Obtaining Meaningful Surface Roughness Measurements on Gear Teeth

Ronald A. Lavoie

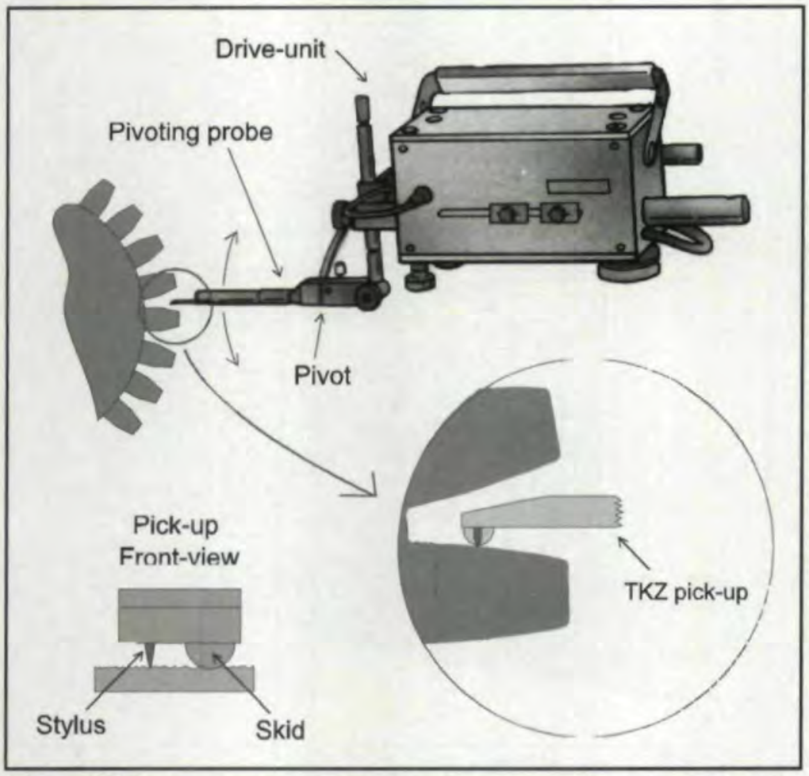


Fig. 1 — The involute form on gear teeth, in most cases, necessitates the use of a skid-type pickup. Gear tooth pickups differ from general purpose pickups in two key areas. The skid is located alongside the stylus instead of having the skid located either before or after the stylus. Also, the skid radius on gear tooth probes is a much smaller radius, typically .8 mm vs. 30 mm. The combination of a smaller skid radius with the side-by-side orientation results in a superior tracking of the involute form.

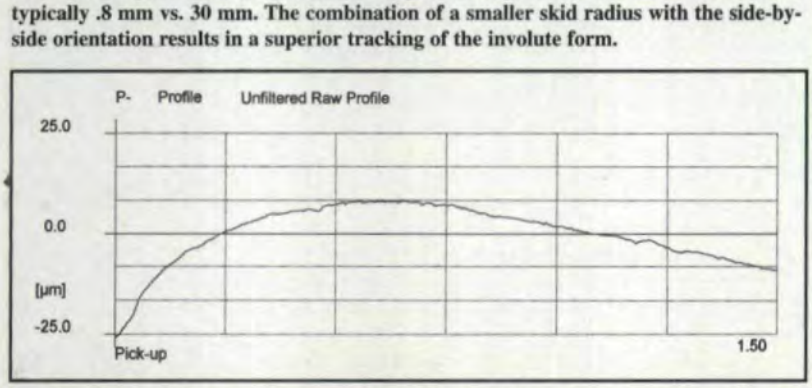


Fig. 2 — The unfiltered profile generated by the signal from the pickup shows the significant amount of curvature that results from the interaction of the skid and the involute form. Also, the roughness signal is hardly discernable.

Surface roughness measuring of gear teeth can be a very frustrating experience. Measuring results often do not correlate with any functional characteristic, and many users think that they need not bother measuring surface roughness, since the teeth are burnished in operation. They mistakenly believe that the roughness disappears in a short amount of time. This is a myth! The surface indeed is shiny, but it still has considerable roughness. In fact, tests indicate that burnishing only reduces the initial roughness by approximately 25%.

This article deals with the key issues that must be addressed if we are to obtain a meaningful surface roughness measurement. We will see that close attention to detail is necessary.

The following areas need to be addressed: equipment, particularly probe selection, filtering and roughness parameters.

