INDUCTION AND DIELECTRIC HEATING EQUIPMENT

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1.0 SCOPE

This data sheet pertains to industrial use of induction heating equipment, including electromagnetic induction heaters and dielectric heaters. Refer to Data Sheet 7-33 for guidance on induction melting for molten material applications.

1.1 Changes

January 2024. Interim revision. The scope was modified as part of the Data Sheet 7-33 revision, and molten material guidance on induction melting was relocated to Data Sheet 7-33.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Equipment and Processes

2.1.1 Where water cooling is used for transformers, capacitors, electronic tubes, spark gaps, or high frequency conductors, the cooling water should be interlocked with the power supply so that the loss of cooling water will interrupt the power supply. Insofar as possible, the equipment should be arranged so that it will not be damaged by leakage or condensation.

Where the loss of cooling water due to a power failure would result in a large loss, arrangements should be made for an emergency water supply.

2.1.2 Where forced ventilation is provided by electric motor driven fans, the air supply should be interlocked with the power supply so that the power is shut off if the cooling air is lost.

2.2 Electrical

2.2.1 The electrical equipment associated with induction and dielectric heating apparatus should be installed and protected in accordance with the requirements of Article 665 of the National Electrical Code (NFPA No. 70).

2.2.2 Where power is supplied to an induction furnace from a separate transformer, periodic tests of the insulation of the transformer winding and the transformer insulating liquid (if liquid-filled) should be made as recommended in Data Sheet 5-4, *Transformers*.

All associated electrical control and protective equipment should be inspected, tested, and cleaned annually to insure its proper operation. (See Data Sheet 5-20, *Electrical Testing.*)

2.2.3 The adequacy of the surge protection should be checked. Low sparkover lightning arresters should be provided for dry-type transformers. Resistance of the ground connections should not exceed 5 ohms. Preferably it should be as near 1 ohm as possible. See Data Sheet 5-11, *Lighting and Surge Protection for Electrical Systems.*

2.2.4 A coordination and short circuit study should be made of the electrical protective devices in the power supply and the furnace circuit, if this has not been done. This is necessary especially if there have been changes made recently in these systems.

2.3 Operation and Maintenance

2.3.1 Develop a documented inspection, testing, and maintenance program for induction and dielectric heating equipment, and utility/support system equipment. See Data Sheet 9-0, *Asset Integrity*.

2.3.2 Operators and guards should be trained in proper procedures in the event of malfunction of the furnace. See Data Sheet 10-8, *Operators*, for operator guidance.

2.4 Protection

Portable carbon dioxide extinguishers of the ten to 15 lb rating should be provided for use in the event of fire in the electrical supply and control equipment, with 1½ in. hose lines equipped with spray nozzles provided for backup protection.

2.5 Contingency Planning

2.5.1 Equipment Contingency Planning

When an induction and dielectric heating equipment breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable induction and dielectric heating equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

2.5.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by an induction and dielectric heating equipment breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.5.2.1 Routine Spares

Routine induction and dielectric heating equipment spares are spares that are considered to be consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the induction and dielectric heating equipment, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer. See Section 3.2 for routine spare guidance.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Loss History

A recent study of the loss experience revealed that the frequency of loss in induction heating equipment had increased significantly since the ten-year study (1963-1972) described in the November 1973 version of Data Sheet 6-3. The reasons for this increase are indicated in this updated version, which also describes the present state of the art, recent applications, associated hazards, and safeguards that are necessary for effective loss control.

A study of the loss experience in a recent five-year period showed that 155 losses occurred during this period.

The remaining losses were due to electrical defects and lightning damage. Inadequate maintenance was a major contributing factor.

3.2 Routine Spares

The following are common routine spares for induction and dielectric heating equipment. Store and maintain the routine spares per original equipment manufacturer recommendations to maintain viability. Refer to Data Sheet 9-0 for additional guidance.

- Spare tubes and circulator
- Rectifier
- Controls
- Conveyor parts
- Fans, water pumps
- Electrode parts (microwave and radio frequency)

4.0 REFERENCES

For more information, please refer to the following data sheets as cited in the text:

Data Sheet 5-4, *Transformers*
Data Sheet 5-11, *Lighting and Surge Protection for Electrical Systems*
Data Sheet 5-20, *Electrical Testing*
Data sheet 7-33, *Molten Metals and Other Materials*
Data Sheet 9-0, *Asset Integrity*

APPENDIX A GLOSSARY OF TERMS

Dielectric Heating: The heating of nonconducting materials by their own dielectric losses (energy used in the current overcoming the resistance) when they are placed in a varying electric field.

Impedance Tuning Stub: A device which controls coupling (impedance matching) of the microwave energy source to the material being treated.

Induction Heating Equipment: Used for melting, forging, hardening, tempering, annealing, brazing, shrink fitting, and soldering materials that are good electrical conductors.

Ionic Conduction: A process which causes free ions at the interface to move about and cause heating through the addition of carbon black.

Magnetron Tube: A vacuum tube surrounded by magnets.

Microwave Heating: Also a form of dielectric heating, but it employs frequencies ranging from 10 to 100 times higher than those used for the ordinary dielectric heating applications.

Reflected Power Meter: Measures reflected power and automatically adjusts tuner, causing the reflected power to be returned to the oven.

Waveguide: A metallic tube used to transmit microwaves.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

January 2024. Interim revision. The scope was modified as part of the Data Sheet 7-33 revision, and molten material guidance on induction melting was relocated to Data Sheet 7-33.

July 2020. Interim revision. Updated contingency planning and sparing guidance.

January 2000. This document has been reorganized to provide a consistent format.

APPENDIX C SUPPLEMENTAL INFORMATION

C.1 General

Induction heating equipment is used for melting, forging, hardening, tempering, annealing, brazing, shrink fitting, and soldering materials that are good electrical conductors. Induction heating provides accurate temperature control for various forging processes involving construction equipment; aerospace, nuclear and petrochemical industries; trucks; mining machinery; rail cars; etc.

No contact is required between the work load and the heat source. Heat may be restricted to localized areas or to the surface of the load.

