Quality Gear Inspection — Part II

Robert E. Smith
R. E. Smith & Co., Inc.
Rochester, NY

GEAR FUNDAMENTALS

Diagnostics

This section will deal with the use of gear inspection for diagnostic purposes rather than quality determination. The proper evaluation of various characteristics in the data can be useful for the solution of quality problems. It is important to sort out whether the problem is coming from the machine, tooling and/or cutters, blanks, etc. An article by Robert Moderow in the May/June 1985 issue of *Gear Technology* is very useful for this purpose.

Machine Problems. The following techniques and devices will indicate when problems originate with the machines.

Lead and Involute Charts. Lead charts will often indicate problems with machine alignment as well as blank mounting (see Fig. 1). A comparison of Examples 1 and 3 in this figure is instructive. Whether the charts of both sides of the teeth are parallel is a good clue to the source of the problem.

Accumulated Pitch vs. Runout Data. If a gear comes directly off a hobber (no subsequent finishing operations) and has a very low runout, but a high accumulated pitch or total index variation, there is probably a problem with a worn-out table drive gear set.

Hob Problems. Hob problems generally show up in involute charts. These problems have several possible causes. The hob could be made very accurately, but sharpened or mounted poorly; or it could be a hob that was made with excessive runout at the time of original manufacture. Even if it is sharpened and mounted correctly, it will not cut a good gear. This problem usually shows up as some form of waviness or slope error in the involute charts (see Fig. 2). These characteristics of slope or waviness may very well fit within the allowable bandwidth of the appropriate AGMA K chart, but the gear may still be unsuitable for many applications, especially when noise is an issue. One must study the characteristics in order to sort out the cause. A good example is the difference between Examples 4 and 5 in Fig. 2. If the waviness is the same on all teeth, the problem is probably within the hob or the accuracy of the mounting. If the waviness is different on every tooth, the cause is likely to be a machine looseness problem.

Hob Feed Marks. When parts are hobbed at a high feed rate, such as for pre-shaving, scallops in the surface characteristics are very evident. Generally, these scallops are so deep that involute charts are quite useless. Usually the only valid data are lead charts. The slope of the charts can show if the lead is correct, and the

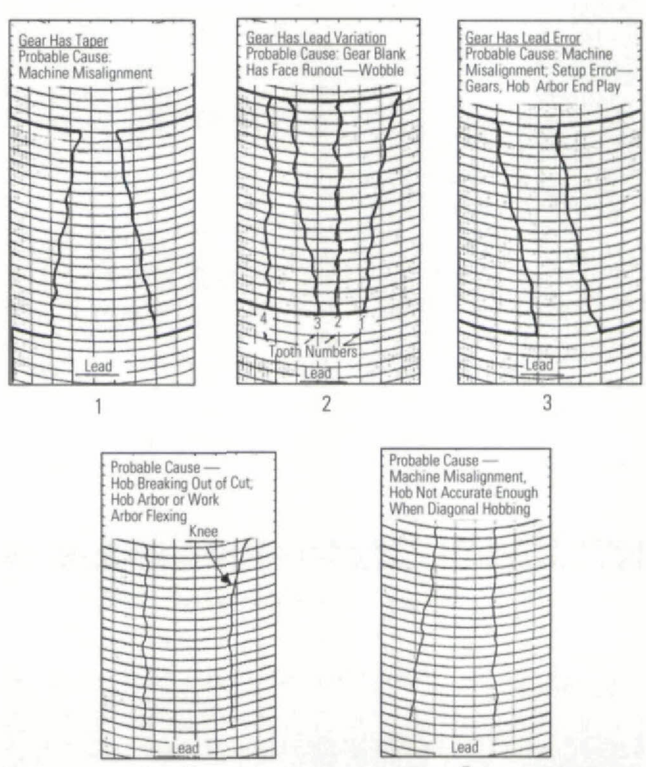
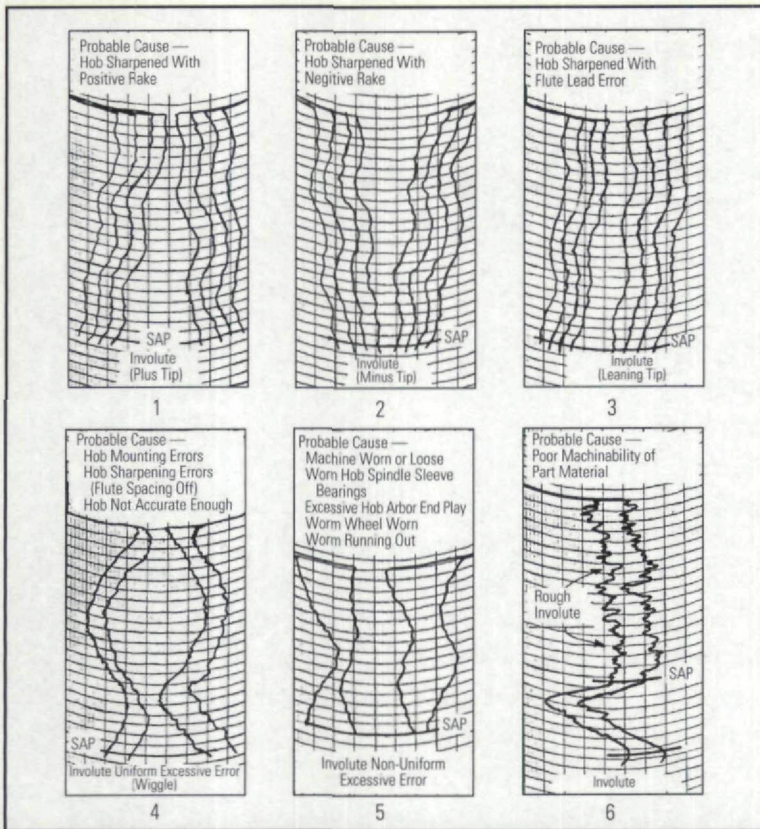


