# How to Achieve a Successful Molded Gear Transmission

Rod Kleiss

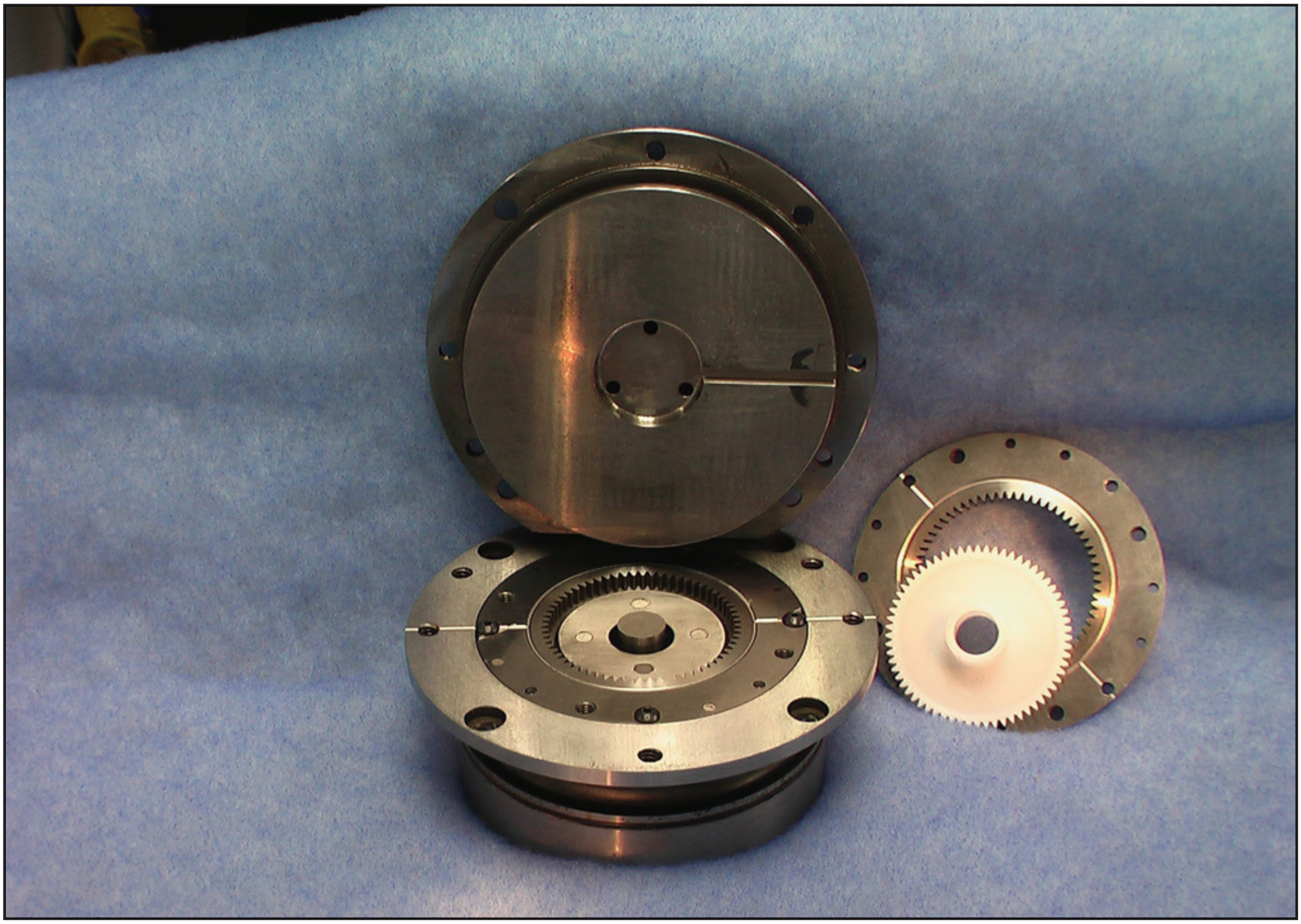


**Figure 1—A molding insert tool alongside the molded gear and the gear cavitiy.**

Molded plastic gears have very little in common with machined gears other than the fact that both use the involute for conjugate action. The differences are quite fundamental. Machined gears are cut to size with specialized machinery designed specifically for the task. Molded gears are formed in gear cavities that are usually cut with wire electrical discharge machines (EDMs). A molded gear, its cavity and the molding insert tool are shown in Figure 1. These cavities are sized so that the molded gear will shrink to the proper size after molding. One cavity might be expected to form more than a million molded gears.