The material to be heated is generally placed inside an inductor coil of one or more turns, which is energized from a source of alternating current. The current frequency may vary from 60 Hz to 9600 kHz. The alternating magnetic field induces voltage in the work piece, which in turn causes current to flow. As the current flows through the resistance of the work piece, heat is generated due to the I^2R loss. These currents tend to be more intense at the surface of the work piece while those at the center are at a minimum. This characteristic, known as the ‘‘skin effect,’’ results in a higher heating rate at the surface. The rate of heat generation for induction heating is proportional to the ampere turns of the coil squared.

The induction coils are made in many different sizes and shapes depending upon the configuration and application of the object, e.g., whether for heat treating, forging, or melting. The construction techniques vary because of the different frequencies employed, the copper sizes and magnetic forces involved, and the end application. In some heat-treating applications, the induction coil may be one single turn in air, while in a melting furnace it may consist of a number of water-cooled coils embedded in a refractory material. For heating large billets, it can be of rectangular shape, large enough to surround the billet as shown in Figures C.1-4 and C.1-5. (See Data Sheet 7-33, *Molten Metals and Other Materials.*)

The power to the induction coil may be supplied by one of the following methods, depending upon the frequency and the amount of power needed for the particular application.

1. The local utility system at 60 Hz.

2. A motor-generator set up to about 800 kW at frequencies up to 9600 Hz.

3. Mercury arc converters up to 300 kW with frequencies up to 1500 Hz.

4. Spark-gap converters up to 50 kW with frequencies from 50 Hz to 200 kHz. (A basic wiring diagram is shown in Figure C.1-1.)

5. Electronic oscillators up to 500 kW with frequencies from 100 Hz to 1000 kHz. (See Figure C.1-2 for basic wiring diagram.)

Induction furnaces operating at frequencies ranging between 60 and 1000 Hz can produce temperatures up to 3,000°F (1648°C). In one type of furnace, the currents are induced directly in the charge. In another type, they are induced in a magnetic case containing the charge. In some installations the coil conductors are hollow and water cooled, and the coil current may be as high as 15,000 amperes.

For special refining or hardening applications, these furnaces are also designed to operate with a partial vacuum or controlled atmosphere.

Induction heating systems are being applied to objects of practically any size or shape, ranging from fractions of an inch (cm) to substantial lengths and diameters. These systems may also involve simple as well as complicated and sophisticated processes that can be automated to meet specific production requirements.

The forging industry uses induction heating extensively for heating billets of many different sizes, temperatures, and production rates. The systems may be packaged or they may be custom-designed to fit more special applications. Figure C.1-3 shows the largest induction heating system in the world. The system consists of six lines of three vertically mounted induction heaters especially built for heating steel slabs up to 2,400°F (1715°C) at the rate of 600 tons per hour, using 210,000 kW supplied at 120,000 volts. Figure C.1-4 shows the arrangement of the power supplies to the heaters, which are of a special design (Figures. C.1-5 and C.1-6).

The heaters are stationary over the heating line (Figure C.1-7) and the slabs (which are supported on stainless steel fingers of the transfer cars) are elevated by means of a box beam lifting mechanism into the heaters, where they are held during the heating cycle.

The main electrical equipment and controls consist of the 120 kV primary transformers, SCR switches, and capacitors and are located on the floor above the heaters (Figure C.1-8).

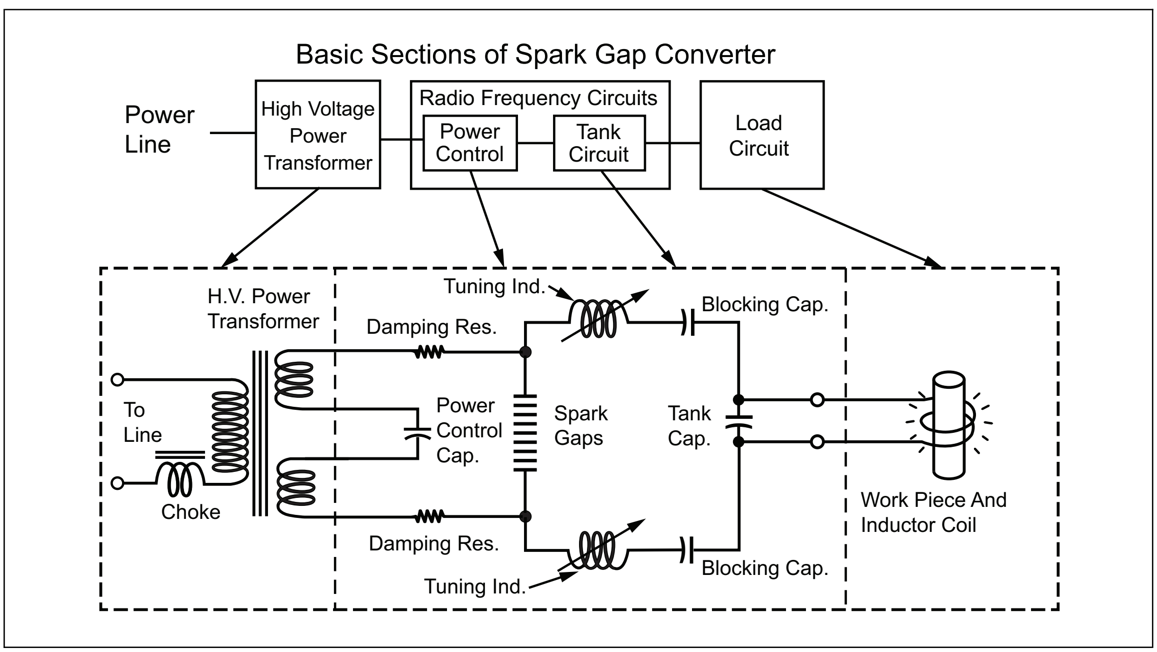

Fig. C.1-1. Spark-gap converter for induction heating. Simplified basic diagram. (Westinghouse Electric Corp.)

