START TO FINISH

When an engineer includes a surface finish spec on a print, the intent is usually not just to make the part look good. Surface finish affects how a part will fit, wear, reflect light, transmit heat, distribute lubrication and accept coatings. The finish should be determined by the part's function: you want a surface that fulfills the engineering requirements of the application, without wasting time and effort on a higher quality finish than is necessary. (In fact, many applications do better with a certain amount of "texture," and too fine a finish can be as bad as too coarse.)

Thirty years ago, when most dimensional tolerances were measured in thousandths of an inch, the difference of a few millionths in surface finish was often irrelevant. Now that tolerances of "tenths" or even tens of millionths are commonplace, variations in surface finish represent a sizable percentage of the total error budget. Note the following example:

The maximum peak-to-valley height on a surface is usually four or five times greater than the average surface finish, as measured by the R_a method. A part with an R_a value of 16µ", therefore, probably has a peak-to-valley height of 64 µ" or greater. If you're trying to meet a dimensional spec of .0001", the 16µ" finish represents over half the allowable tolerance.

As shown in Figure 1, surface finish -- also known as profile -- is composed of two components: waviness and roughness. Waviness, or longer-wavelength variation, is caused by macro-type influences, like worn spindle bearings, or vibration from other equipment on the shop floor. Roughness -- the short-wavelength pattern of tool marks from grinding, milling or other machining processes -- is influenced by the condition and quality of the tooling. Both can be influenced by the operator's choice of feed rate and depth of cut.

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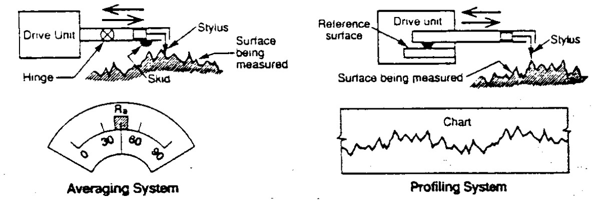


Although fingernail scratch-pads may provide a usable guide to finish, they can't meet the modern requirements of documentation and traceability. Hence the increasing importance of surface finish gages. As shown in Figure 2, there are two basic varieties: skid-type, or averaging systems, and skidless, or profiling systems. Skid gages have a hinged probe assembly, with the probe riding next to a relatively broad skid that also contacts the workpiece. The skid tends to filter out waviness, so the probe measures only short-wavelength variations. A skid gage has a dial or LCD readout to display the measurement as a single numerical value.

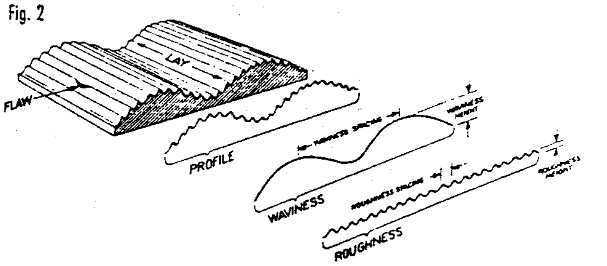
Skidless gages incorporate a smooth, flat internal surface as a reference, so the probe can respond to waviness as well as roughness. In order to allow separate analysis of long- and short-wavelength variations, profiling gages usually generate a chart (on paper or on a computer screen) rather than a single numerical result.

Every application reacts differently to different combinations of roughness and waviness, and industry has responded by creating more than 100 different formulae with which to calculate surface finish parameters from the same measurement data. Many of these are very application-specific, and most shops are able to confine their measurements to a half-dozen parameters or so. In almost all cases, measurements are presented in microinch or micron units.

R_a is the most widely used parameter, because it provides an arithmetic average of surface irregularities measured from a mean line that lies somewhere between the highest and lowest points on a given cut-off length. A slightly more sophisticated variant, R_q, uses a root mean square calculation to find geometric average roughness -- an averaged average, if you will. Both of these, however, tend to minimize the influence of surface anomalies like burrs or scratches. If such factors are critical to the application, R_{max}, R_y, R_t, and R_{tm} all calculate roughness as a function of maximum peak-to-valley height. Also useful is R_z -- the "ten-point height" parameter -- which calculates the average of ten maximum peak-to-valley differences within the sampling range.

