

Specification and Measurement of Plateau Honed Surfaces

BY MARK MALBURG AND MIKE ZECCHINO

The surface texture of a cylinder bore can have a significant impact on engine performance and durability. Surface texture parameters have been developed to control many aspects of this texture in order to improve efficiency, gas consumption, emissions, and wear.

In this article, we look at the types of cylinder bore surface textures, methods for measuring and analyzing the texture, and the best parameters to track texture based on the particular type of surface being produced.

Evolution of cylinder bore surfaces

Historically, a cylinder surface was created by honing the cylinder bore once, to create a single surface texture. The engine's own action was then relied upon to “run in” or “break in” the surface, wearing away the peaks and leaving behind areas of “plateaus.” A single-honed surface is shown at the top of Figure 1.

Starting in the 1980s, concerns for fuel economy and emissions drove a stronger push for more efficient engines with tighter tolerances. This led to the development of processes to create the plateaued surface in the factory, rather than waiting for the engine to do the work. Such a double-honed, “plateaued” surface is shown in the middle of Figure 1.

High performance engines (racing, diesel, etc.) may require even more extreme honing to contend with racing fuels, thinner lubricants, and, in some cases, brief functional lives with virtually no run-in period. An extremely plateaued surface is shown at the bottom of Figure 1.

Figure 1. Three types of cylinder bore surface texture.

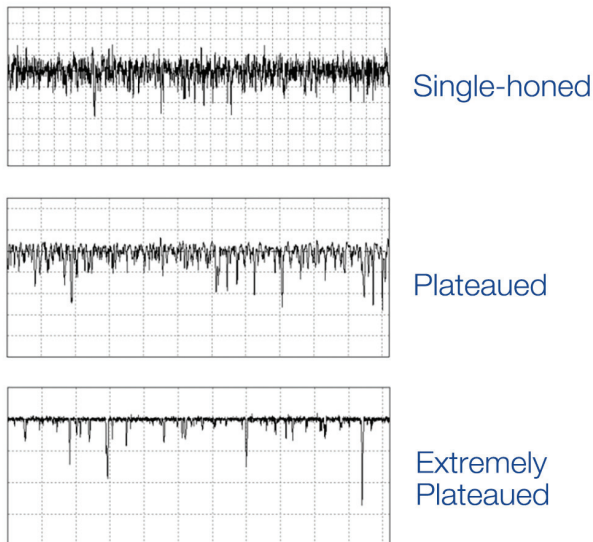
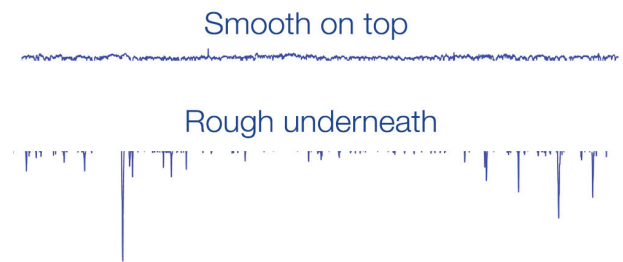


Figure 2. Plateaued surface texture consists of flat plateaus and valley regions.



Plateau honed surfaces

An engine's cylinder bore surface is designed to perform a balance between two, often competing functions: it must provide a high degree of sealing and load bearing, while simultaneously offering a low degree of friction. To make this happen, a cylinder bore surface is typically “plateaued,” consisting of a smooth upper surface and deeper valleys (Figure 2).

The first, coarse honing operation creates the valley structure, to retain lubrication and trap micro-debris that is created as the surface wears.

