Understanding and Controlling the Source of Gear Noise

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There is an irony in the automotive industry: as vehicles are becoming quieter, noise control is becoming more important. Electrification has reduced engine noise, which means other noise sources are now much more prominent. Specifically, one of the most talked about noise sources is gears.

Gear surfaces have always received attention from the friction and durability standpoints, and there has certainly been some level of attention paid to deviations in gear geometry. Much less attention, however, has been paid to waviness along a gear tooth. This "middle wavelength" texture—on the order of perhaps 2 or 3 undulations between the root and tip of a gear tooth—has been found to directly correlate to gear noise [Refs. 1-2].

Middle frequency waviness on gear teeth has been correlated to gear noise, similar to the way chatter in a bearing race has been shown to cause bearing noise. Surface waviness along a gear flank causes cyclic variations in tooth stresses and meshing. These cyclic variations can

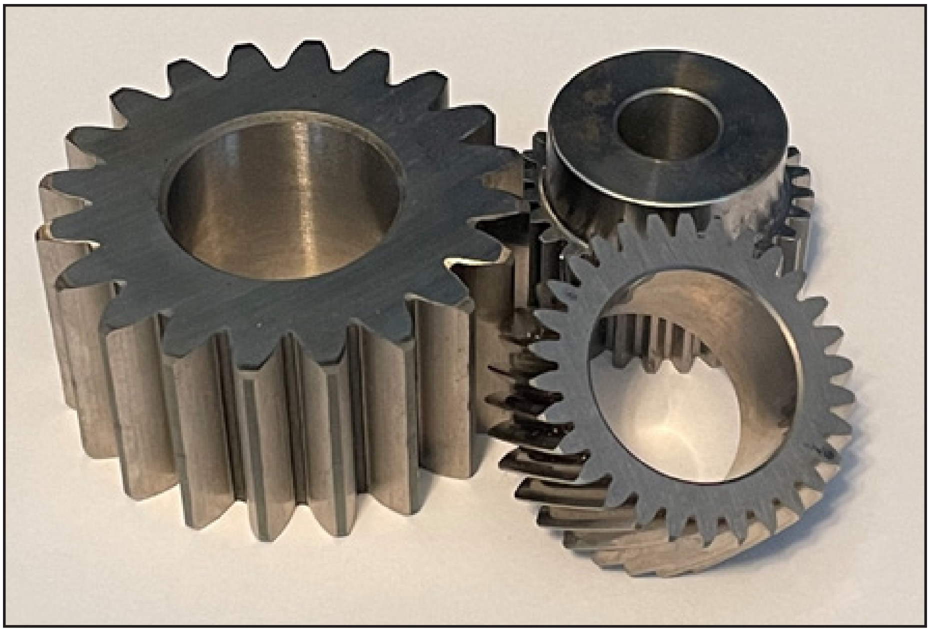

Figure 1 Gear tooth noise can be a prominent source of noise, especially in cars, as engines have become quieter.