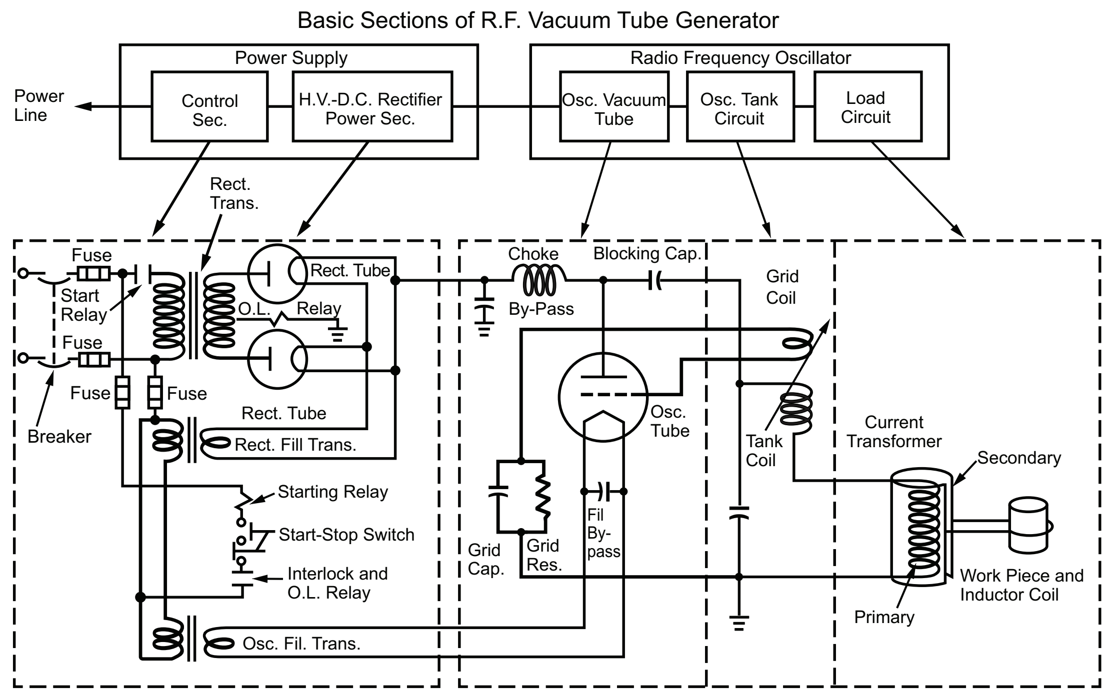

Fig. C.1-2. Vacuum-tube generator for induction heating. Simplified basic diagram. (Westinghouse Electric Corp.)

Fig. C.1-3. World's largest induction heating installation for heating steel slabs, showing discharge side of heaters and heated slab on conveyor to mill. (Ajax Magnethermic Corp.)

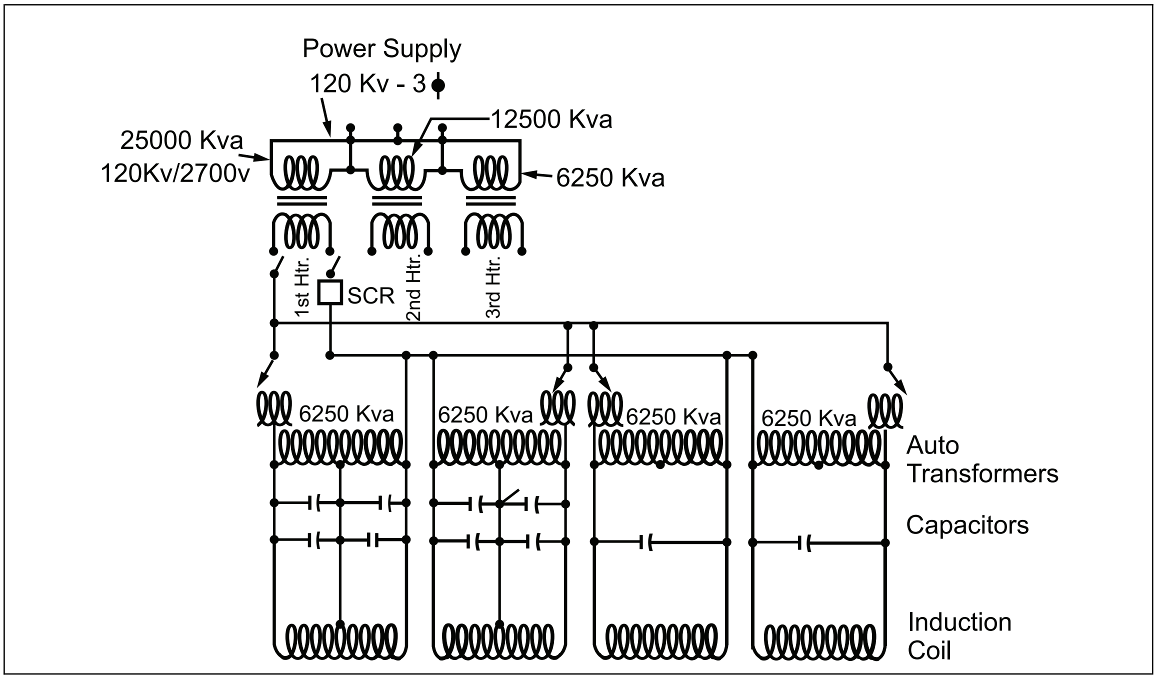

Fig. C.1-4. Arrangement of power supplies to induction heaters. Sketch shows power supplies to one heater line. (Total of six heater lines.) (Ajax Magnethermic Corp.)

