Fundamentals of Surface Finish and Geometry Measurement

by D.J. Sisemore

Preface
Surface Roughness, Form and Geometry Measurement

Introduction

Why measure SFG? Why is it more critical now than 10 years ago? Operating clearances have become smaller in order for products to be more efficient, i.e., automobiles, refrigerators, freezers, A/C's, and electric motors, just to name a few.

Smaller clearances between moving components means smaller manufacturing tolerances. We have gone from .01" to .001" to .00001" in an historically very short period of time. At .01" the surface roughness had little effect on the moving components, but at .001" and smaller, it has a significant effect. As a matter of fact, all of the energy transfer between moving components occurs within .001" of the surface profile.

Wear characteristics, lubrication retention, noise, and vibration are some of the functions that can be controlled through SFG measurement. Process capability and control can also be derived from proper use of the data collected from SFG. How efficient is the grinder wheel? How often does it need to be dressed? Is the speed and feed correct? Is the correct coolant being used? Is the machine tool in good condition (rotational and linear axis deteriorate with usage)? These are just some of the types of functions that can be controlled through SFG.

The purpose of this handbook is to explain SFG in practical terms that the person in the machine shop can understand and apply. This includes the machine operator, the quality control inspector, the maintenance person and the supervisor. The intent is to use language that explains difficult subjects in simple terminology.

My thanks go out to some special people who have had a profound effect on my career in the world of SFG. Bill Drews, whom I consider to be the most knowledgeable person in the field in the U.S. today; Werner Weniger, who spent many long hours teaching me what must have seemed so basic and trivial to such a brilliant engineer; and Peter Ackroyd, who has most recently been a confidant, advisor and friend, who supported me in so many ways in writing this handbook.

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I. Introduction

Surface finish and geometry should be measured for two reasons:

1. To ensure correct product performance
2. To control the manufacturing process

The second reason is very often not utilized because the manufacturer does not understand the interrelationship between finish, geometry and the manufacturing process. The result is that processes usually are not operating at maximum efficiency and very often components are being *over*processed. Overprocessing can be very expensive in terms of manufacturing costs and end product cost to the consumer. This can cause a company to be less competitive, and in today's international market, that could be disastrous.

Control of the surface finish and geometry also ensures that the final product performs as originally intended by the design engineer. If the surface is doing work (i.e., transferring energy) by a rotational movement for instance, then several things must be controlled.

Generally, some sort of lubrication retention must be obtained on the surface, therefore, deep valleys in the finish are desired. At the same time a large plateau of surface peaks is desired to support the loading of forces.

In order to produce this type of surface, several surface finish parameters should be measured. They should ideally contain a minimum of one amplitude, one spacing and one hybrid parameter. For instance, Rz, Sm and Tp. (These are explained later.)

Efficiency of energy transfer (ease of doing the work) and product performance such as vibration, noise, heat build-up, etc., are very much effected by surface geometry. All manufacturing surfaces contain manufacturing flaws of out-of-round, taper, squareness, eccentricity, coaxial and cylindrical errors.

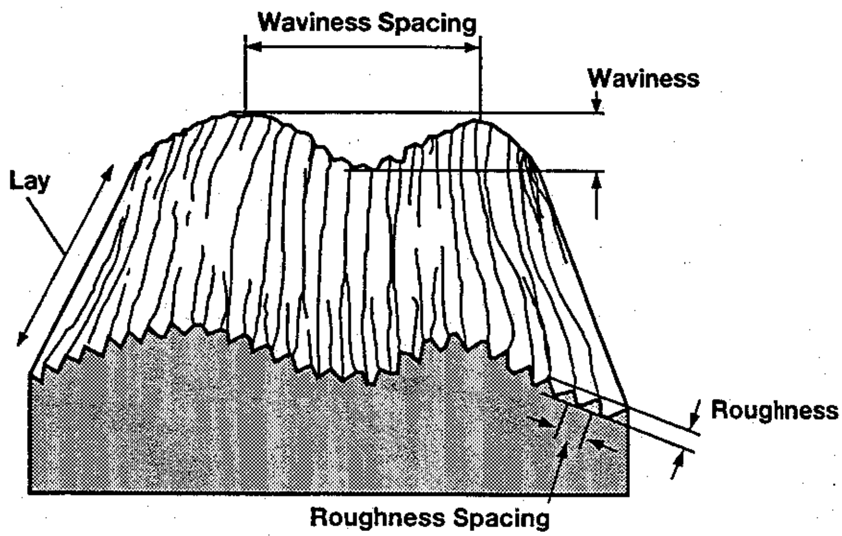
Such things as bearing surfaces on crankshafts, camshafts, pistons, engine blocks, transmission shafts, axle shafts, constant velocity joints, fuel injector systems and anti-skid brake systems are some automotive components in which control of geometry is absolutely critical.

At the same time, geometry measurement can tell us a great deal about the manufacturing process. For instance, measurement of out of roundness can tell us a lot about the condition of the rotating components in the machine doing the processing. It can pinpoint worn bearing surfaces and grinder wheel or feed mechanism vibrations. It can also tell us if we have optimized speeds and feeds, are using the correct coolant and if we are dressing a grinder wheel at the correct intervals. All of these obviously can be used to ensure the process is operating at maximum efficiency.

On the following pages the techniques used to measure the surface finish and geometry are discussed, along with an explanation of the associated parameters and terminology. The knowledge of how to interpret and apply the results to achieve optimum performance from the process and the manufactured component must be left to the manufacturer.

II. Surface Finish

Terminology



Fiqure 1

Form

Machine alignments such as parallelism between bedways and spindle axis or wear of bedways that can cause high and low places are examples of sources of form error that will be transferred onto the surface of the component being machined. There are many others.

Waviness

Vibration both in the machine tool and from external sources, are examples of sources of waviness error that are transferred onto the surface of the component being machined.

Roughness

The surface roughness is a direct result of the cutting action (tool mark) on the surface of the cutting tool. It can be the mirror image of the cutting surface, i.e., the tool surface or the grinder wheel grit pattern.

Waviness Spacing

The distance between the primary waviness peak pattern. Determined by the frequency of the source of the predominant vibration.

Roughness Spacing

The distance between the primary roughness peak pattern. For example, on a lathe, the roughness spacing is determined by the combination of the feedrate of the tool and the rotational speed of the part.

Lay

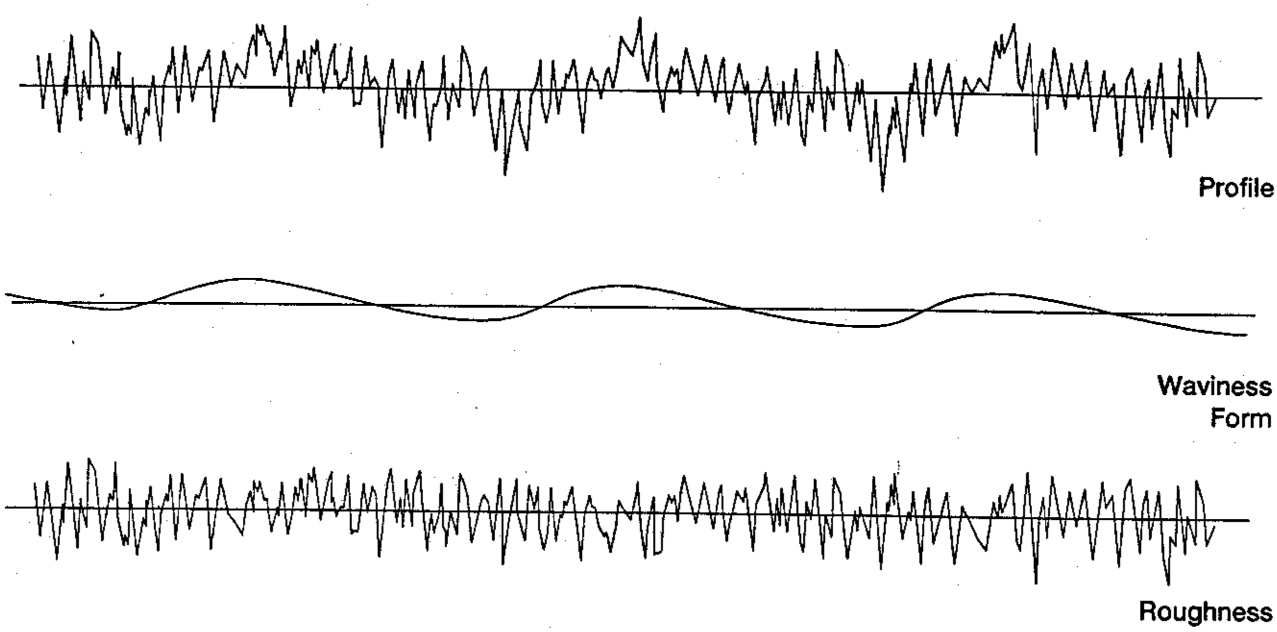
The direction of the roughness pattern on the surface.

