MATERIALS
MATTER

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COMPARING SURFACE ROUGHNESS PARAMETERS

Measurements such as Ra, Rz, and Rsk may not effectively evaluate isotropically superfinished surfaces.

EFFECTIVE GEAR DESIGN MUST ACCOUNT FOR A RANGE OF potential failure modes. As discussed in previous Materials Matter columns, gear failure modes can be fatigue-based and progressive (such as micropitting) or sudden (such as scuffing). Surface roughness is an important design factor in predicting and avoiding gear failure. Therefore, accurate classification of surface roughness is critical to ensuring that a gear performs as expected.

PARAMETERS RA AND RQ

The most common surface roughness parameter is Ra, the arithmetic roughness average of the surface. The majority of the methods for linking surface fatigue or failure to surface roughness use Ra or the similar measure, Rq, the root mean square of the surface roughness. The suitability of these two measurement parameters for use in gear-life predictive calculations is a point of contention, and their prevalence may be linked more to their historic availability on common profilometers than to their accuracy in classifying gear surfaces. The growth of isotropic superfinishing in the gear industry has only served to increase the need to evaluate alternative surface roughness measurements due to its profoundly different surface characteristics.

As introduced in a previous Materials Matter column, "Lambda Ratio," Ra and Rq, in general, are limited in their ability to differentiate surface quality, especially if the surfaces being compared were not generated in a predominantly similar manner. Surfaces with the same Ra or Rq values can vary widely in their surface topology and, therefore, diverge widely in performance (see Figure 1).

Figure 1: Examples of "equal" Ra measurements on obviously dissimilar surfaces (photo courtesy of Hommelwerke GmbH)

PARAMETERS RZ, RT, AND RSK

While Ra and Rq have flaws, there are a plethora of other surface roughness parameters that have been developed and incorporated into measurement standards. After Ra, perhaps the next most common measurement parameter for gears is Rz. Rz is the average of the tallest peak to the depth of the lowest valley from each "cutoff" or subsection of a surface measurement. Rz offers advantages over parameters such as Rt, which is simply the height of the single "tallest" peak to the depth of the "deepest" valley in a surface trace — as it incorporates more of the surface. However, it is an average of only the most extreme instances of the surface of surface roughness and, therefore, has the potential to be overly affected by outliers. Additionally, it may be overly influenced by valley depth, which is thought to be less detrimental to gear performance than peak height.

Another parameter that can be considered in the measurement of gear surface roughness is Rsk or the roughness skewness of a surface. Rsk classifies both the magnitude and direction of surface roughness such that positive numbers represent surfaces that consist predominately of peak asperities, and negative numbers represent surfaces that consist primarily of valleys. Rsk is an excellent parameter for measuring surfaces that are expected to have peaks or valleys. The common interpretation of Rsk as applied to gear flanks would be that a negative value is good and a positive value is bad. However, if a surface has been largely planarized such that few peaks or valleys remain, then Rsk returns to nearly zero. In such a situation, Rsk could inaccurately suggest that a surface with higher roughness is superior to a surface with lower roughness. Therefore, Rsk on its own is not descriptive enough to differentiate between rough and smooth surfaces.

MATERIAL RATIO CURVE AND 3σ50

It could be suggested that the common problem of the aforementioned surface roughness parameters is that they fail to adequately consider or classify the entire nature of a surface. The bearing industry utilizes a curve known as the Abbott-Firestone Curve (see Figure 2) to generate what is commonly referred to as the bearing ratio. This curve seeks to establish the percentage of a surface that is below a specified depth (sometimes referred to as the cutting depth). Effectively, the curve is trying to establish how much of a surface is bearing the load of operation.

There are multiple surface roughness parameters that are derived from the material ratio curve. One such parameter, 3σ50, may be ideal for evaluating gear surface quality. 3σ50 measures the peak height differential between the value of the cutting depth that is needed to obtain a 50 percent measurement (in other words, where 50 percent of the surface is carrying the load of operation) and the value of the cutting depth that is required to obtain a 0.13 percent measurement. While 0.13 percent of the surface may seem arbitrary at first, the value is directly related to statistical quality or, in this instance, 3σ