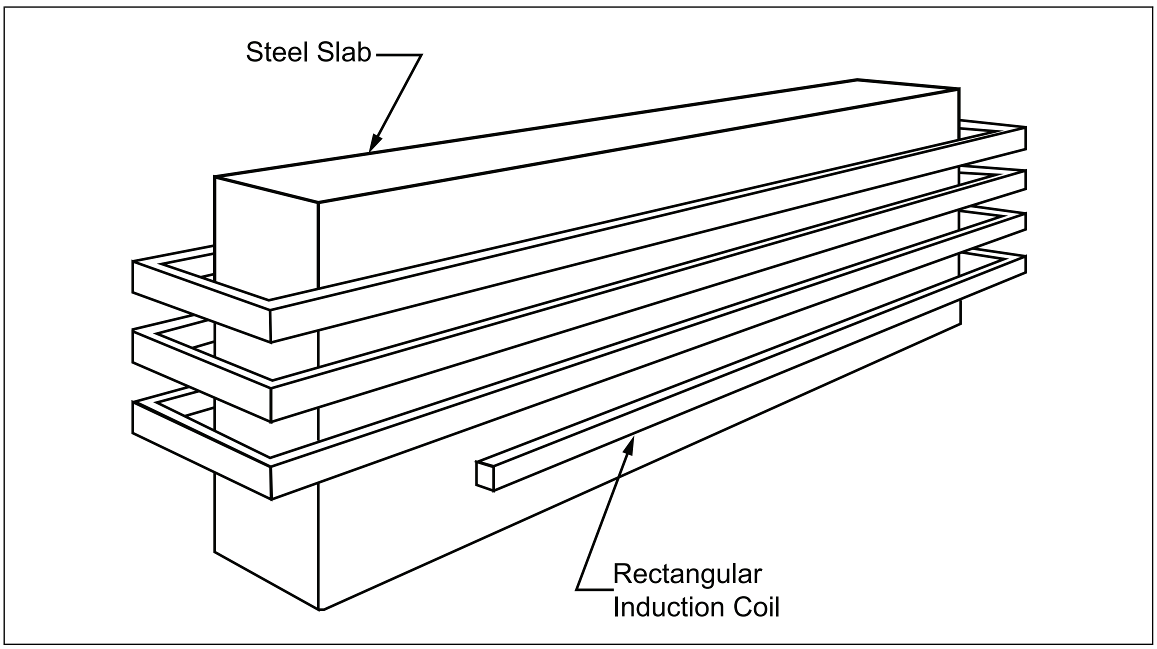

Fig. C.1-5. Rectangular induction coil (Ajax Magnethermic Corp.)

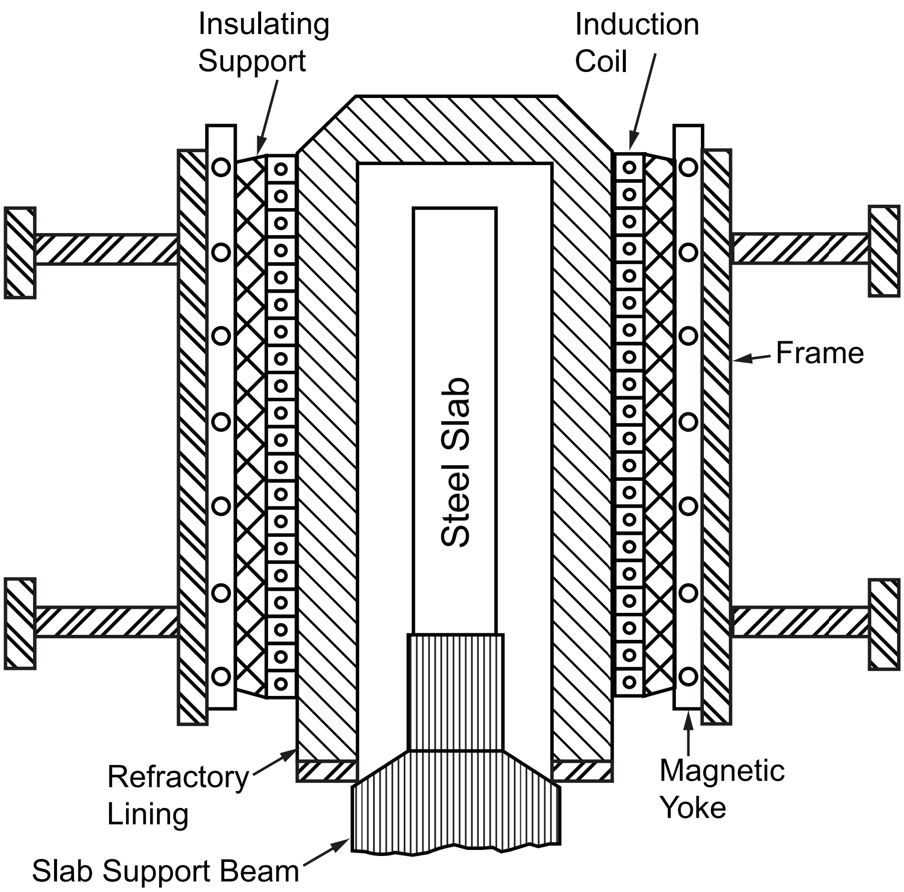

Fig. C.1-6. Induction heater. (Ajax Magnethermic Corp.)

C.2 Dielectric Heating Systems

Dielectric heating is the heating of nonconducting materials by their own dielectric losses (energy used in the current overcoming the resistance) when they are placed in a varying electric field. The material to be heated is usually placed between two metal plates (electrodes) which are supplied by a high frequency generator. The material is actually the dielectric of a capacitor across which high frequency voltage is applied. Heating a nonconducting material in this manner is extremely fast. Power to the electrodes is supplied from vacuum tube oscillators which generate the very high frequencies that are required.

These units have power outputs of up to 599 kW and frequencies ranging from 1 to 200 MHZ (million Hertz per sec). Figure C.2 shows the basic wiring diagram.

Some of the more common applications for dielectric heating equipment are preheating of plastics, food processing, drying and heat treatment of textiles, processing of rubber and synthetic materials, wood drying, curing, and gluing.