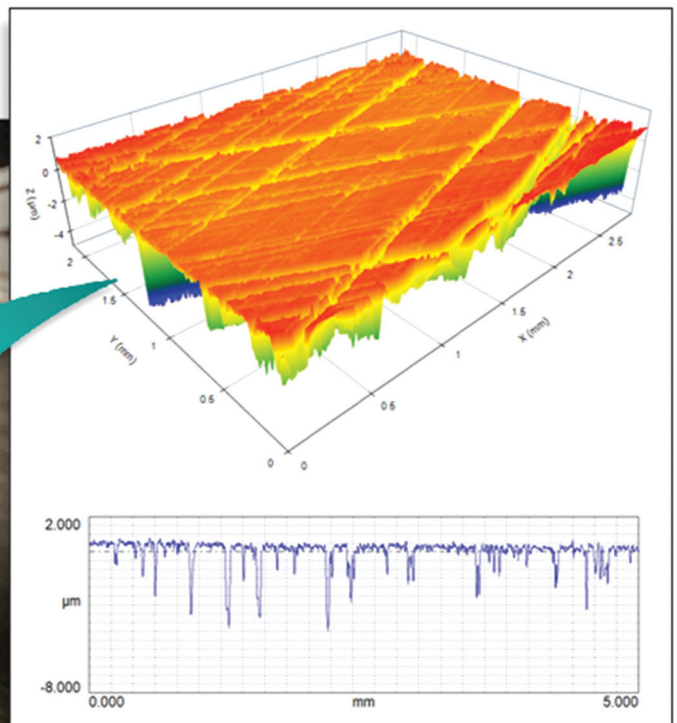
The plateau regions are created by one or more additional, finer honing operations. Plateaus provide a durable sealing surface against the piston rings to contain combustion gases and prevent oil consumption. The plateaus are also optimized to minimize friction.

These surface, then, strike a balance between providing sufficient plateau material for sealing and load bearing, and sufficient valley regions to carry lubrication and debris.

Measuring the texture of plateaued surfaces

Most cylinder bore measurements are performed with a stylus-based roughness gauge (Figure 3). The stylus is moved across the cylinder bore to acquire one or more profile measurements, such as those shown in Figures 1 and 2.

The measurement from the stylus includes the entire spectrum of spatial wavelengths, ranging from short-wavelength roughness through longer-wavelength waviness and form. To isolate the roughness, a series of filters are applied, first to remove the very short wavelengths (typically noise), then to divide the remaining data into roughness and waviness profiles. The roughness profile is then analyzed to determine the roughness parameters described on the following pages.



Courtesy QMP
Racing Engines.

Parameters for controlling cylinder bore texture

Each of the types of surfaces shown in Figure 2 are best controlled using different sets of surface texture parameters.

Traditional parameters

For a single-honed surface (sometimes referred to as a “peak honed” surface), the manufactured texture consists of peaks and valleys of all heights and depths. Over the initial run-in period the action of the piston rings will wear away the higher peak material, leaving behind the plateaus.

Traditional roughness parameters such as Ra (Average Roughness), Rz (10-point Roughness Height), and Rmr (Material Ratio) are often sufficient to control the honing process for a single-honed surface (Figure 3). As the surface wears and becomes more plateaued, Ra tends to be most sensitive to the plateaus since there are more data points in the plateau. Similarly, as the surface wears, Rz tends to be most sensitive to the valleys as they make up most of the peak-to-valley distance. Rmr (based on a user-defined depth) may loosely describe the amount of material where the plateaus and the valleys meet.

Though they were developed more than 80 years ago, the basic parameters Ra, Rz, and Rmr still provide useful feedback for surfaces with a wide distribution of peaks, valleys, and intermediate heights.

The Rk parameter family

When honed surfaces became more plateaued, it became apparent that Ra, Rz and Rmr could not robustly distinguish a plateau honed surface from a single-honed surface. Very different surfaces produced similar values for these parameters.

To better describe plateaued surfaces, researchers developed the “Rk” family of parameters, which are based on the Material Ratio curve. This curve shows the percentage of the surface that is material, versus air, at ever-decreasing depths into the surface

Figure 3. Traditional parameters are sufficient for single-honed surfaces.

