

Characterizing Wear with 3D Optical Profiling

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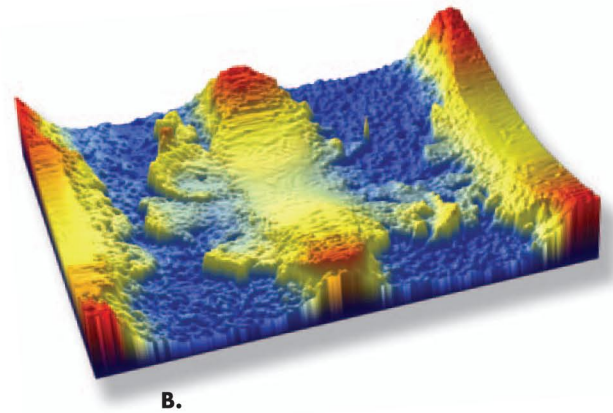
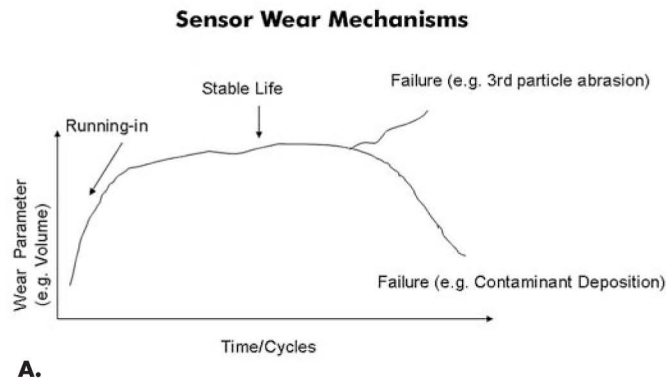


Figure 1. Different wear mechanisms affect the performance of a sensor (a, shown as a 3D, false color map) throughout its lifespan (b).

Understanding wear and its underlying causes is critical to the manufacture and maintenance of structures, seals, drive trains, medical devices, etc. Yet wear is extremely difficult to quantify—no single number can adequately describe how much a surface has worn, or to what degree this wear will affect performance.

Over the years, increasingly effective means have been developed for measuring surface topography and for using this data to understand wear. 3D measurement techniques have led to the development of parameters which allow engineers to correlate wear to particular manufacturing processes and/or wear mechanisms. By further developing these techniques engineers hope to be able to predict, and thereby extend, component life.

Wear Mechanisms

Abrasion, corrosion, erosion, plowing—the list of wear mechanisms could fill a page. Each type of wear results in a different, progressive modification of the surface, from pitting and cracking to deformation or material transfer.

The dominant wear mechanism may also change across the lifespan of a component. Figure 1a, for example, shows the result of accelerated life testing for a sliding contact automotive sensor. A worn section of the sensor's fingers (yellow and red) is shown in a false-color, 3D map. During an initial running-in period material was lost quickly, after which the surface stabilized for a large number of cycles. Improper design could lead to early

failures (Figure 1b) in which accumulated wear debris adheres to, and bridges, the sensor surfaces, generating electrical shorts and thus false readings.

In regard to component performance, wear may be bad, good, or indifferent. Cylinder walls, for example, lose a significant amount of material during the early stages of an engine's life, yet this wear will only marginally degrade the engine's performance. A loss of significant valleys in which lubricant can be retained, however, may lead to increased friction and potential scoring, scuffing, and galling. Defining and quantifying the wear mechanisms which degrade performance or cause failure are the goals of today's more precise wear testing techniques.

Quantifying Wear

In one long-used wear testing technique, a component is weighed, placed into service, removed and weighed again, periodically over the life of the part. The weight of material lost is considered a measure of how much the part has “worn.” While this method serves as a general indicator of wear, it unfortunately gives little indication of the wear mechanism or of any change in the component’s functionality.

Two-dimensional measurement techniques, such as stylus profiling, characterize wear based on a single trace measurement across the sample surface. The most widely specified surface parameter, average roughness (Ra), was developed based on 2D stylus measurements. Ra, however, makes no distinction between peaks and valleys, nor does it provide information about spatial structure, both of which are critical to understanding surface performance. Other 2D parameters have been

developed which are sensitive to these types of surface characteristics, but they are still based upon the limited, single slice of the surface.

Most recently, 3D surface measurement instruments have led to sophisticated methods for visualizing and quantifying wear. Chief among these methods is optical profiling, which uses the interference of light to measure surface shape and roughness. This non-contact method can resolve features from nanometer-scale roughness through

millimeter-scale step heights, operating at the scales typical of mechanical wear.