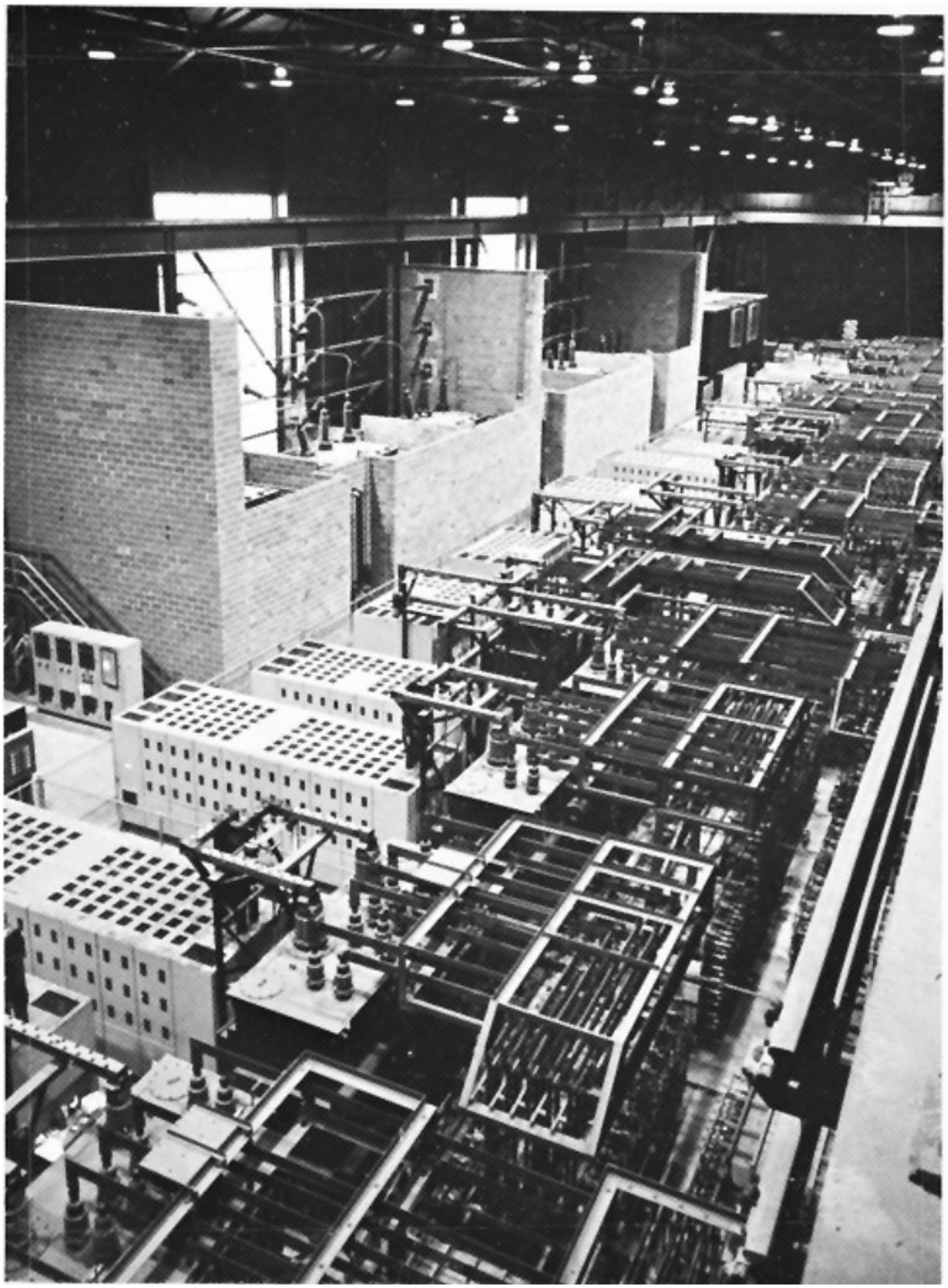

Fig. C.1-7. Induction heaters over heating lines. (Ajax Magnethermic Corp.)

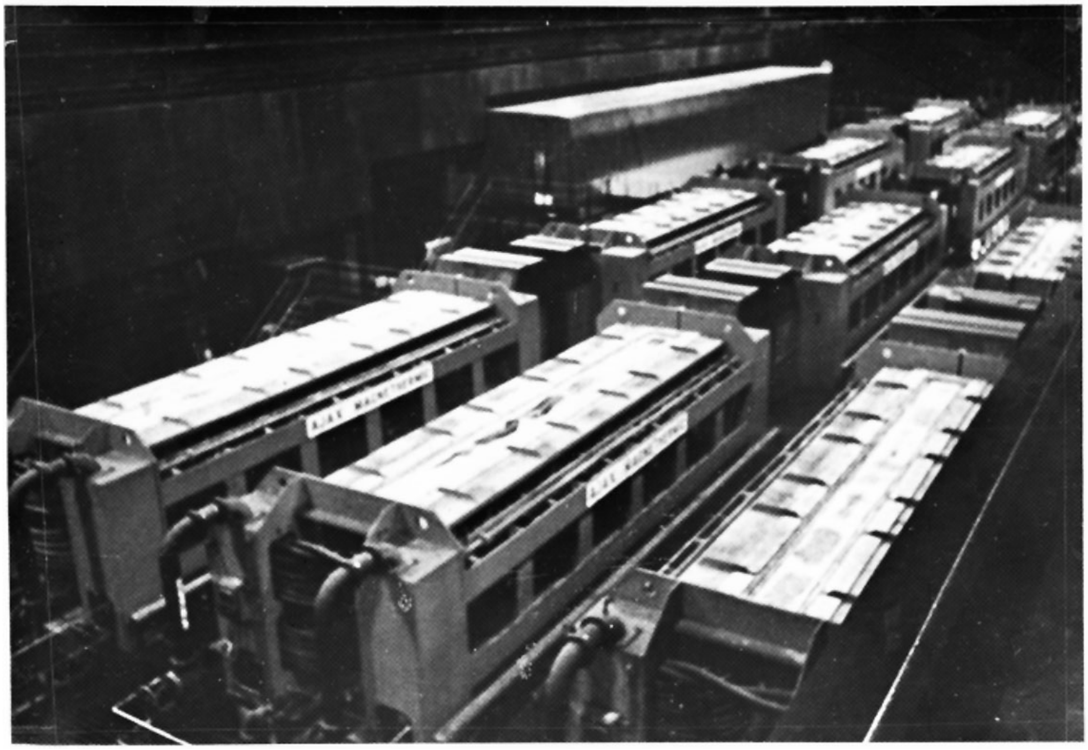

Fig. C.1-8. Main electrical equipment and controls for induction heaters. (Ajax Magnethermic Corp.)

