

INDUCTION HEATING SERVES TODAY'S FORGING INDUSTRY

Induction heating can offer benefits to forgers in certain applications. Process and design requirements for suitable applications are examined, as are common types of induction heating configurations.

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There are many ways to heat metal parts, including the use of induction heaters, gas-fired furnaces, infrared heaters, electric and fuel-fired furnaces, etc. In the past three decades, heating by induction has become more popular because of its ability to create high heat intensity quickly and within the heated workpiece. These properties, in turn, result in low process cycle times (high productivity) as well as repeatable quality. Induction heating is also more energy efficient and inherently more environmentally friendly than most other heat sources, including gas-fired furnaces. Any smoke and fumes that may occur because of residual lubricants or other surface contaminants can be easily removed. A considerable reduction of heat exposure is another factor that contributes to the environmental friendliness of the induction heaters.

Gas-fired furnaces can result in poor surface quality due to substantial scale formation, grain coarsening, burns, oxidation and decarburization. Induction heating provides better surface quality of heated metal with a significant reduction of scale (resulting in substantial metal savings) and decarburization.

Induction systems require far less start-up and shutdown time and lower labor cost for machine operators (Figure 1). Other important factors of induction heating machinery include quality assurance, automation capability, high reliability and ease of equipment maintenance. Also, induction heating requires a minimum shop-floor space.

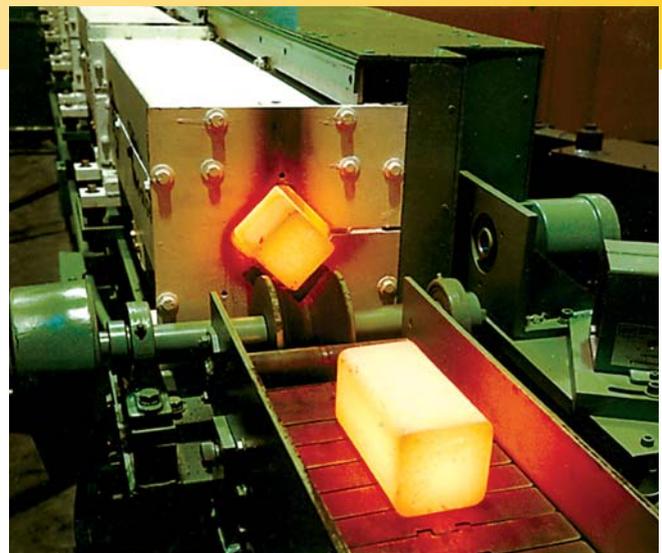


FIGURE 1. Induction heating of round cornered square billets

Process Requirements and Design Criteria

Induction is used to heat various metals to temperatures that will allow hot forming including forging, upsetting, rolling, extrusion, etc. Frequently, the main goal is to raise the part to the specified temperature with required temperature uniformity including maximum tolerable temperature differentials surface-to-core, end-to-end and side-to-side temperature variations.

Aside from temperature uniformity, the other major goal of

INDUCTION HEATING

induction heating is to provide the maximum production rate at which metal can be processed. High powers (i.e., from hundreds to thousands of kilowatts) and relatively low frequencies (typically in the range of 200Hz to 30kHz) are most commonly used for induction heating of forgings and for rolling of steel parts.

Additionally, modern in-line induction heating systems are designed to provide compact systems that have high electrical efficiency. The last criterion, but not the least, is the competitive cost of an induction heating system and the predictability of energy rates (i.e., prices for gas versus electricity).

One thing to be mindful of is thermal gradients in the workpiece. Typically, temperature uniformity is necessary to easily form the heated metal. A piece of stock that is non-uniformly heated can cause premature wear on hammers and presses and may cause problems by requiring excessive force to form the metal. It could also be a safety hazard. However, there are cases in which temperature gradients are desired. For example, when heating aluminum or steel billets prior to direct or continuous extrusion, thermal gradients along the billet's length are often desired. The ability of induction heaters to selectively heat certain areas of the part can be considered an appreciable advantage.

Induction Heating Prior to Metal Hot Working

Billets or bars are heated fully or partially either in cut lengths or continuously. They are then forged in presses, hammers (repeated blows) or upsetters (which gather and form the metal). Steel components by far represent the majority of forged parts, but aluminum, copper, brass, bronze, nickel and titanium, as well as some other metals and alloys, are also inductively heated and forged. The required heating temperature depends upon the metal and the specifics of the metalworking process.