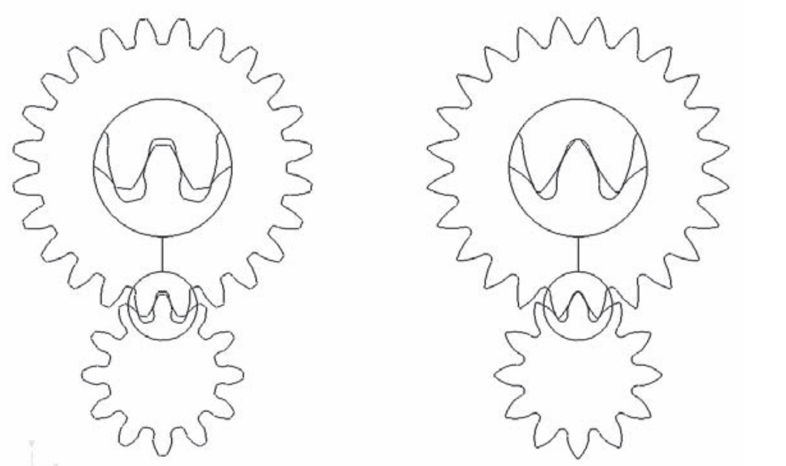
A gear cutting manufacturer is charged with the task of cutting gears within tolerance with every piece made. The gear mold manufacturer is charged with the task of making one nearly perfect gear cavity and then processing each gear from that cavity within tolerance for every piece made. This small but significant difference leads to many other variations. The differences begin as soon as the choice for molded gears is made.

## Design

Molded gears invariably must operate in molded housings. This single fact has significant consequences. Molded housings and the shafts in them are rarely going to have the precision tolerances that a machined transmission can provide. The housings and gears will shrink and expand due to moisture and temperature, perhaps at different rates. The strength, hardness, and even efficiency of the plastic material will also vary due to local conditions. Surface tooth temperatures will rise under load, affecting plastic properties. These variables and others dictate a need for custom design of gear teeth.

The advantage the plastic gear designer has is in the application. Most plastic transmissions are unique. A gear mesh can be designed strictly for its intended function with a single mating gear (Fig. 2). Additionally, the molded gear can be optimized with very little regard for tooling (Fig. 3).

Wire EDMs can generate machined patterns with the precision of computer aided design. A gear cavity can be made with micron tolerances. Given the fact that traditional hobs are not required, diametral pitch or module are not important specifications. The involute base circle




| Shared Attributes: Center Distance: 0.75" minimum — Gear Ratio: 2 to 1 (24 to 12 teeth) | |
|---|---|
| **Differences:** | |
| **Standard Gears:** | **Shape Formed Gears:** |
| 24 Diametral Pitch | 0.11865 Base Pitch |
| 20° pressure angle | 25° operating pressure angle |
| 0.06545 tooth thickness (both gears) | 0.070 pinion tooth thk'ns/0.061 gear tooth thk'ns |
| Max contact ratio: 1.15 | Max contact ratio: 1.59 |
| Max center distance variation: + 0.022" | Max center distance variation: +0.032" |

Figure 2—Comparison of standard gear mesh to custom shape formed gears.