Note: At this point, it is very important to understand clearly the following:

- A surface consists of form, waviness and roughness.
- Form and waviness are the result of imperfections in the manufacturing process and cannot be controlled by a specification on the print.
- Roughness can be completely controlled by specification and process adjustment. For example, on a lathe, the speed, feed and depth of cut can be adjusted to very accurately control the height and wavelength of the roughness component. On a grinder, speed, feed, grit size and composition of the grinding wheel can control the roughness component.
- Thus, parameters we see on prints like Ra, Rz, Rt, etc., are calculated from the roughness component of the surface.
- In order to do this, we have to separate the roughness from waviness and form.
- We use a cutoff filter to do this.

Filtering

The cutoff filter separates roughness from the rest of the surface so we can accurately calculate parameters.



Fiqure 2

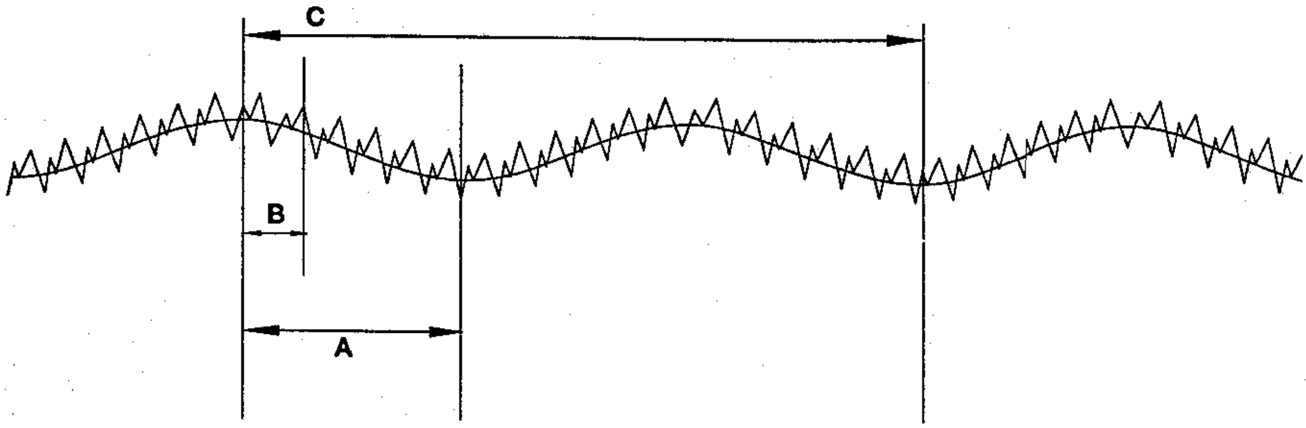
On surface roughness testers, there is a choice of cutoff filter values that can be selected (.003", .010", .030", .100", .300"). This is to allow the user to specify the correct cutoff value for the particular specification and process. Diamond turning to an Ra of $\sqrt[2]{}$ would require a different cutoff value than turning a part to an Ra of $\sqrt[64]{}$ on a turret lathe. Why?

Remember, the cutoff filter must separate the waviness (vibrations) from the roughness. The diamond turning machine may be set up to a feed of .0001,"
a speed of 24000 rpm, and a depth of cut of .00001". At these very high speeds, the resulting vibration will also tend to have high frequencies; therefore, the filter must be smaller in value to do its job properly.

On the other hand, the turret lathe may have a feed of 0.060 ips, a speed of 180 rpm, and a depth of cut of .020". Obviously, vibration in this process will have a much lower frequency, thus the filter value can be larger.

Actually, there are two rules that can indicate the correct filter value in most cases:
See Fig. 3

1. As we have discussed, the cutoff filter value must be small enough to remove waviness.



A = Correct – removes waviness, includes five toolmarks
B = Incorrect – includes only one toolmark
C = Incorrect – does not remove waviness

Fiqure 3

2. The cutoff filter value should be large enough to include at least five tool marks within one cutoff.

More On Filters

From the first surface roughness tester to today's models, the type of filter used for cutoff was what is called a 2CR analog filter. (It's an electrical circuit that that has capacitors and resistors.) It works well on normal surfaces (where peaks and valleys are similar in number and size). So generally, ground or turned surfaces work well. However, the 2CR has a couple of drawbacks that can be a problem:

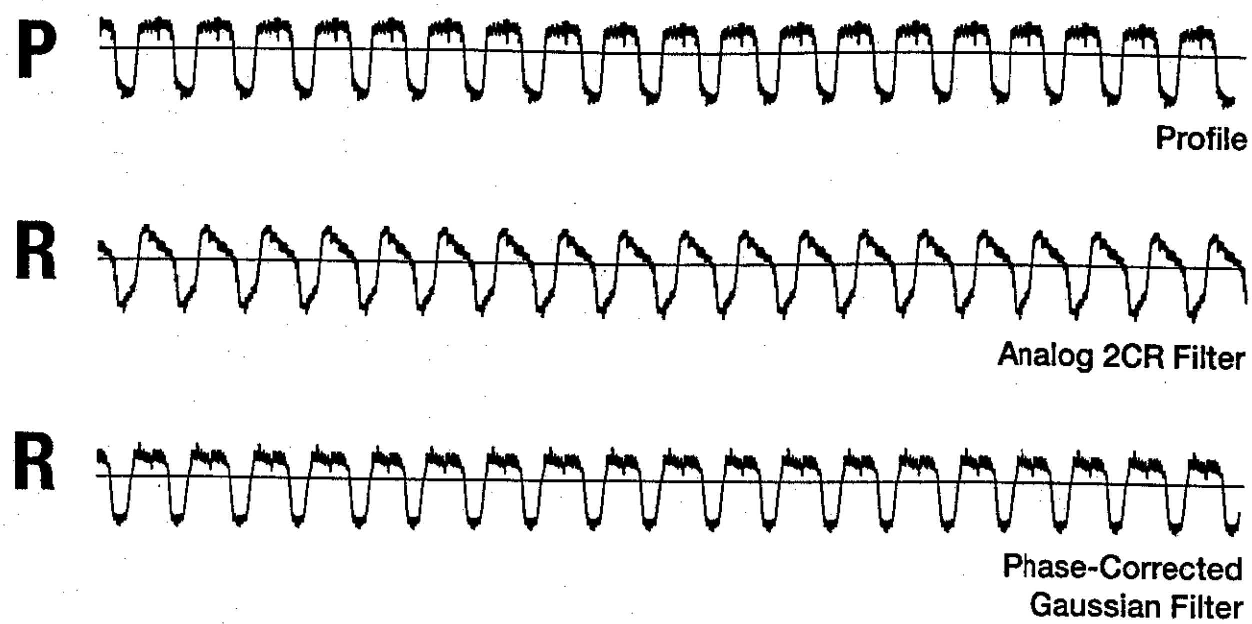
1. Transmission Characteristic.
   A 2CR filter has a 75% transmission, which in very basic terms means that some of the waviness that should be removed "leaks through" along with the roughness. This is not a big problem with Ra because the error is averaged in the calculation. It can be a problem with Rt, Rmax, Rp, etc., because these parameters are looking for a single high point and a single low point so waviness leaking through can have a bigger impact.
2. Phase Shift.
   The capacitors in a 2CR filter cause a phase shift in the data. This is not a problem on normal surfaces, but it can be a big problem on skewed surfaces (surfaces that have larger valleys than peaks). Skewed surfaces can be the result of the manufacturing process or the part material. See Fig. 4.

