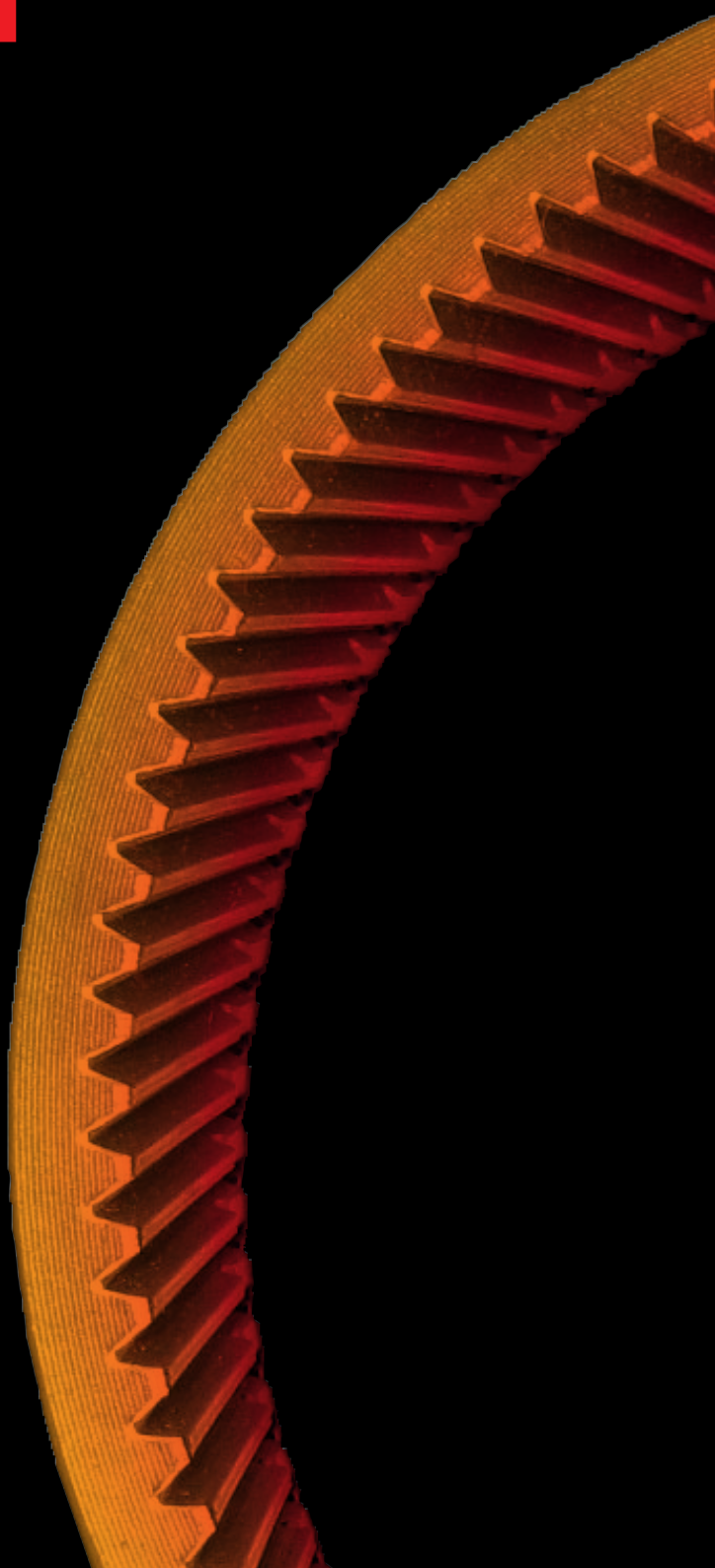
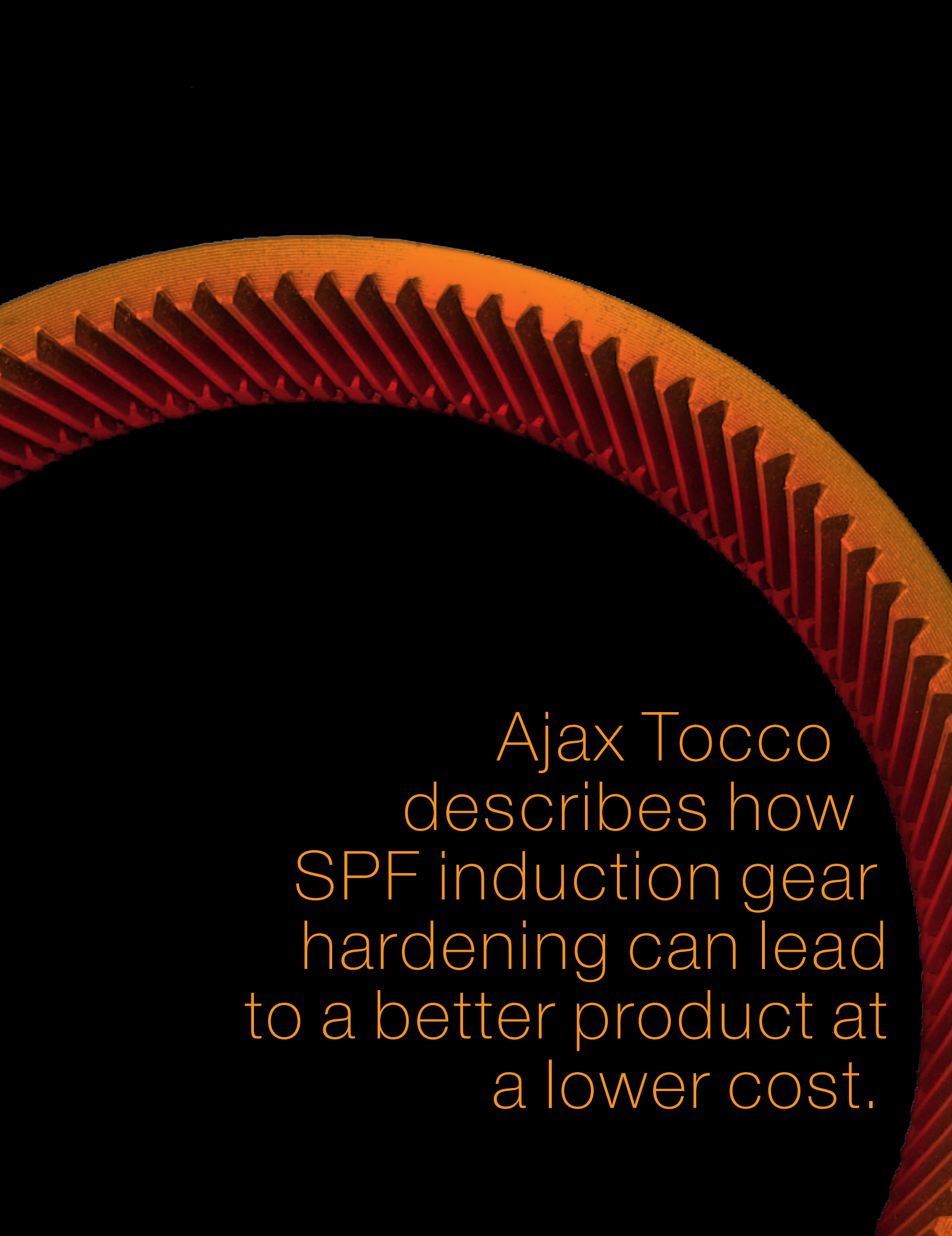
INDUCTION HEATING FOR LOW-COST QUALITY GEARS

