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Innovative Space-Saving Ideas for Induction Heat Treating

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During the last five years, advances in semiconductor technology have allowed induction heating equipment manufacturers to significantly reduce the size of power supply components. Thus, the floorspace requirements of some commercially available induction heating units are now less than 15% of that previously required by older systems. A number of innovative space-saving induction heat treating ideas and practical examples of their implementation will be discussed in this article.

"We must reduce costs, increase productivity, and maintain quality while utilizing a minimum amount of available floor space," say American automotive manufacturers. This requirement for highly efficient utilization of floor space is the last but certainly not least important factor when designing modern induction heat treating systems. During the last three years, manufacturers of induction heat treating equipment have made significant progress in developing highly efficient, compact heat treating systems. The space savings have been achieved by technical innovations in the area of electrical power devices, electronic systems and equipment design.

Many new induction heating power supply designs have been introduced in the past few years. Most of these use relatively new MOSFET (Metal Oxide Silicon Field Effect Transistor) or IGBT (Insulated Gate Bipolar Transistor) fast switching power transistors. Different power supply types and models are available to meet the heating requirements of a nearly endless variety of heat treating applications.[1-4]

The appearance of advanced solid-state power supplies is only one factor contributing to the efficient use of floor space. Other factors which have also had a significant influence on the ability to conserve existing heat treat shop floor space are improvements in concept and the continued growth of microprocessor technology resulting in sophisticated control/monitoring systems.

Fig. 1 Integrated heat station and power supply (150 kW, 30 kHz, 24" x 24" x 51").

Solid-State Power Supply Revolution

Prior to 1970, most audio frequency and radio frequency induction heating processes used motor generator sets and vacuum tube oscillators.[2] Relatively fast switching thyristors (silicon controlled rectifiers - SCR's) with current ratings of up to 300 amperes became available in the late 1960's. These devices made it technically and economically possible to provide solid-state audio frequency induction heating power supplies. This development has led to a gradual extinction of motor generator sets in this industry.

A similar change has recently taken place in both the audio and radio frequency ranges. In the mid 1980's, new power components were developed that were suitable for use in a new generation of induction heating power supplies. These components included power semiconductors, capacitors, and transformers. MOSFET and IGBT power transistors became available with high power handling capability, fast switching speed and low power losses at prices that soon made them cost competitive with vacuum tube and SCR technology.

The state-of-the-art in power transistor technology has been advancing rapidly ever since with new and improved devices introduced almost every month. Modern induction heating power supplies utilize power semiconductors such as SCR's, diodes and transistors to switch the direction of current flow from a direct current source to produce alternating current at the required frequency.

In order to meet the needs of the new high frequency transistor technology,

Fig. 2 CV joint heat treating system with heat station power supplies superimposed over a similar system with balcony mounted SCR power supplies.

changes took place in the design of other circuit components, such as capacitors and transformers. Capacitors with high kVAR, low power losses, and very low inductance have been developed and are provided in a package that is compact and easy to water cool. Transformers using ferrite and ferrite-based cores are now available in many unique configurations that are capable of handling high current at high frequencies. These new transformers have very low inductance and low power loss.

The successful development of power supply components has, in turn, led to the design and manufacture of many different styles of transistorized induction heating power supplies. In fact, the point has come where the phrase "solid state" may be assumed when referring to induction heating power supplies. Just as SCR inverters have, in the past 25 years, replaced motor generator sets, so the vacuum tube oscillator and some older SCR inverters are now being replaced by transistorized power supplies.

Why are Transistorized Power Supplies Preferred?

There are some important characteristics that are common to nearly all types of transistorized power supplies.[1,2] Induction coils are connected to a capacitor to form a resonant circuit tuned to the required heating frequency. Most high frequency transistorized power supplies are designed to operate exactly at this resonant frequency to minimize transistor switching losses and, therefore, maximize conversion efficiency. Below 30 kHz, where transistor switching losses are less significant, it is common to control power by shifting the inverter frequency relative to the load resonant frequency.

The conversion efficiency of transistorized power supplies is typically 85 to 93% compared to 50 to 60% for most vacuum tube oscillators. This means electricity cost savings and reduced plant water cooling system requirements.

