Process Equipment has developed new equipment and software that makes finding flaws a breeze.

By Mark E. Cowan
The conventional CNC gear inspection machine will measure and evaluate helix and involute tooth flank deviations that are relative to a theoretically perfect helix or involute form. Any information relating to the actual mean tooth size, relative to a desired tooth thickness, is lost when plotting the traces. This is because the software is designed to equally space the traces on a given graph to allow the user to clearly identify each specific trace plotted to the correct tooth number tested. In addition, the standard analysis packages only specify attributes such as max, slope, and form deviations that are not necessarily related to the actual tooth size. Again, only evaluating tooth form deviations alone, not comparing to an actual position of the tooth form in space.

This paper will explain and demonstrate how a new measurement and computer analysis package has been developed to allow the user to observe the helix and profile measurements and how they relate to actual tooth size. In addition, the change in the helix and involute form, along with the tooth size (thickness), can be evaluated for “before and after” studies such as heat treatment and sintering processes. The application for this analysis has broad-based benefits. Tooth form and
size changes due to gear finishing processes, heat-treat distortions, and plastic gear shrinkage, can all be determined accurately with the ND430 Next Dimension gear measuring system, coupled with the powerful computer analysis. It will be shown that volumetric accuracy and precise tooth-thickness measurements are a prerequisite to this analysis package.

Typically, tooth thickness is measured at one position along the involute, usually the target diameter being the pitch circle diameter. This is usually done by measuring the distance over two pins (DOP) or balls that are inserted into the tooth gaps of 180 degree opposing tooth spaces (see figure one). The tooth thickness is determined from the DOP. The problem with this method is that the tooth thickness size is only measured at one location. In addition, there is no correlation between the tooth thickness and helix or profile deviations at that location, or any other along the trace.

Since the industry preferred method for performing analytical measurements of cylindrical gears is four axes (including a rotary table) CNC generative gear measuring instruments, they will be the focus of this paper. These machines usually measure index (from which pitch, cumulative pitch, and tooth thickness are computed), helix, and profile measurements. Helix and involute (helix/inv) measurements will usually include four teeth evenly spaced around the circumference of the gear (90 degrees apart). The software on these types of machines is written to insure that the gear measurements adhere to gear industry inspection standards (generating the helix/inv forms as opposed to CMM point-to-point measurements), require no part programming, and analyze the results according to industry standards (AGMA, DIN, and ISO).

The inspection software must include a setup routine that determines the rotational position of both tooth flanks of a setup tooth. If the positions of both tooth flanks are determined as the gear is rigidly mounted on the instrument, the tooth thickness may be determined. This turns out to be
quite a challenging task on helical gears, since probe forces are exerted on the probe tip shank. These forces are along the direction normal to the tooth surface and affect the tooth thickness measurements.

To make matters worse, most CNC gear measuring machines utilize either a 1D analog probe, or a 3D probe that locks out two of the three probe axes during these critical measurements. By not allowing the probe to deflect in all three spatial directions (XYZ), the probe tip shank bends to some extent, inducing an error in the determination of the exact location of the tooth flank in space (see figure two).

This location in space is an absolute measurement that also requires machine volumetric accuracy.

Although the ND430 Next Dimension is also a generative gear measuring system that inspects helix and profile according to the industry preferred generative method, it has some unique characteristics. The ND430 utilizes a 3D analog measuring head manufactured by Renishaw. This probe is constantly monitoring the probe tip position in all three XYZ directions and never locks out any of its axes. Couple this with state-of-the-art gear measuring strategies and techniques, and the ND430 accurately determines the gear tooth flank's absolute...
positions and their relationship to each other. Software compensation for mechanical kinematic and geometric machine errors is an integral part of the ND430’s design strategy, which further enhances the volumetric machine accuracy, thereby achieving an accurate tooth thickness determination.

Now that the absolute positions of both tooth flanks are known, the position of each subsequent helix/inv measurement can be determined. As stated before, according to the standards and typical practice, only the helix/inv deviations from a theoretical form are analyzed. The static position of the helix/inv positions relative to the design tooth thickness is not reported. To clarify this concept, refer to figure three. The traces are usually plotted in a way that the elevations of the deviations are set to zero at the starting sample number one. The trend (slope), form, and maximum deviation are determined. In order to plot each trace cohesively, they are equally spaced on the graph as shown in figure four.

This works fine when applying the industry standard practices for analytical measurements. However, there are various processes that can induce changes in the tooth size around the circumference of the gear that must be determined. This “tooth size” cannot be easily related to the helix/inv measurements conventionally.

This is where the ND430 Next Dimension Compare software takes over. Taking advantage of the capability to accu-
The ND430 Next Dimension gear measuring system allows distortions to be quickly quantified without guessing, which means a shorter development cycle for new products. The measuring software develops a linkage between tooth thickness and the helix/inv measurements. Now the actual orientation of each helix/inv trace is shown relative to the designed tooth thickness. You see the form deviations using the standard analysis methods, but the traces are plotted to include their absolute position in space relative to a design tooth thickness, or, optionally, to a previously tested master gear (see figure five).

As you can see from figure six, each helix/inv trace is plotted in a different color to make it easy to distinguish between traces. This is now required, since the orientation of each trace is no longer offset, as shown in figure four. Furthermore, the average of the left and right tooth flanks are graphically set to the center of each flank window, so the user can visually determine where each tooth is located relative to the average or nominal tooth thickness.

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All of this added analysis capability comes from just a few keystrokes! The Compare software prompts the user to select the first test, then the second. At this point, the operator can choose not to enter a second test. If this choice is made, the helix/inv measurements of a single test are presented as previously described (see figure six). Also, the computer prompts the operator for the nominal tooth thickness. If none is selected, the orientations of the helix/inv measurements are plotted relative to the average tooth thickness. If a nominal tooth thickness is entered, then the helix/inv measurements are plotted relative to that nominal tooth thickness. The operator can then quickly see the offset of the static orientation of the helix/inv measurements relative to the nominal or design tooth thickness. For clarity, with one stroke of a key (the “g” key), the user can select to plot the average left and right helix/inv traces (see figure seven).

If a second “compare” test is selected, the software computes the difference between the first and second set of helix/inv measurements. Since both sets of measurements now include the static orientation relative to a design tooth thickness, the results of the helix/inv traces plotted and analyzed will now include both the change in tooth thickness and form deviation.

If the process removed an excessive amount of stock everywhere and induced an excessive amount of tip relief, it is
quickly and clearly shown. Or, if the process removed an appropriate amount of material to achieve the desired tooth thickness, this will also be shown—both numerically and graphically!

An export feature is included that creates a CSV ASCII file of the left and right average “compared” helix and involute traces. This allows sharing of this information with the process equipment and finishing tool manufacturers to modify the machines or dies producing the components.

**Conclusion**

This new machine and its software enables users to quantify what their processes are doing to both the form and size of their gear components. This analysis tool is ideal for determining plastic gear, or powdered metal gear shrinkage, in great detail. The amount of shrinkage is shown, along with any helix/inv form change. Now heat treatment distortions can quickly be quantified without guessing, which means a shorter development cycle for new products.

**ABOUT THE AUTHOR:**

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