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Embedded High-Power-Density Heating

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Harmonic Inductive Gain technology is redefining heating due to its improved design flexibility and energy-saving potential.

As control electronics get faster and the science of materials advances, a new type of high-performance heating is emerging. Harmonic Inductive Gain (HIG™) technology works by delivering an electrical-current signal rich in high-frequency harmonics directly to a heating coil. The heating coil can have any combination of inductance, resistance and capacitance, giving the system engineer increased design flexibility and the potential for energy savings. This article will describe one application of HIG Technology – embedded warm inductors. These warm inductors, made from non-traditional materials and driven with special generators, are sprouting up to fill the void between high-performance resistive heating and induction heating (Fig. 1).

Applicability

Resistive heating is limited by power density and maximum temperature. Induction heating is limited by complexity. HIG heating is applicable where the design requires:

- High power density
- High temperature
- Cyclical heating/cooling
- Design simplicity

It is common knowledge that it takes less energy to boil water in one minute than in two minutes. Clearly, more power is necessary for the former but not twice as much. This is simply due to the decreased time for losses to occur. Intense, high-power-density heating has the same energy-saving effect on numerous industrial heating processes. Consideration of HIG heating for new designs or process improvements may result in considerable energy savings, a more compact design and even enable some new processes to be accomplished.

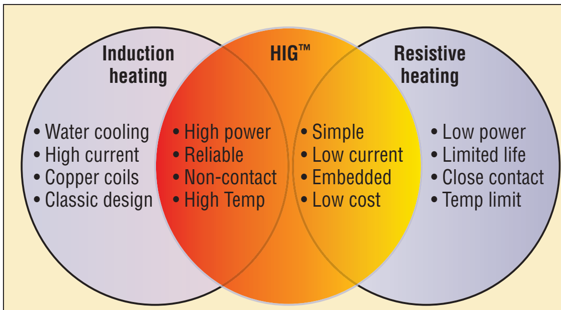

Fig. 1. HIG comparison

State of Computing Power

Digital Signal Processors (DSPs) sampling analog signals 2 million times a second and making decisions 30 million times a second are employed for real-time control of the HIG signal. As a discrete packet of energy is released for heating, the electrical response of the circuit is captured, digitized and then analyzed by the DSP. Circuit timing optimization, maximum capabilities and failure potentials are calculated by embedded algorithms in the DSP. Timing of the switching circuits is then determined. This recognition allows many different types of loads to be effectively heated – in many cases more effective than a purely resistive or traditional inductive system.

Background

Traditional high-current induction heating with water-cooled copper conductors has worked well for years in the melting and heat-treating industries, but installations are as complex as the induction phenomenon itself primarily due to the supporting subsystems such as water cooling (Fig. 2).

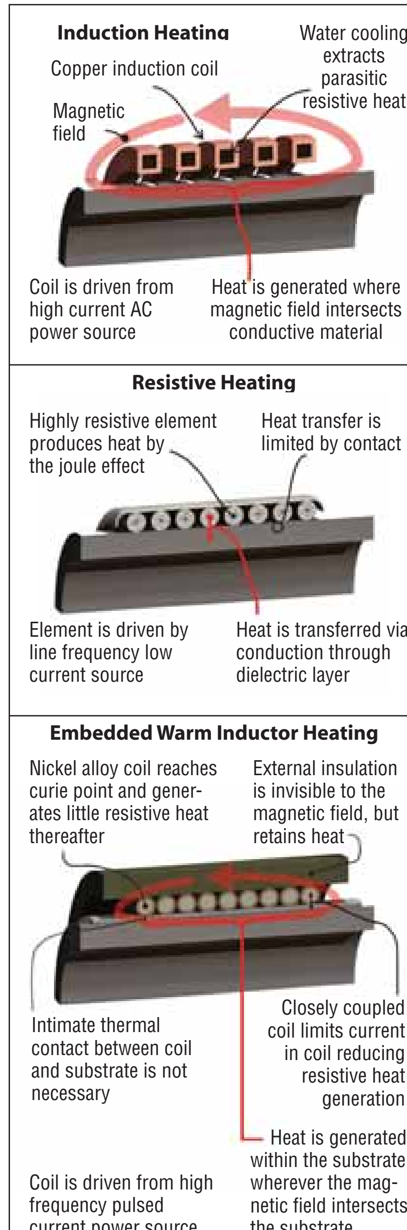

Fig. 2. Traditional induction and resistive heating technologies have physical limitations that are overcome with a non-traditional approach applicable to high temperature, high power density systems.

Induction heating – known for high-power-density, noncontact heating – works by subjecting a conductive load to an intense alternating magnetic field, and a transformer creates high electrical currents in the conductive load. These induced currents flowing in the electrically conductive object encounter some resistance and release energy in the form of heat. The power density of induction heating can be quite impressive and useful, but the complexity of the generators and supporting systems is sometimes cumbersome.