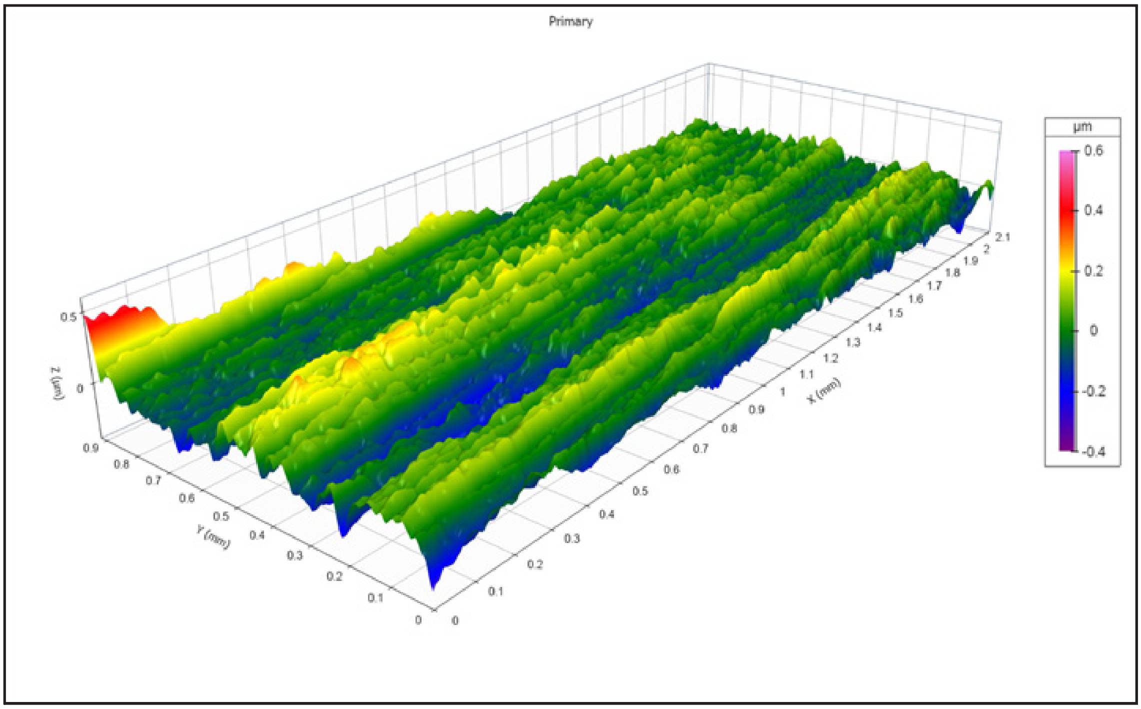

Figure 2 An areal (3D) measurement of a gear tooth after removing the involute shape.

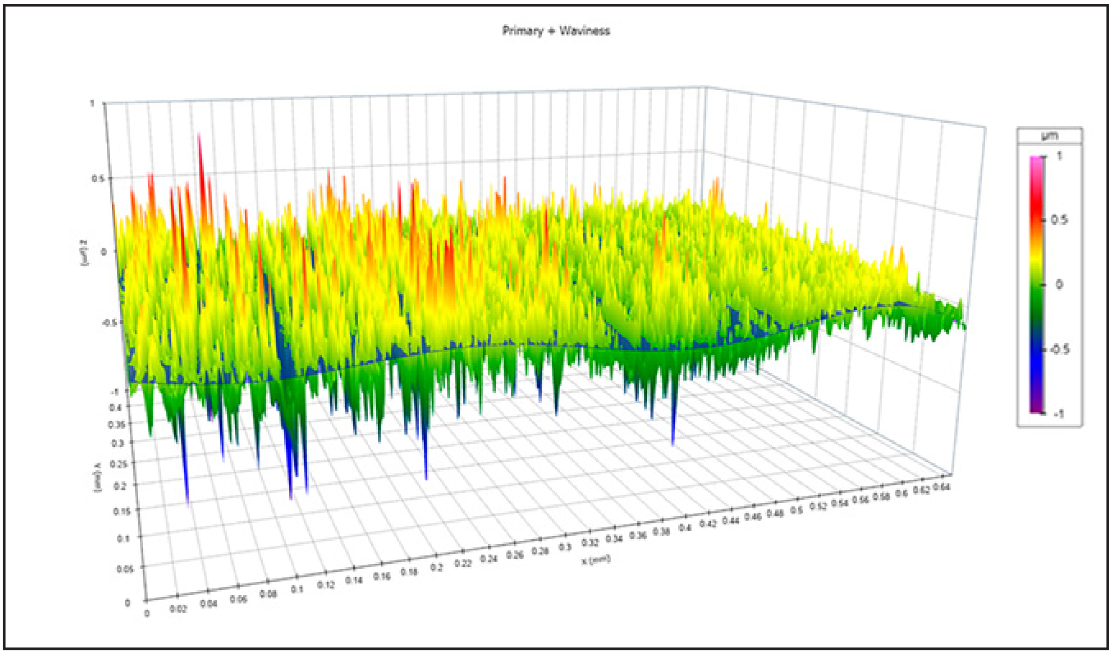

Figure 3 Filtering can isolate the waviness (blue surface) from the overall surface texture.

ultimately lead to vibrations and noise in the audible range [Ref. 3].

