Improving Gear Manufacturing Quality With Surface Texture Measurement

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The working surfaces of gear teeth are often the result of several machining operations. The surface texture imparted by the manufacturing process affects many of the gear's functional characteristics. To ensure proper operation of the final assembly, a gear's surface texture characteristics, such as waviness and roughness, can be evaluated with modern metrology instruments.

What is Surface Texture?

Simply stated, the surface texture of a gear tooth is the surface that is the result of the manufacturing process. In machined gears, surface texture is the result of the tool passing over the tooth; in molded or cast gears, it is the combined result of the material, mold, and molding process.

In more technical terms, the manufactured surface can be defined by three general measurement categories: roughness, waviness, and form.

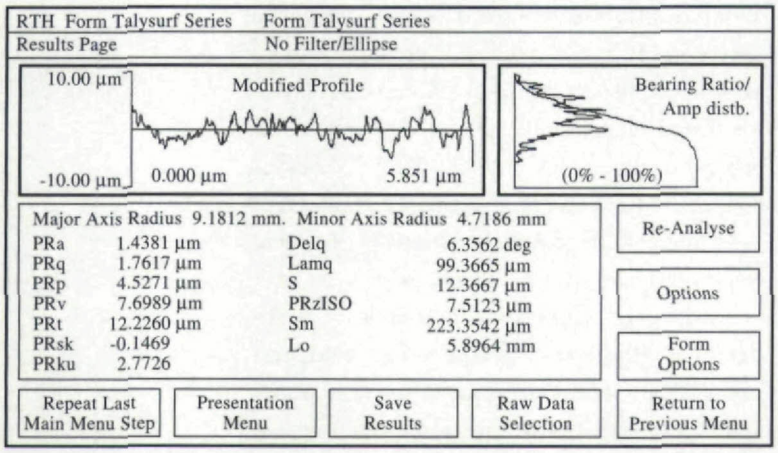

Fig. 1

On today's sophisticated metrological devices, these categories are evaluated by their wavelengths. The short wavelengths of roughness are caused by fracturing, cutting, grinding, or honing. The medium wavelengths of waviness represent short term machine errors, such as a single aberrant revolution of a spindle, while long wavelengths of form are the result of tool path errors, such as straightness.

The process of measuring and analyzing surface finish is called "surface texture metrology." When the technology of metrology is applied to gear manufacturing, the engineer has a powerful tool to assist the analysis of a gear's ability to retain lubrication, distribute force, run quietly, and withstand wear, all of which may be related to surface texture. Lubrication, for instance, is retained in the valleys that have been created on the surface. On the working surface, stress is increased by the presence of robust peaks and deep valleys. Noisy operation may be the result of waviness and chatter, and wear may be attributed to many causes, such as the lack of a load-bearing area.

How is Surface Texture Measured?

With the proper surface metrology equipment, common gear problems can be discovered before a gear goes into the final assembly. Currently, there are two basic categories of instruments used to evaluate surface texture: a) the simple roughness average instrument, and b) the more sophisticated engineering quality instrument.

Standard averaging instruments are low-cost devices that are commonly found on the shop floor. Because they lack the sophisticated technology required to measure complex forms and present multiple parameters, these instruments are capable only of the limited evaluation of a straight surface.

On the other hand, the engineering quality device is capable of detailed analysis of surface texture parameters, waviness parameters, radial size, and straightness. These instruments are generally found in the laboratory or inspection area, but smaller and more durable versions of this instrument are now available for use at the point of manufacture.

Recent Technological Advances in Metrology Instruments

The technological evolution from the averaging instrument to the engineering quality device is a giant leap in metrology. In fact, it can be said that the difference between the two is akin to the difference between superstition and science. A quick glance at the disparity between these two machines will make this difference immediately apparent.

The engineering quality instrument features a high resolution, wide range transducer to a) ease setup, b) permit operation with a range of surface forms, and c) offer improved accuracy by eliminating skids. Transducers with dynamic ranges of .04" make it easier for the user to stage the part being inspected. Accurate readings can be obtained when the traverse is not perfectly parallel with the surface to be measured. For the highly sophisticated user, a transducer with .24" range and .0000004" resolution is available. This transducer is frequently used to measure the size of circular shapes.

And the latest advances in transducers have led to the elimination of skids. Although they eased setup by establishing a local datum, skids also contributed to system error.

Two-axis coordinate measuring machine principles improve the metrology technique. The modern engineering instrument is a true two-axis coordinate measuring machine with extremely high resolution and very good straightness on travel. The high number of data points collected describe the surface with extremely high fidelity.