Example:

Plateau honed surface
Polished surface
Porous material

- nodular iron
- casting
- p/m material
- ceramic

Skewed surfaces look like this:



Fiqure 4, 5, 6

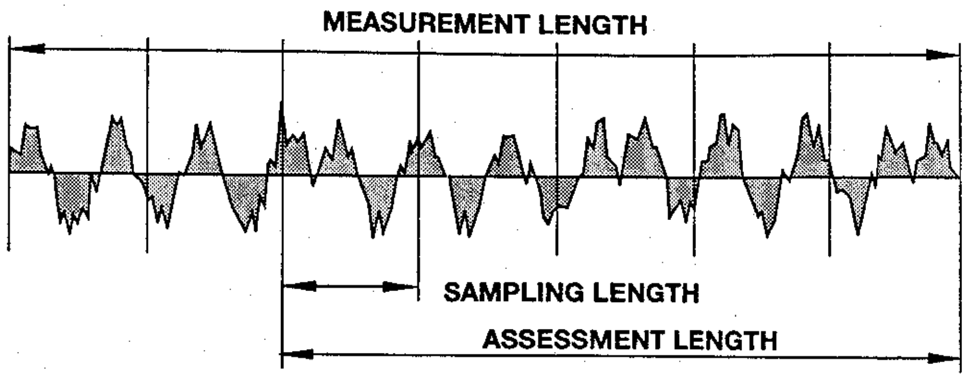
As can be seen, the 2CR filter has distorted the profile so that any calculation, especially Rt, Rmax, Rp, etc., will have significant error due to the filter.

Since the introduction of the microprocessor, a different kind of filter has been available: the phase-corrected Gaussian filter. It has none of the problems we experience with the 2CR filter. Since all instruments today use microprocessors, any new instrument should offer the choice of using the 2CR or the Gaussian filter so that any surface can be accurately evaluated.

Assessment Length

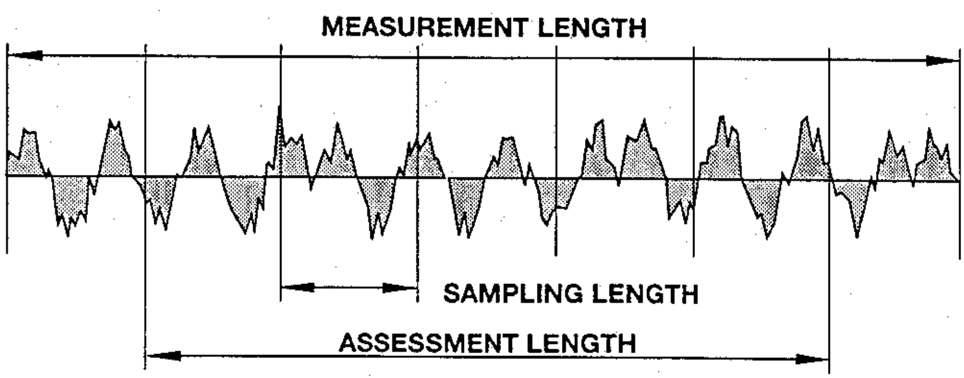
The assessment length is positioned differently by analog and digital filtering techniques. The examples below are typical:

Typical for an analog filter:



Fiqure 7a

Typical for a digital filter:



Fiqure 7b

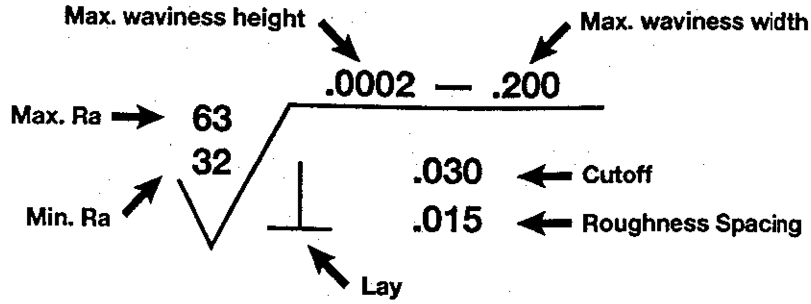
Some computer-controlled surface measuring instruments today are capable of computing a filtered surface roughness using as little as one 1/3 cutoff length.

Cutoffs

Cutoff* is the term used to describe the filtering technique. There are standard cutoffs which are predetermined lengths along the profile. These are established by U.S. and world-wide industrial standards. They currently are .003, .010, .030, .100, and .300 inch.

ANSI Y 14.36M - 1978

Symbols for Specifications and Drawings



Fiqure 8

In the current ANSI B46.1 standard the cutoff, lay and roughness parameter (Ra) are understood by default if not specified by the surface finish symbol.

**Note: Cutoff, cutoff filter, cutoff length and sampling length are often used interchangeably.*

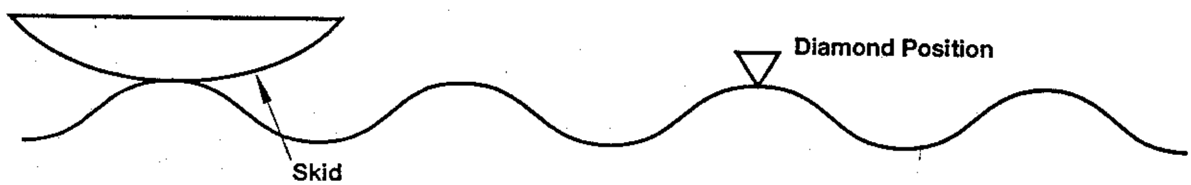
Lay

Primary direction of the machining of the surface to be measured.

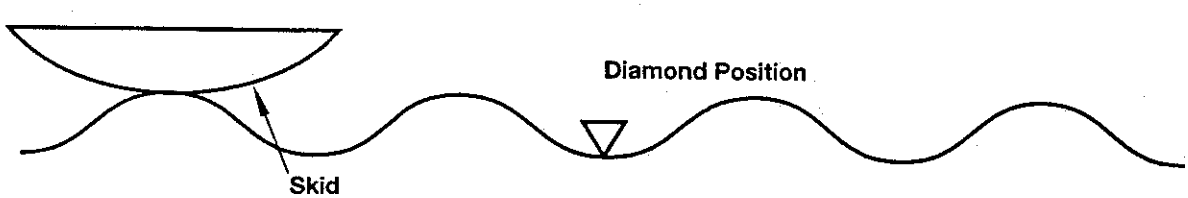
Skids

Used because of low cost to manufacture. A large radius skid is pulled over the measured surface. Its movement is computed as a straight line which becomes the datum and is used by the instrument to compute roughness.

The problem with this technique is that the waviness pattern causes the skid not to move in a straight line, thus creating error in the roughness calculation.



Fiqure 9a



Fiqure 9b

If the skid spacing is such as in Figure 9a, the waviness may have little effect on the roughness calculation. But if the spacing is as in Figure 9b, the amount of induced error in the roughness calculation can be significant.

Skidless

Skidless instruments are more expensive to manufacture than skidded, but they eliminate the waviness effect on the roughness calculation. They do this by using a precision mechanical datum in the traverse unit which is independent of surface conditions such as waviness.

Skidless instruments can also be used as excellent straightness measuring instruments.

Diamond Tip Radius

The U.S. standard ANSI B46.1 currently states that a 10um (.0004") tip radius be used on a diamond.

Most standards of the rest of the world use a 5um (.0002") tip radius.

Most surfaces can be measured with either size tip radius without significantly affecting the results. However, for correlation of results from multiple units, the same tip radius should be used.

Calibration

Old way — roughness patch
New way — step height

In the past, a roughness patch was used to calibrate the instrument. This technique is still used today; however, step height measurement is becoming a generally accepted technique.