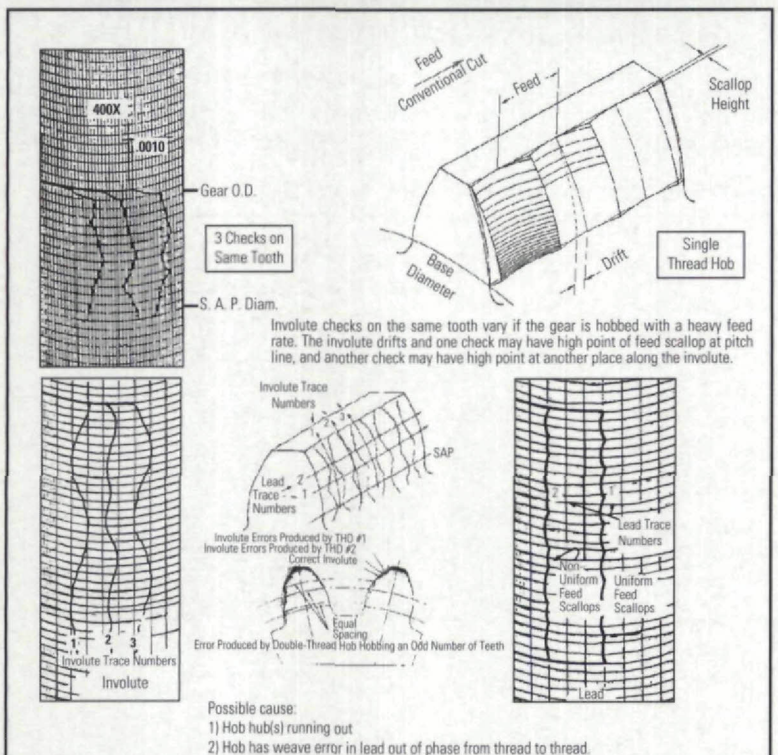
Fig. 1 — Lead and involute chart.

Robert Moderow, *Gear Technology*, May/June 1985.



Robert Moderow, *Gear Technology*, May/June 1985.

Fig. 2 — Lead and involute chart.



Robert Moderow, *Gear Technology*, May/June 1985.

Fig. 3 — Lead and involute chart.

depth of the waves will tell if there is stock for cleanup in the shaving operation. However, the apparent random waviness in the involute charts makes them invalid for the determination of profile shape (see Fig. 3).

Conjugacy—Noise and Transmission Error. As mentioned earlier, K charts are not very useful for diagnosing gear noise and transmission error problems. Other techniques, such as separate determination of "mean involute slope" and waviness in involute charts, should be used for these evaluations. AGMA Q7 or Q8 gears can be made that are noisy, and Q13 or Q14 gears can be made that are quiet. Fig. 4 shows involute traces from a gear that is about a Q7 in terms of runout. The effect of runout shows up in the traces as a variation up to .00066" in slope. However, the mean involute slope is only .00015", and it matches its mate properly. (See the middle example in Fig. 4.) Originally, the mean involute slopes for the gears were like the upper example in Fig. 5. These gears were noisy. Experimentally, gears were also made with the mean involute slope characteristics of the bottom example, and these also were quiet. In all cases, the runout would make them a Q7 set of gears, and they would have slope variation. This points out the inadequacy of the traditional methods of quality determination as far as noise is concerned.