SCR's are capable of surviving large fault currents while transistors are not.[2] However, transistors can be turned off the instant a fault is detected and before the current rises to a destructive level. The control electronics in the transistorized power supplies must, therefore, have fast and reliable fault detection circuitry. The control electronics in these power supplies utilize state-of-the-art components to provide fast and accurate response, high reliability, and are usually designed to communicate with computer control and monitoring systems.

In general, transistorized power supplies are much more compact than the equivalent thyristor or vacuum tube equipment. For example, a newly developed heat station power supply (Fig. 1) is a 150 kW, 30 kHz, IGBT power supply that includes the inverter, heat station, load matching transformer and capacitors. It measures only 24″ x 24″ x 51″ and mounts on a standard heat station base.

The heat station power supply has had a major impact on the design of modern multi-station automatic induction heat treating machines. In the past, the power supplies and their cooling water recirculating systems were mounted on a balcony above the machine to conserve floor space and minimize the distance between the power supply and its heat station. The new generation of power supplies has increased the power density from 1.0kW/ft^3 to about 10 kW/ft^3, yet require less than half the space of previous induction systems with no overhead clearance requirements.

Fig. 2 illustrates this dramatic reduction in size and complexity. A new induction heating machine that uses transistorized heat station power supplies for heat treating CV joints is

Fig. 3 Cell for hardening camshafts with two heat station power supplies.

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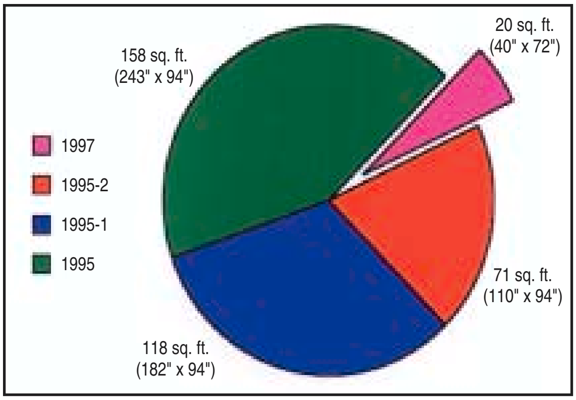

Fig. 4 An evolution of the floor space requirements of camshaft hardening machines during the last four years. (Data from Inductoheat, Inc.)

superimposed over a previous (1995) balcony style system.

The transistorized heat station power supply is also used in compact cells such as the dual position camshaft hardening cell shown in Fig. 3. In this case, two 200kW/30kHz heat station power supplies each provide power to two heating positions.

As seen in Fig. 4, a 1997 model camshaft hardening machine requires less than 15% of the shop floor space than was required by a similar machine built in 1994. An appropriate combination of the design parameters such as frequency, power density, coil geometry, etc., allows the heat treating practitioner to optimize system efficiency, minimize camshaft distortion and obtain the required hardness profile.

Equipment design has become "wholistic." The equipment now consists of a minimum number of components and is more reliable, compact, and easier to operate and maintain. By designing with the whole system in mind, the floor space can be best utilized. For example, if the whole machine is more compact, the distance over which the water is pumped is shorter and the pump sizes can be smaller. All of these items work to the advantage of the user by keeping cost and floor space to a minimum.

Compact In-Line Induction Tempering Systems

The tempering process takes place after the part is hardened.[6] It is a subsequent, but no less important step in metal heat treating. The main purposes of tempering are to increase toughness, yield strength and ductility, relieve internal stresses, improve homogenization, and decrease brittleness of the part.

There is a common misconception that tempering removes all internal stresses. Tempering significantly decreases the stresses but does not remove them entirely. Tempering makes a steel softer and reduces the chance of distortion and the possibility of cracking. If tempering has been done correctly, there will be only a slight reduction in hardness.[6] The benefits obtained, such as internal stress relief, the attainment of the required ductility or toughness, shifting the position of the maximum tensile stress, which is typically located under the hardened surface layer, more toward the core of the part, and improvement in the machinability of the steel, will offset the slight reduction in hardness.[5,6]

It is important that the time from quench to temper be held to a minimum in order to maximize the benefits of tempering. If this "transient time" is too long, the internal stresses may have enough time to allow shape distortion or cracking to take place. Therefore, the tempering machine should be located near the induction hardening machine. In order to achieve efficient utilization of shop floor space, induction tempering is often accomplished as part of the hardening machine or as a separate machine located with the hardening equipment. Fig. 5 shows a machine used for in-line induction tempering of constant velocity joints. The compact design of this machine is its primary advantage.

