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Reader asks, 'How do I select inductors for billet heating?'

This month's column features the answer to a question submitted by a Professor Induction reader. The "Systematic Analysis of Induction Coil Failures" series will continue in the next issue of Heat Treating Progress. *Part 12 of the series will discuss failure analysis of induction coils used to heat a workpiece's internal areas.*

Question: We are planning to replace a gas-fired furnace used to heat large steel billets with an induction heater. Should we go with a vertical or a horizontal inductor arrangement?

Answer: Induction heating is widely used to heat metals prior to hot forming by forging, upsetting, rolling, extrusion, and other methods. [1–3] Billets are heated either in cut lengths or continuously and are forged in presses, hammers, or upsetters, or are extruded. Steel components by far represent the majority of hot-formed billets, although other materials including titanium, aluminum, copper, brass, bronze, and nickel are also induction heated for hot forming.

The initial temperature of the billet prior to induction heating may be uniform (at ambient temperature) or nonuniform. It is typically required to raise the billet's temperature to a specified level and degree of heat uniformity. The uniformity requirement may include maximum tolerable temperature differentials — "surface-to-core," "end-to-end," and "side-to-side."

A longitudinal thermal gradient along the billet's length (profile heating) is sometimes desired when heating certain billets prior to their direct or continuous extrusion.[1]

Depending upon the application, powers from hundreds to thousands of kilowatts and frequencies typically in the line frequency (50 to 60 Hz) to 3 kHz range are the most commonly used for induction heating of large billets.

The most popular billet-heating approaches are progressive multistage horizontal heating and static heating.[1] This column focuses on the advantages and disadvantages of each.

Fig. 1 — Progressive multistage horizontal heating of large steel billets.

Two Approaches Compared

In *progressive multistage horizontal heating*, two or more billets are moved (via pusher, indexing mechanism, or walking beam, for example) through a single coil or multicoil *horizontal* induction heater (Fig. 1). As a result, the billet is sequentially (progressively) heated at predetermined positions inside of the induction heater. (Details of this approach and its variations are discussed in Ref. 1–3.)

In *static heating*, a billet is placed into an induction coil having a *vertical* or *horizontal* arrangement for a given period of time while a set amount of power is applied until it reaches the desired heating conditions (temperature and degree of uniformity). The heated billet is then extracted from the inductor and delivered to the forming station. Another cold billet is then loaded into the coil and the process repeats.

Either approach can use a protective atmosphere if required.

Progressive multistage horizontal heating is popular for small- and medium-size billets (usually less than 6 in. [150 mm] in diameter). When heating large-diameter steel or titanium billets (8 to 12 in. [200 to 300 mm] and larger), it is often advantageous to use static heating with a vertical coil arrangement or a combination of the progressive multistage horizontal method for preheating and the static vertical method for final heating.

The four photos in Fig. 2 show a steel billet being discharged after being statically heated in a vertical inductor. Billet transfer, tipping, and charging mechanisms are located below the platform and operate as follows[1]:

- Billets to be induction heated are brought to

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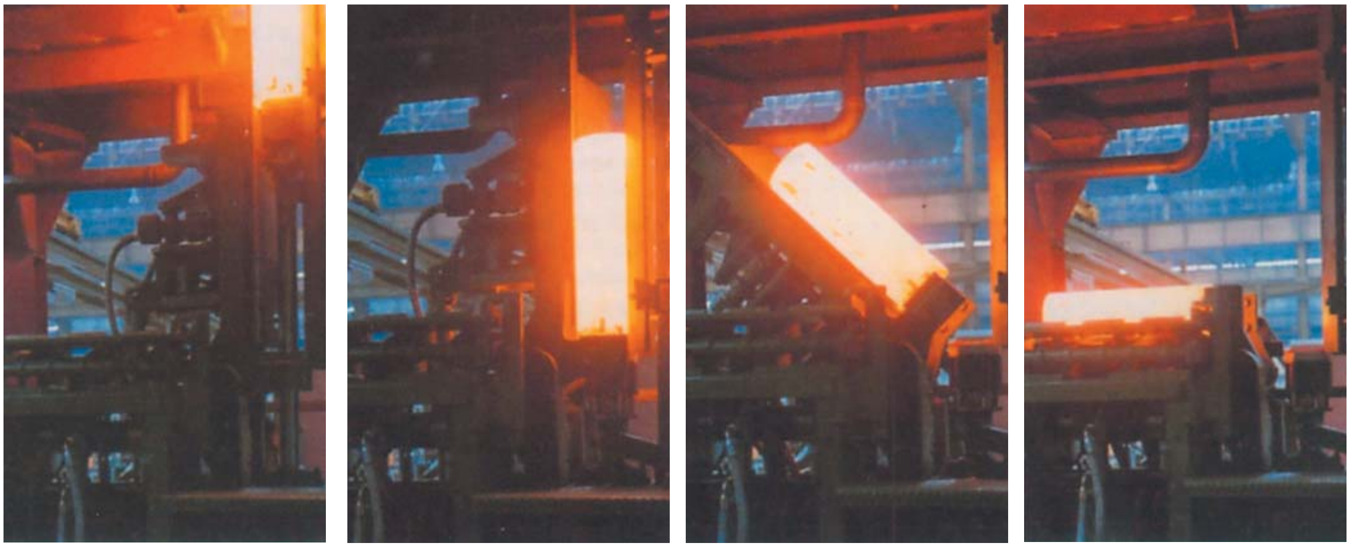

