HIG™: Combining the Benefits of Inductive and Resistive Heating

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Abstract — Harmonic Inductive Gain (HIG™) is a rapidly growing technology that is changing the game in what has previously been a stagnating technology; inductive heating. HIG utilizes a pulsed output signal rich in high frequency harmonics to deliver an intensely changing magnetic field in place of a sinusoidal signal generated from large currents. This approach allows for efficiency gains that permit air-cooled power supplies and coils to be realized. Modulation of the output pulse allows for precise control over output power with 1W precision regardless of coil configuration, coil type, or load type; affording full flexibility in coil design. The resultant system is incredibly versatile and intelligent offering the same 'plug and play' design flexibility as resistive heating while maintaining the highest level of efficiency and reliability available with induction.

Index Terms — Active circuits, digital signal processors, electromagnetic coupling, electromagnetic induction, passive circuits, RLC circuits, signal analysis

I. Introduction

Lean manufacturing techniques have been implemented worldwide requiring the competitive business to go one step further and evaluate how yields can be improved through automation, reduced cycle time, increased repeatability, and the removal of human-error. Harmonic Inductive Gain (HIG™) is one such technology that addresses all the aforementioned concerns in heating applications by combining the advantages of inductive and resistive heating into one technology for use in applications such as; soldering, annealing, tempering, adhesive curing, metal casting, threaded insert assembly (heat staking), and shrink fitting…just to name a few.

II. Background

All Resistive heating has traditionally offered the simplest option to satisfy heating requirements by passing current through a resistive element to generate heat. Although this is the lowest capital cost option, intimate thermal contact is necessary between the heating element and the work-piece to transfer thermal energy. The need for electrical isolation of the heating element further decreases efficiency as high quality dielectrics are seldom good thermal conductors. Additionally, the thermal stress associated with repeated heating and cooling of the heating element can significantly reduce its lifespan. These problems can combine such that the operations and maintenance costs of resistive heating can be substantially greater than that of HIG in many applications.

Unlike resistive heating, induction heating eliminates the thermal impedance and inducing heat in the work-piece itself. The wireless heat transfer mechanism employed by induction operates on the same principle as a transformer. An alternating current passes through a primary coil winding to create an intense, alternating magnetic field that induces AC current in a magnetically coupled secondary. Unlike a transformer however, the secondary current is not induced in a coil connected to an external circuit through which the current flows. Instead, very large eddy currents are generated inside the electrically-conductive object to be heated. The internal resistance of the object itself functions in the same manner as the resistive element whereby heat is generated through internal resistance to the flow of current. This method does not require thermal contact nor does it stress the element or coil with thermal cycling. This negates many of the shortcomings of resistive heating producing more efficient heating of materials with the correct physical properties: adequate permeability, good electrical conductivity, and sufficient internal resistance.

Assuming that the requirements for an application to be compatible with induction heating have been met, there are still physical limitations and difficulties that arise with the traditional inductive approach. With the traditional approach an inductive power supply produces a continuous sinusoidal current signal that delivers current at the resonant frequency of the coil and tank capacitors. This means that the switching frequency of the power supply must be an integer multiple of the load frequency to ensure proper load matching. In such a system matching transformers and large tank capacitors are necessary to tune the resonance circuit resulting in bulky systems that require complex control systems.

It follows that of the three possible methods of delivering higher amounts of power in such systems (increasing the frequency, voltage, or current) that increasing the current is the most logical choice. A step up in voltage would require bulkier capacitors with thicker dielectric plates, and increasing the frequency is difficult given the load matching requirement. Additionally, increasing the frequency is often undesirable due to increased skin effect especially in larger applications requiring deeper levels of thermal penetration. Subsequently the large currents that result from higher power outputs result in greater losses through the switching circuit and coil. These losses are manifested as parasitic heat necessitating the use of bulky water cooled systems and larger, more cumbersome coils with less architectural flexibility.

IV. OVERVIEW OF HIG™

Harmonic Inductive Gain has already proven itself as a cost-effective means of delivering efficient, reliable, and repeatable induction heating by supplementing many of the shortcomings of traditional induction with some of the strengths of resistive heating. This is accomplished by utilizing a pulsed current signal in place of a sinusoidal signal thereby increasing the "effective" heating frequency. The HIG pulse works by rapidly charging capacitors and allowing them to discharge through the coil. The resultant RLC circuit is allowed to oscillate at its resonant (harmonic) frequency until the signal dampens through the internal resistance of the work-piece. This means no more fighting to maintain a fixed frequency and simultaneously negates the need for load matching. The resultant pulse is rich in high frequency harmonics offering increased power density for many applications that can naturally oscillate as high as 500 kHz (Fig. 1).

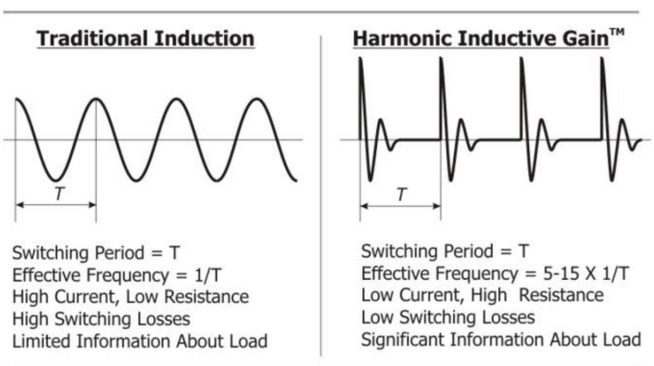

Fig. 1. Overview of the HIG Signal.