Unfortunately, these waviness features often go undetected as they are typically much smaller than the overall form tolerance limits for the gear profile. Nevertheless, this waviness can cause noise and therefore needs to be controlled—which is why this aspect of gear surface texture is getting a lot more attention.

Measuring Gear Texture

Gear tooth waviness can be measured using a 2-dimensional measurement system such as a stylus profiler. However, the configuration and range of a stylus often limits how much of the gear tooth can actually be measured. Larger shapes such as waviness can easily go undetected when the profile length is of a similar length scale as the space between waviness peaks.

To better understand gear waviness, many companies are turning to areal (3D) surface analysis. The resulting data can be far more impactful than a simple profile graph, providing a visual map of the surface features that may be causing noise (Fig. 2).

The ability to see and interact with texture helps connect texture to function. Nevertheless, to address the noise issue we ultimately need to produce an analysis method (geometry removal and filtering) and numerical values (parameters) that can be used to tolerance and control the waviness.

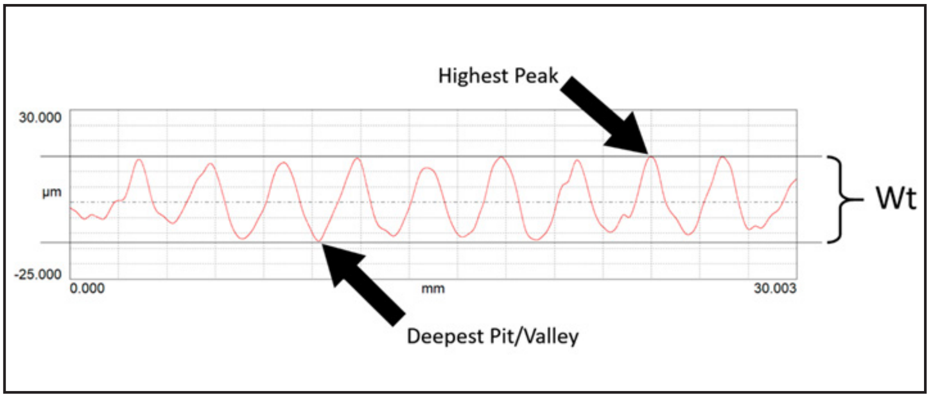

Figure 4 The Wt parameter is based on the highest and lowest points in a 2-dimensional profile.

Filtering for Waviness

To isolate the waviness "shape" in a 3-D dataset, we first remove the overall geometry, or form, of the gear tooth itself. Multiple options are available for removing the tooth geometry. A 4th order polynomial fit is typically the best choice for this operation as it adapts to various positions along an involute. Once the geometry has been removed, we see the surface texture as shown in Figure 2.

Texture consists of multiple "wavelengths" of features, ranging from short-wavelength roughness through longer wavelength waviness. The process of filtering separates the waviness from roughness at a particular cutoff wavelength (Fig. 3). The filter type and cutoff both greatly affect the results and should be specified for a measurement. A 2nd order Gaussian or spline filter type typically provides an accurate fit. The cutoff wavelength will depend on the size of the features of interest, which will vary with the size of the gear.

In Figure 3 the waviness (shown in blue) has been isolated and can now be analyzed separately from the remaining surface texture.

Typical Parameters Used to Describe Gear Waviness

Once the waviness profile/surface is established via filtering, we can then describe the height of the waviness with numbers. Waviness has traditionally been measured in 2-dimensional data, using the Wt (Waviness – total) parameter. Wt reports the largest peak-to-valley height for the waviness profile (Figure 4).