If surface finish is called out on a drawing but not otherwise specified, it is standard practice to assume R_a. But no single parameter is best for all types of parts, and many applications are best served by using two or more parameters: for example, R_a (average roughness) in combination with R_{max} (maximum roughness) may provide a good general idea of the part's performance, and alert QA to the presence of potentially damaging surface anomalies.

Fig. 2



Surface finish is not simply a challenge to meet: it represents an opportunity as well. In some cases, if you can maintain good control over surface finish, you may be able to safely reduce precision in other areas. We'll look at the subject again soon.

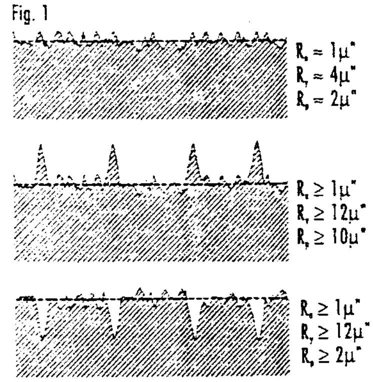
Rx FOR R_a MEASUREMENTS

R_a, or average roughness, is the most commonly specified parameter for surface finish measurements. Because it describes the arithmetic average deviation of a surface from a mean line, R_a provides a good general guide for part performance over a wide range of applications. But, as can be expected of anything intended for general-purpose use, R_a has numerous limitations when applications are highly specific, or when small details of surface finish can make a big difference in part performance.

The key to specifying and using R_a measurements successfully is understanding how average roughness relates to surface finish in general, and the relationship between the machining process and the profile.

As shown in Figure 1, surfaces with different profiles can have the same R_a value, and these differences might be critical in certain applications. The surface shown in the middle trace, if used in a relative-motion application such as a rotating shaft, might score bearing surfaces and cause bearing failure. A part with scratches in its surface, as illustrated in the bottom trace, might fracture prematurely under sheer stress. Clearly, different roughness parameters are required to ensure that the finish is appropriate to the application. In the above examples, the R_p parameter (peak height) could be used to indicate and guard against the condition in the middle trace. To determine maximum scratch depth, as in the bottom trace, one could subtract the R_p value from the R_y (maximum peak to valley height) value.

Fig. 1

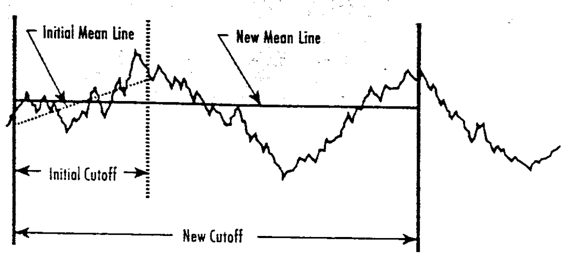


Engineers and quality organizations who do not understand roughness measurements sometimes specify extremely tight R_a values in an attempt to guard against occasional scratches or peaks. This is an uneconomic approach to quality. We have seen one ball manufacturer who was able to substantially undercut the competition for an aerospace bearing contract by showing the end-user how a looser R_a spec, in combination with control over the R_p parameter, could produce bearing life equal to that achieved with the existing, tighter R_a spec without control over peak height. The ball manufacturer understood that it was the peaks on the balls, not their average roughness, that were principally responsible for scoring the races, and he found it much cheaper to knock the peaks off than to meet the high-tolerance R_a spec that had been put in place.

Different machining processes naturally generate different tool patterns. The roughness produced by grinding, for example, is generally of a shorter wavelength than that left by turning. Milling leaves even longer wavelength patterns, though not as long as those produced by single-point boring. (Note that the wavelength we're referring to here is the spacing of the individual tool marks, not the waviness component of surface profile.)