Sometimes the initial temperature of the product prior to induction heating is the ambient temperature. In other cases, the initial temperature is non-uniform, for example, due to uneven cooling of the slab, transfer bar, strip or bloom as it progresses from the caster. Surface layers, and particularly the edge areas, become much cooler than the internal regions.

There are four basic heating modes in induction mass heating (Figure 2). These are:

Static heating — In this mode, the workpiece, such as a billet or slab, is placed into an induction heating coil for a period of time while a set amount of power is applied until the component reaches the desired heating conditions. Upon reaching the required thermal conditions, the component is extracted from the induction heater and delivered to the metal-forming station. The next cold workpiece is loaded into the coil and the process repeats.

Progressive multi-stage heating — This occurs when two or more heated workpieces are moved (via pusher, indexing mechanism, walking beam, etc.) through a single coil or multi-coil induction heater. Therefore, components or their different parts are sequentially heated (progressive heating) at certain predetermined stages inside the heater.

Continuous heating — In this mode, the workpiece is moved in a continuous motion through one or more induction coils. This technique is commonly used when it is required to heat long components such as bars, slabs, strips, tubes, wires, blooms and rods.

Oscillating heating — In this mode, a component moves “back

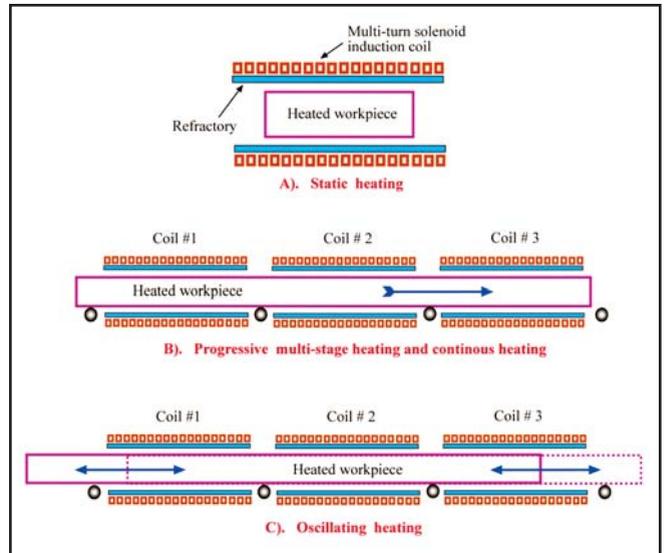


FIGURE 2. Basic heating modes used in induction mass heating

and forth” (oscillates) during the process of heating it inside a single coil or multi-coil induction heater.

Energy Efficiency and Cost Savings

Induction heating manufacturers are paying special attention to maximizing the energy efficiency of their equipment and the reduction of cost. It is often required that an induction heater process billets/bars of several different diameters. The specified cross-section range to be processed in a set of induction coils and how many coil sets are needed requires consideration of a number of factors that affect the system's energy efficiency. The coil heating efficiency is largely a matter of the fill factor (area of the workpiece to be heated compared to the inside diameter of the coil windings). As the fill factor decreases, efficiency decreases, thereby requiring more power. Energy costs rise as the heating efficiency decreases.

On the other hand, energy cost reduced by using a number of coil sets is diminished by the capital cost of the coils. There is also a production loss due to the time required to change coil lines, although advanced “quick change” and coil-shuttle design features can minimize this downtime.

A careful analysis of the product mix is necessary to determine how often the bar/billet size may change and what the duration of each product run will be. These answers will help the user to determine the value of the second and possibly the third coil set. Note that below the Curie point the heating efficiency is not as greatly affected by the bar size variation, thus it may be worthwhile to change only the so-called “above Curie” coils.

In the case of the induction system shown in Figure 3, the smallest bar size was less than 5% of the total production mix. In this instance, it was cost-effective to use the coil set designed for “big runners” to heat the small bars.

If the range of bar/rod sizes is too great, the ability to properly guide smaller bars may be jeopardized. This can lead to product jams, non-uniform heating at a given production rate and excessive scale formation, which negatively affect the cost of coil maintenance and operation.

