Superfinishing Gears

THE STATE OF THE ART, PART II

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Management Summary

Chemically accelerated vibratory finishing of gears using high density, non-abrasive ceramic media has generated much interest among gear designers and users. Increasingly, this gear superfinishing technology is being used to solve real-world problems. However, implementing of this technology has been hindered by several misconceptions.

In a previous *Gear Technology* article, the authors identified and discredited two misconceptions surrounding this gear superfinishing process.

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/harshness, and that superfinishing doesn't distort gear geometry.

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Introduction

More than eight years ago, chemically accelerated vibratory finishing using high density, non-abrasive ceramic media first appeared in the gear industry.

As with any new technology, well-intentioned opposition is usually present before there is widespread acceptance. Chemically accelerated vibratory finishing—superfinishing—has often faced such opposition because of several misconceptions.

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

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

In our prior article, we showed that superfinishing gears using high density, non-abrasive ceramic media did in fact produce an isotropic micro-texture on the surface that facilitated lubrication. The superfinished surface was free of stress raisers, distressed 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 the best surface. It was shown that an R_a of < 3.0 µin. (0.08 µm) ensured optimum performance benefits (Ref. 1).

In addition to those two misconceptions, there are three more that need to be addressed:

3.) Superfinishing has no supporting theory, so its performance benefits must be looked upon with suspicion.

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

5.) Superfinishing distorts gear geometry.

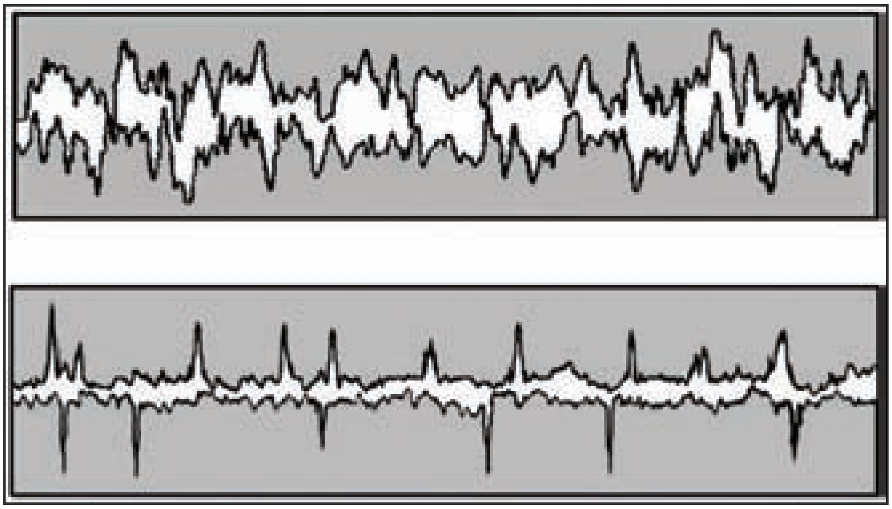

Figure 1—Graphic showing the interaction between surfaces with the same nominal R_a. The upper graphic illustrates random surfaces brought into contact. The bottom graphic shows two planarized surfaces brought into contact. The film thickness required to separate the planarized surfaces is much less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

Misconceptions

Misconception No. 3. Superfinishing has no supporting theory, so its performance benefits must be looked upon with suspicion.

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.

Moreover, existing theories may not take full account of the unique surface properties imparted by 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 planarized surfaces. These surfaces are essentially free of peaks that can penetrate the lubricating film.

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

Since gears have a sliding component, superfinishing reduces noise/vibration/harshness in the majority of cases because it lowers friction and facilitates lubrication.

Spiral bevel gear sets, having high sliding ratios, especially benefit from superfinishing. The process not only reduces noise/vibration (Refs. 2–3), but also improves fuel economy in automotive applications (Ref. 4).

Although new gears may be very quiet initially, they often become noisier with usage. Wear, scuffing and micropitting usually lead to unacceptable gear geometry distortions. Such changes in geometry increase transmission error with a concomitant increase in noise/vibration/harshness. Superfinishing, however, reduces wear, scuffing, and micropitting, thereby slowing noise growth (Ref. 5).

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

Superfinishing has reduced noise/vibration/harshness in a number of gear applications. For example, Sikorsky Aircraft Corp. uses the process on 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).

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 proccess 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 gear size and diametral pitch, media size and shape, and processing parameters.

Is this inherent characteristic a major obstacle? Not necessarily. A skilled technician can develop a process whereby the amount of bias is negligible.

Aerospace gears, for example, 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 lower quality 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 having a wide assortment of geometries.

On the other hand, for 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 asperities. 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 a 3.0 µin. (0.08 µm) R_a 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. 7).

On rare occasions, however, one comes across cases that are problematic. For example, initial attempts 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. Fortuitously, the company was pleased with the outcome because the biased removal provided needed tip relief.

When no bias is desired or can be tolerated, another approach is possible. The gear designer can compensate by leaving more stock at the tip than at the root. Recently, Sikorsky Aircraft used this approach. The company decided it wanted to use this superfinishing technology to take advantage of its performance benefits, so it designed its gears to fit the process (Ref. 8).

Although skill is needed to select the optimum superfinishing parameters, during the last several years, there have been advances in the areas of media, chemicals and techniques that simplify the task. 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 using 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 basis-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 micro-texture that facilitates lubrication.

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