How Computer Simulation Helps to Design Induction Heating Systems

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Abstract

Traditionally, induction heating systems have been designed through the use of "Rules of Thumb" and empirical trials. This development style is expensive, time consuming and labor intensive. It is also limited in its ability to find the best solution. Finally, these traditional methods can only be applied to very similar situations to the one studied and the experience is difficult to pass on to someone not involved in the development.

Computer simulation has none of the limitations attached to the old methods of system design. Induction heating processes can be modeled and optimized virtually without even requiring experimental verification for processes where the material response and properties are known. Also, the results provide a good understanding of why and how changes in the induction coil or process parameters effect the heating. It makes computer simulation a powerful learning tool. Finally, the information can easily be passed on to other people within your organization or conveyed in business relations or presentations.

Introduction

Computer simulation of induction heating systems, which was once a tool used only by academia or at various technical centers, is now more and more penetrating into the industrial world [1]. In industry, computer simulation is used for project evaluation, induction process development, setup, maintenance, marketing and business presentations. There is still some skepticism from the old generation of induction specialists, especially in the USA, but even this group is warming to the modern simulation tools with the ever increasing capability and evidence of their superiority to the empirical method. This increased acceptance has happened faster than most would have predicted and can be attributed to vast improvements in both the computer hardware and software on the market today.

Computer Hardware Improvements

The most obvious factor that has contributed to the growth of computer simulation is the increased speed of personal computers. The computational power of the personal computer has risen exponentially over the past decade. What three years ago would have taken minutes, hours or even days on the average personal computer now takes several seconds, minutes or hours for the most complicated tasks.

Besides the increased processing power of today's computers, great strides have been made in the complementary hardware such as data storage, communications (internet), and peripherals. Three years ago, a good personal computer had a 100 MHz processor, 1 GB hardrive and a 1.44 MB floppy drive. The average new computer today comes with a 1.5 GHz processor, 20-40 GB hardrive and a read/write CDROM (550 MB) drive making it possible to store and transfer much larger amounts of information including pictures and even movies.

The amount of information that is exchanged between computers is also much greater. Through the internet it is possible to send papers, drawings, simulation results and pictures via email. It is also possible now to remotely operate another computer through the internet. One example is a big automotive parts supplier that has people using Flux 2D in the U.S., Germany and France. Through a secure internet site, the users at one of the offices can let someone from one of the other sites take control of their computer and demonstrate how to perform certain operations in Flux 2D.

Improvements to computer peripherals have also helped drive the increased use of computer simulation. Computer monitors are bigger with greater resolution to make the display of objects much clearer. Printers for the standard PC can print much faster, handle more paper sizes and produce much higher quality prints both in color and black and white. New equipment has emerged such as small LCD projectors make it possible to deliver presentations anywhere directly from a computer. Other new devices include digital cameras and digital video cameras whose images can be downloaded directly to the computer and used in R&D or business presentations.

Computer Software Improvements

Programs for computer simulation of generic induction heating problems, such as ELTA and Flux 2D were discussed in the paper presented at ASM 99 [2]. However, significant improvements have been made to these packages since that conference.

ELTA has added several new features since ASM 99. Most notable of these are the Scanning application, single sided heating, busswork, and finite length of system. The Scanning application allows you to model with a 1-D approach an axisymmetrical and flat heating problems with motion. The new single sided heating makes calculations for flat bodies that are only heated from one side. The busswork feature allows you to take into account the busswork in simulation. Several standard shapes of busswork are available and it is possible to connect two pieces of busswork in series.

The most interesting new feature of ELTA from a scientific point of view may be the finite length feature. The induction coil may be equal to or longer than the workpiece. ELTA makes the coupled electromagnetic and thermal calculation for a uniformly distributed magnetic field on the workpiece surface and then takes into account the system finite length using a special analytical method. It is possible to use 1 or more heating coils (hardening and tempering or different coils in a heating line) and a variety of quenchants. In addition to these new features, ELTA has improved several standard features, has a more powerful and stable solver, improved postprocessor and report generator.

Flux 2D has seen drastic changes since the ASM 99 seminar for induction heating simulation. At the top of the list is the new interface for Flux 2D version 7.60, which is completely windows based. The mouse can be used for zooming, selecting different regions, selecting options and a number of other features standard to windows based programs. The new postprocessor allows 3-D plots of results and the possibility to easily create movies of results over the time (or phase) steps of the simulation. In addition, it is possible to display isolines, arrows and color shades simultaneously in the postprocessor. Linear motion has also been added to Flux 2D for simulation of scanning applications.