By George Pfaffmann, FASM





Ajax Tocco describes how SPF induction gear hardening can lead to a better product at a lower cost.

The gear market is looking for increased gear performance, reduction in gearbox package size, and longer gear life. Industry drivers that support these needs include:

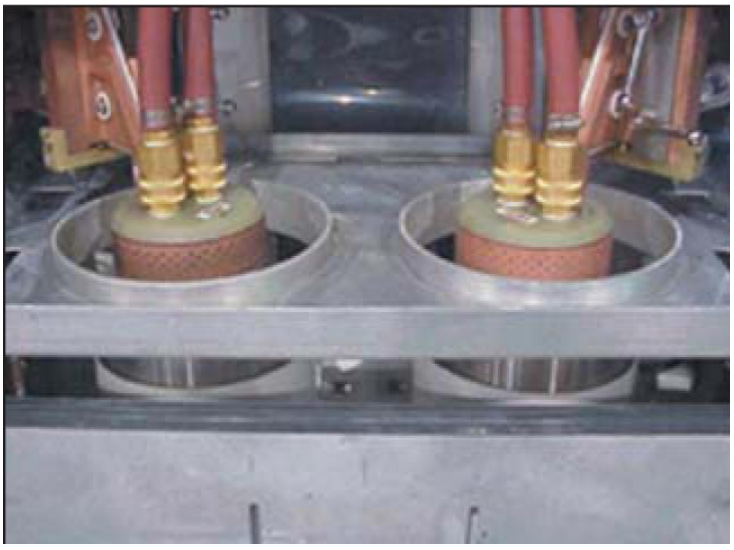
- More consistent quality with regard to dimensional results;
- Consistent process control;
- Reduced operational costs in both material and labor;
- Reduction in capital equipment investment;
- Higher throughput productivity and lower process inventory;
- More flexible, agile manufacturing systems and integration of the heat-treat operation into the machining operation.

The gear-machining industry has improved its capabilities over the years, such as continually increasing the ability to machine to tighter tolerances, incorporating CNC machining systems, and expanding the design and flexibility of systems that can efficiently handle more complex component designs and a variety of part configurations. This makes processing lower lot sizes more practical and economical. However, further progress is needed to handle some of the more difficult to machine hardnesses and microstructures.

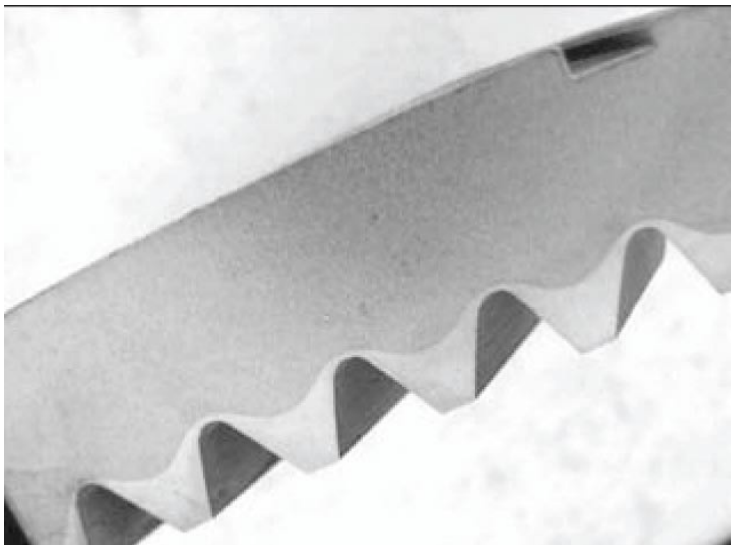
Importance of Heat Treating

Proper heat treatment is critical to meet enhanced gear performance. Traditionally, the heat-treating part of the manufacturing process has drawn criticism primarily due to the unpredictability of the process with respect to dimensional control and other quality issues. This has resulted in the need for a number of

Single precise frequency (SPF) induction hardening machine.


Two-part loading design for increased production capability or to incorporate a temper process.


Ring-gear induction hardening operation.