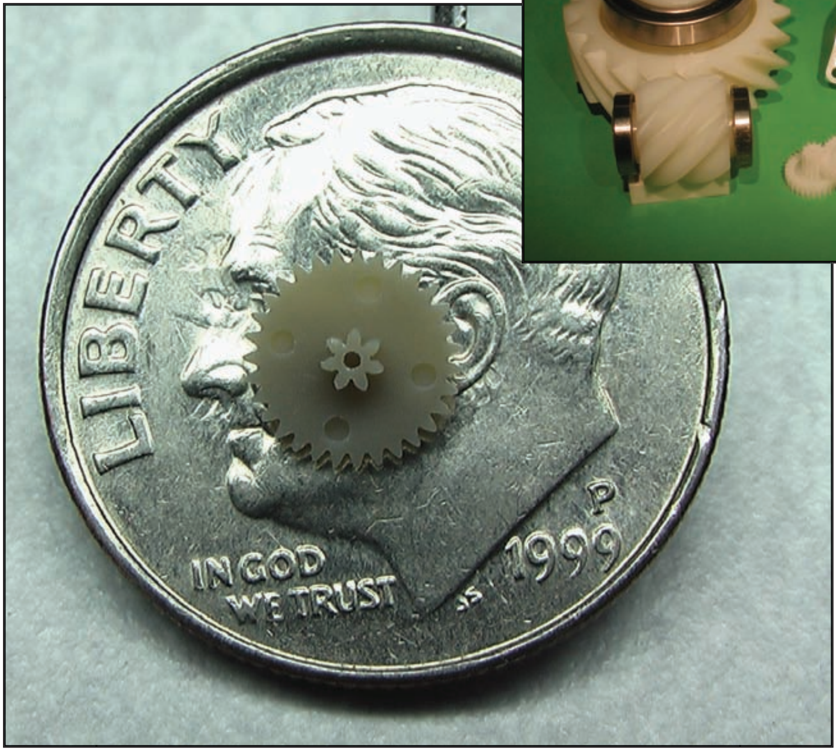



Figure 3—Molded gears can be made in many forms and varied sizes. A very fine pitch gear is shown in the larger image.