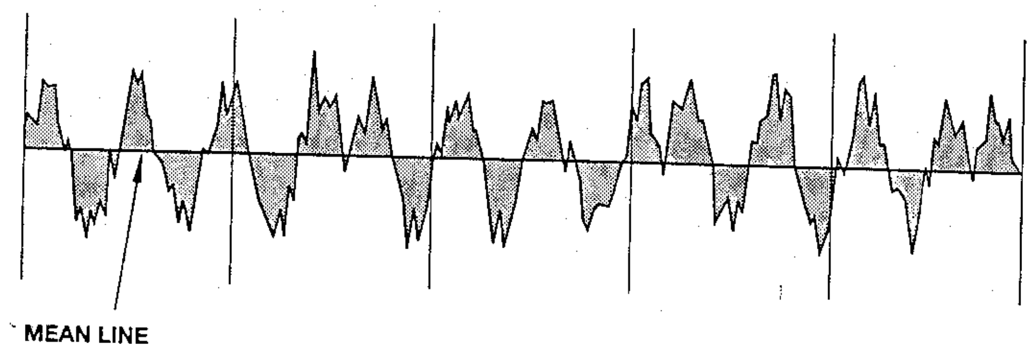
Stylus

The stylus wear patch tells the operator if the diamond tip is damaged or worn. Many calibration standards have both a calibration and stylus wear patch.

Linearity

Most electronics today are linear and calibration with a 120 microinch patch is good for measurements from 1 to 1000. Calibration at lower or higher Ra patches is not necessary.

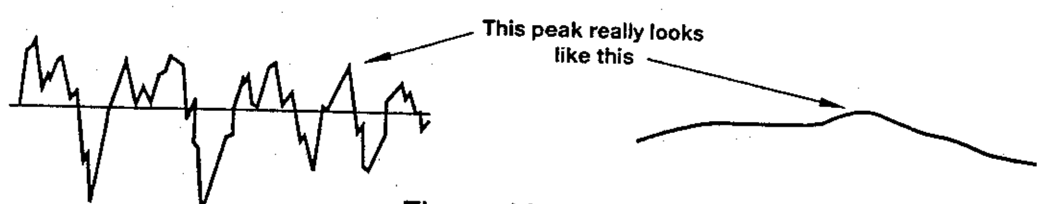
Mean Line



Fiqure 10

The mean line is constructed so that the area between the profile and the mean line is the same above and below the mean line.

Magnification



Fiqure 11

Vertical — high mag /Horizontal — low mag

Large vertical magnifications are used because we are generally most interested in the amplitudes of the peaks and valleys. The horizontal magnification is normally small in comparison to the vertical. This is primarily to keep the width of the displayed profile short in length so that it can be easily viewed.

Surface Finish Parameters

Parameters are simply different ways of evaluating the surface profile and providing a number which tells the operator the relationship of the profile to a given specification.

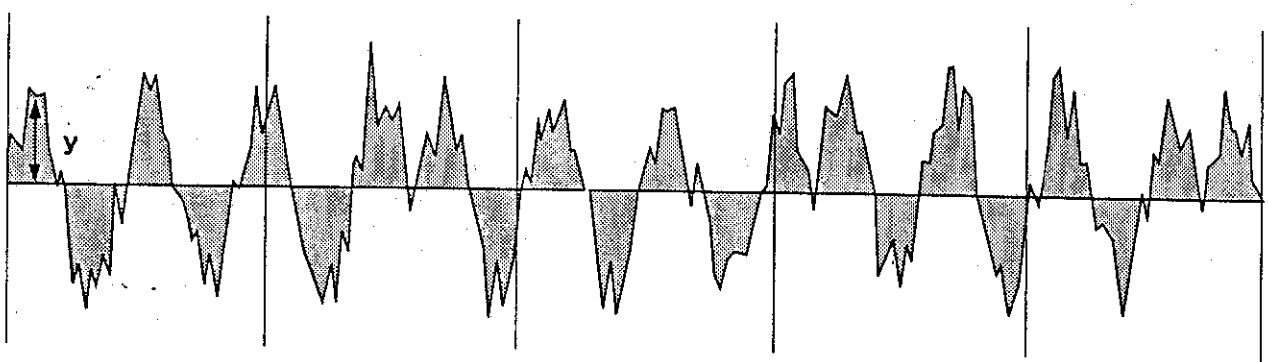
Example: The engineer specifies Ra = 64u inch, so the operator measures the Ra parameter of the surface to ensure that it is equal to or less than 64 millionths of an inch.

Roughness parameters are divided into three groups: amplitude, spacing, and hybrids (a combination of amplitude and spacing). Definition of the most commonly used follow.

Amplitude Parameters

Ra — roughness average (same as AA and CLA)
Rq — roughness root mean square (same as RMS)
Rp — roughness peak
Rpm — roughness peak mean
Rv — roughness valley
Rvm — roughness valley mean
Rt — roughness total
Rtm — roughness total mean (same as Rz (din))
Rmax — roughness max
Rz — ten point height
R_3z

Ra — roughness average



Fiqure 12

Ra is the arithmetic average of the distance of the roughness profile from the mean line.

Advantage: Statistically very stable and inexpensive to manufacture instruments to measure.

Disadvantage: Not good to use for process analysis.

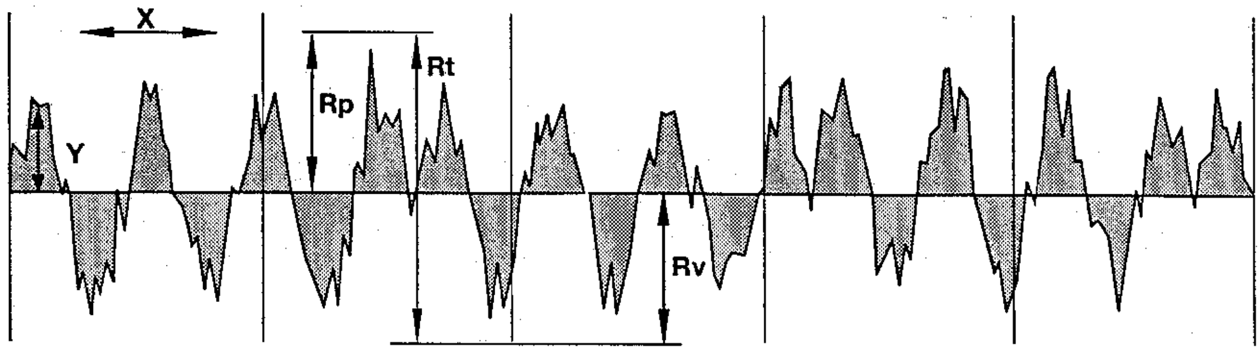
Rq — roughness root mean square

Rq is the root mean square of the distance of the roughness profile from its mean line.

This parameter squares the amplitudes and, therefore, is more sensitive to peaks and valleys.

Advantage: Statistically very stable.

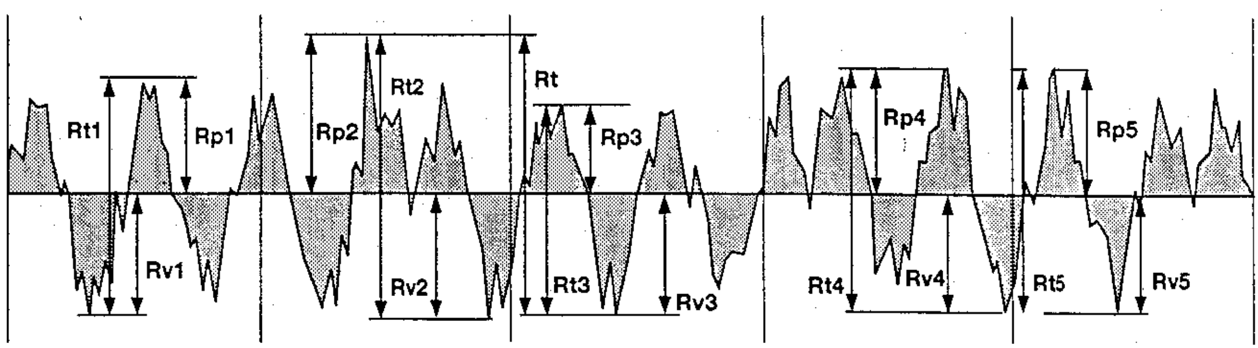
Rt, Rp, Rv



Fiqure 13

Rt — the highest peak to the lowest valley in the assessed length
Rp — the highest peak in the assessed length
Rv — the lowest valley in the assessed length

