Pushing Boundaries

Induction hardening is becoming an increasingly popular alternative to thermochemical diffusion processes such as carburizing, and as it does so, manufacturers are on a never-ending quest to expand the scope of what's possible with the technology.

Alex Cannella, Associate Editor

Dr. Valery Rudnev, director of science and technology at Inductoheat, has been doing a lot of travelling the past few years. Known as "Professor Induction," he's one of the leading experts in the field of induction hardening, and his expertise regularly sees him touring facilities and giving seminars on the latest in the induction hardening industry. Needless to say, during his travels across Europe and the U.S., Rudnev has personally witnessed how a broad swath of the industry is getting along, and he's noticed a few trends.

The most notable one is an attempt to shift away from thermochemical diffusion processes such as carburizing in favor of induction hardening. Manufacturers' reasons for doing so are always different, but everywhere Rudnev has gone, the hottest button topic that always comes up is whether a heat treater can replace thermochemical diffusion processes like carburizing or not.

"Question number one I'm asked: 'Can you replace our thermochemical diffusion processes with induction?'" Rudnev said. "And the answer is sometimes yes, sometimes no, it depends on the gear."

There are a few reasons why the question has become so common. Some of the primary reasons are induction hardening's ability to produce increased compressive residual stresses compared to vacuum carburizing, low distortion and piece-by-piece processing capability with individual component traceability. According to Rudnev, single frequency induction hardening can achieve levels of 400-550 megapascals. And if using simultaneous dual-frequency, heat treaters can achieve 600-700 megapascals.

Induction hardening is also starting to see some promise for use on 7" to 9" hypoid ring gears, with Rudnev having seen some "extremely positive tests." In the future, it may become a widely accepted way to harden those gears.

In Europe, especially, induction hardening is gaining popularity off a wave of environmental-mindedness. The current political climate in Europe is motivating many heat treaters to consider shifting their production processes from vacuum carburizing to induction hardening, which is a more environmentally friendly process. Some, according to Rudnev, don't even feel there's room left for consideration, and that carburizing isn't an option anymore.

But as Rudnev said, induction hardening isn't a silver bullet solution for gear heat treatment. The process has difficulty, for example, with complexly shaped gears such as double helical or herringbone gears. The more complex a gear's shape, the more difficult it is to develop a uniform case hardened pattern, and eventually, the complexity can reach a point where induction hardening simply cannot evenly austenitize a tooth surface, leading to varying case depths on different parts of the gear and potentially producing some undesirable metallurgical structures. In these cases, Rudnev still recommends that heat treaters vacuum carburize or nitride their gears instead, whichever is more suitable.

Similarly, sharp corners on a gear or workpiece can lead to subpar heat treatment. Sharp corners sometimes get excessively heated compared to the rest of the teeth, which leads to grain coarsening and in some instances, even grain boundary liquation (incipient melting). Thus, appropriate chamfering and rounding of sharp edges is always welcomed by induction professionals.

Induction hardening's popularity is rising alongside its flexibility; manufacturers are finding new ways to expand the range of workpieces the technique can be utilized on.

Induction hardening also often requires using different steel grades to start with. Thermochemical diffusion processes (e.g. carburizing or nitriding) alter the actual chemical makeup of the material, thus hardening it. But one critical difference between these processes and induction hardening is that the latter does not alter the chemical composition of the material, which in turn means you need a stronger base material with sufficient carbon content to form the required amount of martensite at a gear's working surface in order to provide sufficient strength and wear properties.

Thanks to surface hardening capabilities of electromagnetic induction, a gear tooth's core remains relatively cool, which allows it to act as a shape stabilizer for the heated surface and in turn lessens the distortion caused by the heat treating process while also making that distortion more predictable.

"Even more important is not just to reduce distortion, but to have predictable distortion," Rudnev said. "Because if the distortion is predictable and repeatable, then this type of distortion can be relatively easily compensated for."

It should be recognized that depending on the size of the gear, tooth geometry and gear working conditions, different techniques can be used to induction heat treat gears. This includes tooth-by-tooth hardening and spin hardening using encircling coils. Single frequency induction systems, as well as sequential or simultaneous dual frequency systems, have been developeed by several induction manufacturers, including Inductoheat.

One gear market segment that has been relatively soft in the last 5-8 years is heat treatment of large gears such as those that go into windmills. According to Rudnev, demand for induction hardening of those gears is quite low amongst large gear manufacturers in the U.S., in part because a lot of the field has been outsourced abroad.

One difficulty large gear manufacturers sometimes run into is actually finding a heat treater that can handle the sheer scale of gears that stretch to multiple meters in diameter, but according to Rudnev, scale isn't a concern for tooth-by-tooth induction hardening. In fact, that's one of the method's strong points.

"Even though that some distortion inevitably occurs when tooth-by-tooth induction hardening large gears and pinions, its magnitude is not nearly as large as compared to carburized gears," Rudnev said. "Carburizing requires soaking of gears for many hours at temperatures exceeding 1500°F. At these temperatures, the large masses of metal expand to a much greater extent compared to the case when only the tooth working surface layer is austenized by electromagnetic induction. The expansion of large masses during prolonged heating during carburizing and the contraction during quenching "move" the metal to a much greater degree, causing considerable gear distortion.

