(B) Diffraction and Irradiation Types. Diffraction- and irradiation-type equipment or installations not effectively enclosed or not provided with interlocks to prevent access to uninsulated live parts during operation shall be provided with a positive means to indicate when they are energized. The indicator shall be a pilot light, readable meter deflection, or equivalent means.

660.24 Independent Control. Where more than one piece of equipment is operated from the same high-voltage circuit, each piece or each group of equipment as a unit shall be provided with a high-voltage switch or equivalent disconnecting means. This disconnecting means shall be constructed, enclosed, or located so as to avoid contact by persons with its live parts.

Part III. Transformers and Capacitors

660.35 General. Transformers and capacitors that are part of an X-ray equipment shall not be required to comply with Articles 450 and 460.

High-ratio step-up transformers that are an integral part of X-ray equipment are not required to comply with Article 450 and are generally used to provide the high voltage necessary for X-ray tubes. Because the fire hazard is lower due to the low primary voltage, X-ray transformers are not required to be installed in fire-resistant vaults.

660.36 Capacitors. Capacitors shall be mounted within enclosures of insulating material or grounded metal.

Part IV. Guarding and Grounding

660.47 General.

(A) High-Voltage Parts. All high-voltage parts, including X-ray tubes, shall be mounted within grounded enclosures. Air, oil, gas, or other suitable insulating media shall be used to insulate the high voltage from the grounded enclosure. The connection from the high-voltage equipment to X-ray tubes and other high-voltage components shall be made with high-voltage shielded cables.

(B) Low-Voltage Cables. Low-voltage cables connecting to oil-filled units that are not completely sealed, such as transformers, condensers, oil coolers, and high-voltage switches, shall have insulation of the oil-resistant type.

Δ **660.48 Grounding.** Battery-operated X-ray equipment shall not be required to comply with the grounding requirements of this *Code*.

According to 90.3, the general requirements of Chapter 2 apply to all electrical installations. Therefore, Part I of Article 250, specifically 250.4(A)(2) and (3), would apply to the grounding of X-ray equipment.

ARTICLE 665 Induction and Dielectric Heating Equipment

Part I. General

665.1 Scope. This article covers the construction and installation of dielectric heating, induction heating, induction melting, and induction welding equipment and accessories for industrial and scientific applications. Medical or dental applications, appliances, or line frequency pipeline and vessel heating are not covered in this article.

Informational Note: See Article 427, Part V, for line frequency induction heating of pipelines and vessels.

To prevent spurious radiation caused by induction and dielectric heating equipment, the Federal Communications Commission (FCC) has established rules that govern the use of this type of industrial heating equipment operating above 10 kilohertz (FCC, 47 CFR 18).

See also

NFPA 86, *Standard for Ovens and Furnaces*, for more information on electric heating systems using an induction heater or a dielectric heater in ovens and furnaces

• **665.5 Output Circuit.** The output circuit shall include all output components external to the converting device, including contactors, switches, busbars, and other conductors. The current flow from the output circuit to ground under operating and ground-fault conditions shall be limited to a value that does not cause 50 volts or more to ground to appear on any accessible part of the heating equipment and its load. The output circuit shall be permitted to be isolated from ground.

If the load (object being heated) accidentally contacts the output coil, a voltage to ground will appear on the load, depending on the various impedances to ground of the coil and the load. If the voltage on the load is limited to less than 50 volts, guarding per 110.27(A) is not required. If the coil is isolated from ground and the load is grounded through an impedance that is low (less than 1 percent) relative to the coil impedance to ground, the voltage of the load to ground will be low no matter where the load contacts the coil.

In induction melting furnaces, an additional reason for isolating the coil from ground is to limit the fault current when a coil does go to ground. Limiting the fault current prevents severe damage to the water-cooled coil, resulting in a water leak and the potential for a water-molten metal explosion. If water is trapped under molten metal, the rapid transfer of heat to the water causes the water to turn almost instantly into steam. The resulting 1600-to-1 expansion of the steam results in the ejection of molten metal from the furnace.

CLOSER LOOK: Solid-State Converter Power Circuit

A solid-state power converter consists of three sections: the rectifier section, the inverter section, and the output section, which includes the load coil and is usually located outside the power supply. Exhibit 665.1 shows an example of an enclosed power supply for an induction heating process.