Quality Assurance Strategies, Process Control and Monitoring

One of the most important features of modern induction heat treating equipment is the process control and monitoring capabilities as part of a modern quality assurance program. Advanced monitoring systems provide an operator with the ability to have instant and precise information about the actual heat treating cycle, and allow verification of the most important process parameters which, in turn, can be used to certify the quality of heat treated parts. Different types of monitoring systems are available in the market.[1] The choice of a particular monitoring system is a matter of operational features of the process, cycle time, technological requirements, and cost. In some applications a relatively simple

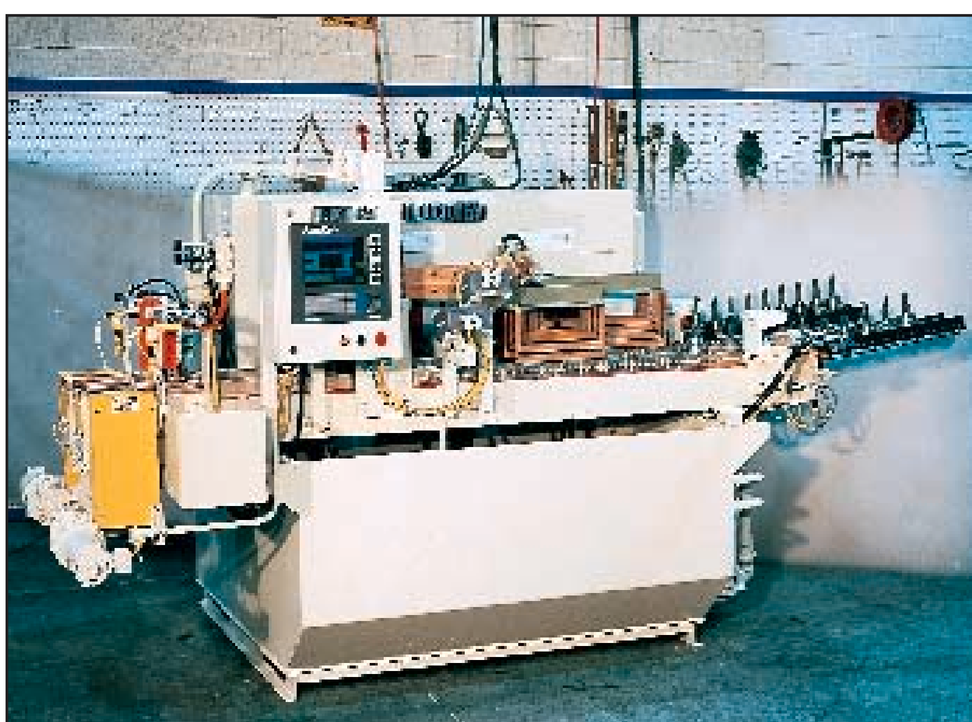

Fig. 5 Compact in-line induction tempering machine.

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coil energy monitor will be sufficient. Other applications may require advanced "signature-type" monitoring devices.[1,4]

The Stativision concept has become an acknowledged standard of advanced signature-type heat treat monitoring.[1] Monitors using this concept have a real-time interface and allow monitoring of many variables at once with corresponding real-time graphing of the function within preset setpoints; often SPC analysis is incorporated. During each successive machine cycle a new signature is compared to the stored ideal signature. This user-friendly diagnostic tool improves system up-time and may also provide tuning assistance for a particular part.

Conclusion

A combination of sophisticated inverter designs, advanced control/ monitoring systems and innovations in concept have resulted in a major reduction of required shop floor space for a new generation of induction heat treating machines. These machines are significant because they are not only electrically efficient, but are space efficient as well.

Transistorized induction heating power supplies offer many advantages over equipment which uses older technologies. These new power supplies are much smaller and can often be mounted close to the heating coil. Interconnection bus or cable losses can be virtually eliminated. Overall system efficiency is generally higher for transistorized power supplies which means lower electric power and water cooling cost.

Additional information about the different aspects of modern induction heat treatment may be obtained by contacting the authors at (248) 585-9393.

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