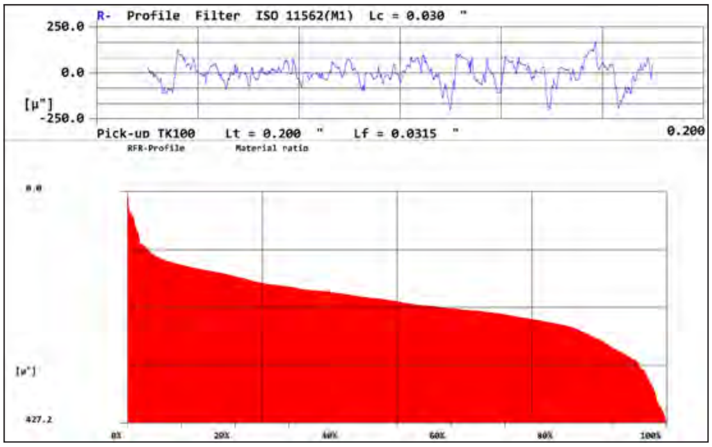
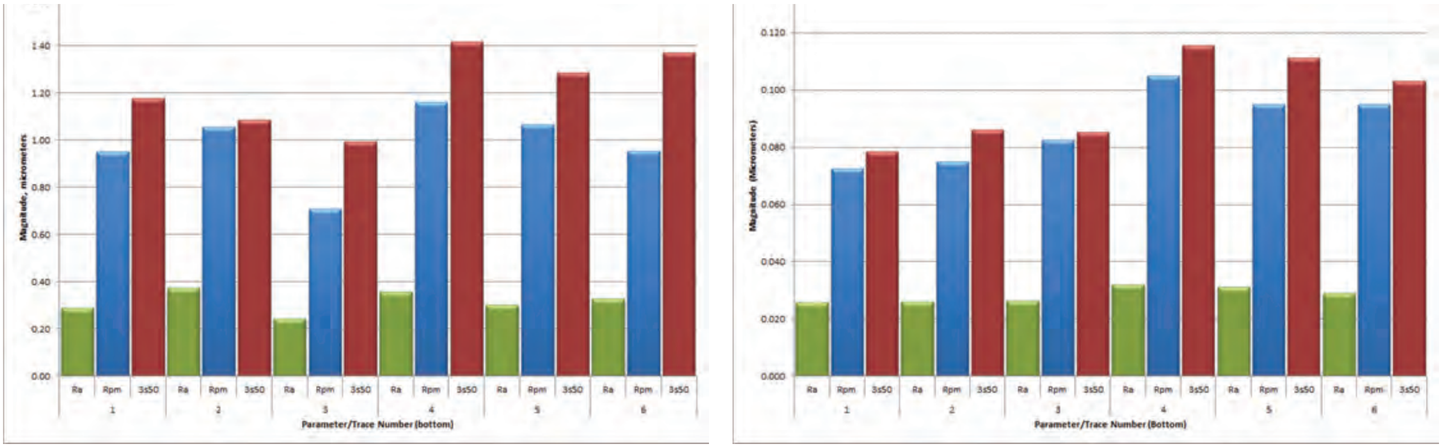


Figure 2: Example of Abbott-Firestone Curve

Figure 3: Comparison of Ra, Rpm, and 3σ50 for a production (machined) gear and an isotropically superfinished gear



Ground gears – nominal 0.3 µm Ra

Isotropically superfinished gears — nominal 0.03 µm Ra

from the average height of the surface. By using 3σ, the measurement is considering the central 99.73 percent of the surface. Half of the remaining 0.27 percent (or 0.13 percent) would represent the bottom of the lowest valleys and the other 0.13 percent would represent the top of the tallest peaks. Therefore, measuring the difference between the cutting depths for the measurements of 0.13 percent and 50 percent excludes only the peaks of the highest asperities while still allowing for residual valleys to be present. By effectively eliminating any outlier peaks and determining how much of the surface will carry the load during operation, 3σ50 would seem to succeed in many areas that other surface roughness measurements fall short.

PARAMETER RPM

Regardless of the efficacy of 3σ50, it must be stated that it is not a commonly available parameter on most profilometers. However, Rpm is a much more common parameter that has been shown to have a strong correlation to 3σ50 when applied to isotropically superfinished surfaces (see Figure 3). Rpm is similar to Rz in the fact that it is a five-point measurement averaged across the surface. However, Rpm only measures the average of each asperity to the mean line in each cutoff instead of to the bottom of the valleys within the cutoff. Thus, while the valleys have an effect on the measurement through their influence on the location of the mean line, the larger effect comes from the consistent peak asperities (which are more likely to penetrate a lubricating film). It is because of these characteristics as well as the correlation to 3σ50 that Rpm may be a superior surface roughness parameter as compared to more common R measurements. However, it must be noted that the correlation between Rpm and 3σ50 when evaluating non-isotropically superfinished surfaces is not as strong as when applied to isotropically superfinished surfaces. Therefore, it may not be as valid a measurement in such an application.

CONCLUSION

The classification of gear surfaces and the ability to verify that the desired surface quality is present on said gears is clearly an important endeavor. There are numerous surface roughness parameters that exist, and many have their merits as well as their limitations. The stark differences between machined surfaces and isotropically superfinished surfaces create added difficulty in classify and quantifying such surfaces. The measurement 3σ50 seems to offer a superior methodology to many other roughness parameters, but it is, unfortunately, not a viable means of verifying production gears. Rpm may be an ideal parameter to evaluate the quality of isotropically superfinished surfaces. Through the increased use of isotropic superfinishing and a more accurate measurement parameter, such as Rpm, gear systems can perform to design expectations with fewer premature failures.

ABOUT THE AUTHOR: Matt Bell has been a research chemist with REM Surface Engineering since 2006. He has developed new products and processes, published several papers, and aided in corporate lean efforts. He is an expert in surface roughness measurements, a member of the American Chemical Society, and serves on the AGMA 925 committee. He graduated from Texas A&M University with a degree in chemistry where he also served as the vice president of the American Chemical Society student affiliate chapter. He can be reached at mbell@remchem.com.