Additional sets of coils will be of little or no value if they are not



FIGURE 3: In-line induction steel bar heater

readily available when needed. They should be stored in a designated area of the tool crib and properly identified as to the size of bars they will process, the direction of bar flow through the coil and, in some cases, their position on the coil line (assuming there are several coils in-line) or shuttle design.

Frequency Selection

In most instances, frequency selection when specifying an induction in-line bar heater is a reasonable compromise. Bar-processing companies can rarely utilize a dedicated induction heating system for each bar size it produces. Consequently, it is often necessary to heat a bar that is too large or too small for a given single frequency. In such a situation the efficiency of the induction machine may suffer. Some solid-state inverters lend themselves to a dual-frequency or multi-frequency configuration that, to a large extent, can overcome this problem. A typical example would be for a heater to be able to operate at 10 kHz and 3 kHz or 3kHz and 1kHz.

A dual-frequency design concept offers a way of improving the overall efficiency of an induction heating system. This concept utilizes a low frequency during the initial heating stage when the bar retains its magnetic properties. In the next stage when the bar becomes non-magnetic, it is more efficient to use a higher frequency to avoid a current cancellation and drastic reduction of coil efficiency.

Figure 4 shows an in-line induction heater for carbon steel bars. The bars are 20 ft. long and of various diameters ranging from 1.5 in. to 2.0 in. with a production rate of 16,500 lb./hour. This system consists of nine coils. A frequency of 1 kHz is used in the initial

heating stage. Final heating is provided by two 750 kW/3 kHz solid-state power supplies. The bars are unloaded from railroad cars outside and placed on a bar bundle table and then fed end-to-end through the building wall to a bar-feeder rack. The bars are released one at a time and fed through the induction heating line. The bar-handling system also includes a reversing system and unloads the table used when there is a press stoppage.

Figure 5 shows the InductoForge modular continuous feed induction bar and billet heating system that is becoming accepted in the forging industry. Some features of this system include:

- Ease of frequency change from 500 Hz to 6 kHz
- Dual frequency capability with no capacitor contacts
- Energy efficiency and temperature uniformity
- Manufacturing and process flexibility
- High temperature control over varying production requirements
- Optimization of "start-up" and "shut-down" stages

Table 1 shows minimum bar/billet diameters as a function of frequency and temperature for efficient induction heating of selected metals.

Induction Bar End Heaters

A progressive multistage horizontal coil arrangement is the most popular mode for the induction heating of steel billets. However, there are applications in which it is advantageous to use a static-heating mode rather than a progressive mode or combination of both progressive and static heating. With static heating only one billet is heated in the coil.

Many of the bars, billets or rods manufactured today lend themselves to processes in which the entire workpiece is heated and fed into a roll or other type of forming machine. In some cases, only a certain part of the workpiece needs to be shaped such as its end. In these instances, it is required to heat only the end area of the workpiece. Examples of these types of parts include "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 a bar.

Bar end heating is achieved by placing the end to be worked into a multi-turn coil and heating it for a specified time. As for all through-heating applications, a sufficient time is necessary to obtain the required axial and "surface-to-core" temperature uniformity. The choice of frequency affects not only the temperature uniformity but also the overall efficiency of the system. Some bar heating applications require a specific temperature profile along the length of the workpiece, including sharp or gradual cut-off of the heat and/

Metal	Temp. °C/°F	Frequency, kHz						
		0.06	0.2	0.5	1	2.5	10	30
Copper	900/1652	68	35	23	17	11	5	3
Aluminum	500/932	68	35	23	17	11	5	3
Brass	900/1652	102	56	35	26	16	8	5
Titanium	1200/2192	304	168	105	74	47	23	13
Tungsten	1500/2732	168	92	58	43	27	14	8
Steel	1200/2192	253	140	94	65	41	19	12