ISO Approach. The International Standards Organization (ISO) uses a different approach to the evaluation of involute and lead charts. In the main body of the standard, they use a rectangular tolerance zone, much as AGMA uses the K chart. However, in an Annex, they have alternate methods of evaluation that are more appropriate for diagnostic evaluation and the control of noise and transmission error.

This process involves doing a least-squares-best-fit line (usually a straight line) to the involute or lead trace (see Fig. 6). This line is laid on the trace and the various parameters, such as slope, average slope, waviness and total error, are read and quantified independently. This is much more useful for many applications and diagnostics.

In addition, the ISO standards give recommended tolerances for accumulated pitch error and transmission error. These are characteristics that are much more direct and functional.

Good Measuring Equipment

Good measuring equipment is essential for achieving quality gear measurements. There are two basic types of gear measuring machines: the older, traditional mechanical generative machines and the newer Computer Numerical Control (CNC) generative or Coordinate Measuring Machines (CMM).

Robert E. Smith
is the principal in the gear consulting firm of R. E. Smith & Co., Inc., and one of Gear Technology*'s technical editors.*

Mechanical Machines. The mechanical machines, an example of which is shown in Fig. 7, use means such as base disks, sine bars, levers, formers, etc., to generate the theoretical motion such as involute or helix (lead). A probe on the tooth surface then measures the variation between the actual tooth surface and the theoretical shape being generated. Usually a recorder of some type makes the resulting charts.

CNC or CMM Machines. The newer CNC machines come in two types. On some, the CNC is used to generate the theoretical motion, much as the older mechanical machines did (see Fig. 8). On the other hand, CMMs measure the tooth forms by moving the probe to a series of X, Y, Z, and θ locations. High resolution and accuracy is necessary.

Calibration. Whether the machines are mechanical or CNC, alignment and calibration are necessary in order to have confidence in the results. Any machine should be calibrated on a regular basis. A new standard, AGMA 2010, Part 1, is in the final stage of preparation. Part 1 deals with involute, but a standard for other parameters will follow, and the same principles apply.

The first step is to check the alignment of the machine for squareness, parallelism, runout of centers and spindle, etc. Then mount a certified artifact such as an involute master. Many measurements are then made and plotted on X and MR bar charts for a statistical evaluation of capability. This establishes bias and variability (accuracy and confidence levels) for the machine. Remember that resolution is not the same as accuracy.

Certified Masters. Unfortunately, the National Institute of Standards and Technology (NIST) has not calibrated and certified masters for about ten years. The recent work by the calibration committee of AGMA has stimulated interest by NIST in resuming its efforts in artifact calibration. A project is now under way to set up a calibration service again.

Cost of Inspection. Many people seem to find it hard to justify the cost of good inspection equipment. After all, the inspection machines don't make chips. However, the best cutting or grinding machine in the world doesn't automatically make good gears. There are still a lot of other variables, such as the cutting tool and its mounting, the gear blank and its mounting, work-holding equipment, operator, etc. If you don't have good inspection equipment and practices, bad product can become very expensive in terms of lost time, poor quality and bad customer relations.

One should look hard at the true cost of not having good equipment compared to the cost of buying it.

A Look At The Competition

A good example of the value of good inspection equipment and practices was found at the 1991 AGMA Gear Expo. A Japanese plastics gear manufacturer was displaying gears made to AGMA quality levels of Q10 to Q11. Our American plastics and sintered gear manufacturers typically claim the ability to make only Q6 to Q7 gears. What is the difference? Good diagnostic measuring equipment and practices. Even though this company is making fine-pitch gears (20 DP and finer), it regularly uses CNC elemental measuring machines and even single-flank testers to mea-

