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Predicting Surface Functions with Morphological Analysis

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Surface texture analysis has become an invaluable tool for understanding how a component's surface geometry will affect its function. Despite the breadth of information that can be tracked with texture parameters, most engineers continue to specify only basic, well-known parameters, such as average height in microns. Unfortunately, most surface functions (friction, sealing, appearance, etc.) aren't measurable purely in units of height, so the specified parameters often only loosely correlate with the intended function.

For measurements to be most effective, the results must predict actual functionality. Using surface texture analysis, engineers can develop parameters that models a particular functionality, build controls for those parameters into part tolerances, and control them throughout manufacturing and over the life of the component.

One analysis tool of this type is known as Morphological Filtering, which can predict how a soft surface will conform to a rigid surface, how sharp protrusions may concentrate stress, etc. In this article we will discuss how morphological filters are applied to surface texture data to quantify function, explore its root causes and track it through production and over a component's life.

When Height-Based Statistics Cannot Distinguish Two Surfaces

The most common surface finish specifications are based solely on heights measured along a profile, such as average roughness (Ra), average peak-to-valley height (Rz), or maximum waviness height (Wt). These statistics are well known and are easy to measure with most surface profiling systems.

Unfortunately, these statistics do not always indicate how the surface will perform. Figure 1 shows two very different surfaces with virtually identical Ra, Rz and Wt values. Measuring any, or all, of these statistics would not reveal whether the sharp valleys in the first surface make the component prone to cracking, or that the scalloping in the second surface may create leak paths between mating surfaces.

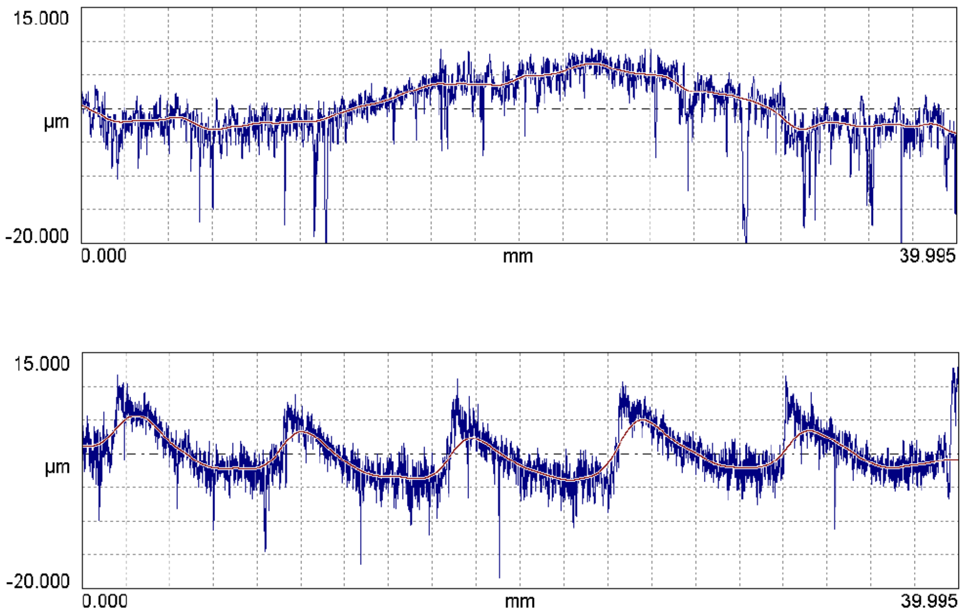

Figure 1. Will these surfaces leak? Identical Ra, Rz and Wt values mean these statistics offer little insight into this potential problem.

Functional Analysis Identifies How a Surface will Perform

In recent years surface topography data is being analyzed to form new "functional parameters" that closely correlate with a particular function. Manufacturers and repair/refurbish facilities are able to implement specifications for these parameters and then monitor them to improve component performance and longevity.

One such analysis is known as "morphological filtering." In this application the morphological filter is a virtual circle (or ball for 3D measurements) of given radius that is moved across surface data to highlight aspects of interest. Figure 2 shows two common types of morphological filters: a "closing filter," in which the mathematical ball rides along the surface, and an "opening filter," in which the mathematical ball is essentially pushing up from below the surface.

