A fresh look at induction heating of tubular products: Part 2

PROFESSOR INDUCTION

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Professor Induction welcomes comments, questions, and suggestions for future columns. Since 1993, Dr. Valery Rudnev has been on the staff of Inductoheat Group, where he currently serves as group director – science and technology. In the past, he was an associate professor at several universities, where he taught graduate and postgraduate courses. His expertise is in materials science, heat treating, applied electromagnetics, computer modeling, and process development. He has 28 years of experience in induction heating. Credits include 15 patents and 118 scientific and engineering publications. Contact Dr. Rudnev at Inductoheat Group, 32251 North Avis Drive, Madison Heights, MI 48071; tel: 248/585-9393; fax: 248/589-1062; e-mail: rudnev@inductoheat.com; Web: www.inductoheat.com.

Part 1 (May/June *HTP*, p. 17–19) discussed the major differences between induction heating of tubular products and solid cylinders, and reviewed several important applications of induction for heat treating and coating of metal tubes. This column focuses on selective induction heating of tubular products. Applications made possible by induction's ability to concentrate the heat within a specific area of a workpiece include localized stress relieving, brazing, parting, friction welding, bending, and annealing of welds.

Features of selective heating

Figure 1 illustrates some thermal features of selective heating of hollow cylinders. A two-turn solenoid-type induction coil is used as an example. The maximum temperature will be observed under the inductor in the middle of the heat zone. As a result of radiation and convection heat losses, there will be cooling from both the OD and ID surfaces. Of course, cooling from the ID surface will be much less pronounced.[1]

Another important feature that strongly affects the required power, coil design, and frequency choice is the existence of transition zones and the cooling effect due to the longitudinal heat sink from the cold ends of the tube. (Specifics of frequency selection when induction heating tubular products were discussed in Part 1.)

It is important to recognize that the existence of transition zones and "heat sink" phenomena are primarily responsible for mistakes in determining the required coil power and temperature profiles when calculations are based on simple formulas, using one-dimensional numerical computation approaches or uncoupled numerical software. Without knowing the length of the transition zone and temperature profiles within these zones, it is very difficult to make a reasonably accurate estimate of the total mass of the heated metal and, therefore, to determine the inductor power required to heat a tube to the final temperature in the desired time. The use of two-dimensional coupled software overcomes this drawback.[1]

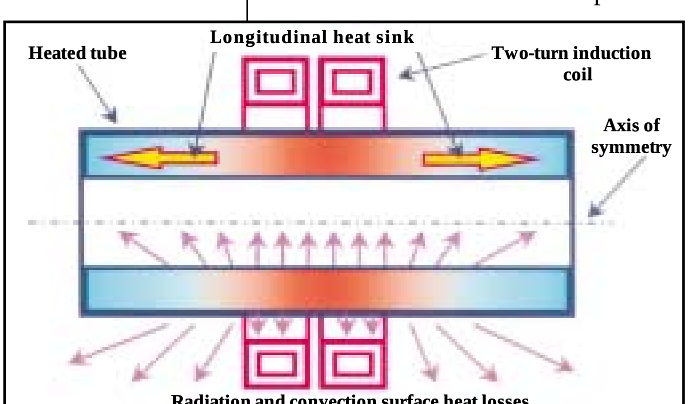

Fig. 1 — Radiation and convection surface heat losses in selective heating of tubes. Cooling from the OD surface is more pronounced. (Ref. 1)

An example is given in Fig. 2, which illustrates the dynamics of selective induction heating, prior to the tube parting operation, of an AISI/SAE 1045 carbon steel tube having a 152 mm (6 in.) OD and a 15 mm (0.6 in.) wall thickness. A 1 kHz power supply was used. The optimal algorithm of power-time variation applied to the induction coil was also obtained during the numerical computation. As a result of computer modeling, the influence of the various factors on process parameters can be evaluated and optimized. For example, in some tube parting applications it is better to use a single-turn coil instead of a multiturn coil.

Effect of coil length

Selection of coil length is another critical issue, which almost always involves a compromise, particularly when designing induction systems for certain selective heating applications, such as induction parting (a cutoff process in which a narrow region of the tube is heated to a certain temperature, and the tube is then pulled apart[1]). A shorter coil results in a smaller mass of metal being heated and, therefore, leads to a lower coil power requirement. From another perspective, coil electrical efficiency is a function of not only the frequency, the properties of the heated metal, and the "coil-to-copper" air gap, but also is a function of coil length. Shortening the coil results in a decrease in the coil's electrical efficiency.

