As the gear industry reinvents itself, “green manufacturing” gains prominence by factoring all aspects of the process into achieving efficient outcomes.

By Mark Davis
In his annual message to Congress in December of 1862, President Abraham Lincoln concluded with the words “We can succeed only by concert. It is not ‘can any of us imagine better?’ but ‘can we all do better?’ The dogmas of the quiet past are inadequate to the stormy present. The occasion is piled high with difficulty, and we must rise—with the occasion. As our case is new, so we must think anew, and act anew.”

Although these words were uttered more than a century ago, Lincoln could’ve been speaking to us today as the gear-manufacturing industry realigns itself and charts a new course into the future. While the challenges are many, we will hopefully emerge with a more-efficient and productive manufacturing model. One approach that will factor into this is known as “green manufacturing,” which takes into account everything from product development and process technologies to energy consumption and material flow. With so many decisions based on cost, function, and quality, green manufacturing encompasses a broad spectrum of economically sound solutions for improving process efficiency and reducing costs, while at the same time conserving energy and resources.

**GAINING BY GOING GREEN**

Gears are among the most complex geometries known to manufacturing. Every aspect of gear making is difficult, including the interdependent interactions of material, machinability, and quality. Gear manufacturers are continually challenged to make the best gears possible, and to do so more affordably. The goal is only accomplished by looking at the entire process chain, and not just particular components or steps in the sequence.

Progress and productivity are still the keys to survival, and green manufacturing is a prime source for innovation. There is no reason that green and gear manufacturing can’t work together. Pioneers focus on developing and settling the frontier, and Eldec Induction is one firm aiming to expand the frontier with simultaneous dual frequency (SDF®) gear hardening and the “green process chain.”

Inductive hardening is characterized by precise energy metering and excellent process capability. Thanks to very short process times, hardening can be integrated into the cycle of the process chain. This is possible with ultra-low power consumption, especially in comparison to conventional case-hardening processes. These advantages are magnified with the use of our SDF generator technology together with its fast, high-power density application for workpieces with complex surfaces like gear components. The targeted simultaneous medium- and high-frequency energy input generates hardness in the surface layer alone. This saves energy and greatly reduces distortions and the rework effort required. Hard processing such as grinding is sometimes unnecessary, in fact.

Challenged with containing costs, as well as maintaining the highest safety and quality standards, aerospace engineers are conservative by nature and practice. They also recognize the parallel necessity to protect and preserve the environment. As an example, the Boeing Company proclaims on its Web site that it “recognizes the serious challenges facing our eco-system and is committed to reducing the effect of its operations, products, and services on the environment. Our greatest contribution to meeting the challenge is to pioneer new technologies for environmentally progressive products and services—and to design, develop, and build them in an environmentally responsible manner.” Boeing has implemented aggressive targets for reducing its impact on the environment and has embedded environmental thought and action into everything they do. At
the 1st International Conference on Distortion Engineering, Boeing engineers presented a case study comparing distortion on AGMA 390.02 class 10 straight bevel gears that were gas carburized versus contour induction SDF hardened\(^1\). Induction surface hardening was shown to be a viable alternative due to the minimal distortion achieved.

Straight bevel gears have traditionally been used on large transport aircraft because they can be manufactured in one piece for straddle-mounted applications, in which the gear is mounted between bearings. This affords a significant weight savings over multi-piece spiral or bevel gear straddle-mounted designs. Non-straddle-mounted applications, such as the 3633 gear, continue to use straight bevel gears for reasons of machine tool commonality. Unlike other bevel gear forms, straight bevel gears cannot be economically ground after heat treatment in order to correct distortion because the crowned tooth form is incompatible with the kinematics required for grinding. The gear teeth must therefore be cut with offsets to anticipate the expected distortion during heat treatment in order to meet the final tolerance requirements. The flow time of all induction hardened gear is typically 40 percent of the flow time for a carburized gear. This reduction is due to the simplified gear cutting setup, elimination of masking, distortion, and other problems (see fig. 1).

Much of the pattern profile movement in carburized gears can be attributed to changes in the pitch cone angle due to heat treat warpage as a function of time and temperature. By comparison, the SDF induction hardened gear variation from nominal is the result of normal machine variation and is expected and well within the tolerances for an AGMA quality 10 gear. This profile is essentially unchanged from the pre-induction hardened profile.