Rtm, Rpm, Rvm, Rmax



Fiqure 14

Rtm - Roughness Total Mean

$$Rtm = \frac{Rt_1 + Rt_2 + \text{——} Rt_5}{5} \text{ (same as Rz (din))}$$

Rpm - Roughness Peak Mean

$$Rpm = \frac{Rp_1 + Rp_2 + \text{——} Rp_5}{5}$$

Rvm - Roughness Valley Mean

$$Rvm = \frac{Rv_1 + Rv_2 + \text{——} Rv_5}{5}$$

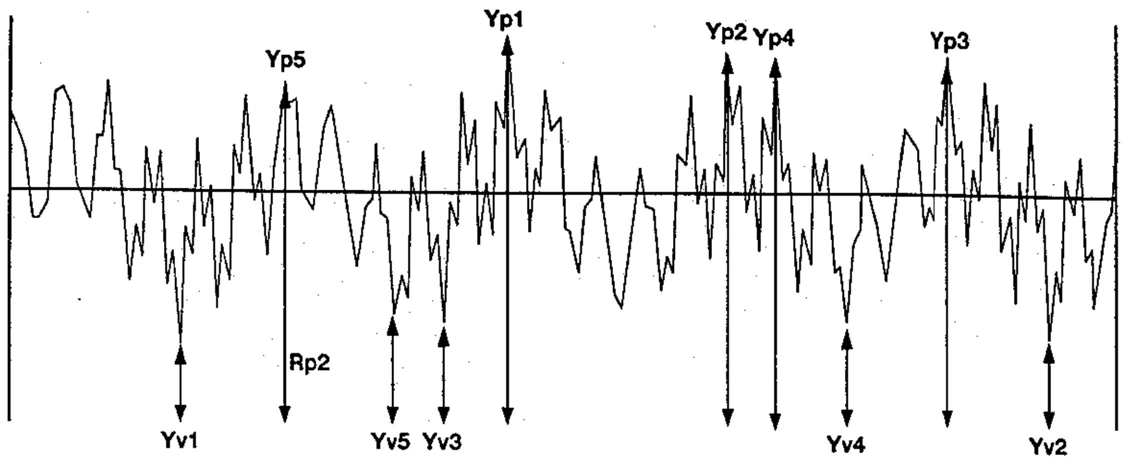
Rmax - Largest Rt of the five sample lengths Rt's.

Rz — 10 point height

Rz is measured using an unfiltered profile. It is numerically the average height difference between the five highest peaks and the five lowest valleys in the assessed length.

Reference Line, Parallel to Mean Line

$$Rz = \frac{(Yp_1 + Yp_2 + Yp_3 + Yp_4 + Yp_5) - (Yv_1 + Yv_2 + Yv_3 + Yv_4 + Yv_5)}{5}$$

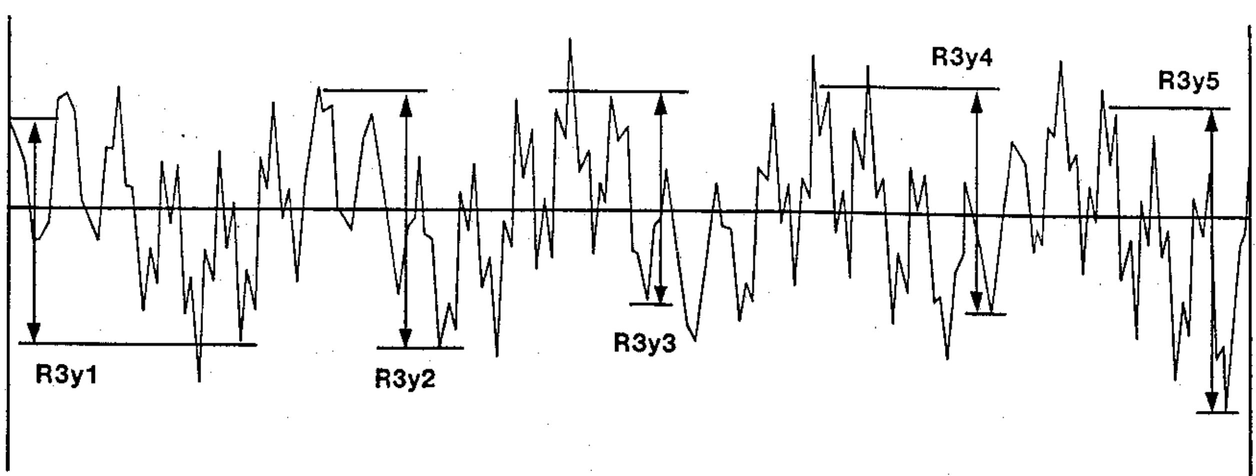


Fiqure 15

R_3z

R_3z ignores the largest and next-to-largest peak to valley in each cutoff and computes the third largest. This reduces the instability in the profile extremities.

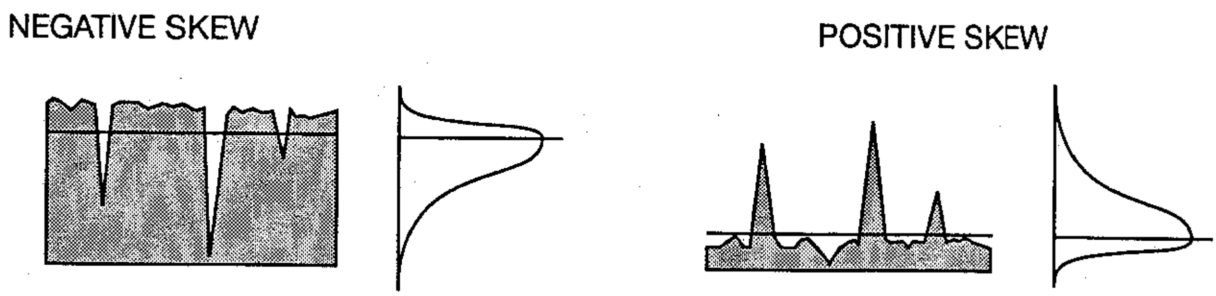
$$R_3z = \frac{R_3y + R_3yz + \text{------} R_3y_5}{5}$$



Fiqure 16

Rsk — Skew

Rsk is defined by the ADF.
Amplitude Distribution Function:



Fiqure 17

Numerous slice levels are taken through the profile from the highest peak to the deepest valley. The number of times the profile is crossed at each slice level is counted and plotted.

Rsk indicates the symmetry of the profile about the mean line of the ADF. A positive skew indicates a surface with a predominance of peaks and a negative skew indicates a surface with a predominance of valleys.

An example of how this parameter can be used would be in evaluating a bearing surface. A plateau of many short peaks and a few deep valleys is needed for a good bearing surface. This would be indicated by a negative Rsk.

A zero Rsk indicates an equal distribution of peaks and valleys.

Rku — Kurtosis

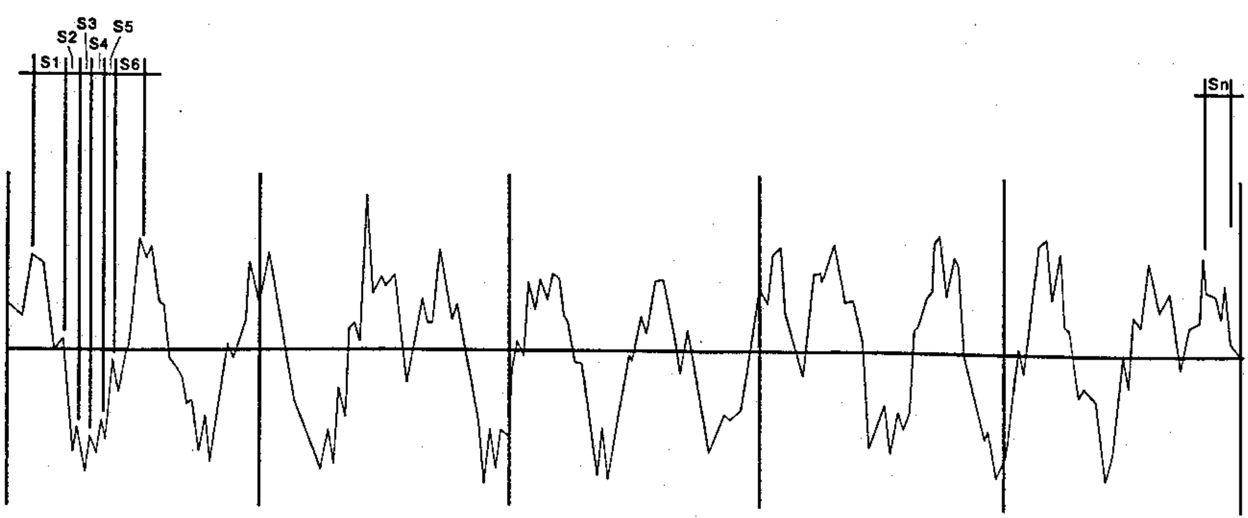
Kurtosis indicates the sharpness of the amplitude distribution curve.