Digital electronics eliminate analog filters and improve stability. Because the metrology equipment now works with numbers rather than analog voltages, a computer is used to mathematically filter the results. This technique greatly improves accuracy and permits the use of filters with less distortion. The benefit is simple: more accurate measurement.

Today's instrument offers high-resolution display of results. Gone forever are strip chart recorders with their poor frequency response and balky operation. For highly accurate and readable displays, the most recently developed metrology equipment takes advantage of VGA graphics and high-resolution printers.

Mathematic removal of the circular form allows improved accuracy. Form removal techniques ensure accurate results on curved surfaces. The computer permits the quick and easy removal of mathematically defined and empirical forms. Once the form is removed, the texture is evaluated as if it were on a straight surface, providing improved accuracy while allowing easier analysis.

More advanced instruments also provide a wide range of analysis in the form of numeric parameters. With today's metrology equipment, the engineer has a wide selection of parameters from which to choose. These are the tools engineers depend on to numerically define an acceptable surface. Commonly used parameters include:

• Averaging parameters; Ra, Rq, Rpm, Rz (DIN).

• Waviness parameters: Wa, Wq, Wz (DIN).

• Peak parameters: Rp, Rv, Rti, Rt, Ry, Wp, Wv, Wt, Wti, Wy.

• Hybrid parameters: skew, kurtosis

• Amplitude distribution and bearing ratio (Abbott, Firestone) curve interpreters: Rk, Vo, Tp, Pc, HSC, Htp.

How Surface Texture Metrology Fits Into The Design and Manufacturing Process

When initiating a new design, a product engineer must choose the surface parameter which controls the features important to the function of the finished product. This is the description that is put on the print for the finished product. Only then can the appropriate metrology instrument and procedure be selected.

The manufacturing engineer's task differs from that of the design engineer. The manufacturing engineer is concerned not only with the finished part, but also with the part in process. If a gear is to be hobbed, ground, and honed, a prudent engineer knows he will need to control the surface texture at each stage to minimize cost and assure final quality. For example, if we can assure a consistent surface texture range from the hob, we can control the grinding operation to minimize