"Furthermore, heavy gears weighing several thousand pounds and being held at austenite phase temperatures for

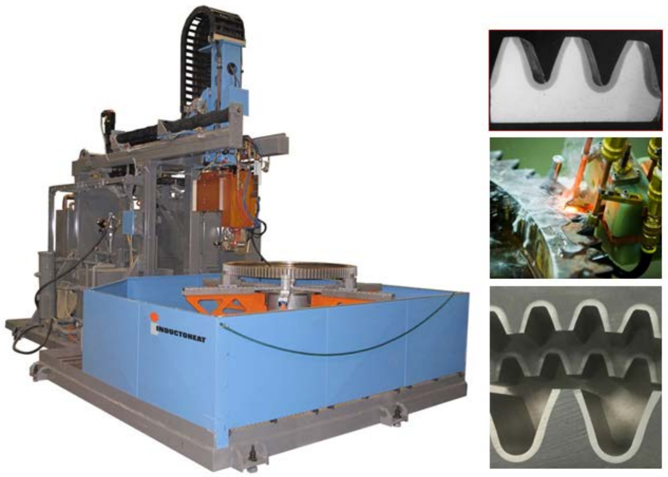


Figure 1 Tooth-by-tooth hardening of large gears. (Photo courtesy of Inductoheat Inc.)

many hours have little rigidity and can sag following their supporting structures. With induction hardening, areas unaffected by heat as well as areas with temperatures corresponding to the elastic deformation range serve as shape stabilizers resulting in not only reduced distortion but also making it more predictable. Induction hardening for those applications is the best process (Figure 1)."

Rudnev also frequently gets questions about shot peening, namely if heat treaters can avoid having to use it after induction spin hardening of small and medium size gears. The answer, again, is that it really depends on your requirements.

"Many times, when induction hardening gets used for a gear treatment, we don't use shot peening," Rudnev said. "But if the performance of the gear requires residual compressive stresses of considerable magnitude being in the range of 900-1,000 megapascals, then most likely, it will be required to have shot peening after induction gear hardening."

But most often, the focus is on the technology's competencies themselves; what it can handle, what it can't, and most importantly, how its compares to vacuum carburizing.

The answer to that question becomes a little more nuanced every year, however, as induction hardening is an evolving field, and the scope of what can be accomplished with the process is always widening. Rudnev's company, Inductoheat, for example, has developed a new power supply called the Statipower IFP (Independent Frequency and Power Control). The idea behind the patented IFP Technology is to fill a gap that the induction hardening industry as a whole currently has between cheaper, less flexible conventional single-frequency induction systems and expensive but effective dual frequency processes in an attempt to capture the selling points of both while minimizing some of their weaknesses (Figure 2).

"IFP Technology is a good compromise between simultaneous dual frequency, which has good results but high capital cost, and

Figure 2 Statipower IFP Technology enables instant and independent adjustment of frequency within 5 to 60 kilohertz range in a preprogrammed manner during the heating cycle. (Photo courtesy of Inductoheat Inc.)

conventional single frequency systems which are less costly but the quality of hardening of certain types of gears might not always be the best," Rudnev said.

Which isn't to say that IFP is the end-all be-all system that you should be immediately leaping to your feet to buy. As Rudnev notes, there are still plenty of gears that single frequency systems can already handle just fine. And on the other hand, some gears require a level of metallurgical quality and hardness pattern contouring only achievable with simultaneous dual frequency.

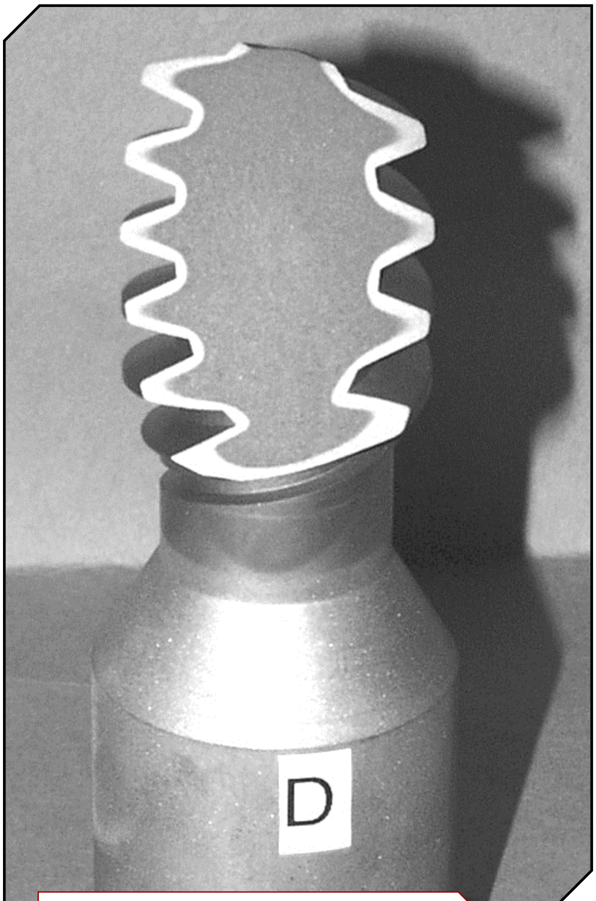
"It's not cure-all medicine," Rudnev said. "There are some limitations associated with IFP Technology. For example, at this point, IFP inverters enable instant and independent adjustment of frequency within a 5 to 60 range kilohertz in a preprogrammed manner during the heating cycle optimizing electromagnetic, thermal and metallurgical characteristics."