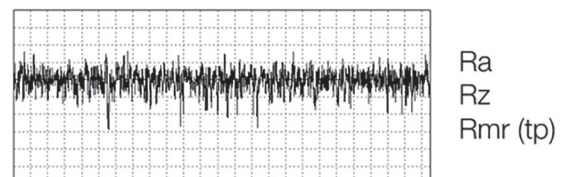
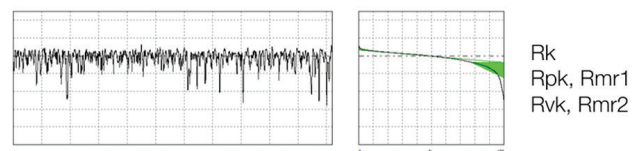


Figure 4. The Rk family parameters are better for controlling plateaued surfaces.



(Figure 4, right). The individual parameters (Rk, Rpk, Rmr1, Rvk, Rmr2) quantify the peaks, valleys, and core (or kernel) material, respectively. These parameters allow for better control of plateau honing as they are more targeted toward the individual geometries within the surface.

The Rk family of parameters work well in cases of general plateauing, where extremely plateaued surfaces are not required. These include not only cylinder bores but gears, bearings, transmission components, and many other surfaces required a degree of sealing, loading, and/or friction control.

(continued)

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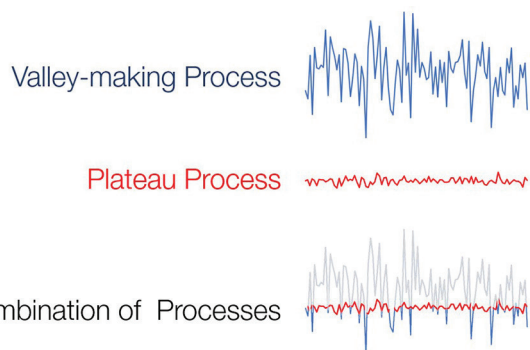
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The Rq (Material Probability) family of parameters

Cylinder bore surfaces for high-performance engines tend to be more extremely plateaued, with a strong distinction between the peaks and the valleys. Unfortunately, neither the traditional nor Rk family of parameters can describe these surfaces sufficiently. The more extremely plateaued the surface is, the worse the Rk parameters perform in terms of describing it.

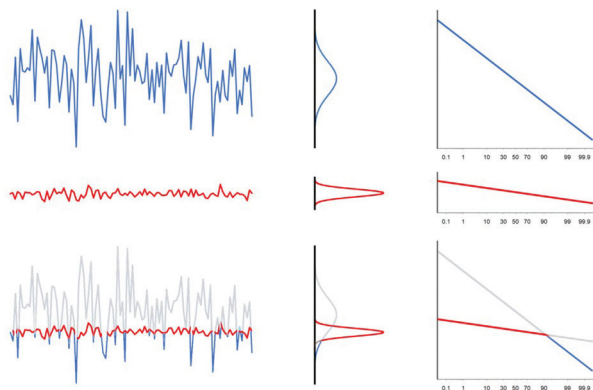
An extremely plateaued surface can be considered to consist of two distinct distributions. The rough, first process is truncated by the second, fine hone (Figure 5).

Figure 5. An extremely plateaued surfaces consist of two distinct distributions. Courtesy The Surface Texture Answer Book*.



Mathematically, we can think of the valley-making process as producing a wide, random distribution of heights (blue), and the plateau-making process as creating a narrow, random distribution (red). Plotted on probability paper, these distributions become straight lines that meet with a sharp knee, forming a material ratio curve like the one described above. However, in this case, the material ratio curve is plotted with a “probability” x-axis, which results in the “material probability” curve shown in Figure 6.

