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Induction Furnace Introduction

The basic principle of induction heating has been understood and applied to manufacturing since the 1920s. During World War II, the technology rapidly developed to meet urgent wartime requirements for a fast, reliable process to harden metal engine parts. More recently, the focus on efficient manufacturing techniques and emphasis on improved quality control led to a rediscovery of induction technology, along with the development of precision controlled solid state induction power supplies.

Electromagnetic induction is the process that allows an induction furnace to work. It was first discovered in 1831 by Michael Faraday. During induction, an electric current is passed through a metal coil which creates a magnetic field. When metal is introduced into the magnetic field, an electrical current passes through the metal and causes it to heat.

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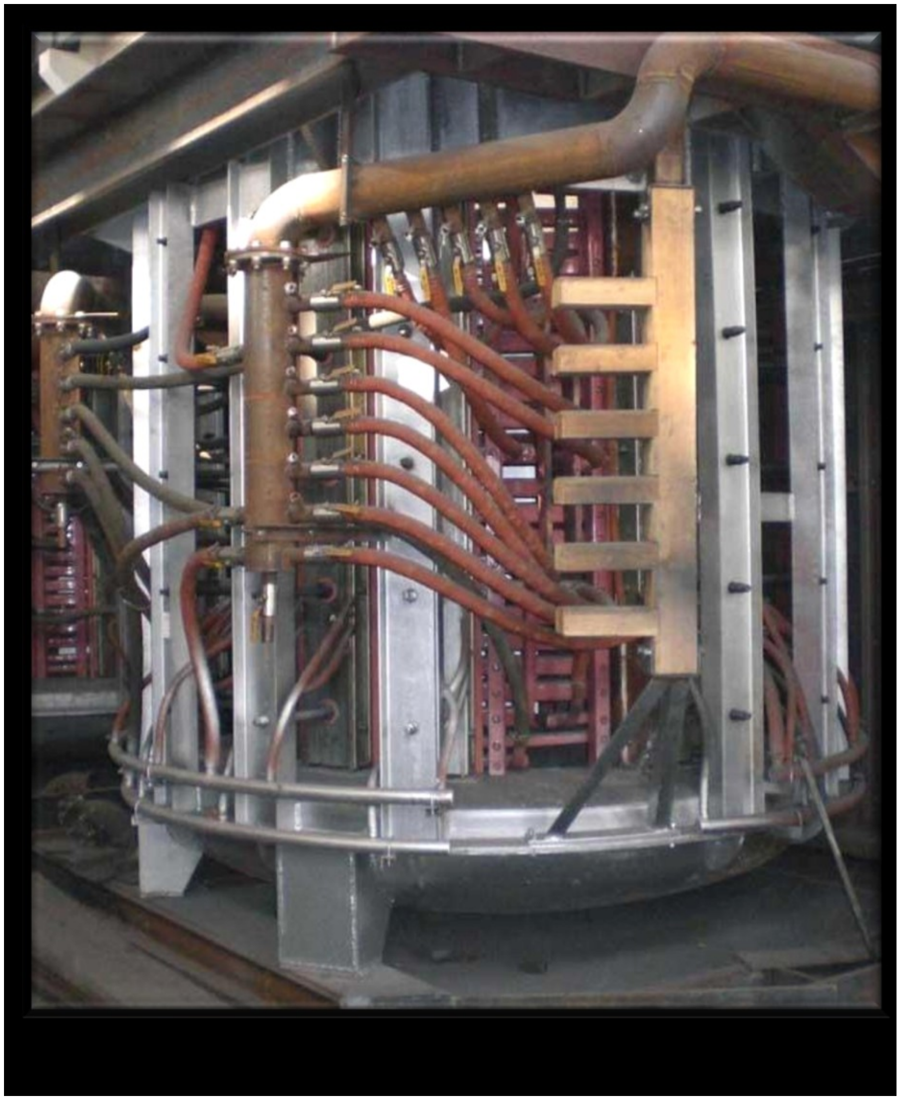
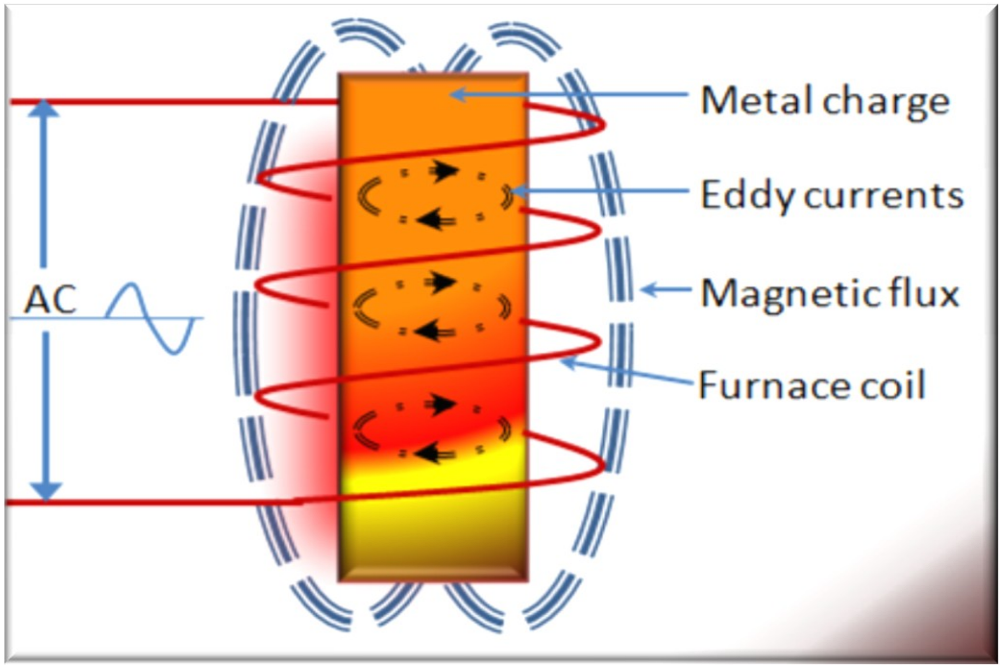