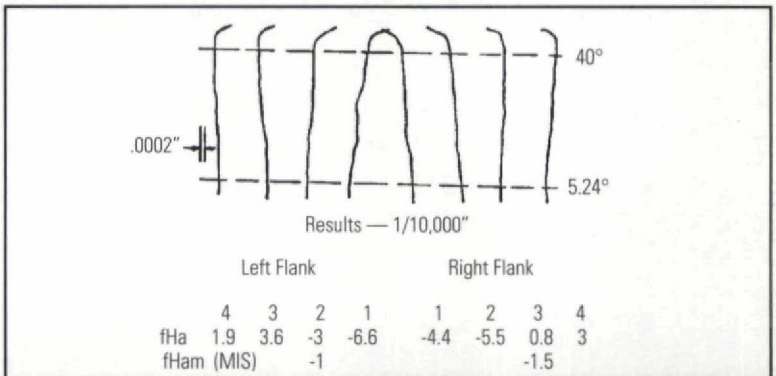


Fig. 4 — Involute traces with runout.

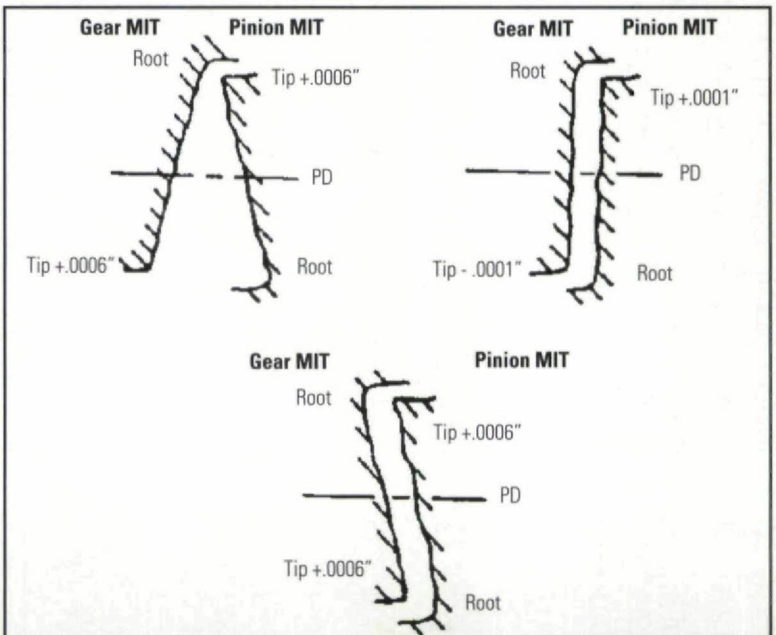


Fig. 5 — Mean involute traces (MIT).

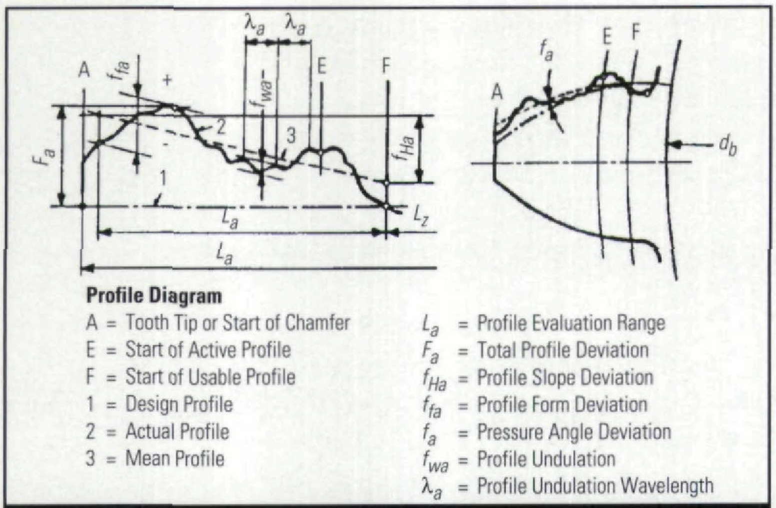


Fig. 6 — ISO tolerance system.