TABLE 1. Minimum bar/billet diameters (mm) for efficient induction heating

INDUCTION HEATING

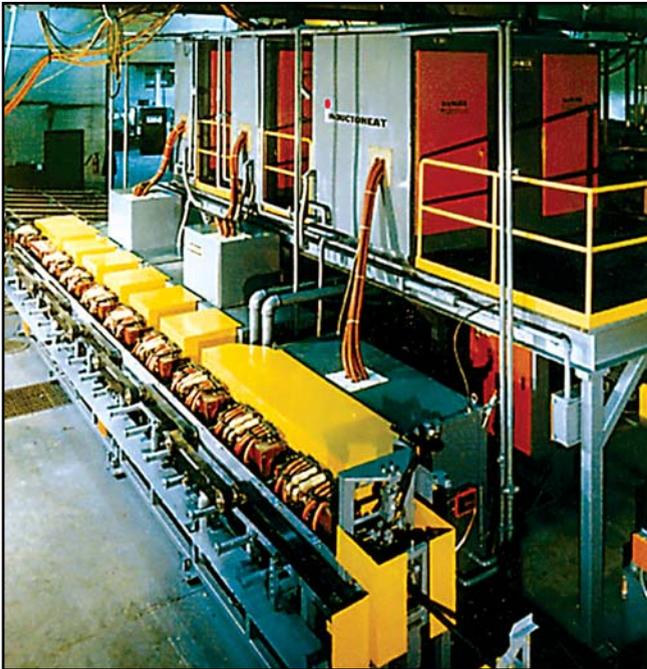


FIGURE 4: Dual frequency (1 kHz and 3kHz) in-line induction steel bar heater

or a specified length of the longitudinal transition zone.

Multiple bar ends can be heated in a single-turn or multi-turn oval coil, as well as in a channel-type coil (see Figure 6), sometimes called a slot or skid coils, or in two, three, four or more coil arrangements configured of individual conventional solenoid coils (see Figure 7). Multiple coils are used to increase a production rate. ●

Author Dr. Valery Rudnev is a world-recognized expert on induction heating applications. The material for this article is adapted from the author's Handbook of Induction Heating, Marcel Dekker, 2003. He may be reached at Inductoheat Group, Madison Heights, MI; (248) 629-5055; or at rudnev@inductoheat.com All photos courtesy of Inductoheat.

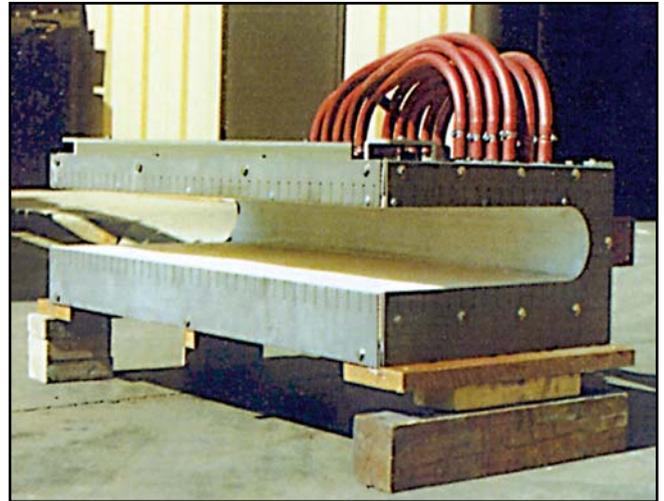


FIGURE 6: Channel coil bar end heater

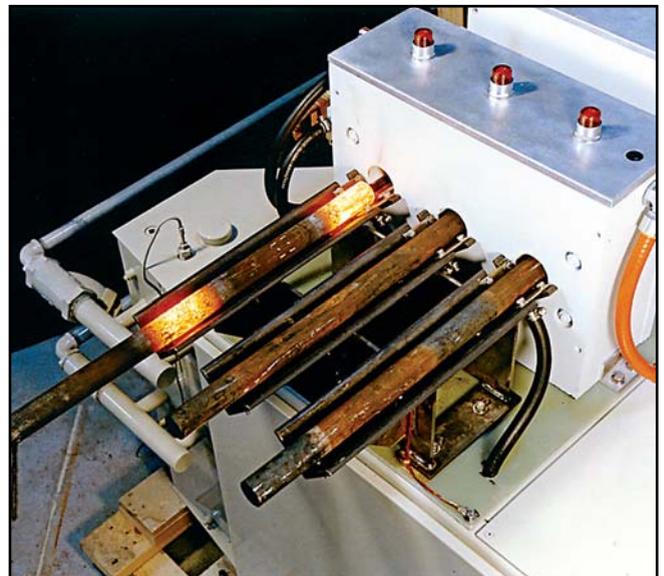


FIGURE 7: Compact induction bar end heater



FIGURE 5: InductoForge modular induction bar and billet heating system