When using selective induction heating, it is sometimes desirable to have a short longitudinal transition zone. In these cases, consider using a U-shaped magnetic flux concentrator. Its ability to localize the magnetic field in the area to be heated, in combination with a brief heating time, can provide a significant benefit in obtaining a short transition zone.

Induction heating for bending

An induction tube or pipe bending machine is sketched in Fig. 3. After positioning the pipe and securely clamping its ends, power is applied to

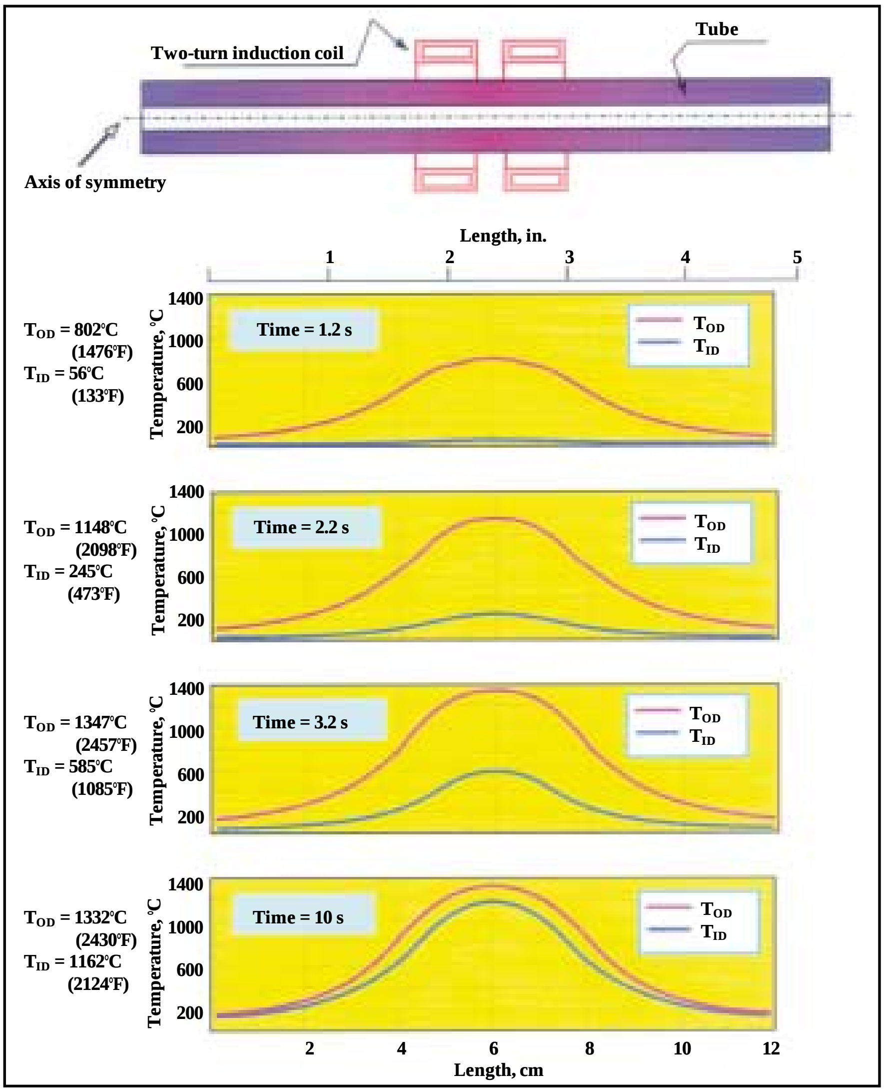

Fig. 2 — Temperature profiles at different stages of induction heating an AISI/SAE 1045 carbon steel tube having an OD of 152 mm (6 in.). Frequency: 1 kHz. (Ref. 1)

a solenoid-type inductor that provides circumferential heating of the pipe in the area where it will be bent. When a temperature distribution that provides sufficient ductility to the metal at the region of bending has been attained, the pipe is then pushed through the coil at a certain speed. The pipe's leading end, which is clamped to the bending arm, is subjected to a bending moment. The bending arm can pivot up to 180°.