Increasing or decreasing power output is easily accomplished with HIG by simply increasing or decreasing the frequency of the pulse delivery. Delivering more power works naturally with applications that readily accept more power as the pulse dampens more quickly to allow for faster switching times. This dynamic change in damping factor based upon load coupling can be similarly viewed thermodynamically: larger parts and/or parts with better coupling serve as larger heat-sinks through which the coil can more readily dissipate its energy. Since load matching is no longer a concern, coils become the same 'plug and play' devices with a HIG power supply as resistive heating elements are with a resistive power supply. This allows for increased flexibility in coil design with regard to materials, configuration, number of turns, and wire types effectively bridging the gap that once existed between induction and resistance heating (Fig. 2).

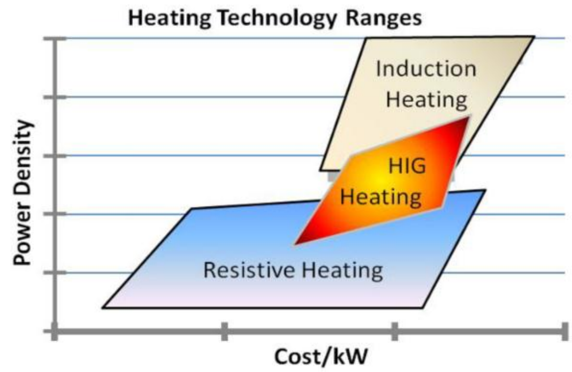

Fig. 2. HIG application potential in 2012. This area is expected to grow rapidly in the upcoming years through advancements in control algorithms and up-scaling of the HIG pulse into larger power supplies.

A. Smart Controls

Oscillation of the HIG pulse may be passive, but acute monitoring of the signal is required. Active monitoring of these quantized energy packets at 2 million times per second allows the HIG power supply to gather and digitize waveform data about the damping characteristics and resonant frequency of the load. Because the RLC values of the power supply are known, significant information about the load characteristics can be calculated from the resultant data and incredibly accurate control algorithms can be applied to control the signal. The HIG pulse typically dampens in as little as two cycles with heavily coupled loads, or as high as ten or more cycles with smaller parts or parts with lower permeability such as copper or aluminum. In either case, the on-time of the pulse is adjusted in to allow the pulse to dampen, and the off-time is calculated such that 0.1% power precision can be maintained across the entire power level spectrum regardless of the coil or load. The non-linear variations in magnetic permeability and electrical conductivity that occur in the work-piece as a function of temperature change are easily managed by simply increasing or decreasing the on-time and frequency of the pulse. Furthermore, smart controls allow for the detection of important factors such as coil failures and maximum power capability based upon the pulse length and minimum charge time needed between cycles.

B. No More Water Cooling

Because the power supply/coil RLC loop is allowed to oscillate at its natural frequency the resultant system is incredibly efficient. Permitting the HIG pulse to fully dampen allows zero-current and zero-voltage switching to occur thus excess heat does not build up in the switching circuit. This means that HIG power supplies can be air-cooled, even at outputs as high as 5kW. Because power increases are achieved through modulation of the pulse signal, peak current levels are no greater for the highest power settings than they are for even the lowest power settings. As a result the coil no longer requires water cooling allowing smaller wire diameters and longer lead lengths to be realized.

The resultant air-cooled coil allows for high quality, multi-stranded (Litz) wire to be used in place of hollow copper tubes, and decreased cooling requirements can help prolong coil lifetime. Voltage levels are more easily maintained at higher frequencies with this wire type resulting in higher power factors. Not only are multi-stranded coils more efficient conductors of higher frequency signals, but the increased flexibility and smaller wire diameters permit tighter windings and greater design flexibility for production of higher power densities in many applications through denser magnetic fluxes and stronger coupling through increased proximity. These tightly focused areas of flux have already proven themselves incredibly effective in applications such as: PCB soldering, interconnect manufacturing, photovoltaic bus soldering, catheter tipping, and stud pressing, applications that are typically less efficient with traditional induction or resistive heating alone (Fig. 3).

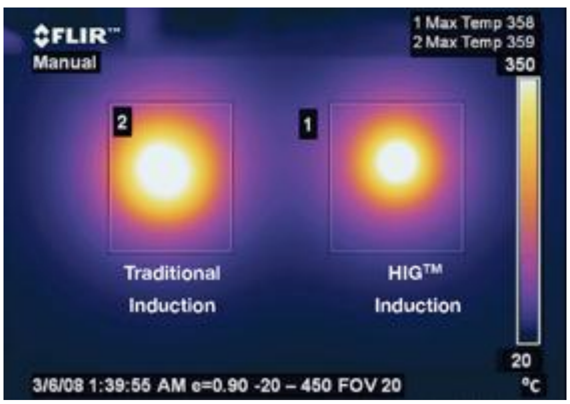

Fig. 3. Thermal image demonstrating the increase in precision and power density of a HIG system compared to traditional induction in one application.

V. Conclusion

HIG has proven itself as a powerful method for heating in many applications and new application possibilities are being demonstrated almost daily. Whether the end user is seeking to satisfy strict process tolerances, reduce cycle times, increase repeatability, or all of these, application engineers are quickly becoming aware of this evolving technology as installations are rapidly increasing worldwide. These larger systems will not only demonstrate HIGs potential in existing processes, but likely enable new processes that were previously inaccessible.

REFERENCES

[1] K. Clark, “Embedded High-Power-Density Heating,” *Industrial Heating*, pp. 87-90, September 2008.
[2] V. Kagan, “Method For Delivering Harmonic Inductive Power,” U.S. Patent US 7,279,665 B2, filed November 1, 2005, issued October 9, 2007.