# Superfinishing Gears

## THE STATE OF THE ART, PART II

Gary J. Sroka and Lane Winkelmann

**Management Summary**

A recent technology, the chemically accelerated vibratory finishing of gears has generated interest. Increasing numbers of gear designers and practitioners are employing superfinishing to solve real-world problems. However, the process also has suffered from a number of misconceptions.

In a previous *Gear Technology* article, the authors identified and discredited two misconceptions surrounding this process for finishing gears.

In this article, they discuss three more misconceptions. Their discussion includes evidence supporting that the performance benefits of superfinished gears are real, that the process can reduce gear noise/vibration, and that superfinishing doesn't distort gear geometry.

**Gary J. Sroka** *is research & development manager for REM Research Group Inc., located in Brenham, TX. He holds a doctorate in physical chemistry. His research interests include development of new products and processes for superfinishing gear and bearing alloys using chemically accelerated vibratory finishing.*

**Lane Winkelmann** *is a senior research associate at REM Research Group. He has developed proprietary products and processes for the superfinishing of stainless steels, brass, and carbon steel alloys and has published several gear-related technical articles.*

**Introduction**

More than eight years ago, chemically accelerated vibratory finishing first appeared in the gear industry.

As with any new technology, there will be well-intentioned opposition before there is widespread acceptance. Chemically accelerated vibratory finishing—superfinishing—has faced such opposition. Unfortunately, it has also faced several misconceptions.

In *Gear Technology*'s November/December 2003 issue, we identified and discredited two misconceptions surrounding this gear finishing process. The first of these was the notion that gear teeth with mirrorlike surfaces will not exhibit adequate lubrication properties because residual machine lines or a dimpled surface are required to facilitate oil retention.

The second misconception was that the relationship between surface roughness parameters and component functionality is not well understood and requires advanced mathematics and sophisticated software to master, leaving no simple method of determining which surface will exhibit the desired performance.

In our prior article, we showed that superfinishing gears with high density, non-abrasive ceramic media does in fact produce a surface texture that facilitates lubrication. The superfinished surface was free of stress raisers, damaged metal, and peak asperities—all of which would reduce the life of a gear.

Also, laboratory and field tests supported the conclusion that monitoring of only average roughness ($R_a$) was necessary during the process in order to attain proper surface finishing. An $R_a$ of < 3.0

µin. (0.08 µm) will ensure optimum performance benefits (Ref. 1).

Besides those two misconceptions, there are three other major ones surrounding the superfinishing of gears:

3.) Superfinishing has no supporting theory, so its performance benefits must be make-believe.

4.) Superfinishing doesn't reduce noise/vibration.

5.) Superfinishing distorts gear geometry.

### Misconceptions

***Misconception No. 3.*** Superfinishing has no supporting theory, so its performance benefits must be make-believe.

Gears, like many inventions now taken for granted, were used for centuries with great success before the advent of modern analytical tools and methods. Many parameters have since been created to fully characterize the properties of a surface, and tribologists continue in their work for a theoretical correlation between gear performance and these surface properties.

Also, existing theories may not take full account of the unique surface properties from chemically accelerated vibratory finishing. For example, in a mated pair, superfinished surfaces, each with an $R_a$ of 8.0 µin. (0.20 µm), will interact much differently than a mated pair in which each surface has been finely honed to an $R_a$ of 8.0 µin. (0.20 µm) (see Figure 1). The difference is due to superfinishing's creation of non-random, planarized surfaces. These surfaces are essentially free of peaks to penetrate the lubricating film.

***Misconception No. 4.*** Superfinishing doesn't reduce noise/vibration.

Superfinishing has reduced noise/vibration in a number of gear applications.

For example, Sikorsky Aircraft Corp. uses the process on the gears in its S-76C+ helicopter gearboxes, reducing noise from the second-stage bevel gears by 3.7 dB and from the bull gear's first harmonic by 7 dB (Ref. 2).

Since gears have a sliding component, superfinishing will reduce noise/

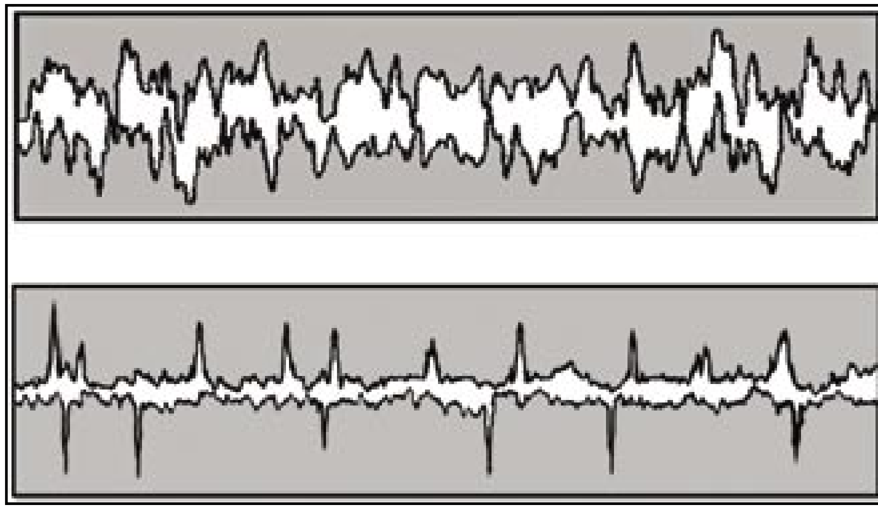

**Figure 1—Graphic showing the interaction between surfaces with the same nominal $R_a$. The upper graphic illustrates random surfaces brought into contact. The bottom graphic shows two planarized surfaces brought into contact. The film thickness required to separate the planarized surfaces is much less than that required to separate the random surfaces.**