When performing an R_a measurement, it is essential to choose a cutoff length appropriate to the process. The cutoff length should be short enough so that the measurement will not be influenced by waviness. On the other hand, it must not be so short that only a portion of a tool mark is measured, as shown in Figure 2. A cutoff long enough to include five complete sets of tool marks is desirable to obtain a good average roughness measurement.

Fig. 2



Surface finish gages of the simplest type, that only measure R_a, aren't much help in determining whether you've got a peak-and-valley problem, or what the proper cutoff length should be. It may be necessary to perform a complete surface finish analysis, including a look at the waviness component, to get a full understanding of the profile. With that in hand, however, straightforward R_a measurements may be all you need to maintain control over your process.

LOOK INTO MY STYLII: CARE OF SURFACE FINISH GAGE CONTACTS

Proper care of contact points is one of the basic considerations in gaging. Whether you're using a simple indicator gage or a sophisticated surface finish instrument, much depends upon the condition of the sensitive contact point, which is the interface between the gage and the workpiece.

Dial indicator contacts are easy to inspect. They're big enough to get your fingers around, and you can check them visually for wear, damage, or contamination.

The tiny contacts on surface finish gages are quite another matter. Compared to blunt dial indicator contacts, a surface finish gage has a fine "stylus" point, enabling it to follow the texture of the surface, but being of a form and dimension so as to avoid scratching the part. Gaging force from a dial indicator is typically 120 grams/1.2 N; in contrast, force from a surface finish gage is light, usually between 100 mg and 1,500 mg (1 mN to 15 mN). But because the stylus is "dragged" across the surface of the workpiece, it is just as subject to wear and damage as a dial indicator contact.

Surface finish contacts are made of diamond, and are conical in form, having a 60° or 90° included angle and a spherical vertex with a radius of 0.0004", 0.0002", or 80 microinches (10 micrometers, 5 micrometers or 2 micrometers). Criteria for choosing between these options are outlined in ASME B46.1 - 1995 paragraph 4.4.5.1.

Even with its small radius, a stylus in perfect condition may be too broad to reach the bottom of the small "valleys" on the part surface, as shown in "A" in the diagram. This inherent "error" is accounted for by calibration, however.

Wear or damage to the stylus will affect measurements. An evenly -worn contact will typically under-report the distance between surface peaks and valleys, as shown in "B". A broken stylus may under-report surface variation, or may over-report it, as shown in "C," depending on the nature of the break and the part surface. On occasion, the break may be so sharp that the stylus could scratch the part: a pretty clear indication that the stylus needs replacement.

Paragraph 11.7.2 of the B46.1 standard describes several more practical methods by which stylus condition may be checked. Because the stylus radius is too small to see with the naked eye, a hand-held magnifier or a microscope is required for visual inspection. If it is necessary to assess the stylus's condition numerically, however, a stylus check patch or reference specimen, rated for about 20 microinches, is required.

To use a stylus check patch, a benchmark reading must first be established when the stylus is in new, unused condition. First, the gage is calibrated to a certified specimen rated nominally at 125 microinches (3.2 micrometers). Then it is tested against the 20 microinch patch, and the reading recorded for future reference. The test need not read exactly 20 microinches, because these specimens contain considerable inherent error (e.g., the inability of the probe to reach the valley bottom). For this reason, the 20 microinch patch should not be used to calibrate the gage, but it is nevertheless useful for the purpose of stylus inspection.

When it is necessary to check the condition of the stylus, the gage is again calibrated against the 125 microinch specimen. Then the 20 microinch specimen is measured, and the reading compared against the when-new results. If the reading has changed by more than 25 percent, the stylus must be considered worn or damaged.