Surface Finish Measuring System

A surface finish measuring system consists of a probe that is moved across the involute surface of a gear tooth by a drive system. Signals from the probe are sent to a computer-based system for filtering and evaluation (Fig. 1). The probe usually consists of a skid and a stylus. The skid is used to support the probe on the surface to be evaluated, and as the probe moves across the surface, the skid tracks the overall curvature of the surface. The stylus, the sensitive portion of the measuring system, consists of a very fine diamond with a tip radius of 5µm. The stylus measures the microvariations in the surface, which make up the "roughness." The involute curve of the gear teeth, as well as the limited space between teeth, particularly on fine pitch gears, requires a special type of probe designed specifically for gear tooth measurement (Fig. 1).

The position of the skid relative to the stylus on a standard surface roughness probe will almost always produce unsatisfactory measurement results on a gear tooth. The special gear tooth probe is designed to fit into relatively small spaces. It also has a stylus skid orientation that is designed to minimize the distortion that would result from the involute curve.

Filter Selection

Selecting the correct type of filter and the correct filter setting is imperative. A great deal of ignorance exists in this area of surface roughness measurement. Misapplication of filtering often results in measurements that are worthless.

The raw, unfiltered profile that is the output of the probe must be filtered if we are to have meaningful roughness information. Fig. 2 shows the large curvature resulting in the raw, unfiltered profile. This curvature is the result of the interaction between the skid and the involute profile. If we did not filter this curvature out of the profile, it would so dominate our parameter calculations that we would never measure the actual roughness of the surface. Fig. 3 shows the roughness of the surface after filtering. Note the absences of any curvature.

There are two types of surface roughness filters in common use today. They are the RC, resistor capacitor filter and the M1 filter that is a digital phase, corrected, Gaussian filter. The RC filter is the original filter found in surface roughness equipment dating back to the 1960s. It is still available on modern surface roughness instruments to allow correlation with measurements on older instruments. The M1 filter was introduced when computers became commonplace within surface roughness instruments. The M1 filter is much more efficient than the RC filter and produces more accurate results. The RC filter is notorious for produce distortions, particularly when the raw, unfiltered profile has excessive curvature, as is almost always the case when measuring gear teeth. When measuring gear teeth, RC filters may produce distortions resulting in roughness readings twice the actual roughness of the surface. Therefore, it is highly recommended that only M1 filters be used when measuring gear teeth.

Using the right filter setting, referred to as the cutoff, is critical. Unfortunately, most surface roughness measuring equipment defaults to a particular cutoff, based on stroke length (cutoff equals 1/6 of stroke length). The cutoff may not produce accurate results. Fig. 4 shows that the average roughness value, R_a, will change continuously with different cutoff settings.

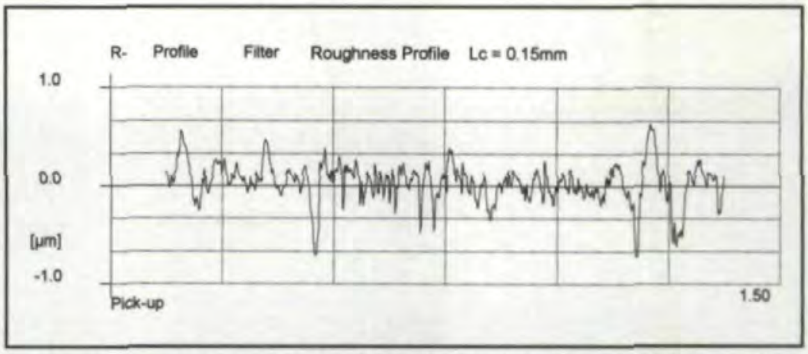


Fig. 3 — The roughness profile is the signal after filtering with a cutoff of .15 mm. Note that the amplification of this chart is 25 times greater than that of the unfiltered profile. Also, the profile is centered down the middle of the chart and shows no residual curvature, indicating that the cutoff was small enough to remove any residual curvature from the unfiltered profile.