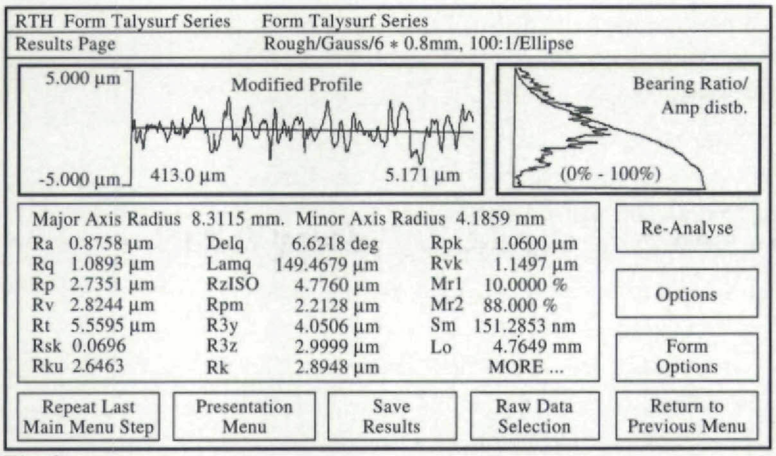

Fig. 2

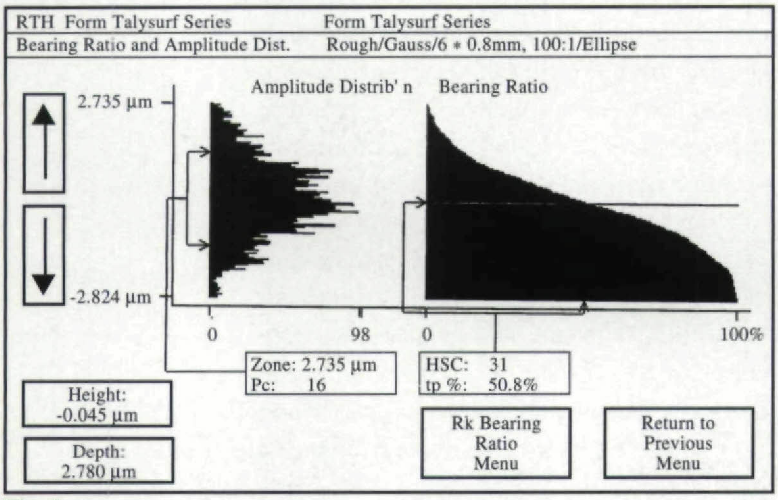

Fig. 3

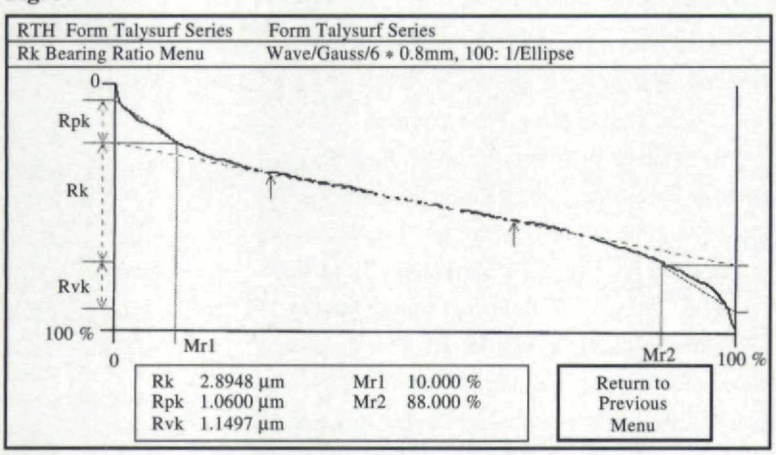

Fig. 4

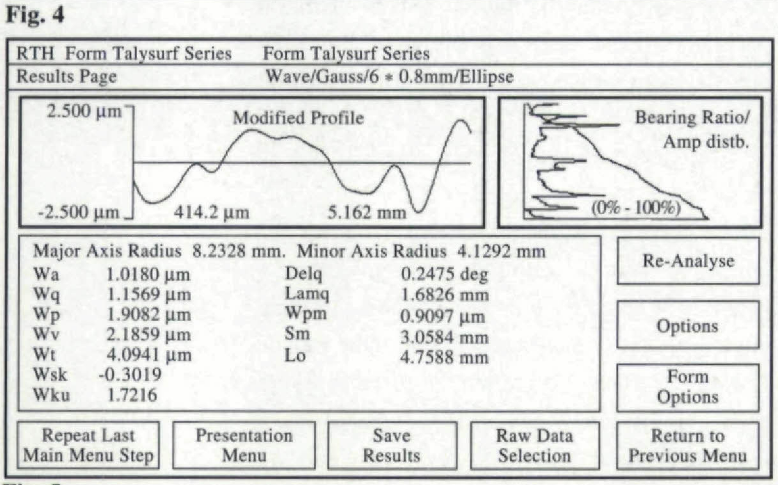

Fig. 5

cutting depths, reducing heat and distortion. A consistent grinding finish means we can predetermine the honing cycle time.

Case Studies

Let's turn to some practical examples. These charts are readings taken from a finished gear with an engineering-quality metrology instrument. Raw data from the surface of a gear tooth was taken from the root out.

Fig. 1. The surface with the circular form removed. The result combines roughness and waviness. The data was acquired with a diamond tipped stylus having a 0.00008" radius.

Fig 2. The result of low distortion filtering to remove the long wavelengths of waviness. The commonly used parameters are calculated.

Fig. 3. This is an examination of the amplitude distribution and the bearing ratio curves. Here is where we will find the description of multi-processed surfaces. Both of these analyses are a summary of the surface examined. Amplitude distribution is the number of events vs. height from the top of the trace to the bottom. This analysis could be used to limit the number of peaks or valleys at a specific amplitude. Bearing ratio is the length of the surface vs. height expressed as a percentage. This analysis could be used to limit the width of the peaks or mandate the width of the valley indirectly controlling their volume.

Fig. 4. This figure shows the Rk parameter with an evaluation of the bearing ratio curve. This analysis was developed to characterize the multi-processed surface of the cylinder bore of an internal combustion engine. A similar approach may be applicable to gears. The parameter is used to control the amount of debris during breaking, the height of the core load bearing surface, and the ability to retain lubrication. Note that each area of interest is described numerically.

Fig. 5. This chart shows the analysis of the low frequencies of waviness. The significant parameters have been calculated.

Our discussion has concerned the metrological needs of the manufacturing process and its control. The investigative scientist may use other analysis procedures to evaluate subjects of interest. These may include the effect of peak height vs. lubrication thickness or peak area vs. stress. The modern surface texture measuring instrument is a versatile engineering device for roughness, waviness, form, and size, and because of its power and precision, it is applicable to more scientific studies as well. ■