In induction bending of carbon steel pipe, the length of the heated band usually is 25 to 50 mm (1 to 2 in.), with a required bending temperature in the 800 to 1080°C (1470 to 1975°F) range. As pipe passes through the inductor, it bends within the hot, ductile region by an amount dictated by the radius of the bending arm pivot, while each end of the heated region is supported by a cold, nonductile section of pipe. Depending upon the application, bending speed can range from 13 to 150 mm / min (0.5 to 6 in. / min). In some applications where larger radii are required, a set of rolls is used to provide the required bending force instead of a bending arm pivot.[1–4]

After the bending operation, the pipe is cooled to ambient temperature using a water spray, forced air, or natural cooling in air. A stress relief or temper can then be conducted to obtain required post-bend properties.

Wall thinning: Induction heating provides rapid circumferential heating of selected areas of the pipe, consuming a minimum amount of energy compared with other hot bending processes in which the entire pipe is heated. There also are other important benefits provided by induction tube bending. These include highly predictable shape distortion (ovality) and wall thinning. Minimization and predictability of wall thinning are particularly critical when producing tubes and pipes for applications that must meet high-pressure requirements,

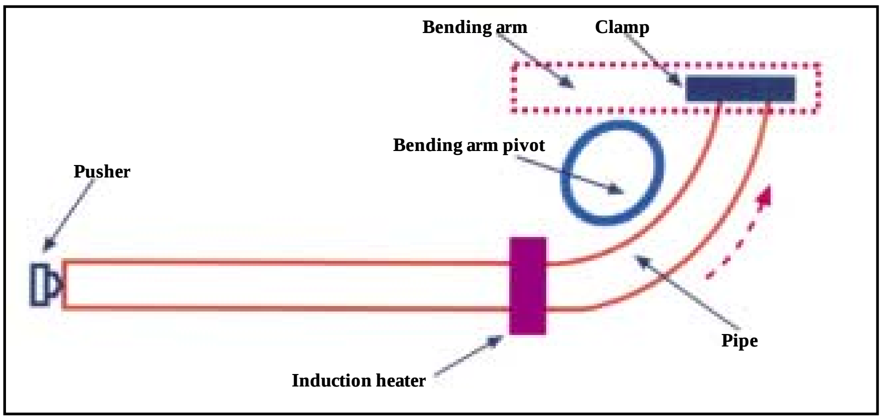

Fig. 3 — An induction tube or pipe bending machine.

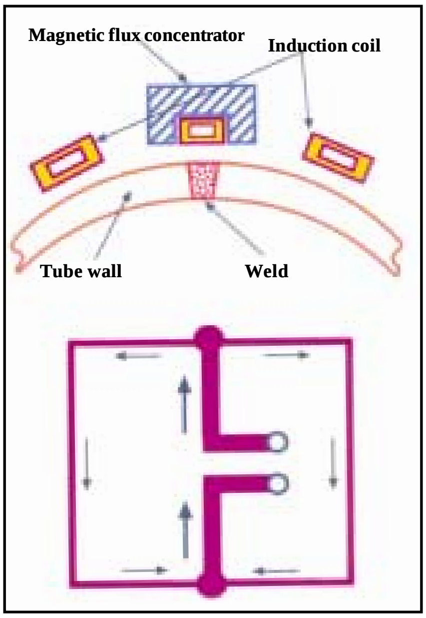

Fig. 4 — Split-return seam annealing inductor, top, and diagram of its electrical circuit, bottom. (Ref. 1)