Similarly, in areal (3D) analysis the St parameter gives the total peak-to-valley height over a surface, as in Figure 5.

The challenge with Wt and St is that both parameters measure the extreme highest and lowest points in the dataset. Since gear tooth measurements extend from the root to the tip of the tooth, the extreme points are almost always at the ends/edges of the data where the tooth blends into the hub or rounds over at the tip (Fig. 6). These extreme heights tend to dwarf the mid-wavelength waviness at the center of the tooth, which is the actual noise source. Wt or St values, therefore, are reporting peaks and valleys that are not associated with gear noise.

Better Parameters to Control Gear Waviness

To get reliable numbers that describe this noise-causing waviness, we must exclude the points at the extreme ends/edges of the data and focus on the peaks and valleys that are fully "contained" within the tooth data. However, as we mentioned earlier, the end points are required in order to ensure that measurements occur in the same location each time.

To address the issue, the parameter Wtc was developed and appears in the *OmniSurf* software package (Digital Metrology Solutions). Wtc measures the total waviness for "contained" peaks and valleys in a profile (Fig. 7). Similarly, the 3-D parameter Stc measures the height of contained peaks and valleys for a surface (Fig. 8). Stc is available in the *OmniSurf3D* software package (Digital Metrology).

Wtc and Stc target the actual noise-causing features in a measured gear surface. These parameters also produce much more stable values since they ignore edge points. For example, if the highest peak is at the edge of a measurement and the measurement location is moved slightly, a different highest peak will be detected. However, the "contained" peaks and valleys are more likely to remain consistent.

Working with areal (3-D) data we can also analyze the Stc parameter in the particular direction that matters most for a given application (Fig. 9). For example, noise in a spur gear will be more sensitive to waviness in the root-to-tip axis. The Stc-x and Stc-y parameters enable analysis of all profiles in each direction, reporting the average contained peak-to-valley value for the respective profiles/surfaces.

The ability to distinguish waviness features and report the magnitude in each direction along the tooth can be very powerful for diagnosing functional issues like noise and for controlling process variables in manufacturing.

Summary

As measurement and analysis techniques have improved, it has become increasingly possible to measure the aspects of surface shape and texture that influence a part's function. In the case of gear noise, the traditional toolset has proven unreliable. However, the custom parameters, Wtc (2-D), and Stc/Stc-x/Stc-y (3-D) can directly track the gear tooth waviness features that can cause gear noise.

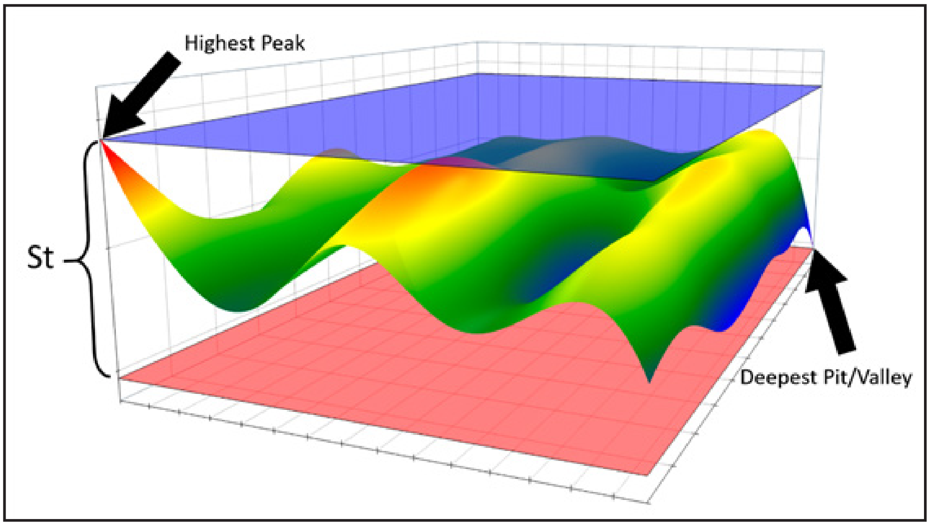

Figure 5 The St parameter is the 3-dimensional counterpart to Wt.