Flux 3D is also significantly improved from the version available at the time of the ASM 99. The computational abilities of Flux 3D are much more powerful now. Flux 3D can handle more memory enabling greater numbers of nodes and the improved solver is capable of higher solution precision. Also, the new version of Flux 3D can handle non-linear electromagnetic problems. Improvements such as windows interface are scheduled to be completed around the time of this conference. But for induction heating computer simulation, the most significant improvement, 3-D coupled electromagnetic plus thermal simulation, is scheduled for completion soon [3]! Information on further improvements to the computer simulation software for induction heating can be found on the internet at www.induction.org.

Computer Simulation of Induction Pipe Heating for Coating

In a surface coating application, the goal is to obtain a predefined uniform temperature on the surface of a worpiece during the coating and curing, drying or remelting process. Depending upon the requirements, surface coating could be over the entire part or only on a selected area of the part.

One typical surface coating applications is polymer coating of long, large diameter pipes. In this application, usually only a certain length of the total pipe must be coated. Usually, a solenoidal style induction coil is used for this process. In the past, the empirical method has been used for induction coil and process design. This method can be very time, labor and capital intensive due to the size of the induction tooling and equipment required for heating the large pipes.

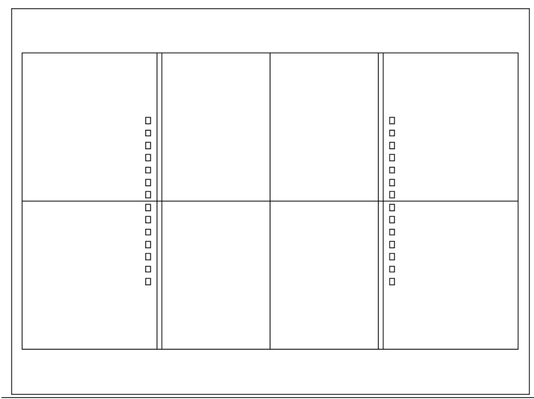

Figure 1. Geometry for large diameter pipe heating simulation

The goal of this study is to demonstrate how the design and optimization of a solenoidal style induction coil for a polymer coating process can be done using computer simulation. The study was made using Flux 2D package for computer simulation.. The workpiece is a 10 meter tube with a 1100 mm O.D. and a 20 mm wall thickness of 0.3% carbon steel. Stranded, flexible copper cables are can be used for carrying current in these systems instead of water cooled copper tubing.

600 mm near the center of the tube needs to be coated, so we will only consider 1200 mm of the tube for simulation. Half of the 2-D, axisymmetrical geometry is used for simulation. The current density distribution in the copper cables is assumed to be uniform.

The desired heating time is 200 seconds and the frequency is 3 kHz. The workpiece needs to be removed from the induction coil prior to coating, so there is a 50 second delay between heating and coating. The required temperature for coating is between 180 and 210 C and the curing time is 120 seconds.

Uniform Wire Distribution

The starting point for study could be a uniform copper cable distribution that is slightly longer than the desired heating area (Figure 1). Figure 2 shows the magnetic field and temperature distribution at the end of heating.

Figure 3 shows the temperature curves at the 3 important times for our process: 200 (end of heating), 250 (beginning of coating) and 370 (end of curing) seconds. At the end of heating (200 seconds), the temperature at the end of the induction heating coil (325 mm) is only half that of the temperature at the center of the workpiece. It means that the temperature at the end of the heating zone is already below the necessary temperature for the coating process.

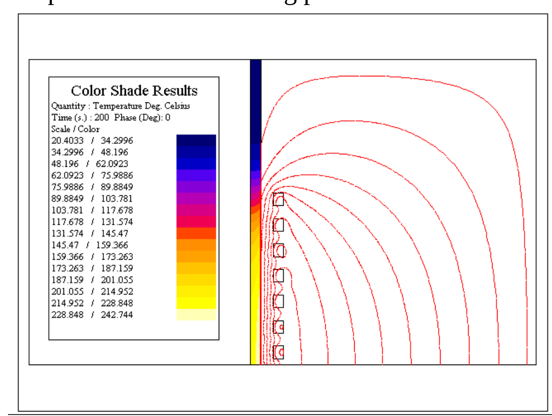

Figure 2. Magnetic field lines and temperature color shade for uniform wire distribution, t=200s

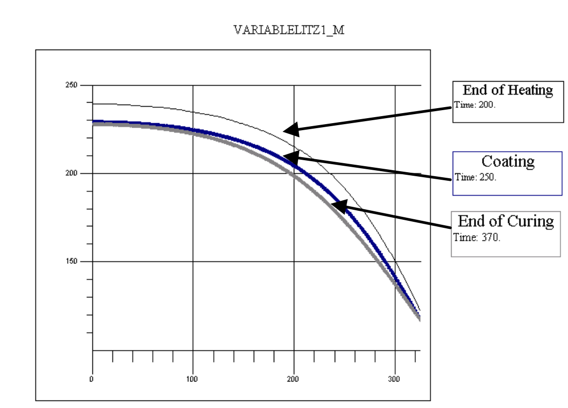

Figure 3. Temperature distribution in the length of the pipe at 200, 250 and 370 s.