As noted above, a broken stylus may be sheared off so that it is either too blunt or too sharp. Conceivably, it could reach exactly as deep into the valleys as a new stylus, and rise exactly as high on the peaks, but the surface pattern that it reports will likely be distorted. So any time readings become non-repeatable, or reflect a sudden change in surface finish with no known change in the manufacturing process, a broken stylus is a likely suspect.

Should damage or wear be discovered, there is only one option available: replacement. Some gages feature easy-on/easy-off contact mounting, while others require a more involved procedure. Users should be aware of the variety of contact shapes available from some gage suppliers. These may include extra long lengths, smaller diameters, or special shapes that provide access to features that are otherwise hard to reach. But no matter what contact shape is used, it should be inspected regularly to ensure accurate surface finish measurements.

MEASURING ROUGHNESS WITH BUTTONS AND DONUTS

The R_a parameter is the most commonly used measurement for surface roughness. Until recently, in fact, it was the only parameter recognized by ANSI, although new ANSI and ISO standards include many different parameters from which to choose. And while these additional parameters are useful in many applications to ensure or enhance functionality, R_a is still included in most specs as a good starting point and a basic benchmark of process consistency.

R_a can be measured with two types of contact gages, which are distinguished from one another by the nature of the probe or contact that traverses over the part's surface. In "skidded" gages, the sensitive, diamond-tipped contact or stylus is contained within a probe, which has a metal skid that rests on the workpiece. Thus, skidded gages use the workpiece itself as the reference surface. This is a relatively simple, inexpensive approach to surface measurement. Skidded gages sell for as little as $1,600, and some are small enough to fit into a shirt pocket.

Skidless gages use an internal precision surface as a reference. This enables skidless gages to be used for measurements of waviness and form parameters, in addition to roughness. The drive unit is larger and more complex, and a computer is required to handle the complex algorithms for numerous parameters. Skidless gages are indispensable for complex surface analysis but, at a cost of ten to twenty times that of skidded systems, they are impractical if R_a is the only parameter required.

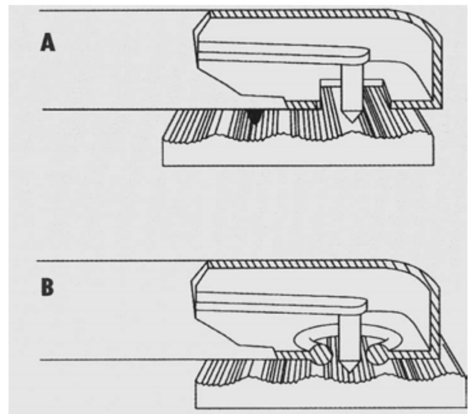
Getting back to skidded gages, it is important to look at the design of the skid itself. Some probes have a simple button-like skid, which may be located either in front of, or behind, the stylus. Others have a donut-shaped skid, with the stylus extending through the hole in the middle. In most applications, both types perform equally well, but occasionally, one or the other might be required to obtain accurate results.

Under high magnification, some workpieces appear to have wavy surfaces of very short wavelength; this is especially so of EDM parts. While the inclination may be to measure these surfaces using a waviness parameter, the pattern is really a tool mark, so a roughness parameter like R_a is required. Surfaces of this type may cause problems for gages with button-type skids. As shown in diagram "A," if the distance between the skid and the contact is roughly half the wavelength of the surface waviness, then the skid and contact will trade places at the tops and bottoms of the waves as the probe traverses the surface. This has the effect of nearly doubling the vertical travel of the contact relative to the reference, which will produce results that may be unreliable or non-repeatable.

The donut-type skid avoids this problem, because it remains at or near the tops of the waves as it traverses, as shown in diagram "B." Thus, the contact's vertical travel is measured against a far more constant reference height.

But because probes with donut-type skids require substantial structure ahead of the stylus, they cannot reach certain features, such as surfaces next to shoulders. Probes with button skids mounted behind the stylus require little or no leading structure, and thus have the advantage of increased access. Special probes with button skids are even available to reach into groove bottoms several millimeters deep.