**EFFICIENT ENERGY TRANSFER**

Hans Barthelmes—former GKN plant manager and currently president of the independent consulting firm Batechma—has decades of experience in the field of engineering and manufacturing drivetrain components like half shafts and constant velocity joints. He recently commented on the induction hardening of CV joint ball tracks\(^2\), a subject to which he is no stranger since implementing multiple lines with various single-frequency induction hardening solutions; state-of-the-art for their time in high volume machining. He indicated that “Medium frequency, in the range of 10 kHz, has proven to be much more consistent in reducing distortion, but you still have too many variables to eliminate hard machining without gathering tons of empirical data regards materials.”
Barthelmes explained the elaborate and time-consuming process of trend ing materials and machinability variables from batch to batch, and the relatively significant rework involved with single-frequency induction. “The simple logical effect of SDF induction hardening process transfers the required energy into the part in the shortest possible time, due to the two frequencies acting simultaneously. The benefit is a controlled and repeatable case depth, and therefore allows for repeatability and minimized distortion due to uncontrolled heat transfer. This makes it possible to think ‘green finish milling’ which we have achieved in production.”

Barthelmes’ firm helps CV joint and drive shaft fabricators optimize the manufacturing process chain with cost and energy saving innovations like SDF. Eldec SDF induction hardening, together with its fast high power density application, has made it possible to green finish mill the ball tracks before induction hardening and then assemble them complete, eliminating the most costly step in the process chain. As seen in fig. 2, there is a three-times energy reduction in the inner race hardening.

Another example is a steering pinion that was induction surface hardened for ThyssenKrupp in order to demonstrate the feasibility of achieving a contour true harden pattern of such a complex geometry, as fig. 3 displays. Two examples were tested in an extensive running test in order to verify the quality of the hardened surface in terms of life time strength. Both steering pinions passed the test and showed no indication of cracks.

All these examples make a clear case for substituting Eldec SDF induction for case hardening whenever possible. It would be wrong to argue that this is a universal alternative because there are certain limitations that are well known.

**NEXT-GENERATION INDUCTIVE HARDENING**

Since SDF is a technology and a process, it requires a vehicle to integrate it into the manufacturing superhighway. That’s why Eldec is introducing a new class of inductive heating systems known as...
the MIND—Modular INduction—machine (fig. 4). In developing this series, priority was given to creating maximum flexibility for maximum productivity. Thanks to this carefully thought-out design, individual solutions are made possible by using time-proven components, allowing for customization without the hassle of a piecemeal, one-of-a-kind model. The result leads to increased system availability and state-of-the-art technology for the best price possible, guaranteeing lowest life cycle cost.

The MIND class of modular machines is the result of vast experience supplying inductive energy sources and complete highly customized heating systems. Eldec MIND hardening machines are available as a manually controlled standalone solution, as a heat treatment system with individualized levels of automation, or also as an inline, single-piece flow hardening cell, totally integrated in the process chain of machining before and after heat treating. This system is as flexible as hardening tasks and workpieces are diverse. Depending on the workpiece dimensions, desired hardness pattern, and requirements for flexibility and lot size, machines are configured as:

- An individual machine, or a linked system;
- A single or two-spindle machine;
- With or without rotary indexer;
- With tailstock, steady rest, or T-groove rails or table;
- PLC or CNC controlled;
- Equipped with medium-frequency, high-frequency or SDF generators from 15 to 3000 kW.

One particularly salient feature of the MIND series is its ability to
integrate into the single-piece flow production required by today’s lower volume economies. Integration saves time, energy, and logistics. The typical task time of the MIND SDF process is under 30 seconds, which is well within accepted targets.

CONCLUSION

Like saving energy, conserving resources is a timeless concept that predates Sir Isaac Newton himself. Fossil fuel reduction—wherever and whenever—has to be the goal moving forward. “Going green” in manufacturing is more than a philosophy, a strategy, or a responsibility, it just makes good “cents” to reduce and conserve. Reduced energy usage in the manufacturing process is a win-win for developing a competitive advantage.

In the Boeing study cited previously, the findings showed significant cost benefits associated with induction hardening, but it’s easy to see how the environmental impact is reduced by SDF induction as well. Induction hardening releases less internal residual stresses as a result of the lowest possible energy input—measured in kilowatt seconds, or kWS—and therefore only a small fraction compared to the total mass that has to be quenched during the final heat treatment, minimizing distortions. The lowest possible energy input and resulting reduced energy consumption translates directly into improved environmental benefits.

Since the connection between gear manufacturing and heat treating is so strong, it is fitting that AGMA’s Gear Expo and the ASM Heat Treating Conference will coincide in Indianapolis this year. There is a tremendous synergy of interest and applications whenever “gearheads” and “hotheads” get together. As frequently stated by Eldec founder Wolfgang Schwenk, “SDF technology will increase throughput, decrease distortion, and slash energy costs, all of which should be very attractive to the gear manufacturing industry.” Change is inevitable, and Eldec is committed to providing innovative approaches toward making green gear manufacturing a reality.

REFERENCES:

3) Schwenk, Wolfgang, Substitution/Replacement of case hardened gearbox components in the...