Induction Heating in the Powertrain Industry

Authors: Valentin S. Nemkov, Robert T. Ruffini, Robert C.Goldstein,
Centre for Induction Technology, Inc.
Chester N. Grant, Shekhar G. Wakade
General Motors Powertrain

Abstract

There is a demand for improved induction heating technique in the powertrain industry today. Continuously changing tighter product requirements mean what was good just a few years ago is no longer good enough. The existing induction heating equipment and technology within the powertrain industry is relatively old. There is also an insufficient level of knowledge possessed by the people working with induction heating processes. In addition, there is a gradual depletion of people experienced in the induction technique within the industry. Several recent advancements in the induction heating technique provide a good opportunity for existing process improvement and new process development. To fully utilize these enhancements, more attention must be paid to education at all levels in the induction technique. An overview of induction heating in the powertrain industry, advanced induction techniques and educational opportunities are considered in this paper.

Status Overview

The induction technique has several inherent advantages for heat treating automotive components. Induction heating produces internal heat sources. These sources provide high power densities and high selectivity of heating in the depth and along the surface of the part, which is very important for local heat treating. In addition, induction heating works equally well in any processing atmosphere (air, protective gas, vacuum).

These physical features give the following technological and economical advantages to the customer:

- Short heating cycles and high production rates
- Better metallurgical results (hardness, strength, ductility)
- Good control and high repeatability of the process
- Small or negligible surface oxidation and decarburization
- Low distortion due to fast localized heating in depth and along the surface
- Energy and labor cost reductions
- Very short start-up times and low stand-by losses
- More simple and economical steels and quenching media (water or polymer solution instead of oil for example) may often be used with the same final properties produced in the parts

- The process is favorable to the industrial environment (no exhaust gases and other emissions, the small size of induction equipment with high reliability, good automation adaptability).

The powertrain industry has used induction heating for over 50 years due to these inherent advantages. It has been employed for a variety of heat treatment processes including surface hardening, through hardening, tempering, normalizing, annealing and sintering, etc. The induction technique is also used for non heat treating processes related to the powertrain industry including melting operations in foundries, forming operations, bonding operations, etc. The various components using these processes are too numerous to be listed here. Types of materials that have used inductive heating in Powertrain applications include various grades of steels including PM grades, as well as, nodular, gray and austempered ductile iron grades of cast iron. The range of frequencies used varies from 3 KHz to 100 KHz depending upon the application. Typical Powertrain components using induction heat treatments are shafts, pins and gears.

Despite the vast experience and knowledge present in the equipment supplier community, rapid product development cycles and the need for reduced variation to meet 6-sigma quality requirements create a demand for better understanding of induction heating as a tailor made process for meeting the increased specifications for newer products. Continuously changing tighter product requirements mean what was good just a few years ago is no longer good enough. At the same time the marketplace price pressures mean the equipment manufacturers must improve the processing capability of their equipment relentlessly without increasing cost. The desire to use the best common practices and yet not being able to use the same make and model at various locations due to aggressive pricing creates a dilemma for the buyer community. The desire to reduce cost also means more dependence on the equipment suppliers to provide additional incentives when it may or may not be possible.

The people responsible for the growth of the induction technique in the powertrain industry are no longer there. The need to reduce structural costs results in early retirement of the knowledgeable workforce, creating situations whereby the experience needed to develop the process is not there or the time required to capture the learning and to implement it is not there, due to "fast to market" development cycles.

In most cases, the existing induction heating processes in the powertrain industry use equipment purchased years ago without any realistic chance of being upgraded. Many of these processes could be drastically improved and other parts not currently heated by induction could be due to recent improvements in induction heating techniques. Advancements in computer simulation, solid state power supplies, intelligent control systems, materials for magnetic flux control and other areas provide a solid foundation for improvement of existing and of new induction process development. However, the segment of workforce educated in how to take advantage of these improvements is relatively small. There is a definite need for an educational program to teach all levels of the induction technique from the operator to the highest technical level.

Advancements in the Induction Technique Related to the Powertrain Industry

DFIH strategy

To take full advantage of induction heating, some companies have begun using a Designed for Induction Heating (DFIH) method for component design. DFIH is a new design strategy when the part and heat treatment specifications are formulated with an account of the special features of the induction technique [1,2].