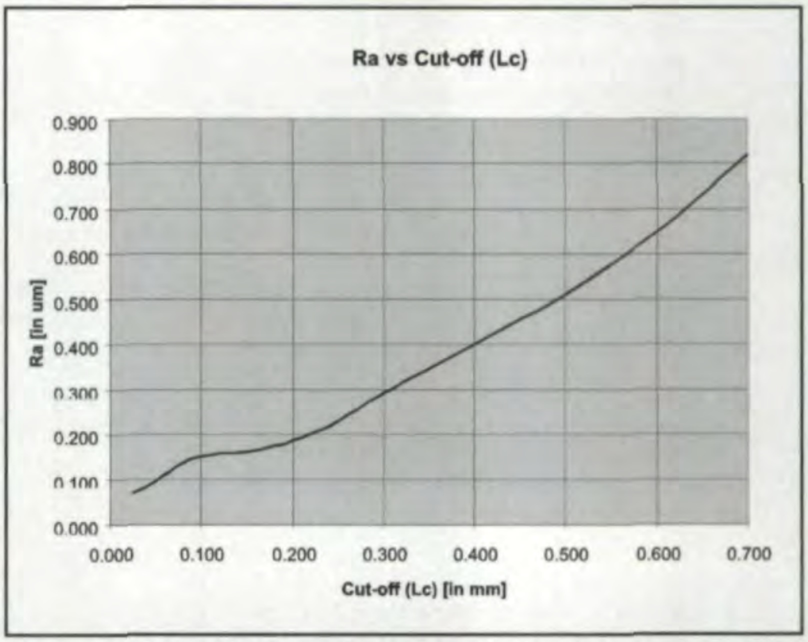


Fig. 4 — It can be seen that the roughness on a gear tooth profile continues to increase as the cutoff increases. This graph is typical of surfaces where there is a high degree of curvature in the measured surface. Note the inflection point that incurs at approximately a .15 mm cutoff. The point where the inflection occurs is usually at the optimum cutoff value. The roughness continues to increase in value after the optimum cutoff value because the cutoff is too large, and residual curvature is becoming a part of the roughness calculation.

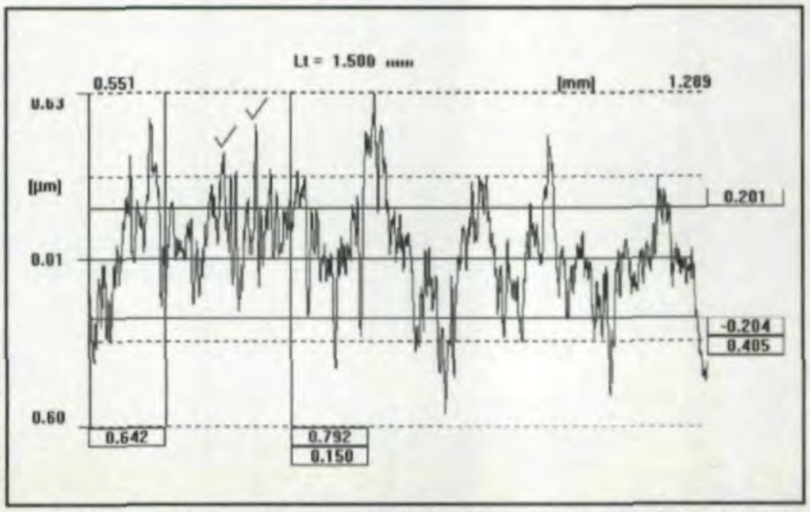
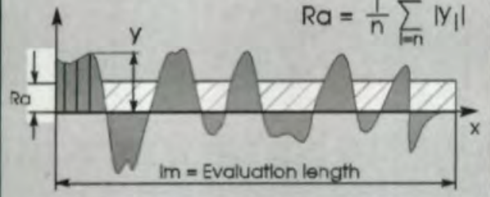


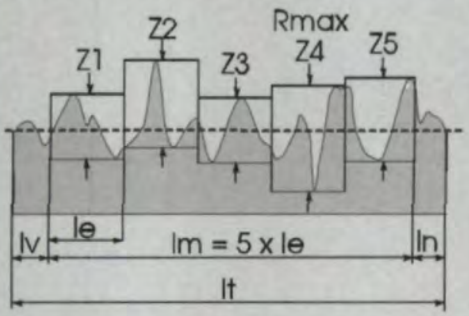
Fig. 5 — An approximate method for establishing the proper cutoff involves zooming on the unfiltered profile and determining the spacing between 2 1/2 major peaks of the surface profile. Repeating this process at different areas of the profile will result in an average cutoff value.

Ra - Arithmetric mean roughness value
The arithmetric average value of the filtered roughness profile determined from deviations about the center-line within the evaluation length Lm.

$$Ra = \frac{1}{n}\sum_{i=n}^{i=1} |y_i|$$



Rmax - Maximum individual peak-to-valley height: The maximum peak-to-valley dimension obtained from the five sampling lengths Le within the evaluation length Lm.

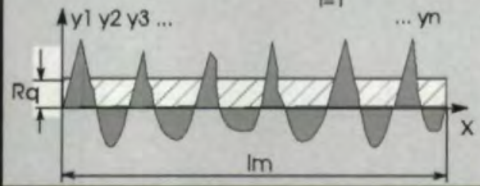


RzDIN - Mean peak-to-valley height
The arithmetric average maximum peak-to-valley height of roughness value Z1 to Z5 of 5 consecutive sampling lengths Le over the filtered roughness profile.

$$R_z = \frac{1}{5}\,(Z1 + Z2 + Z3 + Z4 + Z5)$$

Rq (RMS) - Root mean square roughness value: The RMS value obtained from the deviations of the filtered roughness profile over the evaluation length Lm.