SPF induction hardening pattern profile on transmission gear.

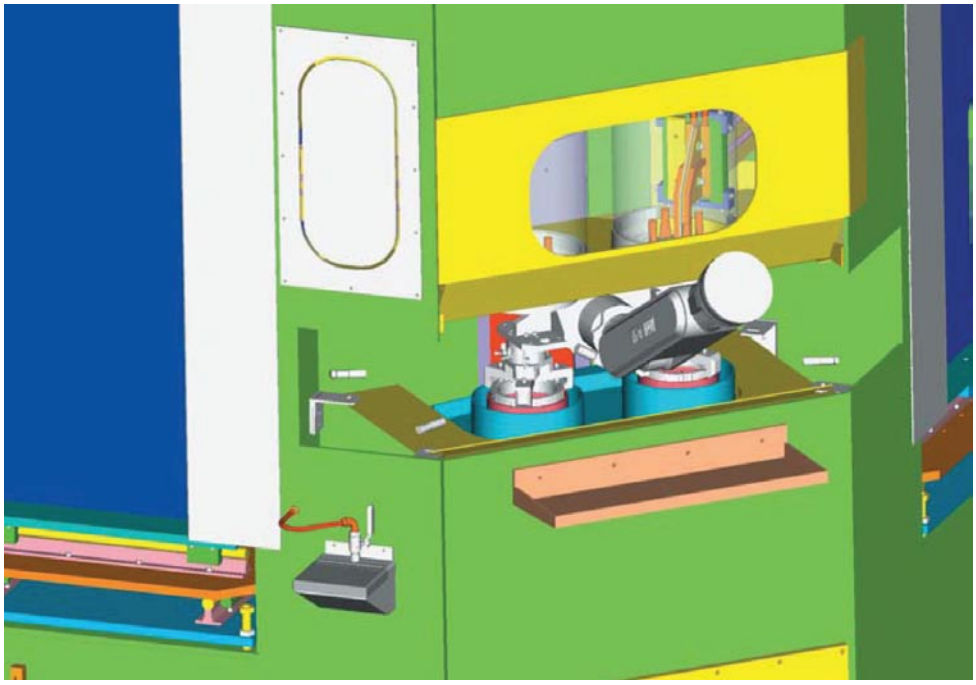
Transmission planetary ring gear.

additional expensive operations such as piloting each new heat run and subsequent final grinding or hard finishing, and also the need to use controlled chemical compositions or alloy additions. The unpredictable variability in the heat treat process and results also frequently causes designers to make modifications in gear geometry and/or gearbox design throughput because the full theoretical capability of the heat treated strength of the gear material cannot be used. An additional process cost stems from the use of batch heat treating, which typically is separated from machining operation combines. These issues make heat treating a major operational cost factor in the manufacture of gears. Given all of these issues, the challenge is to make better gears to meet increasing gear-market needs, and to make good gears even better.

Traditional Gear Heat Treatment

This discussion primarily is directed at what has been done and what is being done in the automotive automatic transmission gear industry. The issues and accomplishments specifically relate to planetary gear reduction systems used in automatic

Transmission planetary ring gear.



Robotic load operation mechanism for SPF induction hardening in-line integration.

transmissions. The concepts and ideas are generic to gears in general, and also have applications in other types of gear systems.

Atmosphere carburizing and oil quenching still is one of the most common heat treating processes for gears. The technology, which has been around for many years, has been slower to produce innovative developments because changes are based on empirical experience, which has resulted in much variability in the systems used and in the controls implemented. This environment has impeded the motivation to change.