The rectifier section converts 3-phase, line frequency voltage to direct current. The output of the rectifier section supplies energy for the inverter section. The inverter section converts the energy to a variable frequency for the output circuit. The variable output frequency controls the power delivered to the load.

The output section consists of a capacitor in parallel (current fed) or in series (voltage fed) with a coil. Capacitance and inductance operate at a resonant frequency, and as the output frequency approaches the resonant frequency, the power to the load approaches its maximum. The output power is very low at minimum frequency.

Induction Heating

Induction heating occurs when an electrically conductive material (load) is placed in a varying magnetic field generated by a coil (inductor) around or adjacent to the workpiece to be heated. The varying magnetic field induces current in the load. Heat is generated by the resulting I^2R losses in the load. Induction heating can be further subdivided into heating, melting, and welding.

Induction heating raises the temperature of the load to a temperature below its melting point, usually for the purposes of hardening, tempering, annealing, forging, extruding, or rolling. Frequencies used for heating range from about 50 hertz to 500 kilohertz. Power levels range from 5 kilowatts to 42 megawatts.

EXHIBIT 665.1 *Enclosed power supply for an induction heating process. (Courtesy of Ajax Tocco Magnethermic, Park Ohio Industries)*

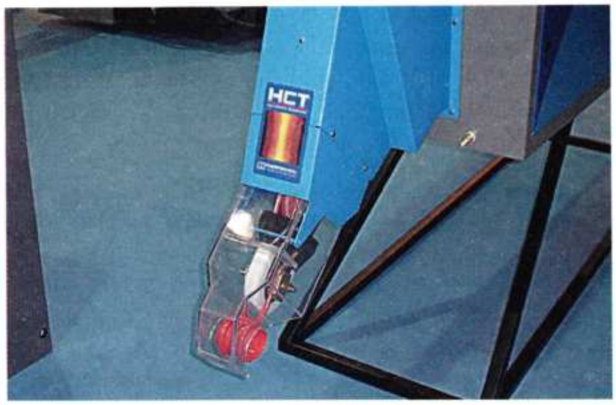

EXHIBIT 665.2 *A solid-state induction welding machine. (Courtesy of Thermatool Corp.)*

Induction melting raises the temperature of the load to a temperature above its melting point, so the molten material can be alloyed, homogenized, and/or poured. Frequencies used for melting range from about 50 hertz to 10 kilohertz. Power levels range from 5 kilowatts to 16.5 megawatts.

Induction welding is primarily used in the manufacture of welded pipe and tubing. In this process, a high-frequency current is passed through an induction coil in the proximity of the conducting metal surfaces to be joined. Selected portions are heated nearly instantaneously to the forging temperature, then are joined under pressure to produce a forge weld. Frequencies used for welding range from about 100 to 800 kilohertz. Power levels range from 20 kilowatts to 1 megawatt. Exhibit 665.2 shows an induction welding machine used in the manufacture of pipe and tubing.

Dielectric Heating

Dielectric heating equipment is similar to induction heating equipment, except that it is used to heat nonmetallic materials as opposed to metals. Typical applications include the drying of textiles after dyeing, drying of water-based coatings on paper, preheating of wood fibers for the medium-density fiberboard (MDF) industry, welding of plastic materials, and food processing.

At radio frequencies, the material to be heated forms a dielectric when placed between metal capacitor plates connected across the output of the generator. A high-frequency alternating electric field is created between the electrode plates. The molecules vibrate in the dielectric field, causing dissipation of energy through the material and frictional heating of the dielectric material. At higher (microwave) frequencies, a similar process occurs, but the generator is coupled to a resonant cavity into which the dielectric material is placed.

The frequency of operation of dielectric heating equipment is considerably higher than for induction heating. These machines operate at the assigned radio frequencies of 13.56, 27.12, and 40.68 megahertz or at microwave frequencies of 915 and 2450 megahertz.

The power for these machines ranges from 0.5 kilowatt to 1 megawatt.

665.7 Remote Control.

(A) Multiple Control Points. Where multiple control points are used for applicator energization, a means shall be provided and interlocked so that the applicator can be energized from only one control point at a time. A means for de-energizing the applicator shall be provided at each control point.

(B) Foot Switches. Switches operated by foot pressure shall be provided with a shield over the contact button to avoid accidental closing of a foot switch.