**Before and After? No.—Gear manufacturers need not worry that superfinishing will have this effect on their gears. Skill is necessary in chemically accelerated vibratory finishing so gears retain their geometry, but it is a misconception that superfinishing distorts gear geometry.**

vibration in the majority of cases because it reduces friction and facilitates lubrication.

Spiral bevel gear sets, with their high sliding ratios, will also benefit from superfinishing. The process will not only reduce noise/vibration (Refs. 3–4); it will improve fuel economy in automotive applications (Ref. 5).

Also, superfinishing slows the growth of gear noise by slowing gear wear. A new gear may be very quiet, but as it wears, it becomes noisier. The wear distorts gear geometry, increasing transmission error. In extreme cases, pitting and surface roughening may increase the negative effects of frictional forces. However, superfinishing reduces gear wear, thereby slowing noise growth (Ref. 6).

Moreover, noise can result from surface undulations introduced during a gear's machining/grinding stage. In superfinishing, the media is usually large enough to bridge the crests of the undulations, reducing their amplitude.

***Misconception No. 5.*** Superfinishing distorts gear geometry.

Superfinishing gears requires skill to avoid unwanted results. Skill is needed because the process has an inherent characteristic: It will remove more stock from the tip of a gear tooth than from the root area. The reason is simple. Since the process is chemical/mechanical, the tip will have greater contact frequency with the media and therefore be subjected to more mechanical rubbing than the root fillet area. The amount of bias depends on the gear's size, the media's size and shape and the processing parameters.

Is this inherent characteristic a major obstacle? Not necessarily.

For example, aerospace gears are typically final ground to an $R_a$ of 12–16 µin. (0.30–0.41 µm). Therefore, only a small amount of stock must be removed to achieve an $R_a$ of < 4.0 µin. (0.10 µm). Consequently, when superfinishing, potential geometry distortion is easier to control in aerospace gears—and high-end auto-racing gears—than in other less high-end gears.

In fact, several years ago, aerospace AGMA Q13 spiral bevel gears with a starting $R_a$ of 12 µin. (0.30 µm) were superfinished to an $R_a$ of < 3.0 µin. (0.08 µm) and still complied with the AGMA Q13 tolerance specifications (Ref. 6). Since that time, the success of this project has been repeated with a large number of aerospace gears.

In another case, however, an initial attempt to superfinish a much finer-pitched internal gear for the Global Hawk UAV resulted in the inadvertent removal of more stock near the tip than at the root. However, the company was pleased because the removal provided needed tip relief.

Sikorsky Aircraft experienced non-uniform stock removal as well, but dealt with it by designing the gear to have excess stock at its tip (Ref. 7).

Superfinishing can also be used effectively on gears of less-than-aerospace quality—automotive gears, for example. With these gears, the inherent characteristic can be neutralized—and uniform stock removal achieved—by optimizing the media and process, thereby preserving gear geometry.

In automotive applications, the starting average roughness ($R_a$) typically ranges from 60–80 µin. (1.5–2.0 µm) with a mean peak-to-valley height ($R_z$) of approximately 300 µin. (7.6 µm). The $R_z$ indicates that about 300–400 µin. (7.6–10.2 µm) of stock must be removed to achieve a surface that is free of grind lines. For ring-and-pinion gear sets, which are usually lapped after carburization and kept as pairs, a much more uniform stock removal process is required to avoid altering the contact pattern and/or increasing the transmission error.

In one case, a DANA 44 lapped ring-and-pinion gear set was superfinished to 3.0 µin. (0.08 µm) after optimizing the media and process. The amount of stock removed from tip to root and across the spiral was extremely uniform. The contact pattern was maintained and transmission error did not increase over baseline. A paper presented at the 2004 AGMA Fall Technical Meeting reported the results of this study (Ref. 8).

Although skill is needed to deal with the inherent characteristic, during the last several years, there have been advances in the areas of media, chemicals and techniques. As a result, a reasonably competent technician working under commercial conditions can now successfully superfinish gears ranging in weight from just a few grams to more than 4,000 pounds (1,814 kg).

Also, once optimal superfinishing conditions have been established, subsequent processing is virtually guaranteed to be successful because the process itself is extremely robust and requires little skill.

**Summary**

In the past several years, superfinishing of gears—that is, chemically accelerated vibratory finishing with high density, non-abrasive ceramic media—has been increasingly accepted by the gear industry. To date, there is no tribological theory to explain the gear performance imparted by this base-metal surface engineering. Nonetheless, this process removes peak asperities, stress raisers and the layer of distressed surface metal from gears and gives them an isotropic microtexture that facilitates lubrication.

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