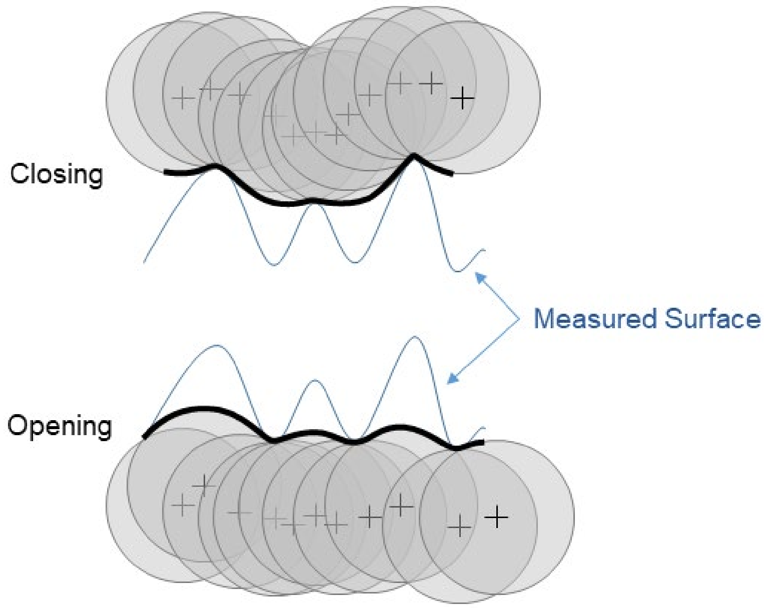

Figure 2. A closing filter acts as a virtual gasket placed onto the test surface, pressing into the peaks and leaving voids below. An opening filter exposes peaks that are sharper than a given radius which may concentrate stress.

A closing filter acts as a "virtual gasket" that follows the peaks and leaves voids in the regions of the valleys. By analyzing the gaps created by the closing filter we can predict potential leakage under an actual gasket, or identify the presence of sharp valleys where stress concentrations could lead to cracking.

An opening filter highlights the peaks in a surface that are sharper than a given radius (Figure 2, right). These sharp peaks can be related to increased contact stresses, oil film penetration points and cosmetic defects.

Perhaps most important, closing and opening filters can be adjusted to explore how changes in materials, manufacturing processes and tolerances might improve performance. Decreasing the radius of a closing filter allows the "ball" to enter more valleys, thereby modeling a more compliant gasket material. Raising the cutoff wavelength for the waviness profile increases how much the virtual gasket will "crush" peak material. This information can show how changing the relative hardness of mating surfaces will affect the seal. This type of exploration can be extremely valuable for understanding root causes and proposing solutions to manufacturing challenges.

Using a Closing Filter to Predict Leakage

In Figure 1 we showed two surfaces that were indistinguishable by the common parameters Ra, Rz and Wt. In Figure 3, a closing filter with a radius of 5000mm is applied to the waviness profile for both surfaces. When applied to the first surface, the gentle change in shape is highlighted with only small voids below the surface. When the same closing filter is applied to the second surface, large, repeating void areas are readily visible. If we are considering whether these surfaces would form good seals, the large void areas in the second surface would be of particular concern.

In order to quantify such leak paths, the functional parameter Wvoid (void area per unit length) was developed. Wvoid (shown via the OmniSurf software in Figure 3) can be tracked as a measure of sealing quality. The parameter is normalized per unit length, making it independent of the evaluation length and therefore more repeatable and stable.