The DFIH strategy requires that the part designer be familiar with areas that could complicate or improve the induction heat treatment. On one hand, the designer must know how to utilize all of the advantages of induction heat treating (elevated hardness, favorable distribution of stresses, local heating, reduced distortion, etc.). On the other hand, the designer must develop a design and processing procedure well suited to induction heat treatment. Often times, a small change in the part geometry or hardness pattern can lead to a drastic simplification of the induction heat treating process. This approach guarantees an effective induction heat treatment and provides significant savings in investments and in process development time.

Progress in Power Supplies, Heat Treating Machines and Control Systems

The progress in high frequency power supplies for induction heat treating continues. With recent improvements in power supply size, weight and efficiency, now the main direction of enhancement is in the control systems. Using new advanced components and technology, power supplies become more reliable and intelligent. Intelligence includes process programming, power supply self-control and adaptation, process monitoring or closed-loop control and data storage.

With small power supplies and hand-held transformers, there are new possibilities in building robotic systems or incorporating induction units into the production line. There are new and emerging processes such as laser assisted induction heating, induction heating in protective atmosphere, induction carburizing, etc.

Computer Simulation

Computer simulation is becoming more and more popular in the study, development, setup and maintenance of induction heating processes and equipment [2,3,4]. Many experts and groups in different countries are developing programs for induction heating simulation. However, computer simulation is not as widely used in induction heating as in electrical and mechanical engineering. This may be explained by the following reasons:

- Induction heating processes are usually complex and complicated. In general, it is necessary to simulate a set of mutually coupled non-linear and multi-dimensional problems (electromagnetic and thermal fields, quenching process, structural transformations, distortions, external supplying circuits etc., Figure 1);
- Induction processes, especially heat treating processes, have very diverse features which may require individual program structures and simulation methods;

- Personal computers with the high processing speeds and large available memory required for simulation of many of induction problems, only recently became widely available;
- The induction heating market is small compared to other industrial sectors and the development of specialized commercial codes for the induction heating sector is low in profit or possibly even unprofitable venture; .
- It is difficult to make an induction coil that does not heat at all and some users do not care much about having the optimum design, only a working design.

Induction heating coil designs and operating conditions are very diverse and different programs are necessary in order to meet the practical needs. Theoretically we can assume that a single, universally coupled 3-D program would be able to meet all the major needs of the simulation of induction heating systems. However, at the present time, no program like this exists despite tremendous progress in computer hardware and software tools. Any 3-D code requires powerful computers and the process of simulation is knowledge and time consuming. One week of work for a skilled operator may be used as an estimate for the average time for one case study of 3-D electromagnetic simulation. This estimate takes into account the operator's laborious preparation of input data, checking and correction of the almost inevitable errors or inaccuracies, geometry and mesh construction, physical property and boundary condition description, the calculations themself and the analysis of the results. The complexity of 3-D analysis and the required skill of the user make a direct 3-D optimization of induction heating processes and systems rather difficult. A strategy based on a hierarchical use of programs is the most effective [4].