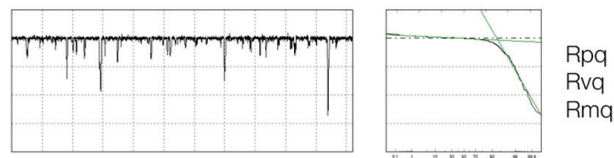
Figure 6. The combined curves form the material probability curve—a material ratio curve plotted with a probability x-axis. Courtesy The Surface Texture Answer Book*.



The Rq family parameters derived from this curve can robustly distinguish the surface regimes for extremely plateaued surfaces (Figure 7). The Rq parameter family includes three independent

parameters: Rpq (the RMS roughness of the plateaus), Rvq (the RMS roughness of the surface that produced the valleys), and Rmq (the material ratio where the plateaus meet the valleys).

Figure 7. The Rq parameters, derived from the material probability curve, are best for describing highly plateaued surfaces.



The Rq family of parameters (Rpq, Rvq and Rmq) works best for two-process surfaces with discrete plateau and valley regimes. These parameters are less reliable when the distinction between plateaus and valleys is less clear. In fact, if the surface isn't distinctly plateaued, these parameters may provide no results at all.

Unlike the Rk parameters, with the Rq family of parameters we can independently monitor the peaks, the valleys, and their relative positions. A change in one parameter does not mathematically result in a change in the other parameters.

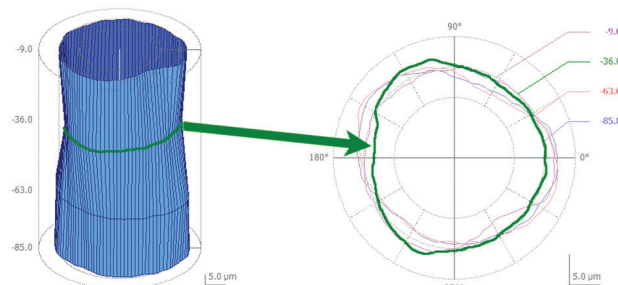
Other aspects of cylinder texture

Several other aspects of cylinder bore texture also have a significant impact on engine performance and should be monitored as well.

Cylindricity

The three-dimensional cylindricity of a cylinder bore is an important consideration. During operation the piston rings will bend to follow these shape errors. However, the rings may not be able to conform and seal to large, severe shape errors with sharper curvatures. Figure 8 shows a bore with a complex three-lobed shape that shifts with increasing depth into the bore. A simple, two-point diameter gauge cannot readily detect these kinds of shape errors—particularly if there are odd-lobed shapes. Scanning devices with a precision reference center are required to truly measure roundness and/or cylindricity.

Figure 8. A 2-point diameter gauge cannot readily detect complex shape errors—particularly if there are odd-lobed shapes.



Crosshatch angle

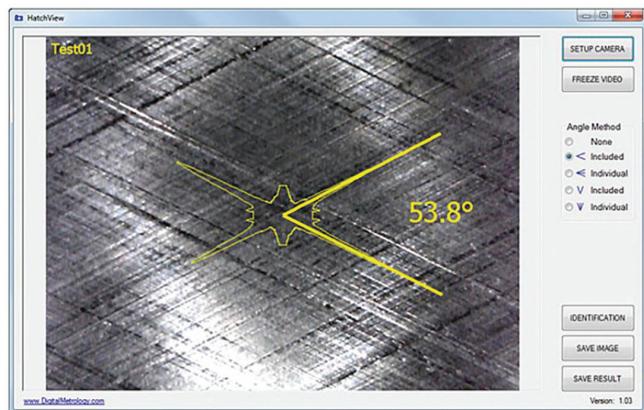
The movement of the hone into and out of the bore results in a “crosshatch angle” in the valley regions (Figure 9). Oil consumption and combustion gas flow are directly related to the

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crosshatch angle, so maintaining the angle is also important to performance.

Figure 9. Crosshatch angle is important for oil consumption and combustion gas flow.