665.10 Ampacity of Supply Conductors. The ampacity of supply conductors shall be determined by 665.10(A) or (B).

(A) Nameplate Rating. The ampacity of conductors supplying one or more pieces of equipment shall be not less than the sum of the nameplate ratings for the largest group of machines capable of simultaneous operation, plus 100 percent of the standby currents of the remaining machines. Where standby currents are not given on the nameplate, the nameplate rating shall be used as the standby current.

(B) Motor-Generator Equipment. The ampacity of supply conductors for motor-generator equipment shall be determined in accordance with Article 430, Part II.

• **665.12 Disconnecting Means.** A readily accessible disconnecting means shall be provided to disconnect each heating equipment from its supply circuit. The disconnecting means shall be located within sight from the controller or be lockable open in accordance with 110.25.

The rating of this disconnecting means shall not be less than the nameplate rating of the heating equipment. Motor-generator equipment shall comply with Article 430, Part IX. The supply circuit disconnecting means shall be permitted to serve as the heating equipment disconnecting means where only one heating equipment is supplied.

Part II. Guarding, Grounding, and Labeling

665.19 Component Interconnection. The interconnection components required for a complete heating equipment installation shall be guarded.

665.20 Enclosures. The converting device (excluding the component interconnections) shall be completely contained within an enclosure(s) of noncombustible material.

665.21 Control Panels. All control panels shall be of dead-front construction.

665.22 Access to Internal Equipment. Access doors or detachable access panels shall be employed for internal access to heating equipment. Access doors to internal compartments containing equipment employing voltages from 150 volts to 1000 volts ac or dc shall be capable of being locked closed or shall be interlocked to prevent the supply circuit from being energized while the door(s) is open. The provision for locking or adding a lock to the access doors shall be installed on or at the access door and shall remain in place with or without the lock installed.

Access doors to internal compartments containing equipment employing voltages exceeding 1000 volts ac or dc shall be provided with a disconnecting means equipped with mechanical lockouts to prevent access while the heating equipment is energized, or the access doors shall be capable of being locked closed and interlocked to prevent the supply circuit from being energized while the door(s) is open. Detachable panels not normally used for access to such parts shall be fastened in a manner that makes them inconvenient to remove.

665.23 Hazard Labels or Signs. Labels or signs that read "DANGER — HIGH VOLTAGE — KEEP OUT" shall be attached to the equipment and shall be plainly visible where persons might come in contact with energized parts when doors are open or closed or when panels are removed from compartments containing over 150 volts ac or dc. Hazard signs or labels shall comply with 110.21(B).

665.24 Capacitors. The time and means of discharge shall be in accordance with 460.6 for capacitors rated 600 volts, nominal, and under. The time and means of discharge shall be in accordance with 460.28 for capacitors rated over 600 volts, nominal. Capacitor internal pressure switches connected to a circuit-interrupter device shall be permitted for capacitor overcurrent protection.

Enhanced protection against rupture of capacitor cases is needed when capacitors are operated at the higher frequencies used for induction and dielectric heating. A high-resistance fault condition can cause case pressure to build up inside the capacitor over a very short time. Capacitor internal pressure switches are the preferred method to detect this type of failure.

Consider a 5000-kVAr (kilovolt-ampere reactive), 2500-volt, 300-hertz capacitor. Nominal current is 2000 amperes. A "high-resistance" fault of 10 ohms results in 250 amperes of resistive current, or a total capacitor current of 2016 amperes root-mean square (rms). This small increase in rms current will not result in the opening of an overcurrent device even though 625 kilowatts of thermal energy are being generated inside the capacitor, which is designed to dissipate about 1.5 kilowatts of losses.

665.25 Dielectric Heating Applicator Shielding. Protective cages or adequate shielding shall be used to guard dielectric heating applicators. Interlock switches shall be used on all hinged access doors, sliding panels, or other easy means of access to the applicator. All interlock switches shall be connected in such a manner as to remove all power from the applicator when any one of the access doors or panels is open.

665.26 Grounding and Bonding. Bonding to the equipment grounding conductor or inter-unit bonding, or both, shall be used wherever required for circuit operation, and for limiting to a safe value radio frequency voltages between all exposed non–current-carrying parts of the equipment and earth ground, between all equipment parts and surrounding objects, and between such objects and earth ground. Such connection to the equipment grounding conductor and bonding shall be installed in accordance with Article 250, Parts II and V.