S

The mean spacing between adjacent local peaks in the assessed length.

A local peak is the highest part of the profile measured between two adjacent peaks.

$$S = \frac{S_1 + S_2 + S_3 + \text{——} S_n}{n}$$



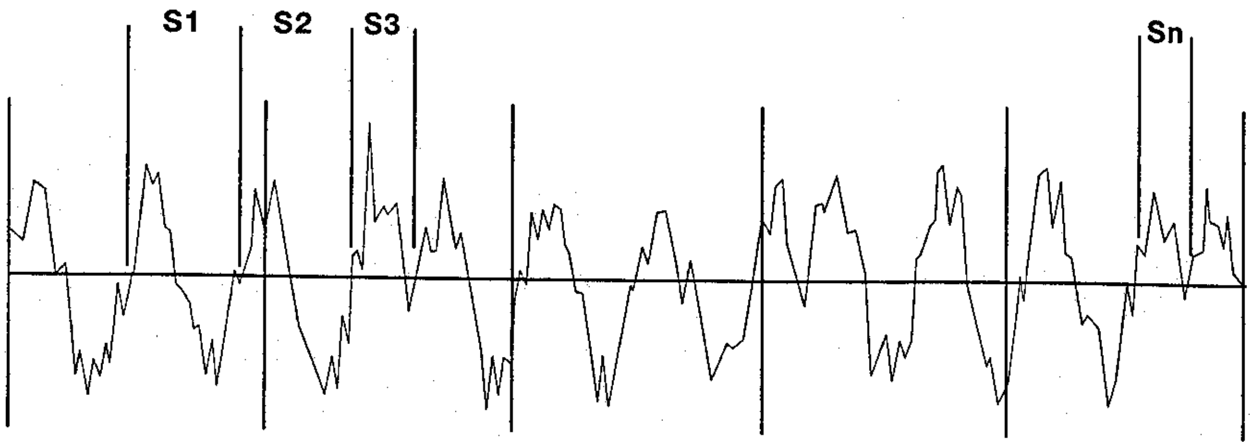
Fiqure 18

Sm

The mean spacing between profile peaks at the mean line in the assessed length.

A profile peak is the highest point of the profile between an upward and a downward profile crossing of the mean line.

$$Sm = \frac{S_1 + S_2 + S_3 + \text{——} S_n}{n}$$

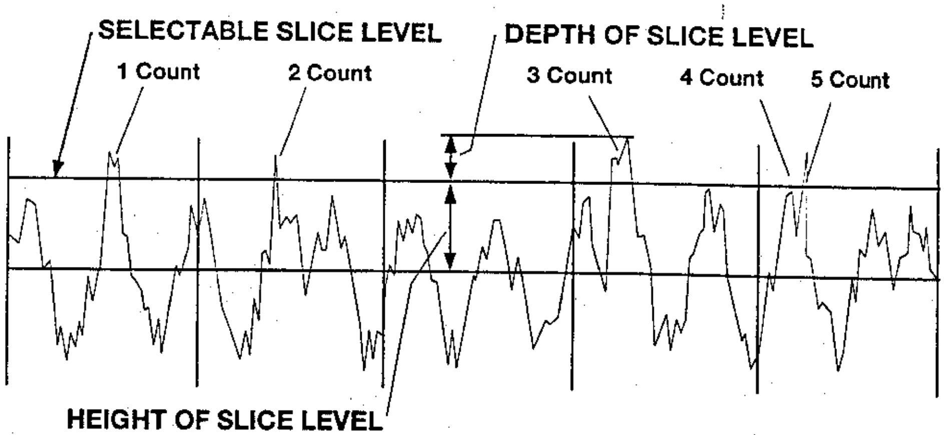


Fiqure 19

Hsc

High spot count is the number of complete profile peaks projecting above the mean line or a line parallel to the mean line.

The parallel line can be at a depth below the highest peak or at a distance above or below the mean line.

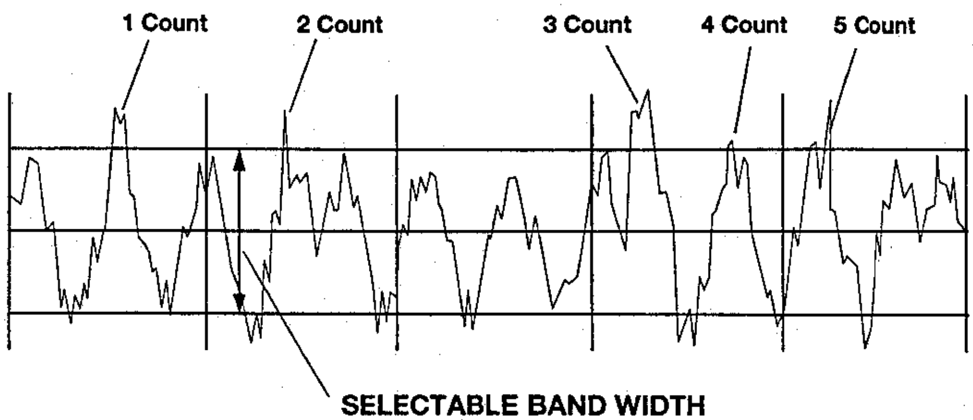


Fiqure 20

Pc

Peak count is the number of local peaks which project through a selectable band width centered on the mean line. To be counted, the local peak must be followed by a valley that projects through the band width. The count is determined over the assessed length and is expressed as peaks per inch.

$$Pc = \frac{\text{number of counts or peaks/inch}}{\text{assessed length}}$$



Fiqure 21

Hybrid Parameters

Tp% — bearing ratio

Rk — evaluates the material ratio curve

Parameters included in this evaluation:

Rk	Mr_1
Rpk	Mr_2
Rvk	

Tp%

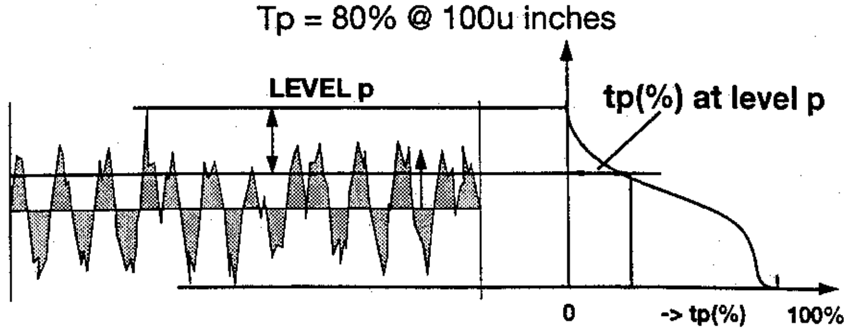
The material ratio curve (sometimes called the Abbott-Firestone Curve, or the bearing area curve) is a graphical representation of the Tp%. The height of this curve is the roughness total Rt and the width is the % of material at different profile amplitudes.

The Mrc is completed by taking numerous slice levels through the profile, starting at the top of the highest peak (0% material) to the bottom of the deepest valley (100% material). The sum of the length of the crossings are plotted on a graph, thus generating the Mrc.