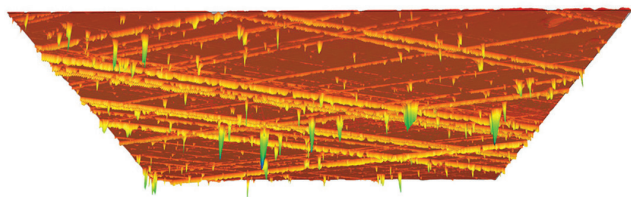
Pullouts and porosity

A plateau honing process applied to a cast surface may tend to tear out chunks of graphite from the surface, leaving pits and pores that could be many times deeper than the valley structures.

The measurement and control of these “pores” is a challenge for stylus-based measurement because the stylus will often trace through the side of a pore rather than the bottom or will miss pores entirely. Furthermore, the profile data cannot distinguish inadvertent pores from intentional valleys.

An areal (3D) measurement, typically from an optical instrument, makes the pores easier to visualize. The areal data in Figure 10 was acquired in Digital Metrology’s OmniSurf3D software.

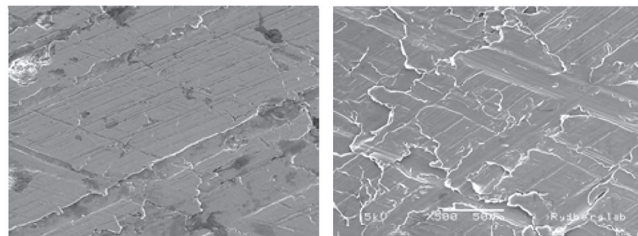
Figure 10. An underside view of an areal measurement. Areal (3D) imaging is more effective for visualizing pores and pits and discerning them from intentional valleys.



Torn and folded material

During the honing process, the honing stones may smear the peak material rather than shearing it. These areas tend to be thin, brittle, and hard, tending to break off and become debris. Torn and folded metal is most easily seen in SEM images, such as those in Figure 11. Research is under way now to determine how much torn and folded material is acceptable, as well as methods to quantify the amount of torn and folded metal in a given image.

Figure 11. SEM images of cylinder liners with different degrees of folded metal. From Cylinder Liners and Consequences of Improved Honing.**



Other considerations for cylinder bore measurements

Skidded vs skidless stylus

There are two common types of stylus measurement systems: skidless and skidded (Figure 12). In a skidded instrument, the measurement probe includes a radiused skid, which follows the general shape of the surface while the stylus detects the roughness. Because of their robustness and ability to tolerate vibration, skidded systems are by far the most commonly used for production cylinder bore measurements.

Figure 12. Two types of stylus instruments. The skidded type is most common for production cylinder bore measurements. Courtesy The Surface Texture Answer Book*.



Filter settings will change roughness parameter values

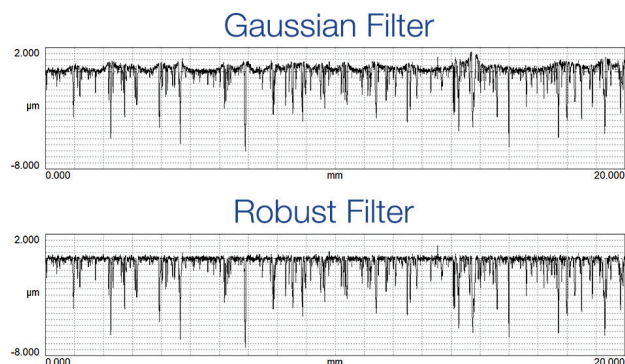
Filtering settings greatly impact the roughness and waviness profiles, and therefore the roughness parameter values. Cutoff wavelengths must always be stated when specifying roughness values, and used when analyzing the data, in order to ensure consistent results.