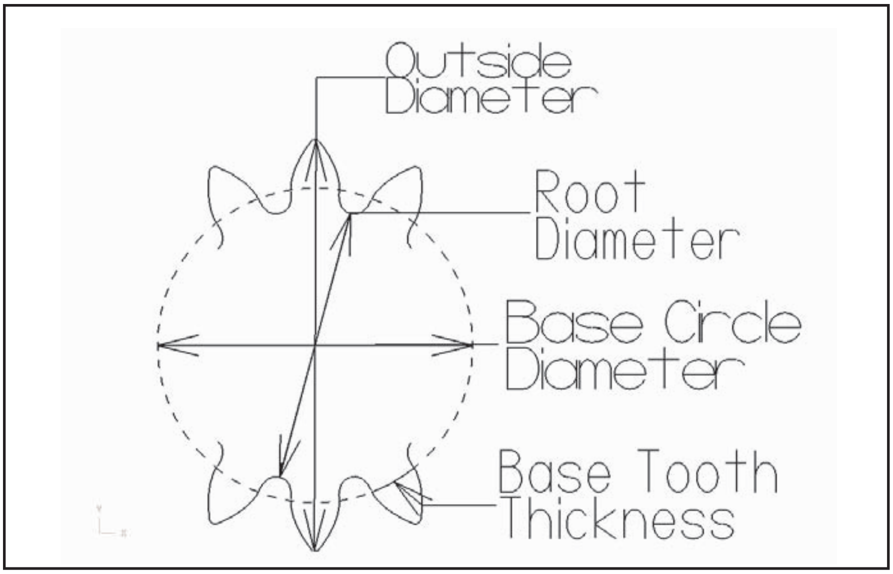



**Figure 4—Distinct shrink rates for general plastic gears.**

**Figure 5—The involute shrinkage of a molded gear.**

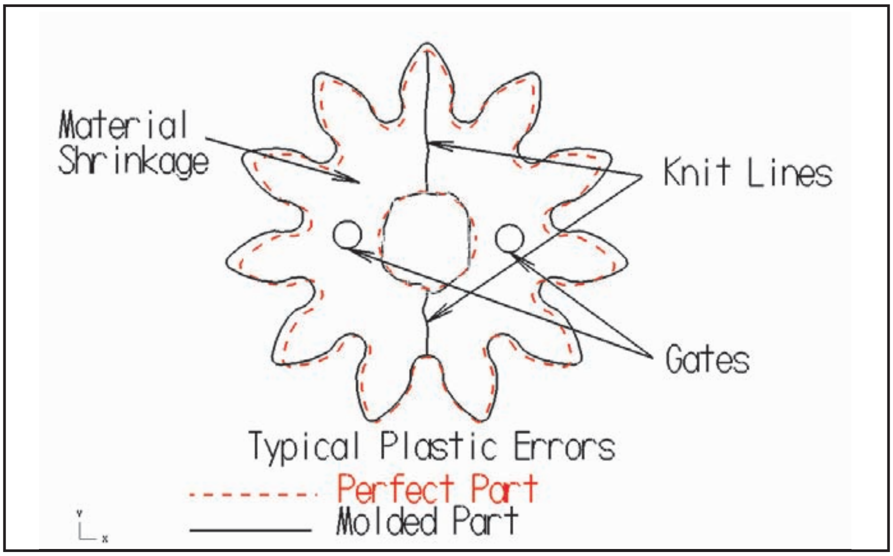



**Figure 6—Typical errors in a molded part.**

is the variable of importance. Pressure angles can be adjusted in an analog fashion to balance strength and depth of tooth engagement. Custom designed gears will offer a great improvement in performance, quietness, and allowable tolerances over standard gearing.

**The Gear Molding Tool**

With the gear mesh designed and toleranced, the next step is tool construction. Gear tooling must be precise, with excellent thermal stability, hardened sleeves and surfaces, exact gear cavity formation, and designed for high-pressure injection molding. The gear cavity itself must be specifically designed for the selected molding material.

There is no way to accurately predict the actual shrinkage for molded plastic gears in a specific application. This is due to a number of factors. Most importantly, plastic does not shrink from the cavity in an isotropic fashion (Fig. 4). The main body of the gear will shrink in a manner that may be similar to manufacturer's estimations, but the individual tooth is surrounded by steel and its cooling pattern will differ from the macroscopic pattern of the larger mass (Fig. 5).

A good method to determine shrink requires a two-step approach. Shrink factors are estimated for the gear in question. After the tool is made and the first gears are molded, they are then profile-inspected for exact involute geometry. The individual shrink rates are then determined, a new cavity is made to the measured shrink, and the final gear geometry is properly sized. Only profile inspection will be able to accurately determine involute shrinkage. Gear roll testing may give some idea of shrinkage anomalies, but it can also be misleading.

Sometimes heavily glass-filled material is selected for gears due to its low shrink rate. Shrinkage then becomes less of an issue in mold design. But this approach can cause its own problems. Unfilled engineering resins, such as nylon and acetal, mold into very precise shapes, albeit with shrinkage. Glass-filled materials will have knit lines where injection flow fronts merge. These knit lines can cause distortion at the tooth surface as well as localized weak spots on the gear (Fig. 6). Glass-filled gears will generally be much more abrasive during their life than equivalent unfilled gears. Generally, filler should only be used when a specific need has been established that outweighs potential problems.

### Mold Processing

All molding is not equivalent. All molding machines are not equivalent. Gears require mold processing that is exact and repeatable. In general, virgin resin is used for high accuracy gears. Even with virgin resin, the material must be of correct dryness; its melt temperature must be controlled exactly and must be repeatable. Injection pressures must be established precisely. The interaction of the mold tool and process control must also be taken into account.

As plastic is injected at high temperature and pressure, the melt must displace air in the gear cavity. Vent paths must be created to allow air to escape, yet thin enough to stop the resin from venting as well. If the vents are too small, gas will be trapped and burning could result. If the vents are too big, plastic melt will flow through and cause flash on the part.

It is often advisable for the gearing customer to visit the molding facility before placing the final order. Just a cursory inspection of molding equipment, general plant cleanliness, inspection capabilities and personnel can help to evaluate the facility's potential for successful molding and control. For instance, it will be very difficult to mold precision gears in a non-temperature controlled environment. Molding precision gears in 90% humidity at 100°F is fraught with difficulty.