Induction furnaces produce their heat cleanly, without combustion. Alternating electric current from an induction power unit flows into a furnace and through a coil made of hollow copper tubing. The tubing allows the coil to be cooled by passing water through it in route to a heat exchange system. The coil creates an electromagnetic field that passes through the refractory material and couples with the conductive metal charge inside the furnace. This induces electric current to flow inside the metal charge itself, which produces heat that which can enable the metal to melt. Although some furnace surfaces may become hot enough to present a burn hazard, with induction the charge is heated directly, not the furnace itself.

Induction furnaces require two separate electrical systems: one for the cooling system, furnace tilting and instrumentation, and the other for the induction coil power. A line to the plant's power distribution panel typically furnishes power for the pumps in the induction coil cooling system, the hydraulic furnace tilting mechanism, and instrumentation and control systems. Electricity for the induction coils is furnished from a three-phase supply side transformer.

When alternating current flows in a conductor it produces alternating magnetic flux. If conducting material (metal charge) is placed within the flux path, emf is induced in the material. The induced emf develops eddy currents within the material. The power loss due to such eddy currents appears as heat. The interaction between the emf and the applied electrical charge produces a stirring action in the molten material. The stirring action is important since it serves to maintain a uniform temperature throughout charge. This action of inducing emf in other material due to alternating flux produced by a current carrying conductor is a transformer action. The only difference between a transformer and induction heating is that with a transformer, electrical energy available in the secondary is utilized outside the secondary as a load, whereas with induction heating it is used to heat the charge itself which acts as a short circuited secondary.