The type of filter will also critically impact the measurement results. A traditional “Gaussian” filter is the default type for most instruments—and often the only option for handheld gages. Unfortunately, the deep valleys of a plateaued surface can cause difficulties for a Gaussian filter, resulting in false peaks in the roughness data in the vicinity of the valleys. An improved “robust” filter does a much better job of following the trends of a plateaued surface and has therefore been standardized by ISO. Most PC-based surface texture software includes the robust filter as an option. Data from handheld gages can be analyzed in an off-line software that includes the robust filter, such as Digital Metrology’s OmniSurf.

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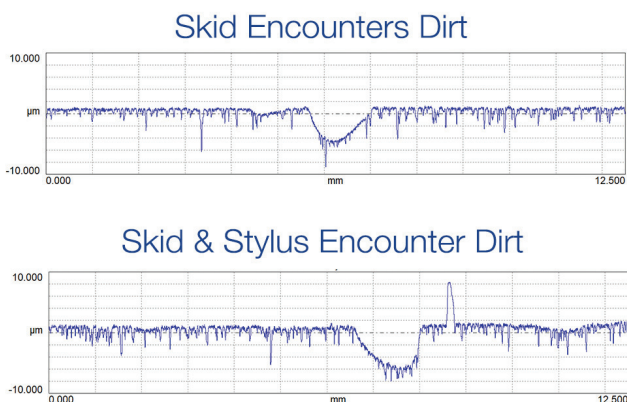
Figure 13. The deep valleys in a plateaued surface are poorly handled by a traditional Gaussian filter. A robust filter is a much more effective tool for plateaued surfaces.



Dirty parts can lead to incorrect data

When the stylus skid encounters debris, it rises up and over the debris, causing the stylus to reach farther down and report an artificial dip. When the stylus runs directly over a piece of dirt, it measures it as a sharp spike in the roughness profile. Figure 14 shows both of these types of data errors.

Figure 14. Error caused by the skid (above), and the stylus and skid (below), passing over debris. Courtesy The Surface Texture Answer Book*.



Both types of error can lead an incorrect analysis of the surface texture and roughness parameters. The only reliable approach to avoiding them is to maintain a clean part surface, and to remeasure when errors like these occur.

A well-maintained measurement system is critical

In addition to maintaining a clean part, to ensure accurate stylus measurements:

- make sure the stylus tip and traverse are in good condition
- maintain the instrument's calibration
- verify that all settings in your software are consistent between measurements
- make sure fixturing is in good working order
- minimize vibration in the measurement environment.

Next steps to understand cylinder bore texture

In this article we've touched on several ways to measure, analyze, and control cylinder bore texture, as well as some pitfalls to avoid. The article digitalmetrology.com/tutorials/plateauhoning goes into these topics in-depth. The Surface Texture Answer Book (Musolf and Malburg, 2021)* includes thorough descriptions on the parameters mentioned here, as well as the material ratio curve and material probability curve.

Ultimately, the best way to understand surface texture is to explore actual data. Software such as Digital Metrology's OmniSurf, OmniSurf3D, and HatchView are excellent tools for visualizing and interacting with cylinder bore measurements. All three packages can be used independent of any measurement systems, making it possible to study data at length without tying up instrument time. Observing the shapes of various surfaces and becoming aware of trends and difference can quickly lead to a great deal of knowledge regarding the manufacturing of cylinder surfaces and their performance implications. ■



Dr. Mark Malburg (pictured above left) 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 automotive to optics. He is a frequent participant in standards committees and has helped shape many of the standards that govern surface specification and control.

Mike Zecchino (pictured above right) has been creating technical content and resources related to metrology and measurement, renewable energy, optics, and other fields for over 20 years. His articles have appeared in dozens of publications, and his training materials and videos support numerous measurement instruments and technologies.

*Musolf, C., Malburg, M., The Surface Texture Answer Book. 2021.

**Anderberg, C., Cabanettes, F., Dimkovski, Z., Ohlsson, R. et al., Cylinder liners and consequences of improved honing. NT2006-11-71. 2006.

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