The Tp% can be determined by setting a depth below the highest peak (P) and computing the % of material present in relation to the length of the measurement (see chart below), or the % of material can be specified and the depth (P) below the highest peak at which that % of material exists can be computed.

Usually the specification will look like the following example:

Tp = 80% @ 100u inches



Fiqure 22

Rk

This parameter is used to numerically evaluate the material ratio curve of surface that has been multiple processed. Multiple processing creates numerous peaks while leaving valleys from previous processes. Examples are finish grinding lapping, plateau honing or any surface with a negative skew (Rsk).

The main parameters used to describe this condition are:

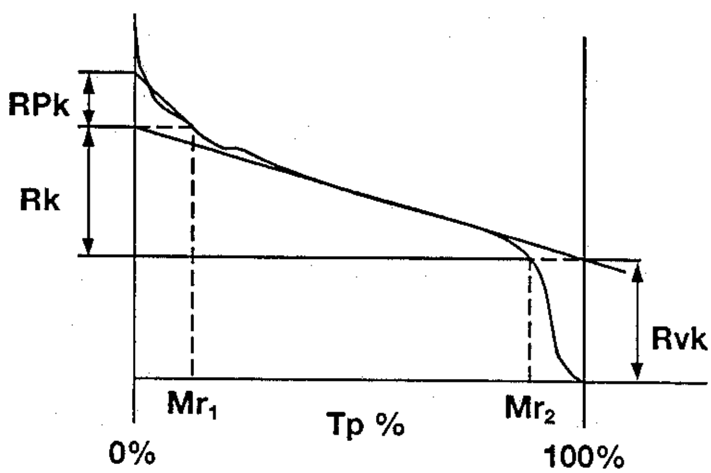
Rk — used to describe the portion of the surface that will support most of the loading on the surface.

Rpk — the portion of the surface that will wear off during initial loading.

Rvk — the portion of the surface which will retain most of the lubrication.

Mr_1 — the material ratio where Rpk and Rk connect (see graph below).

Mr_2 — the material ratio where Rk and Rvk connect (see graph below).



Fiqure 23

- Introduction
- Methods of measurement
- Reference circles
- Roundness specification
- Filters
- Undulations per revolution
- Center and tilt
- Eccentricity
- Concentricity
- Squareness
- Straightness
- Coaxiality
- Parallelism (taper)
- Cylindricity

Geometry Measurement

Geometry measurement is useful in order to be able to control dynamic properties of the manufactured component. It is also just as important in controlling the manufacturing process.

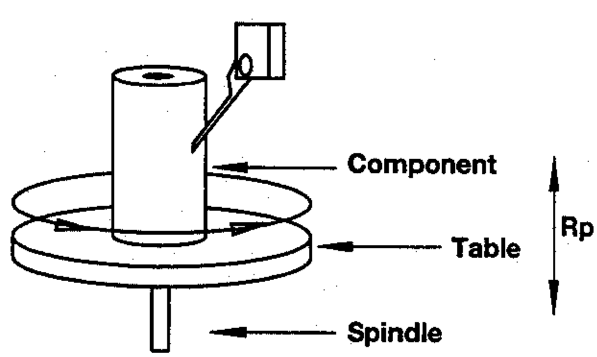
Roundness, eccentricity, concentricity, squareness and taper are very straightforward and seem to be well understood by most engineering and manufacturing persons. However, cylindricity seems to be a bit more difficult to grasp and, as a result, very often is not specified. Even when it is specified, it very often is not measured.

Let's start with basic roundness and finish with cylindricity.

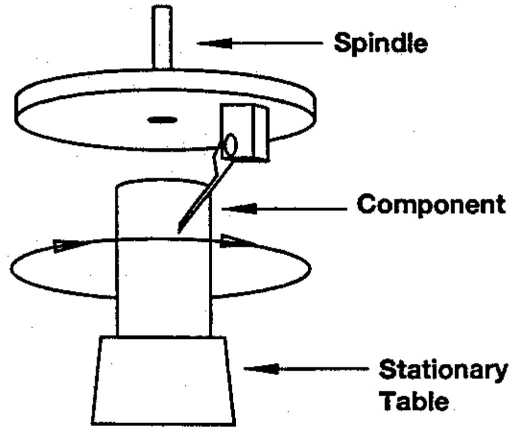
Roundness: Is the measurement of the change of radius. This can only be accomplished by measuring from the center to the diameter of the component. This means that vee block methods are not acceptable. Neither are machining centers because you would be measuring the centers as well as the component and therefore, adding another unknown source of error to the results. The component or the measuring gage must be rotated accurately. The more accurate the rotation, the more accurate the results.

Methods of Measurements: Two types of systems are used. First, rotate the component. An accurate spindle is used with the component's center the same as the spindle center as possible. See figure.

Fiqure 24



With the second method, the component remains stationary while the gage head is rotated about the diameter.



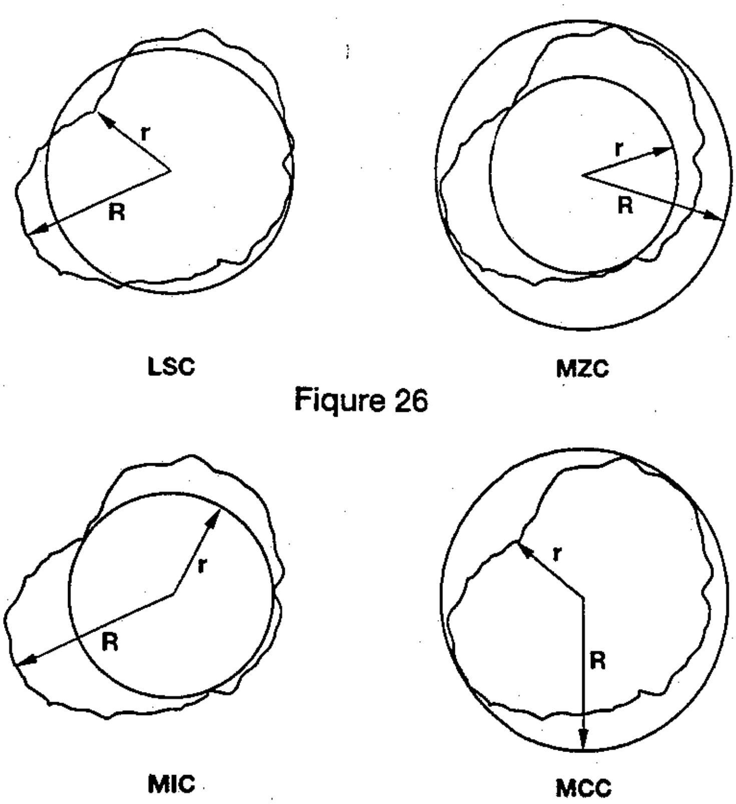
Fiqure 25

Reference Circle

The measure of out-of-roundness is essentially the difference between the largest radius and smallest radius from a given center of the data. In order to find a center we have to construct a reference circle that best represents the measured data. The ANSI B89.3.1 on roundness permits the use of four different methods of constructing the refernece circle.

LSC — least square circle
MZ (MZC/MRS) — minimum zone (min. radial zone and min. radial separation) circle.
MIC — maximum inscribed circle
MCC — minimum circumscribed circle

Examples of use:
- LSC — most commonly used
- MZC — ANSI B 89.3.1 preferred method
- MIC — measuring roundness of an I.D.
- MCC — measuring roundness of an O.D.



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Roundness

The roundness specification often used by engineers is as follows:

○	.0003	MZC	150	.031
Out of roundness	maximum out of roundness	reference datum circle	filter	ball tip radius

Fiqure 27

OOR = UPR = Lobing

Filters

Filters are used to separate the number of lobes exiting on a component's surface. This is done for one or more of the following reasons:

- Remove "noise" from the measurement. The noise often is a result of vibration which exists for a number of reasons. Vibrations in the machine tool, vibration of the cutting tool, vibration from another process close to the machine tool or vibration from the measurement instrument itself.

- To separate low frequency lobing from high frequency to simplify the measurement results evaluation.

- To separate different lobing frequency to evaluate the process.

