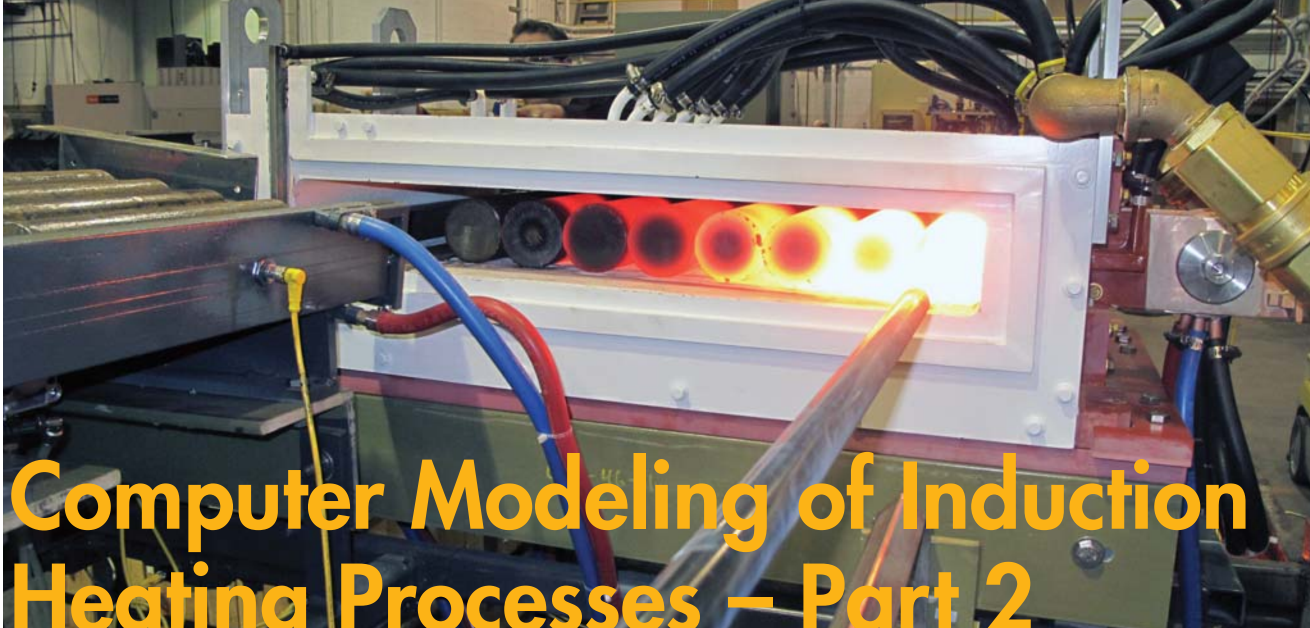

Computer Modeling of Induction Heating Processes – Part 2

Figure 1. Induction bar-end heating using an oval inductor *(Courtesy Inductoheat)*

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Part 1 of this article covered the critical aspects of the computer modeling of induction heating processes. Common misassumptions were covered as well as answers about the use of finite element analysis and why some commercial modeling software has limitations. This final installment continues to provide tips about the computer modeling of induction heating.

In a fast-paced global economy, the ability of induction heating manufacturers to minimize time between a customer's request for a quotation and a prepared quote based on efficient computer modeling is critical to a company's success. A competitive industrial environment does not offer the luxury of several days of waiting in order to obtain the results of computer modeling. Rather, reliable modeling results are needed within a few hours.

Recognizing the importance of computer modeling and what must be accomplished to improve process effectiveness to determine the most appropriate process recipes, ASM International recently published two comprehensive volumes on modeling as it applies to the computer simulation of different metal-processing technologies. The information in these books was submitted by experts from leading universities, national research laboratories and industrial corporations from 13 countries. This compilation is now available in a new two-volume set published as a part of the ASM Handbook series. The first part, Volume 22A, *Fundamentals of Modeling for Metals Processing*, was published in 2009. The second part, Volume 22B, *Metals Process Simulation,* followed a year later.

The volumes cover a range of subjects related to modeling metal processes including hot and warm forming, rolling, casting, forging, coating, machining and many others. Among other useful information, Volume 22B contains two articles that are exclusively devoted to computer modeling of induction thermal technologies: "Simulation of Induction Heating Prior to Hot Working" and "Coating and Simulation of Induction Heat Treating."

Induction Heating of Bar Ends

Many bars, billets or rods manufactured today lend themselves to processes in which entire workpieces are heated and fed into a roll former or other type of forming machine. In some cases, however, it is necessary to hot form only a portion of the workpiece (its end, for example). Some examples of these types of parts are sucker rods for oil country goods or various structural linkages in which an eye or a thread may be added to one or both ends of the bar.