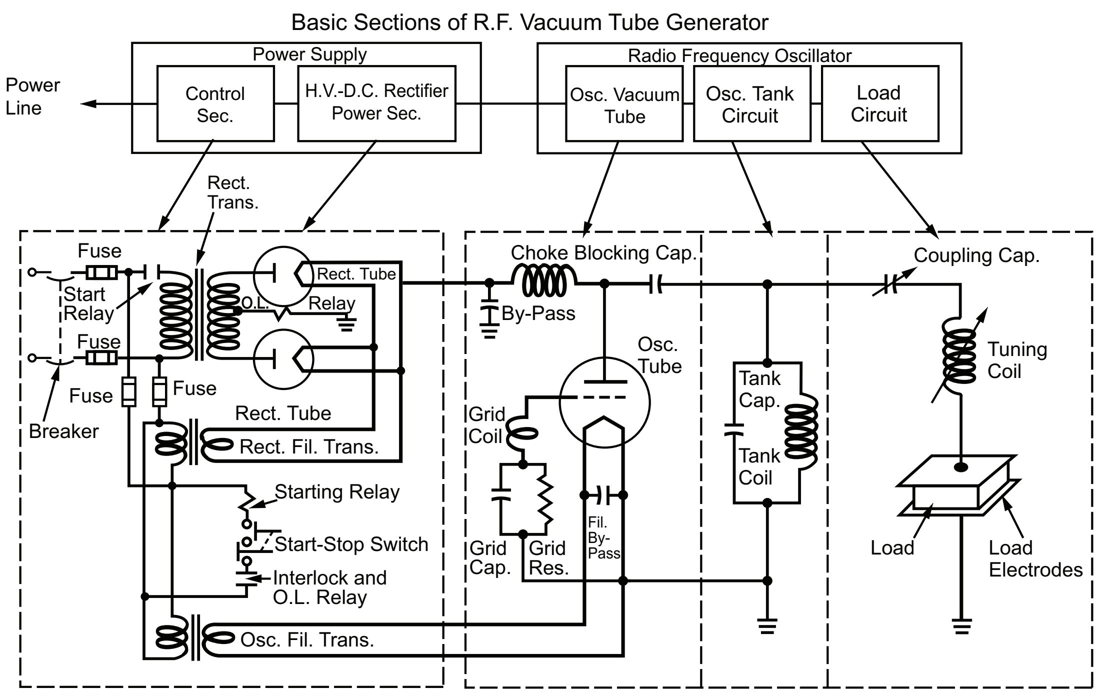

Fig. C.2. Vacuum-tube generator for dielectric heating, simplified basis diagram (Westinghouse Electric Corp.)

C.3 Microwave and Radio Frequency Ovens

Microwave heating is also a form of dielectric heating, but it employs frequencies ranging from 10 to 100 times higher than those used for the ordinary dielectric heating applications. Microwave and radio frequency (rf) ovens are becoming increasingly common in industrial settings. These ovens initially cost more than fuel-fired ovens, but are more efficient and offer production and operational advantages. There are both batch and continuous (conveyor) type microwave and rf ovens.

This method of heating is being used for large-scale food processing such as in cooking, sterilization, and freeze drying, and for industrial processes involving heat treating, drying, foaming, bonding, curing, polymerization, and sealing of products such as ceramics, chemicals, coatings, electronics, forest products, graphic arts, paper, pharmaceuticals, plastic, rubber, and textiles.

Large Business Interruption exposures can exist at locations with industrial microwave or radio frequency ovens. Although these ovens are not subject to a fuel explosion hazard, and operate at lower temperatures (only the product experiences temperature rise) than conventional ovens, they are subject to fires mainly as a result of improper or infrequent cleaning, and improper operation. Also, certain critical components can fail suddenly in normal use or due to overheating. While a total loss of these ovens is uncommon, a component failure could lead to a large business interruption if routine spares are not readily available. Proper cleaning and maintenance, availability of routine spare parts, and possibly fire protection are important for this type of equipment. Proper operation and adhering to the intended use will also help prevent losses.

There are about 500 continuous microwave lines worldwide. These ovens are manufactured to operate at one of two frequencies, 915 MHZ or 2450 MHZ, and range in power from 6kW to 60kW for industrial use. Ovens operating at 915 MHZ are typically used in the food processing industry for meat processing. This type of oven appears to be prone to more problems than the 2450 MHZ oven, and is particularly subject to fires if thorough cleaning is not done on a regular basis.

An overheating condition can lead to failure of components, causing a costly business interruption. Some of the parts which can fail are the magnetron tube, circulator, rectifier, controls, and conveyor belts. Most of these parts should be readily available from the manufacturer, and might be kept on hand at the plant.

Several manufacturers claim to stock magnetron tubes as routine spares. Magnetron tubes are warranted for about 2,000 hours. These tubes can last from 6,000 to 8,000 hours if operated below the maximum rating and kept properly cooled. Keeping the dummy load water (see below) clean and in the correct temperature range is important to maximizing tube life. Tubes can cost from about $4,000 to as much as $8,000 depending on the power rating. Some ovens operate with more than one tube, and can be operated at a reduced load if one part fails.

One manufacturer indicates that it could take two or three months to replace a circulator for its ovens, but that its routine spare parts inventory is improving. A circulator is needed to protect the tube from reflected power (microwave energy which is reflected back to the energy source rather than absorbed by the product). Reflected power will overheat the tube and greatly reduce its life. An oven may be operated at a reduced load without the circulator.

Another company which manufactures both the high and low frequency ovens claims to have an adequate supply of routine spare parts available. The company indicates that its ovens should not experience an unplanned shutdown of more than four days because of a component failure.