Informational Note: Under certain conditions, contact between the object being heated and the applicator results in an unsafe condition, such as eruption of heated materials. Grounding of the object being heated and ground detection can be used to prevent this unsafe condition.

Because of stray currents between units of equipment or between equipment and the ground, bonding presents special problems at radio frequencies. Special bonding requirements are particularly needed at dielectric heating frequencies (100 to 200 megahertz) because of the differences in radio frequency potential that can exist between the equipment and surrounding metal units or other units of the installation. Bonding has been accomplished by placing all units of the equipment on a flooring or base consisting of a copper or aluminum sheet, then thoroughly bonding by soldering, welding, or bolting. Such special bonding holds the radio frequency resistance and reactance between units to a minimum, and any stray circulating currents flowing through the bonding will not cause a dangerous voltage drop.

The operator can be protected from high radio frequency potentials by shielding at dielectric heating frequencies. Interference with radio communications systems at such high frequencies can be eliminated by totally enclosing all components in a shielding of copper or aluminum.

665.27 Marking. Each heating equipment shall be provided with a nameplate giving the manufacturer's name and model identification and the following input data: line volts, frequency, number of phases, maximum current, full-load kilovolt-amperes (kVA), and full-load power factor. Additional data shall be permitted.

ARTICLE 668 Electrolytic Cells

668.1 Scope. This article applies to the installation of the electrical components and accessory equipment of electrolytic cells, electrolytic cell lines, and process power supply for the production of aluminum, cadmium, chlorine, copper, fluorine, hydrogen peroxide, magnesium, sodium, sodium chlorate, and zinc.

Not covered by this article are cells used as a source of electric energy and for electroplating processes and cells used for the production of hydrogen.

Informational Note No. 1: In general, any cell line or group of cell lines operated as a unit for the production of a particular metal, gas, or chemical compound may differ from any other cell lines producing the same product because of variations in the particular raw materials used, output capacity, use of proprietary methods or process practices, or other modifying factors to the extent that detailed *Code* requirements become overly restrictive and do not accomplish the stated purpose of this *Code*.

Informational Note No. 2: See IEEE 463-2013, *Standard for Electrical Safety Practices in Electrolytic Cell Line Working Zones*, for further information.

Within a cell line working zone, both an electrolytic cell line and its direct current (dc) process power-supply circuit are treated as an individual machine supplied from a single source, even though they might cover acres of space, have a load current in excess of 400,000 amperes dc, or have a circuit voltage in excess of 1000 volts dc. The cell line process current passes through each cell in a series connection, and the load current cannot be subdivided the way it can in the heating circuit of a resistance-type electric furnace. Because a cell line is supplied by its individual dc rectifier system, the rectifier or the entire cell line circuit is de-energized by removing its primary power source.

In some electrolytic cell systems, the terminal voltage of the process supply can be significant. The voltage to ground of exposed live parts from one end of a cell line to the other is variable between the limits of the terminal voltage. Hence, operating and maintenance personnel and their tools are required to be insulated from ground.

• **668.3 Other Articles.**

(A) Lighting, Ventilating, Material Handling. Chapters 1 through 4 shall apply to services, feeders, branch circuits, and apparatus for supplying lighting, ventilating, material handling, and the like that are outside the electrolytic cell line working zone.

(B) Systems Not Electrically Connected. Those elements of a cell line power-supply system that are not electrically connected to the cell supply system, such as the primary winding of a two-winding transformer, the motor of a motor-generator set, feeders, branch circuits, disconnecting means, motor controllers, and overload protective equipment, shall be required to comply with all applicable sections of this *Code*.

(C) Electrolytic Cell Lines. Electrolytic cell lines shall comply with the provisions of Chapters 1 through 4 except as amended in 668.3(C)(1) through (C)(4).

(1) Conductors. The electrolytic cell line conductors shall not be required to comply with Articles 110, 210, 215, 220, and 225. See 668.12.

(2) Overcurrent Protection. Overcurrent protection of electrolytic cell dc process power circuits shall not be required to comply with the requirements of Article 240.

(3) Grounding. Except as required by this article, equipment located or used within the electrolytic cell line working zone or associated with the cell line dc power circuits shall not be required to comply with Article 250.