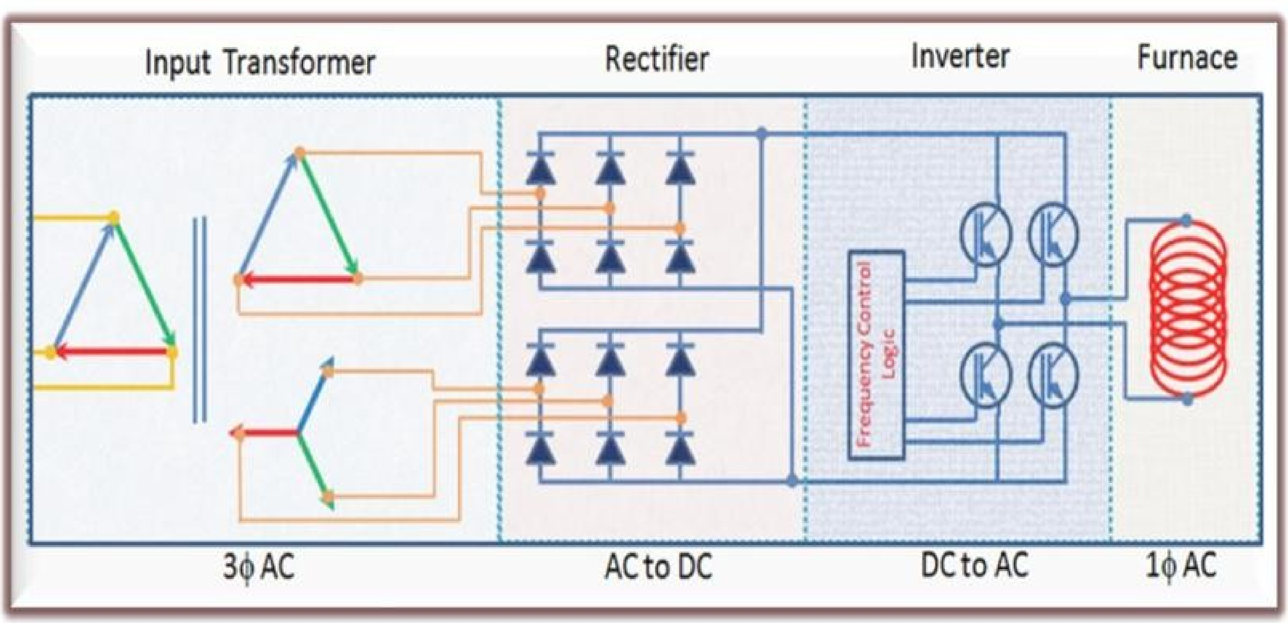


Frequency plays a critical role in the control of induction furnace melts. The lower the frequency, the deeper the penetration into the melt volume. Up through the end of the 1970's, most large induction furnaces operated at line frequency (50 or 60 Hz). Furnace coil current levels were adjusted via transformer taps and switched capacitor banks. The highest power level was reached when the resonant frequency of the coil and capacitor network equaled that of the line frequency.

Line frequency power supplies severely limited melting point control. Since the frequency was fixed at a low level, it was difficult to control the speed of the melt which could lead to excessive stirring or turbulence in the melt volume. Line phase balancing was also a problem since the line frequency induction furnace was primarily a single phase device.

Modern industrial batch melt induction furnaces operate at frequencies ranging from 250 to 500 Hz or higher depending on the type of material being melted, the volume capacity of the furnace, and the desired melting speed. In general, the smaller the melt volume, the higher the furnace frequency, due to the skin depth which is a measure of the distance that alternating current can penetrate the surface of a conductor. For the same conductivity, higher frequencies have a shallow skin depth (less penetration into the melt volume). As mention above, lower frequencies can generate stirring or turbulence in the melt volume.

With the availability of high current silicon controlled rectifiers, came the development of solid state power supplies capable of resolving line frequency constraints. It became possible to construct inverters with output power exceeding 10 kW at output frequencies over several hundred hertz. Today, the most efficient furnaces run at full power varying the frequency to optimize the melt. Solid state technology also provide a solution to the phase balancing issues. Multi-phase line voltages are now rectified prior to being inverted to single phase, variable frequency furnace coil inputs.



The preceding diagram is a simplified representation of the induction furnace electrical system. A 3-phase line frequency supply feeds a 3 phase transformer. The output feeds a full wave rectifier circuit which produces a DC output. Then, the DC is changed into single-phase AC via the inverter circuit. The inverter is IGBT (insulated gate bipolar transistor) based which enables precision frequency control. The variable frequency is then fed to the furnace coil.

These technical advances have resulted in significant advantages over earlier furnace types. The inductive and non linear nature of the load does however, present supply side problems. While in operation, the furnace solid state power supply system can produce supply side harmonics and thereby waveform distortion due to high frequency inverter pulses.

Although an induction furnace operates on AC, the fact that it is fed by a solid state power supply necessitates that the transformer which feeds the power supply be designed to accommodate the resultant harmonic loading in addition to properly managing the furnace load profile.