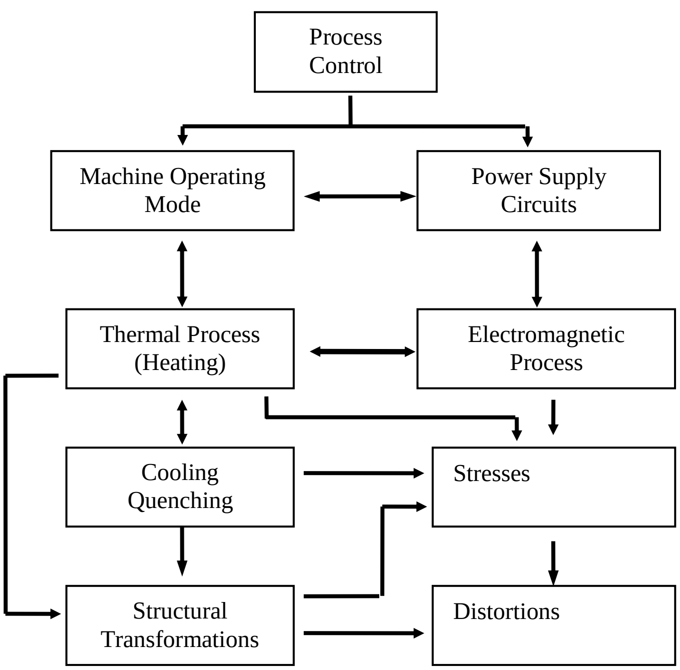

Figure 1 Main processes in induction heat treating machine

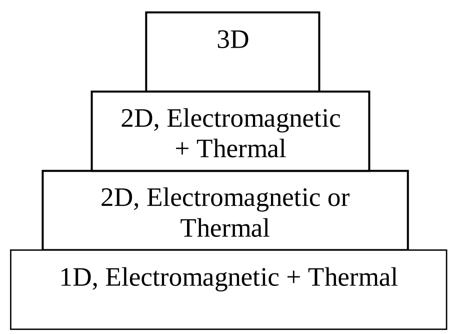

Figure 2 A rule of pyramid for computer simulation of induction heating

For most cases, the first stage in the simulation of the induction heating system should be a 1-D coupled program. This allows you to study the influence of frequency, power density, quench type, and time variations on the process. The ranges of interest can be studied quickly and effectively. A good estimate for the heating time, coil power and coil voltage can be made from the results of the 1-D simulation. In some cases 1-D simulation is sufficient for the process design. In other cases, next stage of simulation with more complicated software is necessary.

The second stage in the simulation may be done using 2-D electromagnetic or coupled codes. The coil current, tube profile, coupling distance and magnetic flux concentrator type and dimensions that provide the required field and power intensity may be determined. With this strategy, a 3-D simulation may often be unnecessary or only required for the final coil design and operating condition corrections for the zones where 3-D effects are significant.

This general approach may be called "a rule of pyramid". It states that more simple programs must be used as a basis for the further use of more complicated packages (Figure 2). Experiments are only required to verify the material response to processing and the phenomena not covered in simulation (Figure 1). In some cases where the material properties and behavior during heat treatment are well known, experiments may not be necessary at all.

The above analysis is based on the author’s current experience, but we believe that it reflects well the simulation situation in general. The high tech inductor, in many cases, is made from a solid piece of copper by CNC machining and it is difficult and expensive to modify it after it has already been built. Computer simulation plus the application of versatile magnetic flux controllers made of magnetodielectric materials provide an effective solution for induction coil design [2,3,5].

Power Inductor Technology

As discussed above, induction heating processes have recently seen many technological breakthroughs in power supplies, computer simulation tools, control and measuring systems and other components. These changes were not followed by essential improvements in the most critical components of the installation - work coils. And it is not because the work coils are perfect and nothing may be improved in their design. On the contrary, the coils are the least efficient and reliable elements of the whole installation. In the meantime, the development of the methods and programs for mathematical simulation of induction heating systems, new materials for magnetic flux control and technologies constitute a good base for the coil and process improvement. The work coil design and manufacturing technology essentially define the workpiece heating quality, installation efficiency and reliability.

The Centre for Induction Technology in cooperation with Fluxtrol Manufacturing, Inc., has developed a procedure for designing induction work coils called Power Inductor Technology^{TM}. This state-of-the-art technology is based on the following four principles:

1. Detailed analysis of specifications and industrial environment conditions
2. Computer aided analysis and design
3. Application of magnetic flux controllers
4. Advanced manufacturing techniques

The end result of Power Inductor Technology™ is the Power Inductor™. Power Inductors are more efficient, reliable, and technologically advanced than traditional inductors designed by "Rules of Thumb". This technology is described in the "Power Inductor Technology for Induction Heat Treating of Automotive Parts" [2] and in the articles "Advanced Design of Induction Heat Treating Coils: Part I & II" [3, 5].

Education in Induction Heating

Induction heating is not considered a scientific discipline but a certain technological know-how. To the authors knowledge, there is no curriculum or courses in induction heating or electrotechnology in universities in the USA. It is supposed that people with other technical backgrounds (mechanical, material science, chemical, etc.) can use and develop induction technologies and equipment. This approach works, but it isn't optimal with many opportunities being lost.

Currently there are several opportunities in teaching/learning induction technique – general educational seminars and clinics, on-site classes, and self-education.

Generic Induction Heating Seminars

General Educational Clinics and Seminars are important, but sporadic and aren't focused on induction problem solutions for powertrain manufacturers. Lasting 1.5 – 2 days they are too short for any profound education. This format is good for initial acquaintance of non-specialists with the basics of induction techniques and for knowledge updating for more experienced people. In addition, these seminars must teach all types of attendees so they contain information that may be too advanced for some and too low a level for other people.

On-Site Training

In-Plant Seminars and Training are more effective. There is very good experience in this kind of personnel training, for example in GKN where an International College of Engineering provides continuos education for personnel of different levels. GKN has a regimented system where they visit their facilities on a regular basis and teach and train people in material processing, including the fundamentals of induction heat treating technique. However, this program still teaches induction at the technical level. It does not provide higher education for the most advanced users. More advanced courses for equipment designers and floor engineers are also required.