Fig. 2 — Discharge sequence for a steel billet after being heated in a static vertical inductor. (Courtesy Inductotherm S.A., Herstal, Belgium.)

Comparison of horizontal and vertical approaches to billet heating

The pros of each arrangement		The cons of each arrangement	
Horizontal, in-line arrangement	**Vertical arrangement**	**Horizontal, in-line arrangement**	**Vertical arrangement**
• Lower overall capital cost. • Bigger inverters can be used because coils can have a group connection. • Easier billet handling and automation. • Inverters of different frequencies can be used to power different inductors (that is, low frequency at the front of the line and a higher frequency at its end).	• Better overall flexibility and controllability since each coil has its own individually controlled inverter. • Easy to provide billet holding if press is not ready to accept a workpiece. • Is relatively easy to create/ compensate for a longitudinal temperature gradient if required. • Can provide the required temperature distribution when the geometry and/or the initial temperature of the billet varies. • Easy to start-up and compensate for a variation of "cold" refractory. • Superior heat uniformity around the billet's perimeter. • Lesser effect on the billet's surface during handling.	• A challenge to provide billet holding if the press is not ready to accept workpieces. • Billet length variations dictate a need to have a special holding section at the exit of the induction heater. The holding section can be a small gas-fired furnace, resistance heater, or low-power/higher-frequency induction heater. • Difficult to provide required final thermal conditions (average temperature and uniformity) when the initial temperature of the billet varies (for example, after piercing). • Limited ability to create longitudinal temperature gradients (thermal profiles). • "Dummy" billets are required for start-up, or an appreciable number of "real" billets will have to be rejected during this phase. • Possibility of obtaining undesirable temperature nonuniformity around the billet's perimeter due to "cold" sink effect and proximity effect (when coil and billet are not concentric, a condition encountered when a variety of billet diameters are heated using the same coil).	• Cost is typically higher. • Automation and handling are more complex. • Necessity to compensate for a "chimney" effect.

the vertical cells by a trolley conveyor or roller track.

• The billet is then transferred sideways by tipping the trolley platform or by a canted diverting arm inserted into the roller track. The billet rolls off into an intermediate station and then onto a horizontal cradle.

• This cradle forms part of a rocking hanger which pivots 90° and sets the billet vertically over a charging jack, which raises the billet vertically into the inductor.

When the heating cycle is completed, the control system checks whether the press is ready to accept the billet. If it isn't, the inductor changes its mode from heating to holding.

The pros and cons of the progressive multistage horizontal and static vertical billet heating approaches are given in the Table.

Modeling Can Save Time, Money

Experience gained on previous jobs and the ability to computer model induction processes provide a comfort zone when designing new induction billet heating systems. This combination of advanced software and a sophisticated engineering background enables manufacturers of induction heating equipment to quickly determine details of the process that could be costly, time-consuming, and, in some cases, extremely difficult, if not impossible, to determine experimentally.

Evaluating software: There are several software program available for modeling progressive multistage horizontal induction heaters. It is more difficult to find software appropriate for computer modeling of static vertical billet heaters. To decide whether a program is suitable for modeling vertical heaters, its capabilities must be thoroughly understood. What follows is a checklist of what users should consider when evaluating potential software for modeling vertical billet heating systems:

• Electromagnetic end effect.