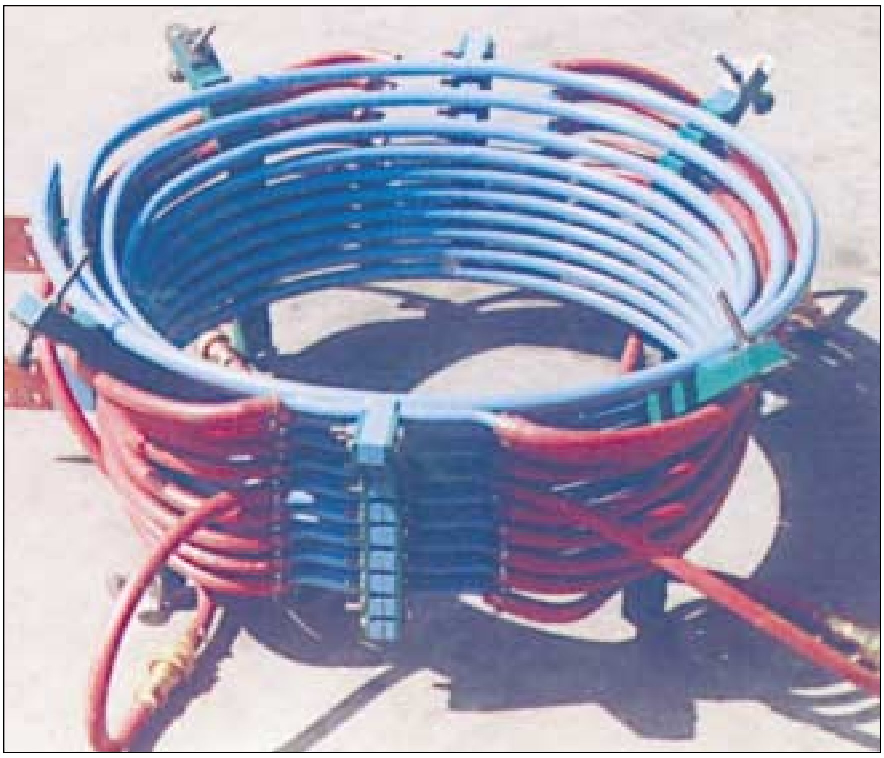

Fig. 5 — Split coil (clamshell) inductor for pipe joint weld annealing. Courtesy IHS, an Inductotherm Group company, Fort Worth, Texas. (Ref. 1)

such as nuclear power and oil / gas pipelines.

For example, oil and gas pipeline ratings are based on wall thickness. During bending, the outer side of the bend is in tension and has a reduced cross section, while the inner side is in compression. When conventional heating is used in bending, the cross section of the outer side of the bend area often is reduced by 20% or more resulting in a corresponding reduction of the total pipeline pressure rating.[5] The pipe bend becomes the pipeline's pressure-limiting factor.

With induction heating, the reduction in cross section is reduced to typically 11% due to very even heating, an optimized bending program via a computerized bending machine, and a narrow plasticized (ductile) zone. Consequently, induction heating not only reduces production costs and increases bend quality, but also reduces total pipeline cost.

Other important advantages of induction bending: it is not labor intensive, it has little effect on surface finish, and it has the ability to make small radii, which enables bending of thin-wall tubes and the production of multiradius curves / multiple bends in one pipe.[1–4]

Seam anneal, stress relieve

Induction can provide noncircumferential heating of selected areas of steel pipes in weld seam annealing and stress relieving applications. The inductor design shown in Fig. 4 uses a split-return coil for seam annealing of straight welded tubes. The high-temperature tube welding process produces an undesirable Widmanstätten-type structure in the weld heat-affected zone (HAZ). This brittle, nonhomogeneous structure consists of coarse elongated grains "shooting" into the matrix. Brittle martensitic areas are found in the weld zone as a result of self-quenching (mass quenching) due to the adjacent areas of unheated "cold" metal. The narrower the HAZ, the more extreme the cold-sink effect, the coarser the grain structure that forms, and the more brittle the weld area.[1]

To properly anneal a weld it is necessary to heat the weld zone to a minimum temperature of 600°C (1110°F). Inductors typically are mounted in the tube mill line immediately after the welding and scarfing stations. In addition to coil geometry, inductor-to-tube air gap, and frequency, the required heating power depends upon the mill's line speed and the width of the zone to be heated. The heated zone typically varies from 12 to 50 mm (0.5 to 2 in.), depending on tube diameter, wall thickness, and other factors.

When determining the power required, the residual temperature of the weld zone also must be considered, bearing in mind that the amount of residual heat after induction welding is noticeably greater than the heat generated as a result of laser welding, for example.

The split coil or clamshell inductor shown in Fig. 5 is representative of that used for localized annealing in the field of large, circumferentially welded oil and gas pipes. The coil is assembled around the pipe and then disassembled after heating the weld area.[1]

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