Placing the end of the bar into an inductor and heating it for a specified amount of time accomplish end heating. Multiple bar ends can be heated in single-turn or multi-turn oval coils (Figure 1), in channel-type coils (also called slot or skid coils, Figure 2) or in multiple coil arrangements that are configured out of individual conventional solenoid coils. Upon leaving the coil, the bar's ends are at the required temperature, and the bar moves to the forging operation. For high production rates (1,800 pieces per hour or higher), both oval and channel inductors are the most suitable options and are often employed with fully automated or semi-automated handling.

Computer Modeling of End Heating

A bar that is only partially inserted in the heating coil does not lend itself easily to most analytical methods of computing this process. This is because those methods are based on the assumptions of an infinitely long coil with a symmetrically located workpiece. The majority of commercial software packages used for modeling of induction heating processes are all-purpose programs developed

Figure 2. Induction bar-end heating using channel (slot or skid) inductor *(Courtesy Inductoheat)*

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for other applications and later adapted for induction heating. They experience difficulties in taking into consideration certain features of induction bar-end heating. Among these features are:

- Multiple workpieces progressively move side-by-side through an inductor
- The presence of thermal refractories and the necessity of considering radiation view factors
- Initial temperature distribution might be nonuniform
- Presence of end plates, profiled turns, guides, fixtures, liners, etc.

It is important to be aware that some critical features of bar-end heaters could be limiting factors to the application of all-purpose software, which can affect the ability to adequately and accurately model results. Although commercial software can be used as a check, we also utilize several proprietary application-oriented programs that allow us to select the most appropriate modeling technique, taking into consideration process specifics and important subtleties.

As an example, Figure 3 shows a computer simulation of the sequential dynamics of end heating carbon-steel bars utilizing an oval coil. The bar's OD is 2 inches, and the required heated length is 5.25 inches at a volume of 112 bars per hour. Five bars were progressively heated side by side in an oval inductor at a frequency of 3 kHz. The temperature variation at four critical points is shown. Figure 4 shows the variation of coil power during the cold start, steady-state processing and coil-emptying stages, assuming a constant coil current. To avoid high power demand during the initial cold-start stage, the coil is typically partially loaded with bars.

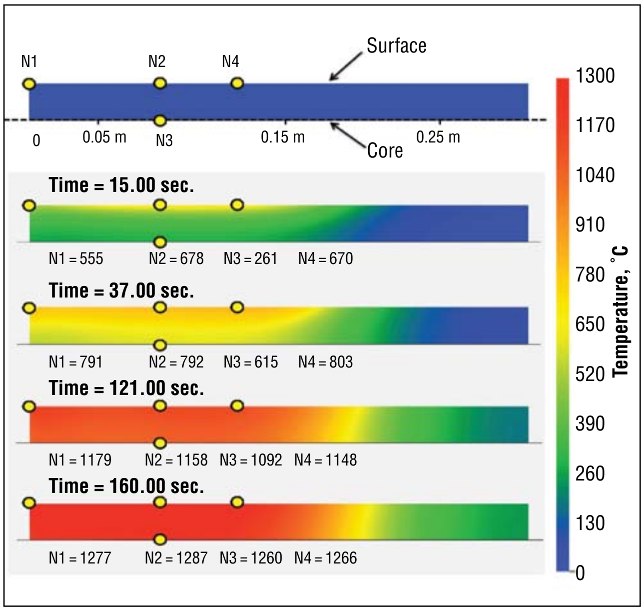
Crucial Tips Executives Must Know

Tip # 1: It is important to remember that any computational analysis can at best produce only results that are derived from the correctly defined theoretical model, governing equations and boundary conditions. Therefore, before you hire somebody to do computer simulations, make sure that the analyst has a clear understanding of the process specifics, as well as an appropriate education in the area in which you are seeking help. When flying in an airplane you need a pilot; when you are ill you need a doctor. Apply the same principle when you are choosing a company to do your computer simulations. Otherwise, you might get pretty graphics but erroneous and technically inadequate results followed by excuses as to why the analysis does not match practical data. Due diligence is needed when deciding which model to apply and who should apply it.

Tip # 2: Make sure that the physical properties of the heated materials are properly defined. Though crude, the well-known saying "garbage in/garbage out" clearly indicates the necessity of having accurate physical properties of the heated material. Experience shows that poorly defined material properties are responsible for a significant amount of simulation errors.

Tip # 3: In order to minimize the risk, it makes sense to deal with companies that offer one-stop service (Figure 5, right) and that are responsible for all stages of R&D (including computer modeling), design, fabrication, testing, equipment start-up and aftermarket support, rather than dealing with a number of companies with vague overall process responsibilities (Figure 5, left).