### Inspection

Over the years, gear inspection has been refined to pinpoint most errors that create trouble in gear cutting. A profile scanning inspection of the involute profiles is usually done for only a few teeth around the gear. Metal gears are produced on turning machinery, and patterns can be expected from tooth to tooth. Plastic molded gears can have large solitary

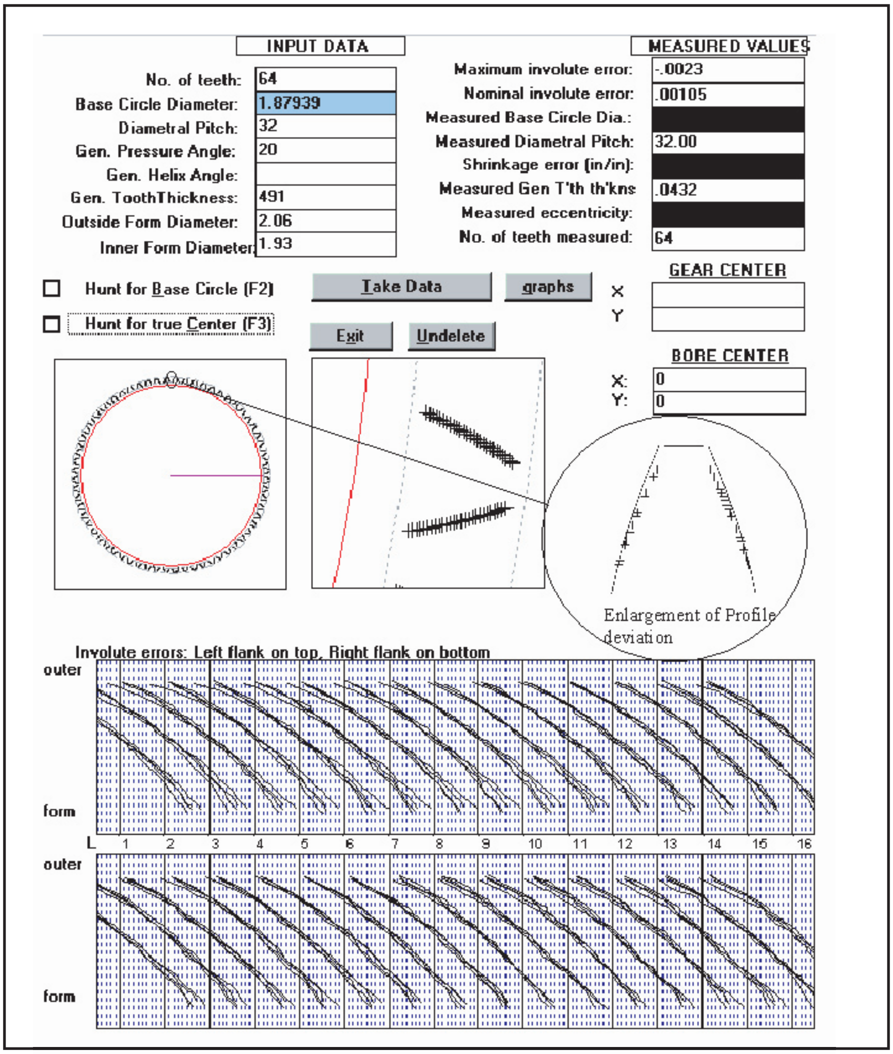



**Figure 7—A poorly shrunken plastic molded gear.**

errors anywhere on any surface of the gear. Furthermore, the molding process can introduce a much different kind of error than in traditional manufacture.

Since any molded gear will shrink, the involute profile is a target, not a given value. Whether one considers diametral pitch, module, base pitch, pressure angle or any other involute feature as the controlling geometry, this feature will be a variable in the actual part. It is necessary to set realistic tolerances for these truly variable features.

The only way to be certain that a plastic molded gear is within tolerance is by scanning the involute profile and determining the actual physical geometry of the gear. The molded part can be completely out of specification and still produce acceptable roll test results. Figure 7 shows a profile inspection of such a

| Table 1—Suggested Gear Data Specification for Molded Plastic Gears. | |
|---|---|
| Number of Teeth | |
| Base Pitch (Basic Dimension) | |
| Base Circle Diameter | +/- |
| Base Circle Tooth Thickness | +/- |
| Root Diameter** | +/- |
| Outside Diameter | +/- |
| Involute Form Diameter | max |
| Tip Radius | max |
| Center Distance with Master Gear | TBD |
| Master Gear Specification | TBD |
| Tooth-to-Tooth Composite Error | max |
| Profile Form Tolerance (*fi*) | max |