Not all materials are suitable for microwave processing. Materials must be capable of absorbing microwave electromagnetic energy. Microwave energy is converted to heat inside the material as the molecules realign with the microwave field at the frequency of the microwave. (Some materials which are not receptive to microwaves can be made so by the addition of carbon black. This causes free ions at the interface to move about and cause heating, a process called ionic conduction.) Coupling of microwave power to the product in the oven is important to keeping reflected power at a minimum, i.e., the amount of material being processed should be properly matched to the power of the tube. Microwave ovens have a power supply which converts ac to dc power. A magnetron tube (a vacuum tube surrounded by magnets) converts the dc power to microwave energy which is transmitted by means of a wire or waveguide to the application cavity, or oven.

Microwave energy can be absorbed, reflected, or transmitted, depending on the material. The tube must be protected from reflected microwaves passing back through the waveguide. The circulator is the most effective device for this purpose. It acts like a check valve, only allowing waves to pass through the waveguide in one direction. Reflected power is directed through a separate port to a water supply (dummy load) which carries away wasted microwave energy. Other protective devices in the waveguide are a temperature switch and a reflected power switch. These devices have proven to be less reliable than a circulator, and will interrupt the operation of the oven, whereas a circulator provides continuous protection without shutting down the oven.

Another device which protects the magnetron tube is called an impedance tuning stub. This device controls coupling (impedance matching) of the microwave energy source to the material being treated. Reflected power is measured by a reflected power meter and the tuner is automatically adjusted, causing reflected power to be returned to the oven. The ability to monitor reflected power is also important for indicating equipment or product material problems.

Arc protection circuits are also important for quenching arcs. High intensity fields in a microwave oven can cause arcing if foreign materials, such as dust at a waveguide port, enter the oven. Small metallic objects may cause arcing. An arc will follow a path back to the tube, causing destruction of the magnetron tube.

Other important controls include instrumentation to read power output and material temperature (infrared detection). This enables an operator to tell if a problem with temperature rise is related to the equipment or the material. Various values of microwave receptivity (ability to absorb microwave energy) for different batches of material will require adjustment of the power output.

Safety interlocks can include the temperature of the magnetron tube, generator cabinet (which contains the magnetron tube) temperature (which is cooled by water or air), and cooling water temperature and flow. There are no national safety standards, with the exception of emissions health standards, for microwave ovens.

Some microwave ovens that process combustible materials have optical fire detectors which sense the flickering of a flame. Smoke detectors may also be used. These devices could serve as an interlock and shut down the oven, or could activate a fixed suppression system such as CO_2. If a fire occurs in one of these ovens, the oven may be shut down or the conveyor may continue to operate to remove the product.

Rf ovens are similar to microwave ovens, but operate at lower frequencies, typically from 10 to 25 MHZ. The frequency at which an electromagnetic wave type of oven is designed to operate depends on what type and shape of material is being processed. Rf ovens are used for high moisture removal applications.

Rf ovens use a power triode tube rather than a magnetron tube to generate the radio frequency waves. These tubes can be rated as high as 1MW, and can cost as much as $50,000. Because of the high cost, these tubes are not stocked by manufacturers. Replacement times can be as much as 14 weeks or longer. One insured reportedly keeps a new tube on hand as well as two used tubes with 4,000 to 5,000 hours of use. Normal tube life is expected to be about 5,000 hours. This can be as much as doubled if the power tube is not operated continuously. Operating at a constant power level and keeping the voltage as low as possible will also extend the tube life. Reflected power is not a problem with rf ovens and circulators are not used; these ovens are able to idle with no load (power levels at a minimum — distance between electrodes increases).

Safety controls interlocked with rf generators include: high pressure coolant (for triode cabinet) temperature, low coolant pressure, cabinet doors open, no coolant flow, conveyor stopped, and high kilowatt output. Monitoring moisture levels at the inlet and outlet of the oven is also important. Small plexiglass observation ports protected by aluminum screens can be provided to enable operators to discover problems (smoldering) inside the oven.

Industry experience with this equipment has been satisfactory. There were two recent losses involving fires inside radio frequency ovens due to arcing. Both were caused by arcing between the product and the electrodes. One incident was a result of improper positioning of the product on the conveyor (spools of yarn were placed with the metal spools facing electrodes); the other was a result of failure of the electrode insulators. In the latter case, laboratory testing showed that the plastic electrode insulators in the two-year-old oven were cracked due to embrittlement.

If a recommendation is made to provide internal water protection in a microwave or rf oven, the oven manufacturer should be consulted. Automatic sprinkler heads cannot be used as fires will typically start out as smoldering product. A deluge type system activated by means of ionization type smoke detectors located in special ducts connected to the exhaust ducts can be used. This system would have to interlock with the power to the oven so that all power is shut off upon activation of the fire protection system. The piping inside the oven should be located so as to minimize the chance of arcing. Water damage to the product might also be a concern. Halon suppression systems have been commonly used with rf ovens; CO_2 could cause condensation or freezing of moisture.

It should also be noted that plants with this type of equipment may experience problems with electrical harmonics. The static conversion of ac to dc power inside the microwave or rf power supply will cause harmonics in the plant's electrical system which may overheat and slowly disintegrate neutral leads inside circuit breaker panels and motor control centers.

C.4 Current Source Power Supply for Induction Heating

Another method of providing reliable power control for high frequency power supplies for induction melting is referred to by the manufacturer (American Induction Heating Corp.) as the current source power supply. The current source power supply permits power to flow from line to load and from the system to line. Thus, any stored energy in the systems during operation or shutdown is controlled by this ability to regenerate. The current control permits the power supply to operate at a constant output power factor throughout its operating range.

This current source solid state power supply is illustrated in Figure C.4-1 and is available in frequencies of 180 Hz through 3 kHz and sizes of 50 through 3,000 kW. Maintaining constant current control and continuously monitoring the voltage eliminates nuisance shutdowns due to blown fuses and damaged SCRs, diodes, and similar components.

The various components that make up this power supply are contained in a separate steel enclosure along with the operator's control panel as shown in Figure C.4-2.