During transportation and the curing process, there is thermal diffusion and heat flows from the central zone of the tube outward. The temperature at the end of the zone declines even further, while the temperature at the center of the tube remains too high for good coating.

With a uniform wire distribution, only 55-60% of the workpiece under the coil face would be heated properly. The heating under the outer 40-45% of the induction heating coil is wasted heating. In order to treat the tube with a uniform wire distribution, the induction coil would need to be between 1000 and 1100 mm long to treat the 600 mm zone.

Variable Wire Distribution

In the uniform wire distribution study, it was apparent that there was insufficient heating at the end of the heating zone. For good uniformity during the curing process, the temperature at the end of heating must be higher near the ends than in the central zone for a coil that is reasonable in length (less than 20% longer than coated zone).

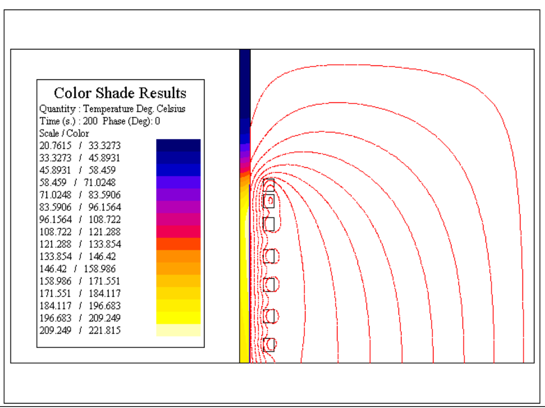

Figure 4. Magnetic field lines and temperature distribution for variable wire position, t=200s

The heating in the outer area of the heating zone can be increased relative to the center by making the outer turns closer together. Figure 4 shows the magnetic field and temperature distribution at the end of heating with an induction coil with variable turn positioning. The temperature is higher near the end of the induction coil than at the center of the pipe.

Figure 5 shows the temperature curves at the 3 important times for our process: 200 (end of heating), 250 (beginning of coating) and 370 (end of curing) seconds. At the end of heating (200 seconds), the temperature at the end of the desired coated zone (300 mm) is higher than the temperature at the center of the workpiece.

During transportation and the curing process, there is thermal diffusion and heat flows initially from the area near the end of the heating zone both to the center of the tube and outward in the length of the tube. As the curing process occurs, the maximum temperature declines and shifts

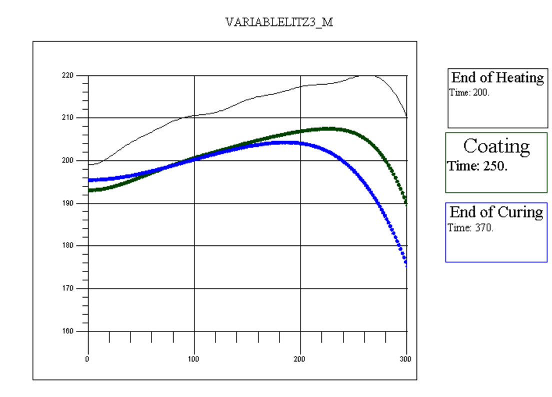

Figure 5. . Temperature distribution in the length of the pipe at 200, 250 and 370 s.

toward the center of the tube and the temperature at the end of the heating zone declines. At the end of the curing process, the minimum temperature in the required area is about 176 C. Additional fine tuning of the induction coil could be made to ensure the temperature does not fall below 180 C in the curing process, or the power could be increased during the heating process (maximum temperature at the time of coating is 206 C, below the 210 C upper limit). The results show that by using the variable turn positioning instead of a longer coil, we have energy savings for the installation of 25-30%.

Besides the thermal profile, computer simulation provides the electrical parameters of the induction heating system. It is easy to determine the number of coil turns for matching to the power supply and the necessary copper cable cross-section. In addition, the potential exists for automatic optimization of the induction coil turn number and positioning through the use of special algorithms [4]! Automatic optimization could be used effectively in the case of multiple installation design.

Conclusions

Computer simulation of induction heating processes is no longer only a tool for academics. Induction heating computer simulation has gained wider acceptance due to significant improvements in both computer hardware and software. More and more companies are beginning to use computer simulation for practical induction process and system design. Simulation is also a powerful tool for fundamental study of basic induction systems for educational purposes. ELTA, Flux 2D and Flux 3D are computer software packages designed with an account of the specific features of induction heating systems. A study of a 2D system for surface coating of large diameter pipes demonstrates the procedure for induction coil and process design using computer simulation. Soon, we will be able to do complete coupled electromagnetic plus thermal simulation not only for 1D and 2D systems, but also for 3D systems in order to predict temperature patterns and optimize complex induction systems without experiments.

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