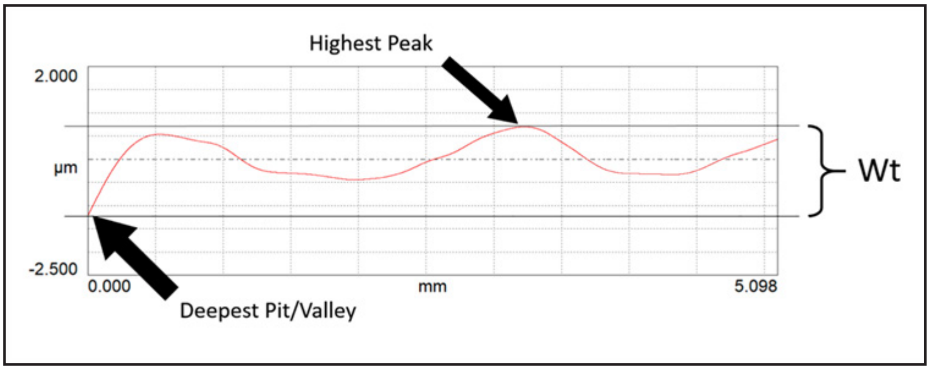

Figure 6 In a gear measurement the extreme points are almost always at the ends of the measurement—at the root and tip—eclipsing the waviness in the middle of the tooth which is typically responsible for gear noise.

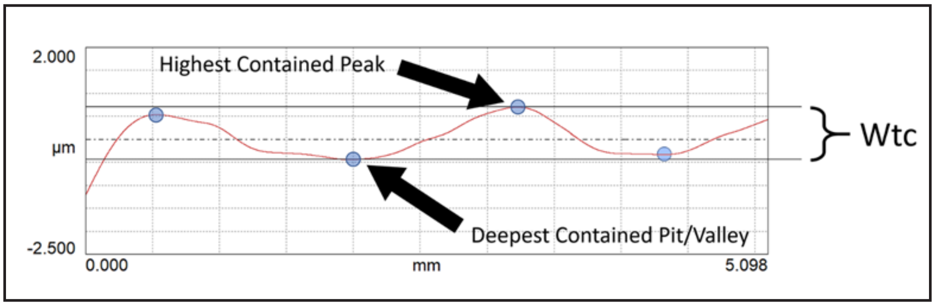

Figure 7 Wtc measures waviness in the middle of the tooth, where noise may occur.