However, now there has been a major shift (low-pressure vacuum carburizing and high-pressure gas quenching, LPVC, and HPGQ) in progress in the furnace industry. Started in the mid 1990s, it uses a substantially improved furnace envelope with enhanced carbon atmosphere integrity and control plus more sophisticated computerized controls. LPVC now has consistently reduced process unpredictability and some of the environmental issues associated with atmosphere gas carburizing. There is considerable activity to shift from traditional atmosphere carburizing to LPVC and HPGQ to improve the cooling/quenching predictability. There is considerable information about the improved capabilities of LPVC technology in the literature, and a number of systems have been implemented into automotive automatic transmission gear manufacturing. While it is an improvement over atmosphere gas carburizing, there still are improvements needed in a number of areas, and it still is a batch operation.

Where Does Induction Stand?

Induction heat treating also has made substantial progress in the past 60 years. The selective heating capability of induction hardening includes a variety of techniques for hardening the root and/or tooth flank of individual teeth sequentially, along with a number of single-frequency and multiple-frequency techniques used to process the entire gear face. Induction hardening of planetary ring gears was launched about 50 years ago, primarily to reduce pitch circumferential line run out.

There are about a half dozen somewhat different induction hardening process techniques currently in use, which have progressively improved induction hardening capabilities. Some improvements are a result of increased capabilities of the basic power equipment and its associated hardware and controls, while other improvements derive from a better understanding of what is required in a gear to meet its operational requirements. However, the evolution of these design improvements is largely based on empirically evolved experience validated by field testing.

Induction Heat Treating Requirements

The gear industry needs improved technology at a lower cost to make better gears having more consistent dimensional quality and improved durability.

This requires that induction heat-treating process capabilities be raised to a higher level, while at the same time reducing the capital investment requirements of the user. Also, heat-treating systems must be designed to be more reliable and simpler to operate.

Modification of tooth geometries—such as higher contact ratios that increase root-bending stress in volute tooth form, together with other new tooth geometries—provide additional challenges to controlling the heat treating process variability. The reduction in gearbox package size requires a more complete understanding of the operational dynamics under load, and these requirements are further challenged by the ever-present demand for noise reduction. All of these factors have a great influence on heat-treating process results.

An important consideration that affects the change in gear dimensions during heat treating is the structural rigidity of the total part geometry. The issue is when the active profile elements comprising the "tooth form and root area mass" become a substantial portion of the total part mass geometry. Control of the part during heat treating becomes more difficult; for instance, when planetary ring gears have a relatively thin rim of material under the root. These design issues make obtaining consistent dimensional quality even more important.

Better Gears Using Induction

Because of these multivariant issues in heat treating gears and their interrelationship with the total manufacturing process to make good gears better, Ajax Tocco Magnethermic (ATM) recognizes the need for a more structured scientific approach to address the problem. This enlightened approach of simulation-based engineering (SBE) is needed to meet these complex challenges to make gears better. ATM is now using this SBE philosophy of conducting computerized studies of the cause-and-effect analysis of all applied factors including process system components (both heating and quenching), equipment requirements, required tooling/inductor coil design, and final part thermal/hardness profiles, as well as resultant beneficial residual stress profile. This is an interactive process used to develop the optimum combination of equipment capability, hardware design, and processing parameters to produce the maximum capable performance of that particular gear design.

This is a comprehensive plan using several modeling formats since many mathematical models are incomplete or imperfect, plus pedigree data to drive them is not available. Therefore, these SBE studies are driven by specialized engineers who developed the required skills to use those formats that work.

Putting Into Practice

It is rare in gear manufacturing to have a comprehensive understanding of gear machining, testing, and heat treating. Working with a highly experienced transmission gear manufacturer, Ajax Tocco was able to capitalize on its comprehensive knowledge

of the various machining issues, various heat-treating choices, and suitable material selection. Using the gear manufacturer's experience-generated knowledge base, coupled with ATM's extensive engineering induction/metallurgical and FEA modeling skills, ATM launched its single precise frequency (SPF) induction gear-hardening concept. The SPF system is substantially less complex in design and operation than the traditional multifrequency and pulse-cycle systems. SPF offers more reliable control and operational functions for consistent results. The system can be programmed to provide an optimum balance of root versus tip hardening. The technique uses a precisely adjusted single frequency (within ±1 percent) applied at a high intensity energy input to suit each particular tooth size and shape relative to the diametrical pitch (module). Thus, it produces the required profile pattern with substantial pitch line depth (to prevent both surface and subsurface failure) plus the required rootbending strength. It uses programmed accelerated high intensity short heat cycles that prevent overheating, which provides the optimum thermal/mass structure rigidity for excellent, repeatable dimensional results. System features include:

"The need for high-performance gears having more complex designs will likely increase with the advent of more efficient alternate drive systems for automobiles."

- Precise, adjustable programmable frequency selection to suit every gear shape for optimum results. The frequency selection can only be properly selected based on analytical—"what if"—FEA simulation analysis. This is integrated with subsequently validated actual tests;
- Accelerated high-intensity short time heating reduces total part heat input, thereby providing improved consistent dimensional results. FEA simulation analysis is also used to optimize the effect of the tooth/root mass geometry to adjacent support mass structure and required structural rigidity related to the total accelerated thermal energy logistics for consistent minimal dimensional change;
- Efficient FEA-derived single-frequency IGBT driven power supplies;
- Computer-modeled power supply output surface tuning components and inductor systems that optimize the capability of the total system to produce the required thermal profile;
- Reduced gear-hardening system complexity for improved process control capability and ease of operation. State-of-the-art smart sensor controls ensure quality performance;
- Reduced capital equipment investment and lower operational costs;
- Reduced maintenance and increased productivity throughput;
- Total integratability into cellular or inline manufacturing system suitable for a wide range of gear diametral pitch (DP). It has

been successfully applied to 13 to 16 DP gears;
- "Batch-of-one" inline operation.

Today there are six SPF transmission gear-hardening installations, with several more being planned. The success thus far is largely due to taking a holistic approach to understanding all issues in design and performance requirements, manufacturing and heat treating, testing, and validation of gear systems. The experience shows that attempts to understand the multivariant character of many manufacturing/heat-treating operations along with their complex interrelationship are not always intuitively obvious. Therefore, an experience-based empirical process approach is no longer adequate for today and tomorrow's challenges to make good gears even better.

Gears are critical components in power-transfer and delivery systems in today's engineering environments. The need for high-performance gears having more complex designs will likely increase with the advent of more-efficient alternate drive systems for automobiles. In addition, the requirement for more effective gear systems is expanding into other areas, such as wind turbines. Therefore, the gear manufacturing industry will continue to be challenged to make a better product at lower cost. The capability of the gear heat-treating industry to meet industry needs and deliver improved products presents major challenges that will continue in the future.

The SPF concept offers a step in the right direction, and progress is being made to refine this concept. For example, several additional improvements and innovative changes are being studied that provide a product having substantially improved durability using even lower cost standard materials. The thermal/mechanical and metallurgical mechanisms that produce this capability are not fully understood at this time. It appears to be related to the ability to focus dynamically highly accelerated thermal energy selectively only in the active profile area of the gear face. Plus, incorporating the high-speed removal of thermal energy (quenching) allows for a minimal effect on gear dimensional change with improved consistency along with other beneficial performance improvements that are unique to the SPF induction process.

ABOUT THE AUTHOR:

George Pfaffmann, FASM, is vice president of technology at Ajax Tocco Magnatherm, Inc. He has spent the majority of his career working in the area of induction heating/heat treating technology, both as a practitioner and research scientist. He is a long-standing member of the ASM Heat Treating Society's R&D Committee and actively promotes collaborative R&D to advance all heat treating processes from an experience-based technology to a more structured engineering/science-based technology. Pfaffmann can be reached at (248) 691-2281 or gpfaffmann@ajaxtocco.com. Go online to [www.ajaxtocco.com]. This article appears courtesy of *Heat Treating Progress* magazine.