Resistive heating and its derivatives have always struggled to function reliably in high-temperature and cyclical applications. Widely used in industrial applications due to its simplicity and low cost, resistive heating allows the thermal-heating engineer to embed localized heating elements into dies, platens and various other substrates with considerable freedom – the limiting factor being power density. Power density is limited for two reasons. Firstly, in order to maintain a reasonable current through the controls and connecting wires, the resistance of the heating element must be high:

$P = I^2R$ (Power equals the square of the current times the resistance)

A high resistance comes from a long, thin wire of a resistive material such as NiChrome. Long, thin wires subjected to continuous heating and cooling, expanding and contracting are destined for failure. Micro-cracks develop on the surface and slowly work their way through the thin material as oxygen reacts with the newly exposed crack surface. Secondly, the resistive heating element is "live," meaning it must be dielectrically insulated from its surroundings. Most dielectric materials are poor thermal conductors. Therefore, the resistive element must get very hot to drive the energy into the object that needs heating.

If we try to capitalize on the benefits of induction while maintaining the simplicity of a resistive heater, how much inductive heating can one create without moving to a water-cooled copper coil? This becomes a power/electronic and materials-science problem, and the answer is … quite a lot.

Embedded Warm Inductor Heating

The coupling, which is the electromagnetic connection between an induction coil and the object it is heating, is dependent upon the proximity of the coil to the object. Naturally, if a high-current coil is water cooled, it must be thermally separated from the object. With embedded warm inductors, the coil is allowed to get hot, which enables low currents and good coupling. Additionally, the coil material is specifically chosen to be electrically conductive at high temperatures, and the current is kept low. Often the coupling is so good that sustained resonance, and therefore a traditional sinusoidal signal, is impossible.

Heating Control-System Technology

In low-current, low-frequency systems such as resistive heaters, the controls are quite simple. Resistive heating elements are generally switched on and off at periodic intervals independent of the line frequency. The proportion of on-to-off periods is modulated to accommodate the necessary power of the system. Quite simply, the more on-time relative to off-time, the more power is delivered to the system.

In induction heating, where the load maintains a significant amount of "inertia" in the magnetic field surrounding the coil, one must be very careful of when the conducting switches are put into a nonconducting or "open" state. If a switch is opened when the inertial energy is high, the energy will manifest itself as a voltage spike and likely catastrophically fail the switch. Therefore, all switching must be done in synchronization with the oscillations of the load. Two possible methods to maintain safe switching are to switch at the zero crossings of current or to wait until oscillations are completed.

Warm inductors are generally more closely coupled to the load and thus have high damping coefficients. Therefore, it becomes feasible to fully drain the energy in the circuit before introducing more energy. By doing this, a higher effective frequency can be attained and many different loads can be driven from a single power supply (Fig. 3). But there is a drawback. The controller must predict when it is safe to open a switch, and therefore, near real-time decision making and very fast sampling must be employed. Essentially, an oscilloscope is put inside every power-supply controller. In electromagnetic heating, load characteristics can change very quickly from any number of sources, including temperature changes and mechanical motion,

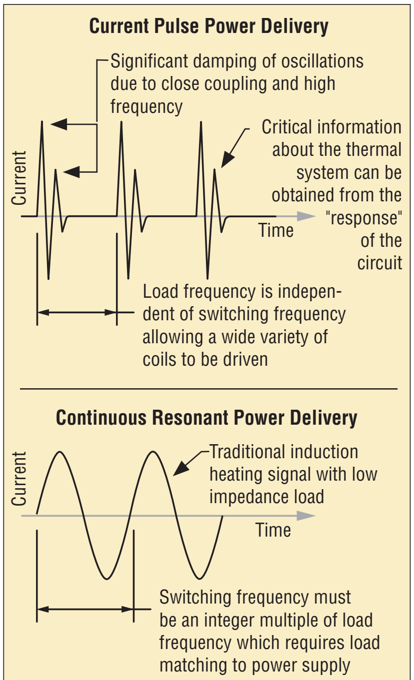

Fig. 3. Discrete energy packets are delivered to the load (top) for effective energy transfer into closely coupled embedded inductors as opposed to traditional induction (bottom) where a continuous signal is delivered to the induction coil.

