the product as it is being manufactured. The other set, *inspection gages*, are made to approximately one-half this tolerance, to reduce the chance of rejecting good parts.

Where many gages of the same type are used, master gages are sometimes constructed with tolerances 10% of the working gage tolerance for checking the gages themselves.

SURFACE FINISH

In addition to conformance to a general geometric pattern, many applications require that a surface have high quality finish.

Surface Variations of Different Frequency and Type. Three kinds of irregularities may occur on a surface. The one most evident is *roughness*, a term used to describe surface irregularities that are relatively close together. Surface roughness is usually a result of machining or other processing procedure that produces finely spaced irregularities.

A second surface fault is *waviness*, which refers to irregularities of wider spacing than those termed *roughness*. Waviness may be the result of warping, deflection, or springing while the workpiece is being worked upon, or the result of a tool movement pattern while the workpiece is being cut.

The third fault is an irregularlity called a flaw or imperfection, which is relatively infrequent and usually randomly located. Flaws consist of such things as scratches, holes, ridges, and cracks.

Surface Quality May Affect Function. The quality of some surfaces can play an important part in their function. Both flat and rotating bearing surfaces must usually be relatively smooth to function properly and often have their maximum roughness quality specified on their drawings.

Surface Marks Affect Fatigue Strength. Materials that are likely to be highly stressed in service, particularly by repeated or reversed load applications, may need good quality surface finish to reduce chances for fatigue failure. Any surface irregularity or discontinuity may be a point of stress concentration that can serve as a source of fatigue failure. As a precaution, the highly polished wing surfaces for high performance aircraft are frequently covered with a plastic coating for protection against nicks and scratches during manufacture because any marks on the surface might be a source of wing failure during flight.

Appearance Important to Saleability. The effect of surface finish on appearance alone should not be discounted. It is often the case that appearance is the only factor available for making a decision as to whether or not to purchase a product. It should be noted, however, that finish quality and light reflective ability are not necessarily synonymous. A newly finished clean surface with small, regularly spaced tool marks, particularly those made in a grinding process, will reflect light to produce a polished appearance. A random pattern of even smaller tool marks, such as might be made in a superfinishing operation, will not reflect light as well but will measure better, although appearing to be of lower quality finish.

Finish and Dimensions Closely Related. A close relationship exists between surface finish and linear measurement. Most measuring procedures involve the use of tools or instruments that physically contact the work surface and touch only on the high spots or peaks. A bearing surface might lose these peaks very quickly in use, and the large change of dimension that would occur with a rough surface would cause the original measurement to be meaningless. Good surface finish is certainly called for whenever close tolerances are required.

SURFACE FINISH MEASUREMENT

The roughness of a surface is made up of two qualities — the height and depth of irregularities, and the spacing between these. Most measurement methods take both into consideration to some degree without actually defining their relationship.

Lay — the Direction of the Principal Marks or Scratches. Most surfaces also will show different roughness measurements and characteristics in different directions. Measurements across the *lay* will in general be much higher than those with the lay. Lay is the direction of the predominant surface pattern. For example, a measurement across the lay on a piece turned in a lathe would be taken parallel to the workpiece axis.

Surface Comparison by a Variety of Methods. Some surface quality measurements depend upon comparison with standard samples displaying measured and known roughness. Visual comparison is sometimes satisfactory but often may not be too accurate because of the effect of dirt, corrosion, and irregularity of pattern on appearance. Accuracy of the comparison can be considerably improved by scraping a fingernail across the surfaces, adding a sense of feel. A visual method of comparing optical projection through a plastic film that has been pressed against the surfaces is also available. A film softened by solvent takes on the surface irregularities and by its refraction effect on the projected light rays causes a third-dimension effect on the screen, making accurate comparisons possible.

Electrical Instruments Most Common. The majority of accurate surface quality measurements are made with instruments that trace the work surface with a stylus, which in traveling over the hills and valleys disturbs an electrical circuit to make a reading possible. With some instruments, a pen is actuated to draw a magnified profile of the surface on a moving tape, in addition to a meter reading showing the average value of the surface traced. Other instruments show only the meter reading.

SURFACE SPECIFICATION

The specification of surface quality is indicated on the drawing, as shown in Figure -18. A 60° check mark is usually placed on the surface to which it refers, although in some cases, it may be located on a witness line, or an arrow may be used to indicate the surface. A number representing the maximum permissible roughness is located inside the V of the check mark. On the right side of the check mark is the lay symbol indicating the direction in which measurement should be made and the width of the maximum permissible roughness. Waviness is shown above a horizontal crossbar on the check mark.

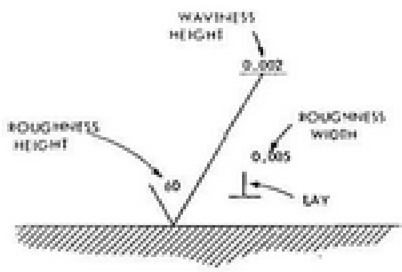

Figure 18
Drafting symbol for surface quality

On the drawing should be a note indicating whether the roughness value is total height, average height, or average deviation from the mean, either arithmetical or root mean square (RMS). It is most common to show only maximum value figures, although lower limits also may be indicated whenever they are of value.

Following are the lay symbols used to indicate a direction of measurement for which the figures in the specification apply:

- = — Parallel to the boundary line of the nominal surface
- ⊥ — Perpendicular to the boundary line of the nominal surface
- *X* — Angular in both directions to the boundary line of the nominal surface
- *M* — Multidirectional
- *C* — Approximately circular relative to the center
- *R* — Approximately radial relative to the center of the nominal surface