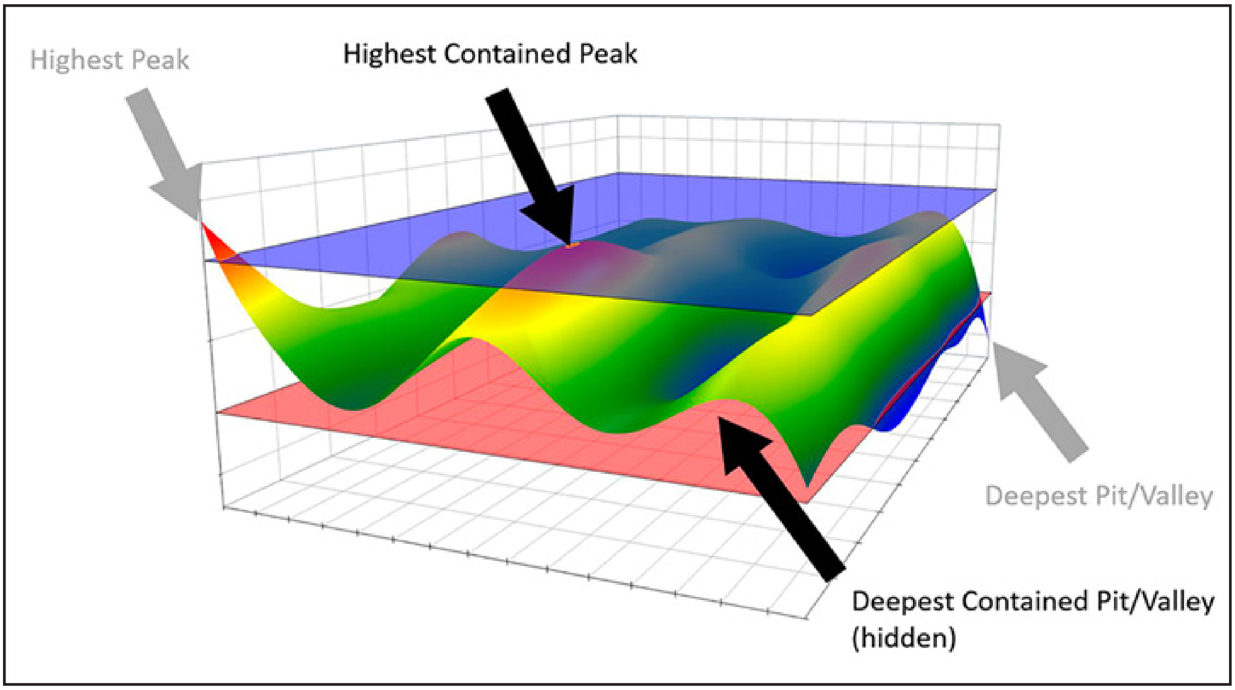

Figure 8 By excluding the edge peaks/valleys and focusing on contained pits/valleys, Stc correlates better to the gear tooth waviness that may lead to noise.

References

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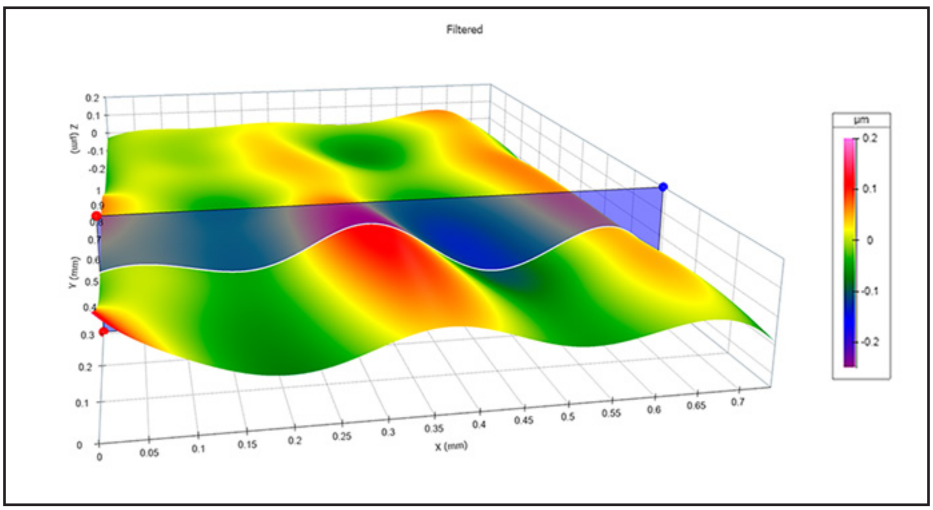

Figure 9 The Stc parameter can be analyzed in the particular direction that matters for a given application.

Dr. Mark Malburg is the president of Digital Metrology Solutions. With over 30 years in surface metrology, he is the chief architect of a range of standard and custom software for surface texture and shape analysis. Dr. Malburg has consulted in numerous industries ranging from optics to aerospace. He is a frequent participant in standards committees and has helped shape many of the standards that govern surface specification and control.

Mike Zecchino has been creating technical content and resources related to metrology and many other industries for over 20 years. His articles have appeared in dozens of publications, and his training materials and videos support numerous measurement instruments and technologies.