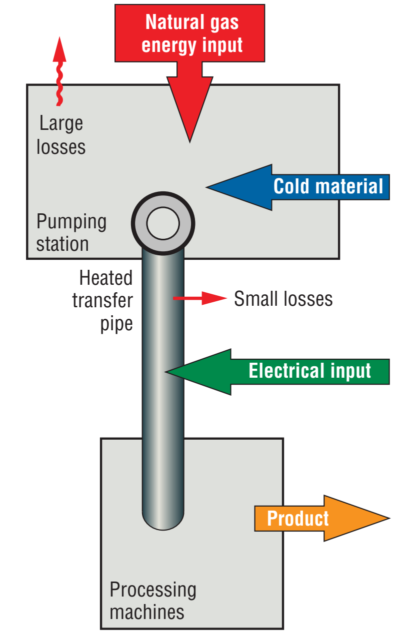

Fig. 4. Reducing furnace temperature and adding a heated transfer pipe saves significant energy due to the reduced heat flux from the large surface area of the furnace

Embedded Induction Heating in Liquid Metal

Although all electrical heating is 100% efficient at transforming electrical energy into thermal energy, not all electrical heating systems are nearly as efficient at transferring thermal energy into the medium that requires the heat. For example, in traditional external induction heaters some thermal energy is expended in the power converter and the high-current coil. Other technologies, although very reliable and proven such as lid-mounted radiant heaters, are still only as good as the absorption characteristics of the metal surface. Embedded induction heating powered by current pulse technology enables long, warm inductors to be submersed in liquid melt and reduces overall losses while improving thermal uniformity within the melt (Fig. 5).

As the melt drops in level, the load characteristics change and a dynamically tuning power supply accommodates the changes by re-tuning to the new load. Power is redistributed along the length of the immersion heater, and only the portion of the heater that is below the melt surface continues to deliver heat. Adaptable non-continuous-signal induction heating enables such a response.

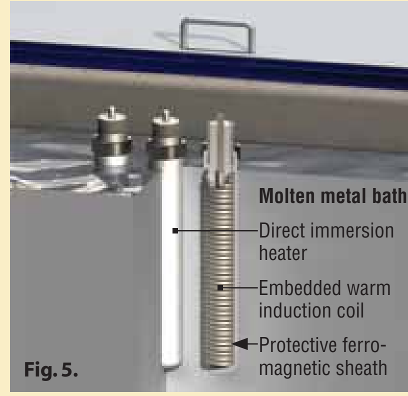

Fig. 5.

which both require dynamic adjustment of switching times.

Choosing the right heating technology for a particular process and understanding how to apply it are two critical issues that determine the success of an installation. Particular installations can benefit from this new breed of heating. Some of these are high-temperature, cyclical, high-power-density and demanding embedded applications. Still further, this heating method can enable significant energy savings when applied in concert with a thorough understanding of the heating needs of a process. The following application example describes how a small investment in understanding your process, coupled with new enabling technology, allows for significant process-heating energy savings.

Application Example

A Fortune 100 company with casting operations stumbled upon significant energy savings while trying to solve a frozen transfer-pipe problem (Fig. 4). Molten metal would freeze in the transfer pipes between a gas-fired melting furnace and a caster feed system whenever a stoppage occurred downstream in the processing line and the operator wasn't nimble enough to back-drain the metal feed system into the furnace. Simply heating the transfer piping might eliminate the immediate problem of frozen feed lines, but the factory had a bigger problem on its hands … rising gas prices.

The temperature loss between the melting furnace and the casting machine was measured at 30°C. Therefore, the furnace had to initially superheat the melt by 30°C to accommodate these losses. Insulation was considered along the transfer pipes, but it proved impractical and obstructive when the pipes froze and needed to be melted from the outside. If enough energy could be added to the melt in the heated region of the transfer pipe, was it possible to lower the furnace temperature by 30°C? The answer was yes, but the casual observer might argue that energy is energy, no matter the form. The more seasoned eye would look at the system and understand that lowering the furnace by 30°C would significantly reduce losses across a furnace exposed surface area of 32m^2 while only adding losses over an insulated and heated pipe with a surface area of 1.5m^2.

The furnace can now run 32kW lower delivered power via gas while only adding 5kW delivered electrical power in the pipe, yielding a return of investment to the customer of less than one year in energy savings alone. This savings, coupled with the increased up-time due to the elimination of frozen pipes and reduced oxidation because of the lower furnace temperature, has a net ROI of approximately seven months.

The transfer pipe was heated with an embedded warm inductor that supplied a specific input-power profile necessary to accommodate large losses at the flanges, yielding a very uniform temperature profile and leaving none of the target areas susceptible to freezing.

New materials and very fast control systems have enabled a new type of induction heating that is just beginning to find its place in industrial heating processes. High temperature, cyclical, high power density and in some cases loose or noncontact heating may benefit from this technology. A careful assessment of a particular process as a whole can further add to energy savings of a system or increased system performance. **IH**

Potential applications for embedded warm inductors:

- Molten-material transfer pipes
- Holding-furnace heating
- Polymer and fiber processing
- Compression molding
- Mold heating, die casting, injection molding
- Press stamp and print heating
- High-performance cartridge heaters

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Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: induction heating, resistive heating, high-frequency harmonics, line frequency, electromagnetic heating, immersion heater