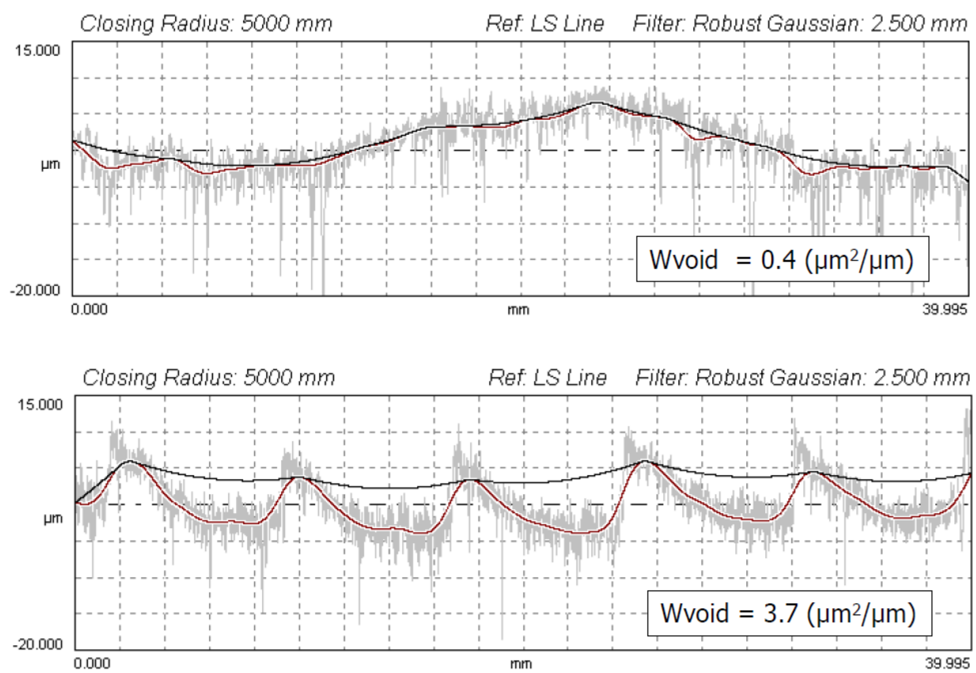

Figure 3. Where Ra, Rz and Wt could not discern a leakage difference between these two surfaces, the Wvoid parameter, generated based on a closing filter, located and quantified potential leak paths.

A Closing Filter as a Virtual Feeler Gauge

A closing filter can also be used as a “feeler gauge” to locate potential stress concentrators. Figure 4, left, shows a feeler gauge being used to verify the radius of a crankshaft fillet. This Go-NoGo measurement looks for small radii where the shaft would be most susceptible to cracking. The use of the feeler gauge, however, depends to a great extent on the individual inspector’s interpretation of how much light is visible through the gauge gap.

On the right in Figure 4 is a laser line scan of an elliptical fillet. By applying a closing filter to this scan we can measure the departure of the surface from its specified value (the red area) and locate the smallest radius. This method is far more repeatable than a physical feeler gauge and provides a quantitative rather than qualitative evaluation of the fillet. Furthermore, whereas the feeler gauge is typically only used for a “simple radius,” the morphological filter can be applied to any geometry.

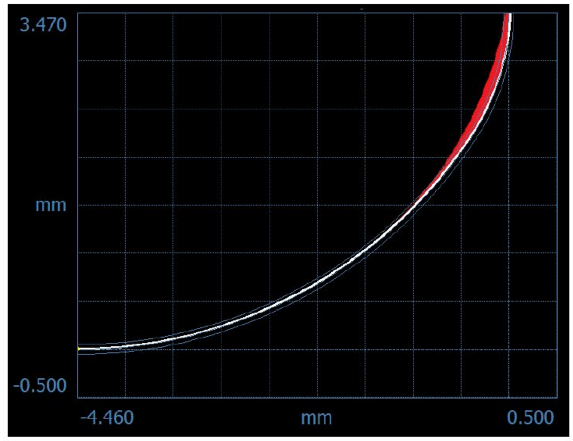

Figure 4. A closing filter acts as a virtual feeler gauge, repeatably locating the sharpest radius on a fillet where stress is most likely to concentrate.

An Opening Filter Reveals Sharp Bumps

An opening filter is used in applications where bumps or peaks are more critical to function that the overall waviness of the surface. A common example is a roller bearing, where local stresses along the surface and its edges must be managed, typically by crowning the surface.

Two controls must be employed to ensure that the surface will wear correctly. First, the general shape of the crown must be maintained, which can usually be handled using traditional profile measurements. Secondly, local bumps within the crown, which would cause stress, must be controlled. This control is best handled by a morphological opening filter and the Wcvx (“waviness convexity”) parameter.