Center and Tilt

Often referred to as center and level adjustment. In order to obtain the highest accuracy of roundness and geometry measurement, the component centerline must be centered over the spindle centerline and the two centerlines must be coaxial (parallel in two planes). This is accomplished by adjusting the table using centering and tilt mechanisms. The adjustments are usually done by manually rotating knobs on the side of the table, although some of the more sophisticated measuring systems today have motor-driven mechanisms controlled by a computer.

The computer-controlled automatic center/tilt is considered the most accurate because the computer and motor adjustments are more consistent than humans.

Many of the new measurement systems utilize a centering aid such as a bar graph. The table and part are rotated while taking a measurement and the results of off center and tilt are shown on a bar graph. The center/tilt mechanisms are adjusted until the bar graph goes to zero. This is much simpler and faster than the meter method.

There are two types of filters being used in surface finish, analog and digital.

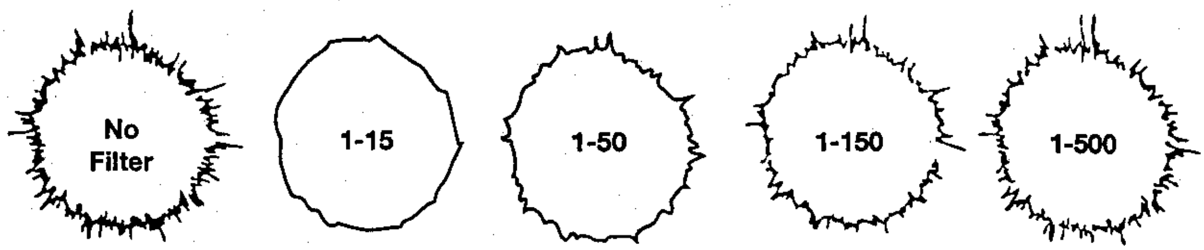
The analog type was developed before the use of computers in roundness measuring systems and is still available on most systems today. As with surface finish, the analog filter can introduce some error in the measurement because of its inability to follow rapid changes on the surface profile. The digital techniques generally eliminate this problem.

Undulations Per Revolution (UPR)

UPR is the number of surface profile deviations from a true circle in one revolution (360°).

The stylus tip acts as a mechanical filter and depending on the tip radius will eliminate some of the surface profile deviations from the measurement.

Electronic filters using different frequency response are also used to evaluate the surface profile. Typical filter responses used are 1-15, 1-50, 1-150 and 1-500. For example, 1-50 filter removes undulations above 50 per revolution from the measured profile.



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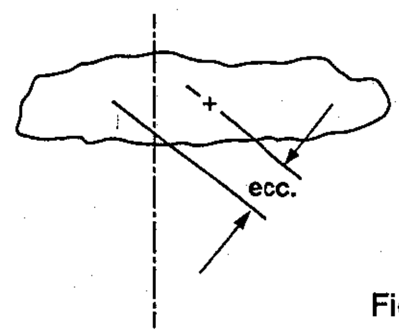
Without filtering, the high frequency UPR's can make evaluating the out of roundness difficult because they can conceal the lower frequencies. Often the low frequency UPR's are of larger amplitude and of greater importance to the manufacturer of the component.

Magnifications

The roundness variations we are generally concerned with are very small in ratio to the diameter of the component being measured. In order to be able to evaluate the roundness more accurately, large magnifications are used to magnify the variations but not the diameter.

Eccentricity

The distance between centers of two roundness measurements. The roundness measurements should be in at the same level for example, ID to OD.



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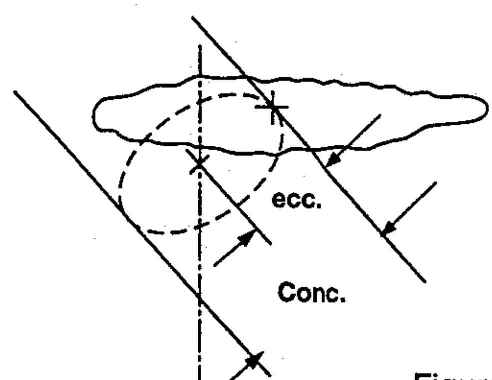
Concentricity

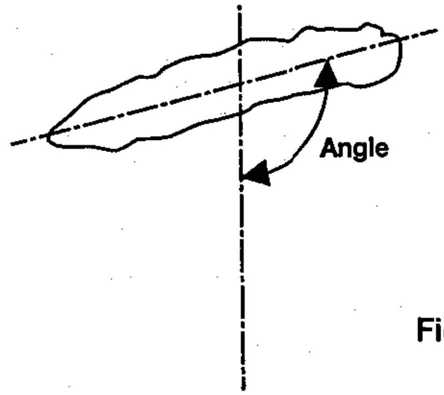
This is double the eccentricity. The roundness measurements should be at the same level.



Fiqure 30

Squareness

The amount in degrees of angle that a surface is not at right angle to an axis.



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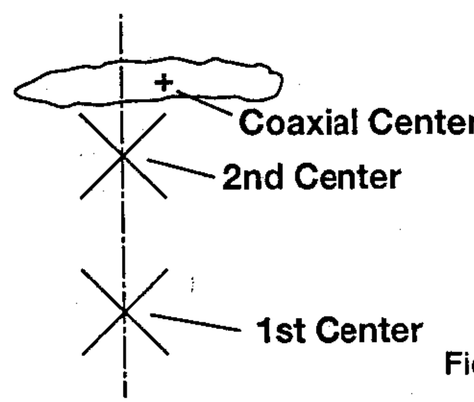
Straightness

The amount that a surface deviates from a straight line. The straight line generally is represented by a precision machined straightness datum such as vertical straightness column.

Fiqure 32

Coaxiality

This is the distance of the center of a roundness measurement to a datum axis. Generally, two roundness measurements at different levels are made and an axis is created using the two centers. Then another roundness is measured and the distance from its center to the created axis is coaxiality.



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Parallelism

The angular difference between two surfaces which could be a line or a plane. An example would be two round surfaces that are supposed to be in parallel planes. Another example would be opposite sides (180° apart) measured on a cylinder-shaped component.

Sometimes the callout on the engineering specification can be for taper or deviation from parallel.

Cylindricity

This is simply the difference between a measured cylinder and a mathematical cylinder. In measuring instruments, three things are required in order to mechanically represent a cylinder: rotational accuracy, straightness and parallelism. The better the mechanical accuracies of these three, the better the cylindricity measurement accuracy.

Generally the cylinder measurement is accomplished by making numerous roundness measurements on a cylindrical component and relating them all to common axis. This axis is usually created by making a roundness measurement at two levels and creating a datum axis

References

1. ASME/ANSI B46 *Classification and Designation of Surface Qualities,* American Society of Mechanical Engineers.

2. ASME/ANSI B89 *Dimensional Metrology*, American Society of Mechanical Engineers.

3. H. Dagnal MA; *Exploring Surface Finish*; Leicester, England; March 1980.

4. H. Dagnall MA; *Let's Talk Roundness*; Leicester, England, October 1976.

5. C. Dougherty; *Questions and Answers on the Measurement of Roundness and Surface Texture;* Leicester, England; July 1988.

6. William Drews and Werner Weniger; *Rediscovering the Abbott-Firestone Curve;* Des Plaines, IL; September 1989.

7. William Drews; *Measurement Update Seminar;* Des Plaines, IL; 1982 through 1991.

8. *Surface Roughness and Roundness Measurement Reference Guide;* Tokyo Seimitsu America, Inc.; April 1993.

9. *Surface Texture and Roundness Measurement; Sheffield Measurement;* Dayton, OH; 1989.

10. Werner Weniger; *Technical Papers on Surface Texture Analysis;* Des Plaines, IL 1988.

About the Author

Mr. Sisemore is a graduate of Tennessee Technological University with a B.S. degree in mechanical engineering. During the 1960's and 1970's he worked in engineering, manufacturing and quality control. In the early 1980's, he specialized in the area of precision surface metrology and continues to work in that field today. He serves on the ANSI B46.1 surface texture committee and is the Eastern U.S.A. Regional Manager for Mahr Corporation, Cinncincinnati, Ohio.

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