• Thermal edge effects (Lambert's law and view factors, for example).

• Tight coupling of both electromagnetic and thermal processes. ("Step-by-step" coupling should be used. "Two-step" coupling should be avoided because it does not provide the accuracy required for most applications.)

• Presence of thermal insulation, and the ability to model heat exchange between refractory and heated billet.

• Nonlinear interrelated nature of the material's physical properties.

• Specifics of coil windings and copper tubing.

• Surface losses due to thermal radiation and convection.

• Presence of magnetic flux concentrators, diverters, and/or flux extenders.

• Heat transfer between heated billet and pedestal.

• Transient processes ("cold" and "warm" start-up, and an ability to hold the heated billet inside the induction coil if the forming machine is not ready to accept it).

• Possibility of the billet having a nonuniform initial temperature distribution prior to induction heating (for example, the existence of radial and longitudinal temperature gradients after piercing or continuous casting).

• Cooling of the billet in air during its transfer from inductor to forming machine.

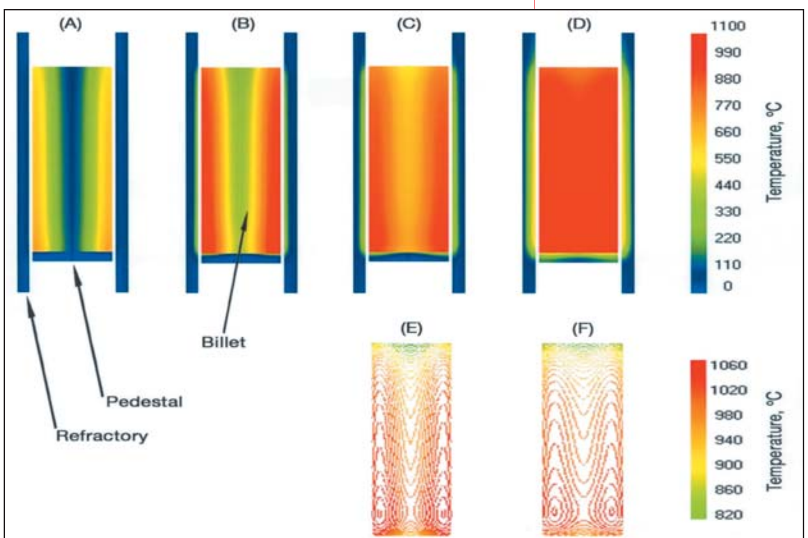

Fig. 3 — Sequential vertical induction heating of a Ti-6Al-4V billet to provide a temperature profile having a bottom warmer than the top. The flux concentrator (located below the pedestal) and multiturn induction coil are not shown. A: Initial stage. B & C: Intermediate stages. D & E: End of heating. F: After air cooling for 60 seconds during transfer from inductor to forming machine.

Titanium Alloy Example

Figure 3 shows the computer-modeled dynamics of induction heating a Ti-6Al-4V titanium alloy billet in a static vertical inductor using line frequency (60 Hz). Billet dimensions: 7.8 in. (200 mm) in diameter and 26.2 in. (665 mm) long.

A "cold" start-up was assumed, where the refractory insulation was initially at ambient temperature. The billet was positioned on a non-electrically-conductive pedestal. The stack of laminations acting as a magnetic flux concentrator was located below the pedestal. A longitudinal temperature gradient (heat profile) was desired, with the top of the billet being cooler. The effect of billet transfer in air after heating is also shown.

By adjusting coil overhangs at top and bottom and the position of the flux concentrator, it is possible to obtain either a uniform axial temperature distribution, or a reverse heat pattern where the top of the billet is warmer. This emphasizes the flexibility advantage of static vertical billet heaters. **HTP**

References

1. *Handbook of Induction Heating,* by V. Rudnev, D. Loveless, R. Cook, and M. Black: Marcel Dekker Inc., New York, 2003, 800 p.

2. "Induction Heating Serves Today's Forging Industry," by V. Rudnev: *Forge,* November 2004, p. 11–14.

3. "Modular Induction Systems Offer Billet-Heating Advantages," by D. Brown: *Forge,* January 2008, p. 13–16.