Figure 5 demonstrates the application of the opening filter on a roller bearing waviness profile (shown in OmniSurf software). In the graph we can see the general crown shape, but we also see sharp, stress-causing peaks protruding above the opening filter profile. The largest upward peak (relative to the opening profile) is reported as Wcvx. By placing a tolerance limit on Wcvx we can specify and control the sharp peaks which could lead to premature part wear or failure.

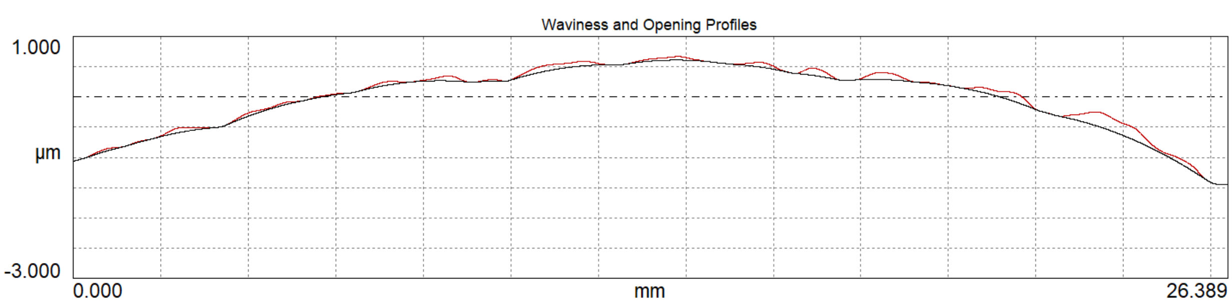

Figure 5. The Wcvx parameter, derived from the application of an opening filter, reveals the sharp bumps on a roller bearing that can cause increased stresses.

An Opening Filter Identifies Cosmetic Defects

The Wcvx parameter also proves useful for detecting blemishes that are discernable to the human eye but escape common parameters. Figure 6 shows a cosmetic panel which passed physical inspection but failed visual inspection. An opening filter was again applied here, and the Wcvx parameter was measured. In this case the analysis revealed a ridge in the surface. The eye accepts gentle changes in the surface shape, even if they are relatively high. However, sharper features register to the viewer as defects, even in if they are relatively small. In further study the Wcvx parameter was used to determine the threshold at which sharp features were viewed is unacceptable blemishes. A quality check was established specifying a Wcvx limit to control these features.

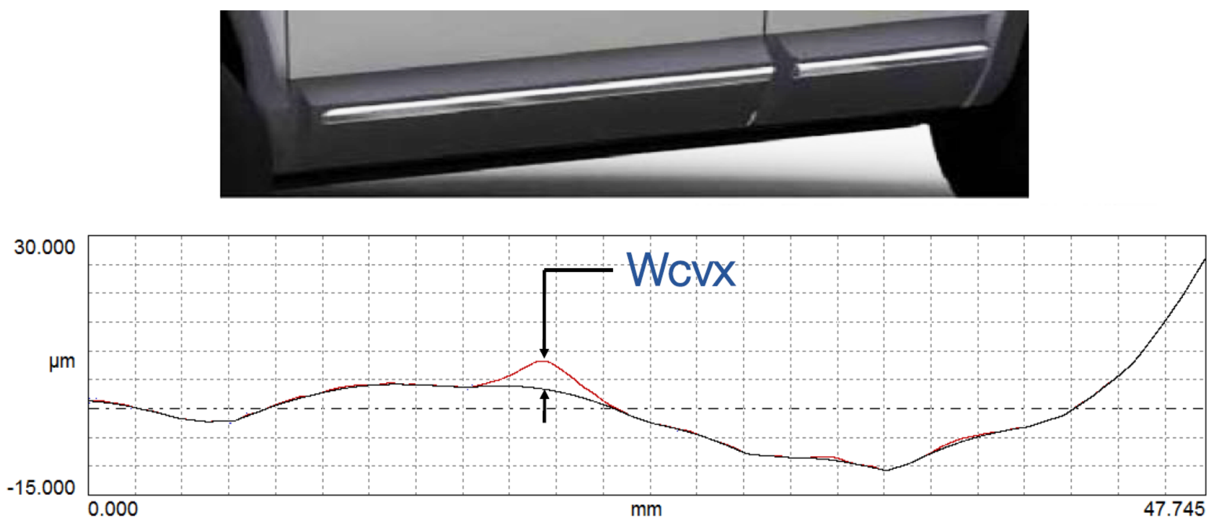

Figure 6. The Wcvx parameter was also helpful in determining the size of ridges or bumps that registered as cosmetic defects.