Some pocket-type roughness gages offer users the ability to switch probes. This can extend the capabilities of the gage, allowing the user to select a probe with a donut skid for use on short-wavelength EDM'd surfaces, and a trailing-button skid for use where access is restricted.



SURFACE TEXTURE FROM R_a To R_z

The irregularity of a machined surface is the result of the machining process, including the choice of tool, feed and speed of the tool, machine geometry, and environmental conditions. This irregularity consists of high and low spots machined into a surface by the tool bit or a grinding wheel. These peaks and valleys can be measured, and used to define the condition and sometimes the performance of the surface. There are more than 100 ways to measure a surface and analyze the results, but the most common measurement of the mark made by the tool, or the surface texture, is the roughness measurement.

However, there are several different methods of roughness measurement in use today, and the method used on any given part depends largely on where in the world the part is manufactured, and the measurement parameters the manufacturer and the customer prefer to use. It is not uncommon for different parties involved in the production to use different methods for roughness measurement. In this article we will talk about only two of the many methods of roughness measurement, how to convert between these two methods, and how to avoid the problems caused by the inevitable use of more than one roughness measurement.

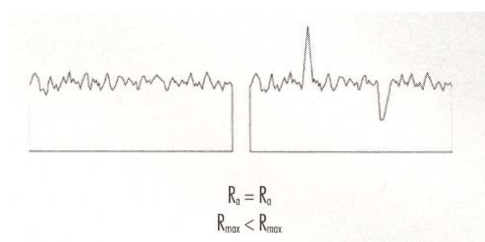
In North America, the most common parameter for surface texture is Average Roughness (R_a). R_a is calculated by an algorithm that measures the average length between the peaks and valleys and the deviation from the mean line on the entire surface within the sampling length. R_a averages all peaks and valleys of the roughness profile, then neutralizes the few outlying points so that the extreme points have no significant impact on the final results. It's a simple and effective method for monitoring surface texture and ensuring consistency in measurement of multiple surfaces.

In Europe, the more common parameter for roughness is Mean Roughness depth (R_z).
R_z is calculated by measuring the vertical distance from the highest peak to the lowest valley within five sampling lengths, then averaging these distances. R_z averages only the five highest peaks and the five deepest valleys—therefore extremes have a much greater influence on the final value. Over the years the method of calculating R_z has changed, but the symbol R_z has not. As a result, there are three different R_z calculations still in use, and it is very important to know which calculation is being defined before making the measurement.

In today's global economy, machined parts are being made and shipped around the world. As a result, manufacturing and quality control engineers are often forced to decide whether or not to accept a part when the print requirements are not consistent with measurement on the surface gages in the local facility. Some quality control engineers might even assume that if a part is checked and passed using the parameter available, the part would also pass other checks. In these cases, the engineers are assuming a constant correlation, or ratio, exists between different parameters.

If there were no choice but to accept some assumptions, there are rules of thumb that can help clear up the confusion and convert R_a to R_z or R_z to R_a. If the manufacturer specifies and accepts the R_z parameter, but the customer uses the R_a parameter, using a ratio range for R_z-to-R_a = 4-to-1 to 7-to-1 is a safe conversion. However, if R_a is used as an acceptance criteria by the manufacturer, but the customer accepts R_z to evaluate the part, then the conversion ratio would be much higher than 7-to-1, possibly as high as 20-to-1. Keep in mind that the actual shape of the part's profile will have a significant impact on these ratios.

Communication at the outset of the project can avoid most surprises. The approximate, and sometimes questionable comparisons, can be avoided by developing an understanding of exactly what a parameter on a print means, and how the various parties involved in the production plan to check surface texture.



The best way for those involved in the production to be in agreement on the parameters for measurement is to have capable evaluation equipment in both the manufacturer's and customer's facility, making the same check using the same method. If the manufacturer or the customer uses conversion ratios, then both parties should be aware of the use of the ratio and be comfortable with the ramifications.