But Inductoheat has positioned IFP as a happy middle ground, giving induction hardening professionals a gradient of options instead of just two choices. And more importantly, the IFP is flexible, which according to Rudnev, has made it appealing to heat treat other components for automotive suppliers.

"Suppliers need to have flexibility. If tomorrow one automotive [company] comes to them and then, a day after tomorrow, another one with a different requirement, suppliers would like to process those parts using the same equipment," Rudnev said. "Obviously in induction, the coil would be different, being dedicated to a particular part, but the cost of the induction coil is relatively small compared to the cost of the entire system and in particular an inverter...Therefore, if the power supply will provide them greater flexibility, that's a big deal in our highly competitive world. Parts suppliers would not have to buy a new power source all the time to process different gearbox or powertrain components while still assuring high metallurgical quality of heat treated parts. Instead, now they can utilize universal inverters with flexible yet highly accurately controlled output frequency, which will extend horizons and the applicability of their induction equipment. Needless to say that such equipment can also be moved from one plant to another plant, optimizing overall cost savings."

The IFP Technology, couples with an advanced signature process monitoring system, is targeted towards automotive, aerospace, agriculture and off-highway industries and is best suited for heat treating gearbox components, as well as shafts, sprockets and splines of almost every variety. It's also particularly beneficial when tooth-by-tooth hardening a variety of large-sized gears. And the breadth of projects that can be undertaken with Inductoheat's IFP Technology is widening as the company works to introduce new models that expand coverage of different ranges of frequencies and maximum powers.

Inductoheat is, of course, not the only company innovating in the induction hardening space. Eldec has also been pursuing new technologies that expand



Both Inductoheat and Eldec are creating new induction hardening products capable of handling new shapes of gears.

the scope of the process's usefulness. In particular, they've been working with pushing the cutting edge of what can be done with simultaneous dual frequencies.

One of their most recent developments is a coil specifically designed to work with helical gears, a move meant to appeal to gearbox manufacturers. It's a bit of a leap of faith on Eldec's part, as gearboxes are still firmly vacuum carburizing territory, and getting customers onboard requires a lot more than just buying a new coil; it requires a complete changeover of their processes, and affects more than just the heat treatment. You have to consider materials and your chip making process, for example.

Eldec's coil certainly has merits to warrant the switch, however. All the previously discussed advantages that induction hardening has over vacuum carburizing still hold true here. But one of the process's biggest weaknesses, complex gear shapes, also remains. There are still difficulties with gears with a helix angle of more than 15–20 degrees, but Eldec has established a toe-hold that can be built upon, and that may change in the future.

In addition, Eldec has designed their induction hardening machines to work as part of a production line. Instead of having to take parts off the line to divert to a furnace before going back to the line, Eldec's machines can be incorporated directly into the workflow. And if you do ultimately decide to make the leap, Eldec has a full force of consultants to help make the transition as painless as possible.

According to Managing Director of Eldec, Thomas Rank, however, the best advice he can give those looking to incorporate induction hardening into their production line is to take stock of their entire process chain.

"Look at the whole process chain before you do that step," Rank said. "Investigate in all the process steps before and after hardening in order to have a result that doesn't surprise you in terms of cost."

Another frontier that Eldec is braving is that of IIoT technology. Whether you call it the Industrial Internet of Things or Industry 4.0, it's worked its way into almost every manufacturing process known to man, and induction hardening is no different.

Eldec's introduced a software suite dubbed Eldec Quality Control (EQC) for use with its induction coils that uses RFID tags to constantly monitor more than 20 different parameters in an induction hardening machine. EQC studies everything from energy, water temperature and the voltage of the coil during the process to even how many workpieces the coil has heat treated during its lifetime.

The benefits of this are the same as in other industries: having access to an unprecedented level of data means that engineers can not only better understand and control how their coils are functioning, but they can also use that information to predict when a coil looks like it will fail and preemptively replace it before it halts production. EQC also automatically shuts down a machine if any of its parameters go over previously designated levels, preventing catastrophic damage that might otherwise put a machine out of commission.

One unusual twist that is different from other industries, however, is that Eldec had to design around the electromagnetic field when developing EQC. In particular, the field could wreak havoc with EQC's RFID tags, but Eldec found a solution by monitoring the field itself.

There are numerous other advances also coming out of Eldec — 3D printed induction coils chief among them — but every advance shares a single goal: to expand the scope of what's possible with induction hardening. That similarly rings true for Inductoheat. And between them, the technology gains new footholds each year, and with those footholds, broader appeal.

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