**Root trochoid must be directly generated. (Re: AGMA standard 1006-A97, Appendix F)

| Operating Data | |
|---|---|
| Nominal Operating Diametral Pitch | |
| Nominal Operating Mesh Angle | |
| Nominal Operating Tooth Thickness | |

gear. The involute base circle was very far off the defined value. The gear had 64 teeth, and a master used to measure the gear had 64 teeth. With such a large number of meshing teeth in roll testing, there was almost no tooth-to-tooth error. The gear simply appeared large, even though the base circle was small. The molder thinned the teeth, brought the gear into good specification with a roll test, and supplied parts to the customer. The parts immediately failed when meshed with a cut metal gear of correct size.

To prevent this type of error, the gear must be completely specified with each variable toleranced. One such method is recognized by the AGMA in the recently completed Information Guide for Inspection of Molded Plastic Gears. This specification layout is shown in Table 1.

**Suggested Gear Data Specification for Molded Gears**

In the AGMA approach, the base circle geometry of the gear is used as the fundamental control. The indirect specification of diametral pitch and pressure angle are included in the operating data field as a reference for traditional analysis.

Gear roll testing is almost always the best way to assure consistency of the molded part in production. Rather than simply describe allowable total composite error (TCE) or tooth-to-tooth error (TTE), the actual center distance with a given master can be specified with indicated +/– tolerances (Fig. 8). This will provide an easy method to assure that the gears are molded consistently day after day. Roll tests of sample gears can be gathered to assure both the general form and the absolute size of the gears are within tolerance. Roll testing for plastic gears is more like establishing a roll test signature and confirming that the parts conform to that signature day after day.

The future for plastic molded gears is quite promising. Materials are improving greatly. Molding machinery is becoming more accurate. Inspection equipment is now capable of measuring these unique parts with great precision. In the future, plastic can be expected to replace metal gears in lighter duty applications. Companies continue to find uses for plastic gears in areas that cannot be served by metal gears.

In order to reach these new potentials, every step must be taken correctly and every advantage exploited. The result will be a remarkable new generation of power transmission products.

**Rod Kleiss** *spent the first five years of his engineering career working in the field of precision mechanics with Hewlett-Packard and Ball Aerospace. He has spent the remainder of his career focusing on plastic geared transmissions as a dynamically controlled precision mechanical system. Kleiss is president of Kleiss Gears Inc., a company that specializes in the design, inspection, and molding of high performance plastic gears.*

GEAR DATA

| | |
|---|---|
| Customer: | |
| Part Number: | |
| Gear #Teeth: | 16 |
| DP/phi/Tn: | 32/25/.0456 |
| Master #Teeth: | 64 |
| Master T'th Thk'ns: | .04935 |
| Center Distance: | 1.2465 |
| Part Bore: | .1895 |
| Gage Blocks: | 0.9018 |
| Master Gear ID: | 124203 |
| File: | 10821-3 |
| Date: | 8/21/01 |
| Force(Oz): | 4 |
| Yscale(inch): | +/- 0.003 inches |
| Xscale(revs): | 1 |

STATISTICAL DATA

| Trace # | Minimum | Maximum | Mean | TCE |
|---|---|---|---|---|
| 01 | 0.00038 | 0.00157 | 0.00092 | 0.00119 |
| 02 | 0.00016 | 0.00170 | 0.00080 | 0.00154 |
| 03 | 0.00021 | 0.00172 | 0.00094 | 0.00151 |
| 04 | 0.00040 | 0.00179 | 0.00095 | 0.00139 |
| 05 | 0.00046 | 0.00187 | 0.00104 | 0.00142 |
| 06 | 0.00018 | 0.00148 | 0.00080 | 0.00129 |
| 07 | 0.00004 | 0.00170 | 0.00080 | 0.00166 |
| 08 | 0.00040 | 0.00169 | 0.00096 | 0.00129 |
| 09 | 0.00023 | 0.00180 | 0.00101 | 0.00157 |
| 10 | 0.00024 | 0.00177 | 0.00081 | 0.00153 |
| Min | 0.00004 | 0.00148 | 0.00080 | 0.00119 |
| Max | 0.00046 | 0.00187 | 0.00104 | 0.00166 |
| Mean | 0.00027 | 0.00171 | 0.00090 | 0.00144 |
| STD DEV | 0.00013 | 0.00011 | 0.00009 | 0.00015 |