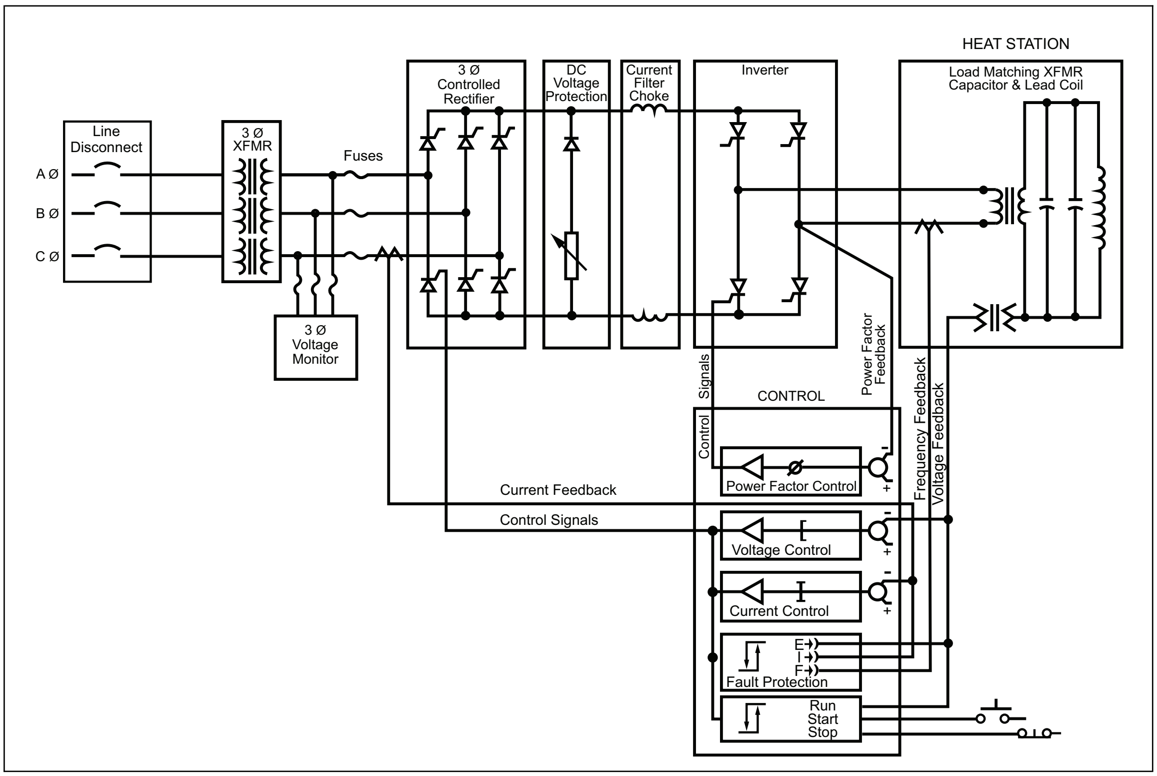

Fig. C.4-1. Block diagram of current source power supply. (American Induction Heating Corp.)

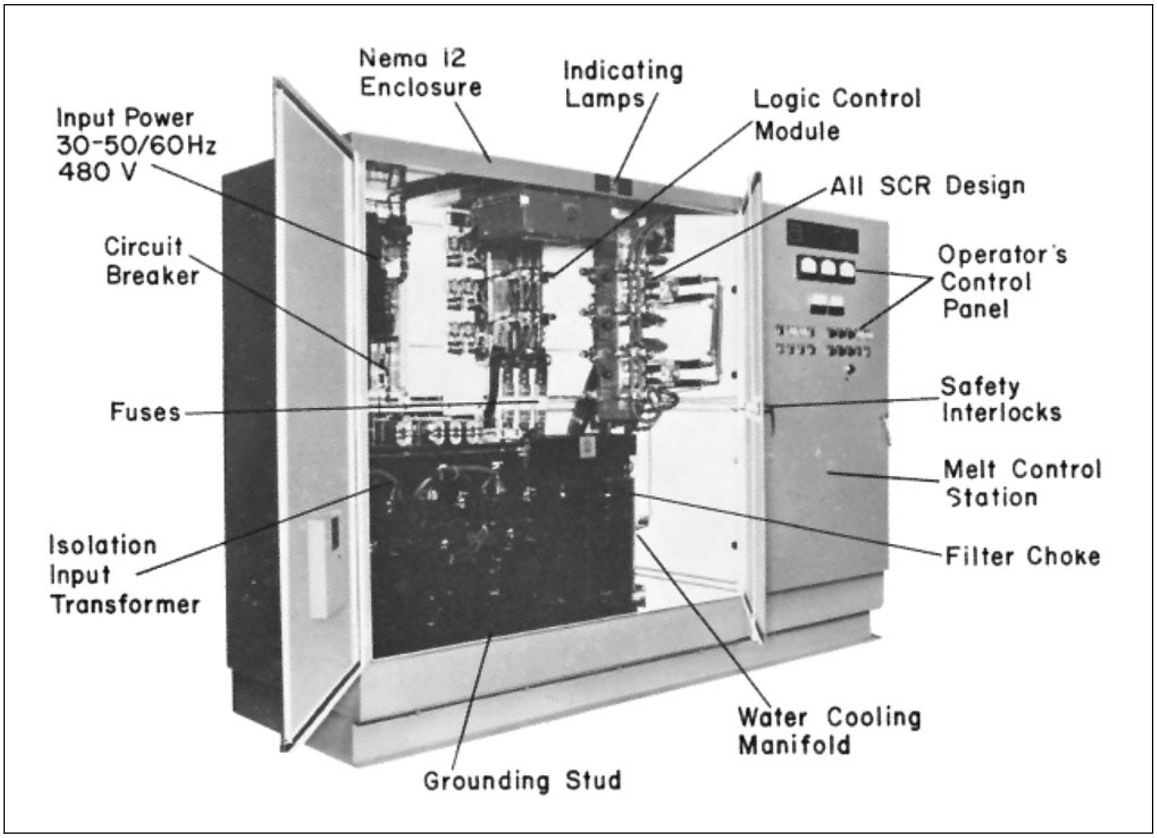

Fig. C.4-2. Current source power supply and control cubicle. (American Induction Heating Corp.)