$$R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{i=n} y_i^2}$$



POPULAR ROUGHNESS PARAMETERS

Popular roughness parameters

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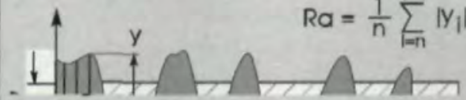
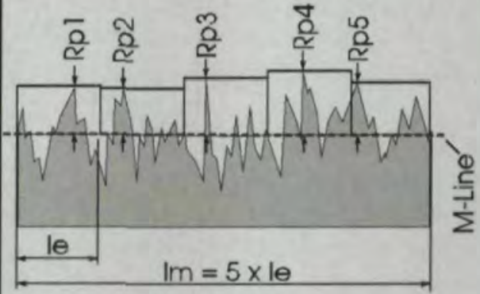


Rp - Single highest peak above the mean-line: The value of the single highest peak above the center line of the filtered *profile as obtained from Rpm.*



Pc - Peak count: A peak count taken over a standard length of 10 mm of the filtered roughness profile. Whereby a peak is only read after the profile has passed through both a lower and an upper variable preset threshold C1 and C2. Both threshold lines are set parallel to the 'center-line'.

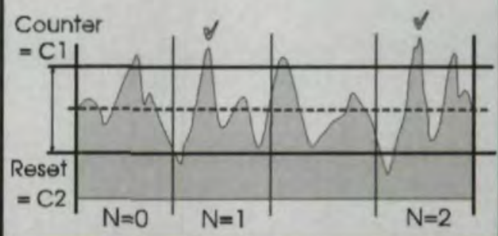


Fig. 6 — Popular roughness parameters.

So what is the appropriate cutoff value? A very small cutoff will insure the elimination of any curvature resulting from the involute of the gear tooth, but it will also eliminate virtually all the roughness. A very large cutoff will include all the roughness, but also a great deal of the involute curvature. The optimum cutoff value is that one that is small enough to eliminate the involute curvature and at the same time large enough so that it is not attenuating the actual roughness profile. Once this cutoff value is found for a particular process, it need not change and will probably be adequate for any measurements on gear teeth made from that process.

THE OPTIMUM CUTOFF IS SMALL ENOUGH TO ELIMINATE THE INVOLUTE CURVATURE AND AT THE SAME TIME LARGE ENOUGH TO NOT ATTENUATE THE ACTUAL ROUGHNESS PROFILE.

Obtaining the proper cutoff setting requires a surface roughness system which is capable of producing a profile of the unfiltered signal. Zooming on this profile will allow the inspector to determine the spacing between the dominant peaks of the surface. Generally speaking, the optimum cutoff value will be a distance which is equal to 2 1/2 peaks. (See Fig. 5.) Also, another indication of proper filter selection is a roughness trace that runs straight down the middle of the chart with no residual curvature evident. For example, in the measurement shown in Fig. 2, the default setting for the cutoff would have been .25 mm. However, careful study of the unfiltered profile, as well as the roughness profiles at various cutoff settings, indicated that a more appropriate cutoff would be .15 mm. Note that the default cutoff setting would have produced a roughness value 50% higher than the correct value.

Parameter Selection

Surfaces are digitally and objectively characterized by roughness parameters. There are many roughness parameters, each intended to describe a particular feature of a surface. If a surface roughness parameter cannot predict the functionality of a gear surface, it is worthless. For example, the average roughness parameter R_a may be a useful production monitoring tool, but it cannot differentiate between significantly different surfaces and, therefore, may be of little value in predicting functionality. Discussing all of the various roughness parameters is beyond the scope of this article. However, a good understanding of the 25 core roughness parameters in common use is critical if a designer is going to be able to select the proper parameter for a particular application. The most popular of these core parameters are described in Fig. 6.

Even the material of the gear will affect surface roughness parameter selection. For example, sintered gears or gears manufactured from cast iron are highly porous. This produces a roughness profile with many deep valleys. These valleys may have little effect on function, yet they will have a dramatic effect on the magnitude of any roughness parameter that involves data from the valley portion of the profile. For example, the R_z parameter, average peak to valley, would be very much affected by these pores. In this situation, if one is trying to measure the efficacy of a manufacturing process, a parameter such as R_{pm}, the average peaks above the mean line of the profile, would be far more relevant than the R_z parameter.

Parameter selection is not as difficult as it may seem. A good understanding of how the parameters are calculated and an understanding of the functional requirements of the surface will facilitate the selection of parameters that can indeed predict functionality.

Accurate surface roughness measurements on gear teeth can be a valuable quality analysis tool. Attention to the basic requirements of surface finish analysis such as proper equipment, correct filtering and the use of surface roughness parameters that will predict the functionality of the gear are key to successful implementation of surface finish discipline. ○

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