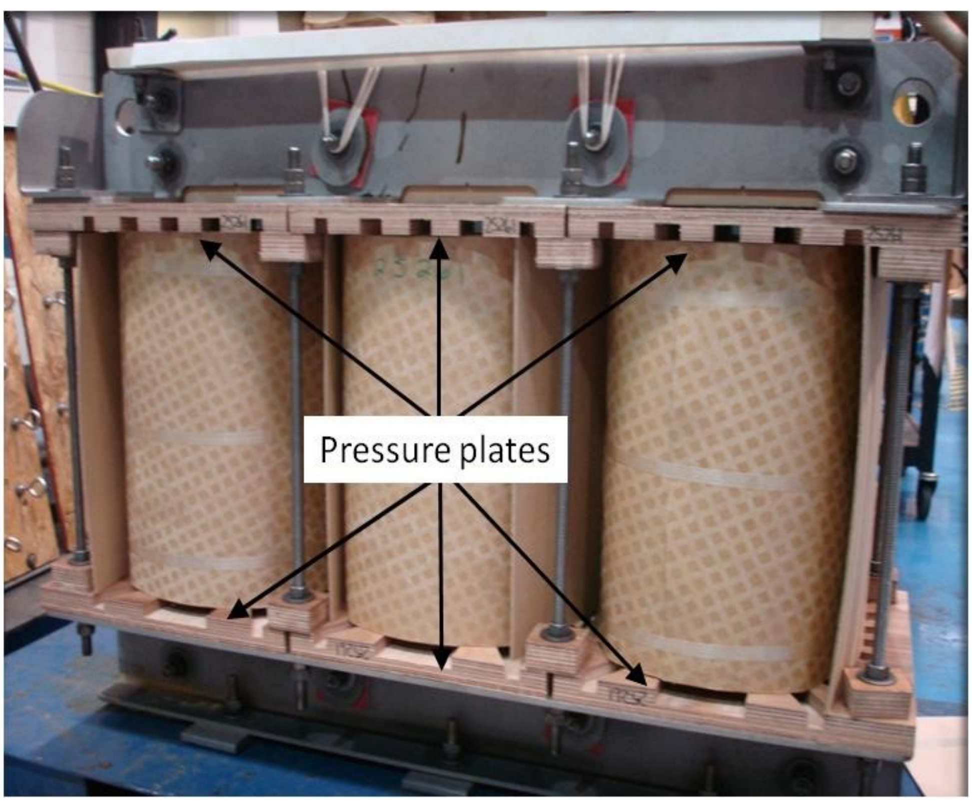
12 pulse core/coil assembly

Wave form distortion from harmonic loading can be significantly reduced by utilizing a 12 pulse transformer which limits the impact of 5th, 7th, and 11th harmonics due to the 30 degree phase shift from the additional secondary windings.

Whether 6 pulse or 12 pulse, rectifier loads must be accommodated for in the transformer core/coil design. Non-sinusoidal loading can lead to localized coil heating. Radial and axial forces due to heavy loading and short circuits must be accommodated.

The utilization of round coils with cruciform stacked cores allows for 360 degree coil cooling thereby minimizing hot-spots. Round coils also effectively manage radial forces since they are equalized throughout the circumference of the coils. Management of coil heating and radial movement protects the winding layer insulation system from premature aging and rupture.

Axial forces must also be managed, especially during fault conditions. Failure to do so can lead to telescoping of the coil turns which in turn results in coil failures.



Round coil construction coupled with cruciform stacked cores provide for the capability of adding pressure plates to the top and bottom of each coil.

The pressure plates have numerous routered ducts which allow for unrestricted flow of the cooling fluid. Metal all-thread bolts secure the top and bottom pressure plates thereby providing protection against coil movement due to axial forces.

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Summary

Although today's induction furnace is an AC device, the furnace supply voltage is a product of the power supply system feeding it. The energy ***to*** the power supply is AC provided by a line frequency transformer. The output from the transformer feeds a full wave rectifier in the furnace power supply. The resultant DC is then inverted to a frequency controllable AC which powers the furnace coil.

To dependably manage the harmonic content and load profile demands associated with the induction furnace and its' solid state power supply, it is essential that the supply side transformer be specifically designed and constructed for such a purpose. Pacific Crest Transformers's experience and expertise in the industrial market can provide the confidence that the best transformer solution is provided.