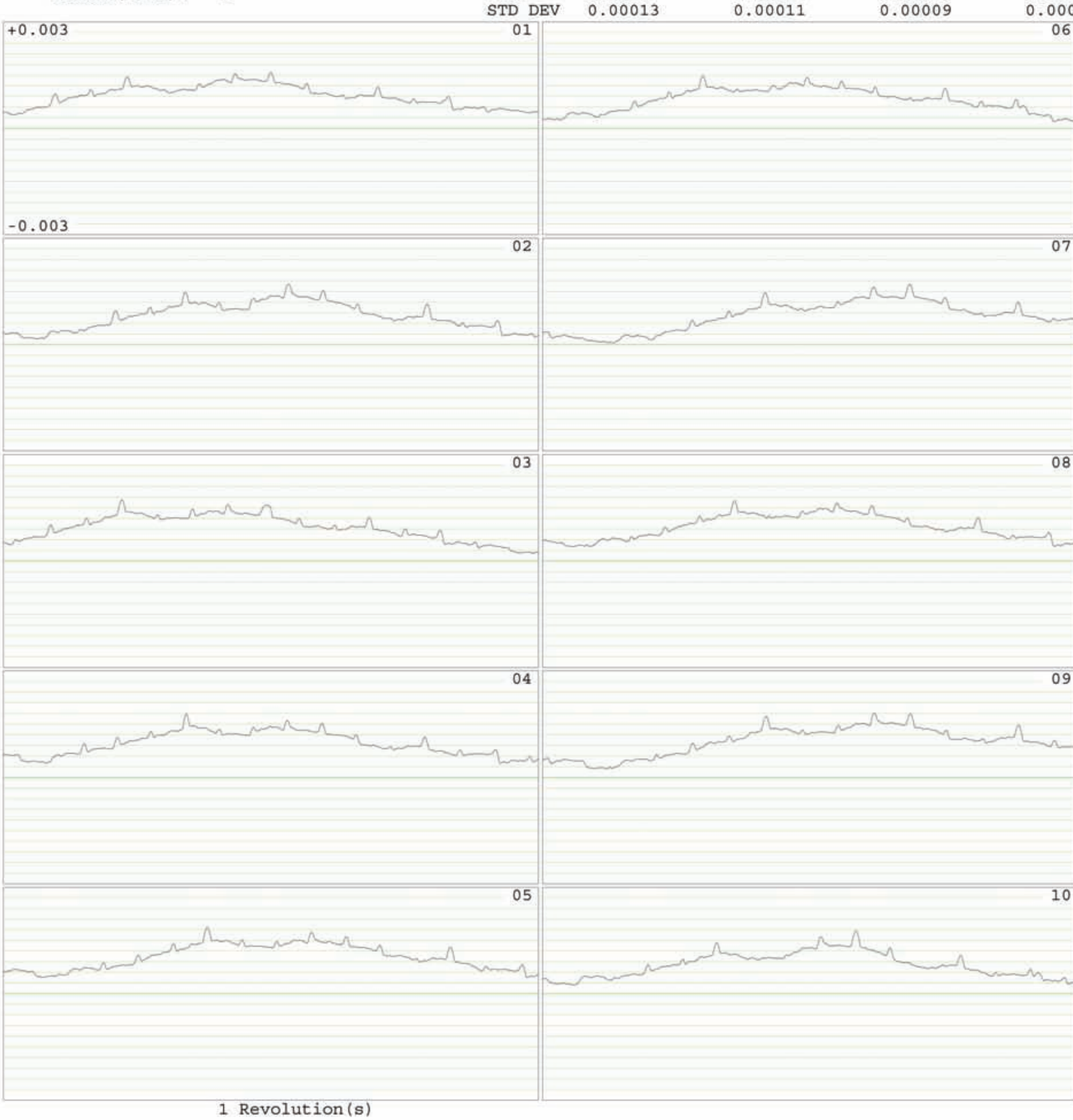



**Figure 8—Typical roll test signature of 10 molded gears.**