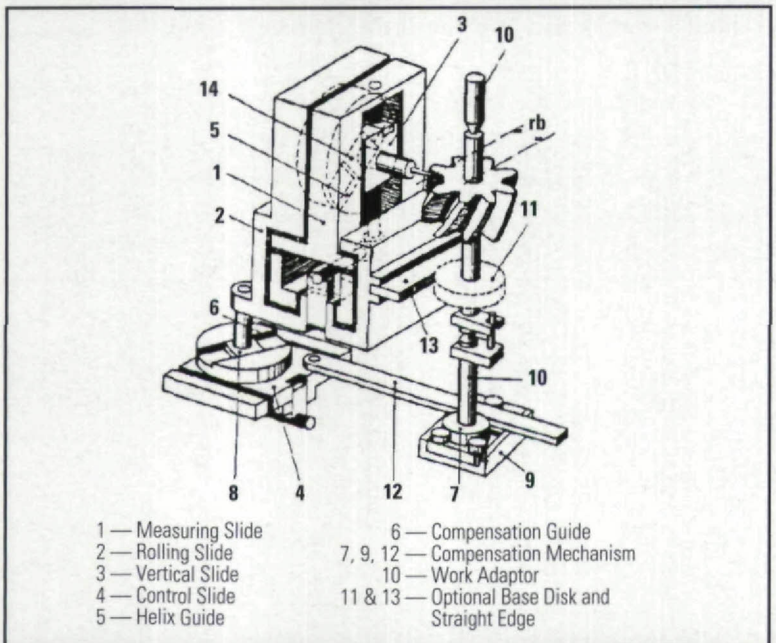


Fig. 7 — Mechanical generative involute and lead tester.

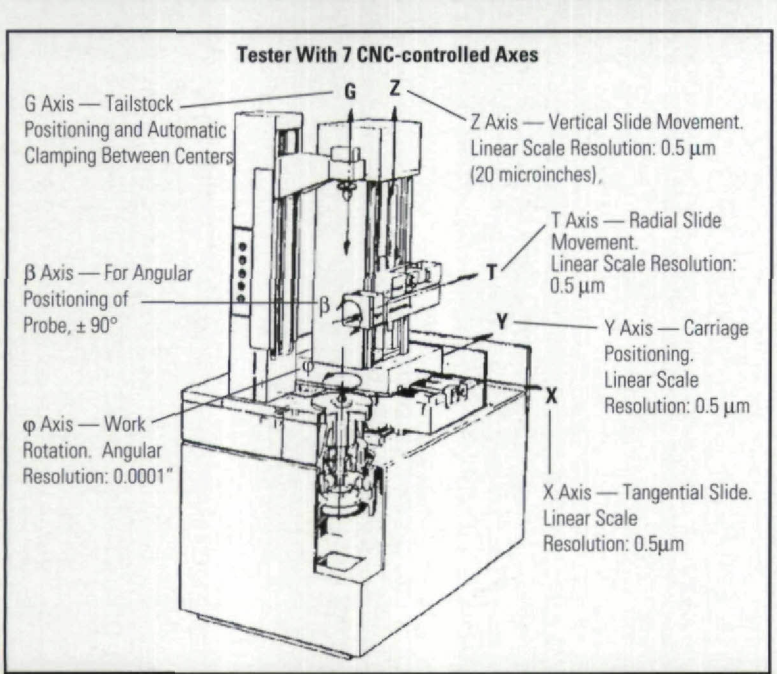


Fig. 8 — Generative machine involute and lead tester.

sure gear quality. The company also has a good symmetrical gear blank design that promotes uniformity of teeth around the gear.

American gear manufacturers in this field only use double-flank testers. They can't really tell what tooth form they are making or even know what is wrong when the product doesn't meet the specifications. Double-flank testers are not good measuring devices for diagnosing problems; therefore, engineers don't do the iterations necessary to develop good gears. One of the major reasons that American plastic gear quality is as low as Q6 or Q7 is that the gears have too much runout caused by not centering the hole in the center of the gear. This should be an easy problem to solve with proper mold and cavity design.

Better measuring techniques would soon point manufacturers in the right direction for meeting the competition and opening up new potential markets for their products. Their products are very uniform from piece to piece, so it is just as easy to make all parts good as to make all parts bad.

Conclusions

Process Control. More use should be made of elemental inspections rather than double-flank composite methods. This also applies to gears that are finer than 20 DP. This kind of information fosters better diagnosis of problems as well as better process control.

Standards. Our AGMA standards need changing. Elemental tolerances and inspection need to be extended to finer pitches (even as far as 80–100 DP). We should be using accumulated pitch variation rather than runout. The standard should also allow the optional use of single-flank inspection as well as double-flank and elemental methods.

One way of doing this is to make use of the new ISO standards currently being developed and published. In fact, AGMA is now very active in the development of these standards, and perhaps someday that is what our gear industry will be using. ■

References:

1. Moderow, Robert H. "Gear Inspection and Chart Interpretation," *Gear Technology*, Vol. 2, No. 3, May/June 1985, p. 30.

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