Figure 2 shows an optical profiler analysis of a honed cylinder wall. In such an analysis, hundreds of parameters can be calculated to describe surface wear, including the volume of material lost over time, the ratio of peaks to valleys, directionality of wear, etc. Recently-developed 3D parameters, such as the S-Parameter set, describe not only surface shape but functionality as well.

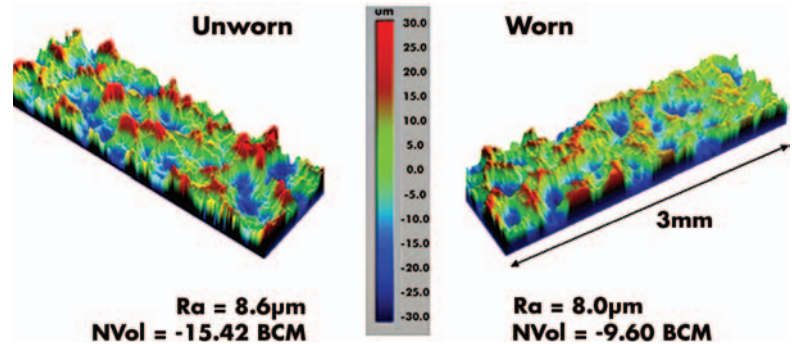


Figure 3. The “Normalized Volume” (Nvol) parameter was found to be a better indicator of wear than Ra for this shaft.

Relating 3D Parameters to Wear

This wealth of 3D parameters is a boon for engineers, yet the goal remains to find those parameters which are sensitive to performance-affecting wear. As an example, the shaft shown in Figure 3 tended to cause loud squeaks in operation after a period of time. The manufacturer specified an average roughness (Ra) value for surface finish. Yet optical profiler analysis revealed that the Ra of new and worn shafts was virtually identical—no prediction of performance could be made based upon Ra alone.

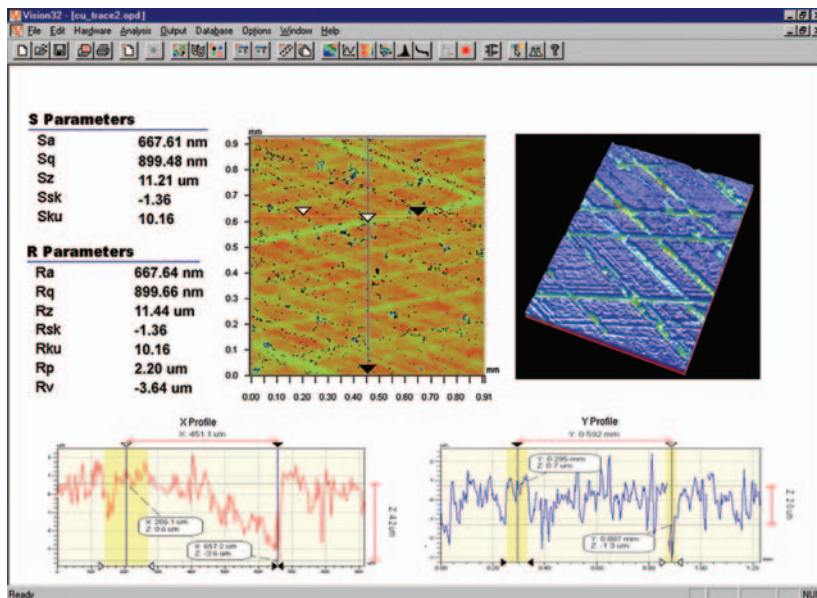


Figure 2. 3D optical profiler analysis of a honed cylinder wall, including 2D and 3D plots, R parameters and S parameters.

Another 3D parameter, Normalized Surface Volume (Nvol), was found to have changed by almost 40% over the wear period. Nvol describes the void area beneath a plane placed across the peaks of a surface. It decreases rapidly as spiky, peak material is removed, as occurs during the running-in phase of a component. The large change in Nvol indicated that peak material had been worn away, creating a larger load bearing surface, which led to the stick/slip mechanism causing the squeak.

Component designers can use information such as this to anticipate wear and to engineer surfaces that perform well both initially and predictably over their lifetimes.

In some cases, a combination of parameters may be more meaningful than a single one. One such combinational parameter is Sbi, the Surface Bearing Index. Sbi indicates a surface's overall roughness relative to the surface area that would bear a load. Sbi increases as peaks wear down and a surface becomes more plateau-like. It is a stable parameter which tends to change only when a process or surface is altered dramatically, as by a significant defect.