Morphological Filtering in 3D: A Closing Filter Locates Zones of High Stress

Morphological filtering can be extended to 3D, areal surface data as well. Instead of gap areas below a profile, we now see a "gap surface," based on the difference between a closing surface and the test surface. The gap surface can be used to explore leak paths, or to locate areas of maximum stress.

Figure 7 shows a measured surface in OmniSurf3D software. The 3D measured surface (left) is covered by machining marks from various operations. As the measured component is used in a high stress environment it is critical to locate stress concentrators that may lead to cracking. It would seem useful to look for the deepest scratches to predict where cracking may occur. However, cracks tend to form at the *sharpest* concentrators, not necessarily at deep departures.

On the right of Figure 7 a closing filter has been applied to the surface. The yellow area on the right "void surface" reveals the sharpest valley, of greatest concern for cracking, despite all of the competing surface marks.

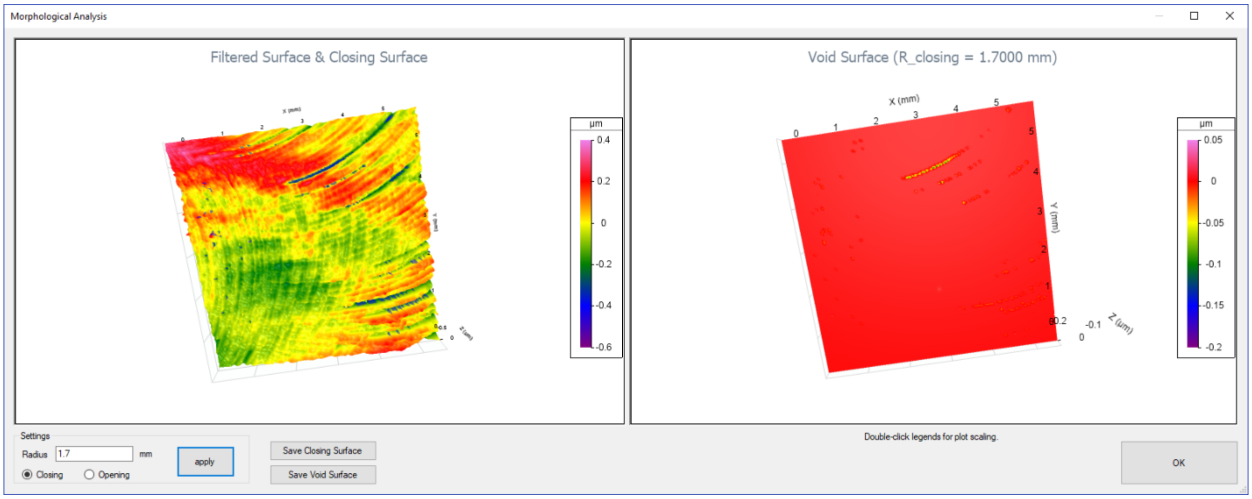

Figure 7. The 3D surface on the left is covered with machining marks. OmniSurf3D's closing filter produces the void surface on the right. This reveals that the area of highest stress is not the deepest scratch but the sharpest valley (shown in yellow on the right).

Conclusion

Morphological filters and functional parameters make it possible to measure the properties of a surface most specifically tied to a desired function. Closing and opening filters can reveal the aspects of a surface hidden in the height data that will impact the function. These filters can be used to explore changes to materials and methods that may address the root causes. Such techniques give engineering staff powerful and interactive tools to better understand surface function. More important, they provide parameters that can be specified on prints to guide production and to review critical features over the life of a component.

More information on morphological filtering, OmniSurf and OmniSurf3D software and Digital Metrology Solutions is available at www.digitalmetrology.com.