Self-education

Self-education plays an important role but it has limited potential due to a lack of modern educational tools and programs. It must be stated that practical use of computer simulation is a powerful method of self-education because simulation provides an information not only on what will happen in the case under consideration but also why it happens. Remote education via the Internet can provide other opportunities for effective teaching and learning.

International Consortium for High Level Training in Induction Technique

Wide International Networking in teaching induction heating could be very effective. It will provide a possibility to develop modern courses and teaching tools, based on computer simulation, and to use new educational technologies.

Conclusion

Rapid product development cycles and the need for reduced costs creates a demand for better understanding of induction heating as a tailor made process for meeting the increased specifications of newer products. Significant advancements have been made in the induction technique that could lead to drastic improvements in many heat treating processes for powertrain components. Efforts to improve the existing technology must come from both inside and outside the powertrain industry, because the supplier community alone is not capable of meeting these needs alone. More cooperative efforts of the end users, technical centers, suppliers and academia are required for improvement of induction technology, equipment and adequate preparation of human resources.

References

1. Pearson, E., *17th Interational ASM Heat Treating Soceity Conference*, Indianapolis, Indiana, 15-18 September, 1997
2. Ruffini R.S., Ruffini, R.T., Nemkov, V.S. and Goldstein, R.C., Power Inductor Technology for Induction Heat Treating of Automotive Parts, *Global PowerTrain Congress*, Stuggart, Germany, October 1999
3. Ruffini R.S., Ruffini R.T. and Nemkov V.S., Advanced Design of Induction Heat Treating Coils, Part I: Design Principles*, Industrial Heating, June 1998*.
4. Nemkov, V.S. et. al,. Computer Simulation of Induction Heating and Quenching Processes, *3rd International Conference on Quenching and Control of Distortion* Prague, Czech Republic, March 1999.
5. Ruffini R.S., Ruffini R.T. and Nemkov V.S., Advanced Design of Induction Heat Treating Coils, Part II: Magnetic Flux Concentration and Control, *Industrial Heating, November 1998*.

Authors’ Biographies

Valentin S. Nemkov
Chief Scientist
Centre for Induction Technology

Since graduating from the St. Petersburg University of Electrical Engineering, Russia, in 1960, V. Nemkov worked at the Vologdin Research Institute of High Frequency Currents and then taught at his alma mater. He holds a Doctor of Science degree in Electrotechnology. Dr. Nemkov is widely recognized as an expert in the education, theory and practice of induction heating. He is an author and co-author of 6 books, 10 patents and more than 220 papers in this field. His present research is devoted to development of new induction processes, computer simulation of induction systems and magnetic flux control.

Robert T. Ruffini, Jr.
Vice President
Fluxtrol Mfg., Inc.

Since graduating from Michigan State University (B.Sc. ’90) Robert T. Ruffini has been employed at Fluxtrol Mfg., Inc. Three years ago he was promoted to Vice President and is in charge of daily operations. He has lectured extensively throughout Europe and America on induction coil technology and application of magnetic flux controllers. He co-authored two US patents on magnetic concentrators. He is a member of Society of Automotive Engineers (SAE), Society of Manufacturing Engineers (SME), American Society of Metals (ASM) and American Powdered Metal Institute (APMI).

Robert C. Goldstein
Research Engineer
Centre for Induction Technology

Robert Goldstein graduated from the University of Michigan in 1998 with a Bachelor of Science in Chemical Engineering. Since graduation, he has been conducting research at the Centre for Induction Technology. His current research is in the areas of computer simulation, the development of new induction heating processes and powder metal composites. He is a member of the Soceity of Manufacturing Engineers (SME), American Soceity of Metals (ASM) and the American Institute of Chemical Engineers (AIChE).

Dr. Shekhar G. Wakade
Senior Materials Engineer
GM Powertrain

Dr. Shekhar Wakade upon receiving a Ph.D. from Michigan State University in Materials Science, joined General Motors in 1985. Since then he has worked in Manufacturing as well as Product Engineering areas. He has worked as a materials engineer on 3800 as well as Northstar engine programs. He has been responsible for use of powdered metal bearing caps application for the 3800 engine, which won an international "Innovative use of PM in automotive Industry" award. Also he has been responsible for the use of SMC vinyl ester for cam cover application for a new in-line 6-engine program.