Figure 4 shows an optical profiler analysis of a shaft that has been worn down by a mating component. The shaft's surface texture changed dramatically during the wear period. Seeing this degree of wear one might believe that performance would be significantly impacted. Yet while Ra decreased by more than 50%, the shaft still continued to function well. Ra alone could not indicate whether the part would or would not function.

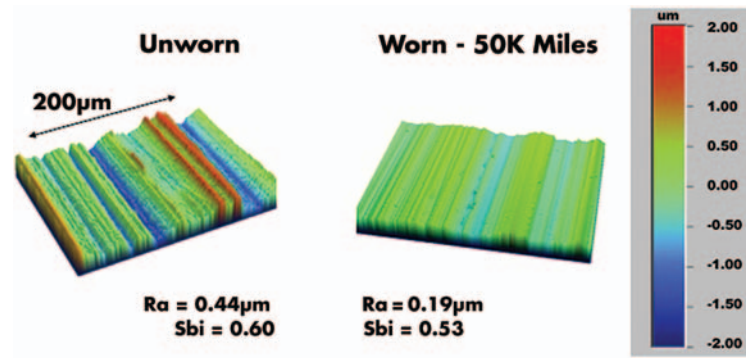


Figure 4. 3D Optical profiler analysis of a new and worn shaft. Functional parameters such as Sbi indicate what the eye cannot: that both of these shafts will perform similarly.

Sbi, on the other hand, was found to change very little over the wear period. Even though peak material had worn away, the percentage of the surface bearing the load did not change dramatically. In fact, in this case, the worn surface was more stable than a new surface: it was smoother, but not so smooth as to squeak, bind or overheat.

The Sbi parameter highlighted a feature of this shaft that was indiscernible by the eye, intuition, or Ra. Parameters such as this can indicate component life effectively since they relate to function more than to a statistical description of texture.

Advanced 3D wear measurement techniques can be a significant competitive advantage for component designers.

As use of these techniques spreads it becomes increasingly important for design and quality professionals to understand wear and 3D wear parameters, to avoid expensive design and testing pitfalls. One engineer for an automotive component manufacturer recounted a customer's new test requirement, which his company's sensor design did not pass. But by using an optical profiler to compare

the test sensors with ones removed from high mileage vehicles, his team noted a buildup of wear debris in the laboratory-tested parts that was not present in actual-use sensors. In normal use, the wear debris was able to clear away as it was produced, but the test caused it to accumulate. His team was thereby able to work with the customer to redesign a test that better reflects real-world conditions.

Predicting Wear and Component Life?

By testing components over their lifetimes, then constructing a model of wear mode versus various surface parameters, one can determine which parameters serve as accurate wear predictors for each given case. The ultimate goal of such studies is to predict—and extend—the life of components and systems.

One of the most exciting outcomes of such testing is the growing use of "engineered surfaces," in which designers build particular wear-fighting characteristics into component surfaces. Knowing which wear mechanisms lead to performance deterioration, and anticipating how the part will change

throughout its life, engineers can combat the effects of wear, making more effective use of lubricants, materials and processing.

For the foreseeable future, wear mechanisms will remain somewhat unpredictable, challenging component and system designers and limiting the lives of their products. Yet armed with new tools for identifying and monitoring destructive wear, engineers are better able to develop designs that reduce wear—or even to use wear to improve component performance. 3D surface characterization provides the data required to make informed decisions about wear, part performance, and ultimately component life.



References

1. Bharat Bhushan, Introduction to Tribology, John Wiley and Sons, New York, 2002.
2. ANSI/ASME B46.1-2002 "Surface Texture (Surface Roughness, Waviness and Lay)," American Society of Mechanical Engineers, 2002.
3. ANSI/ASME Y14.36-1996 "Surface Texture Symbols", 1996.
4. ISO 4287:1997 "Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters"
5. ISO 13565-2:1996 "Geometrical Product Specifications (GPS) - Surface texture: Profile method; Surfaces having stratified functional properties - Part 2: Height characterization using the linear material ratio curve"
6. ISO/TC 213 N 470-1 "Geometrical Product Specification (GPS) -Surface Texture: Areal – Terms, definitions and surface texture parameters"
7. D. J. Whitehouse, Handbook of Surface Metrology, Institute of Physics, Bristol, 1994.
8. Leigh Mummery, Surface Texture Analysis, The Handbook Hommelwerke GmbH, 1992
9. K. J. Stout, Development of Methods for the Characterisation of Roughness in Three Dimensions, Penton Press, London, 2000.



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