Tip # 4: It is important to understand that the use of modern numerical software modeling methods (including finite elements, boundary elements, finite difference, edge elements, etc.) does not in itself guarantee the generation of perfectly correct simulation results. Rather, these techniques must be used in conjunction with experience in numerical computations and the proper training and experience of those interpreting the analytical results. This is especially so because even in commercial software programs, regardless of the amount of testing and verification, they may never have all of their possible errors detected. Consequently, the analyst must guard against various kinds of possible errors. The more



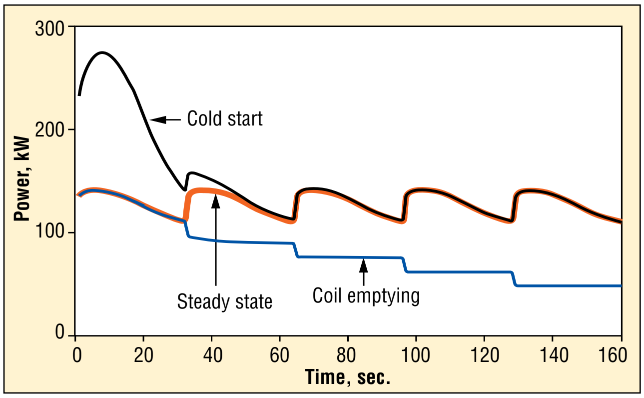


Figure 3 (left). Results of a computer simulation of the sequential dynamics of the end heating of carbon-steel bars utilizing an oval coil (due to the system's symmetry, only the top half of the bar is shown). Five bars were progressively heated in an oval inductor with a 3-kHz frequency. Temperature variations at four critical points are shown. **Figure 4 (right).** Variation of coil power during a cold start for the fully loaded coil, steady-state and coil-emptying stages, assuming constant coil current *(Courtesy Inductoheat)*.

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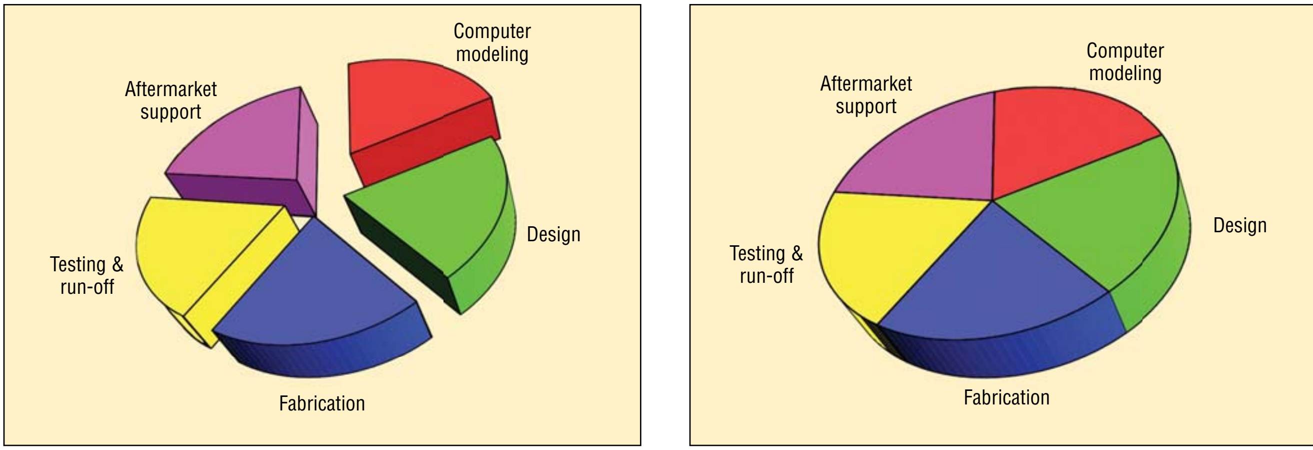

Figure 5. Pie charts representing multi-stop service with segregated process responsibilities (left) vs. one-stop service (right) with integrated responsibilities for computer modeling, equipment design, fabrication, testing and support *(Courtesy Inductoheat)*.

powerful the software, the more complex it is, increasing the potential for errors. Be aware that computer-generated attractive pictures might be misleading if they are obtained by a novice to the process. Common sense, engineering "gut feeling" and advanced education in the area of modeling are always the analyst's helpful assistants.

Author Dr. Valery Rudnev, FASM, Director, Science and Technology at Inductoheat Inc., Madison Heights, Mich., is a globally renowned expert on induction heating applications. Known to many in the industry as Professor Induction, he is a frequent contributor to FORGE. He may be reached at 248-629-5055; or at rudnev@inductoheat.com