April 23, 1968 W. V. LAPHAM 3,378,917

INDUCTION HEATING INDUCTORS

Filed April 28, 1965 2 Sheets-Sheet 1

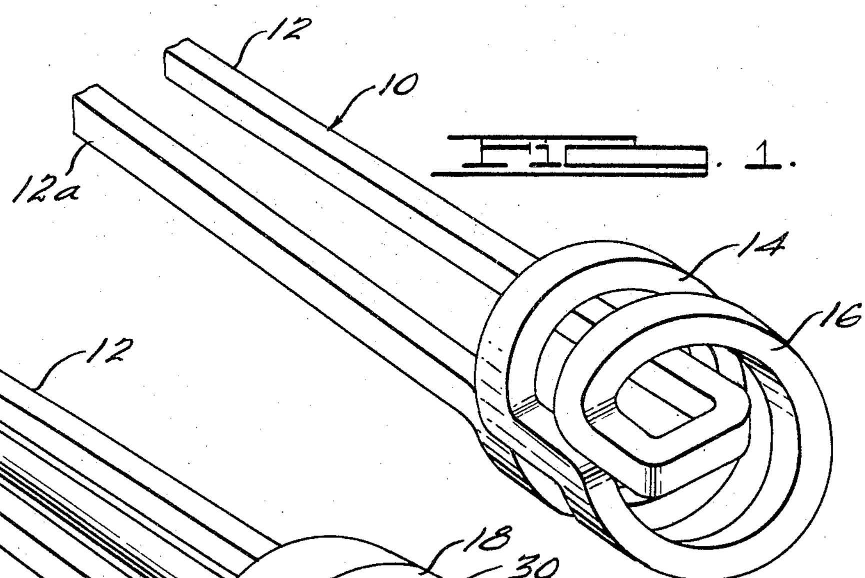

FIG. 1.

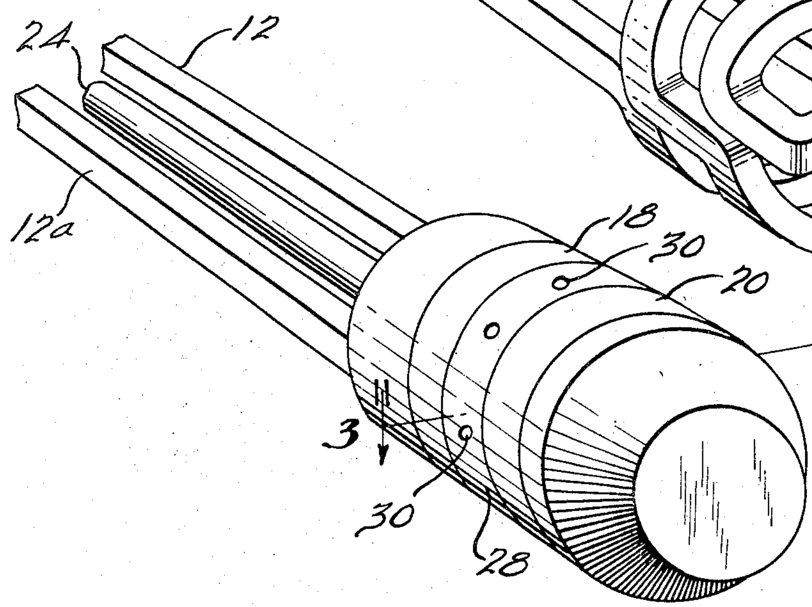

FIG. 2.

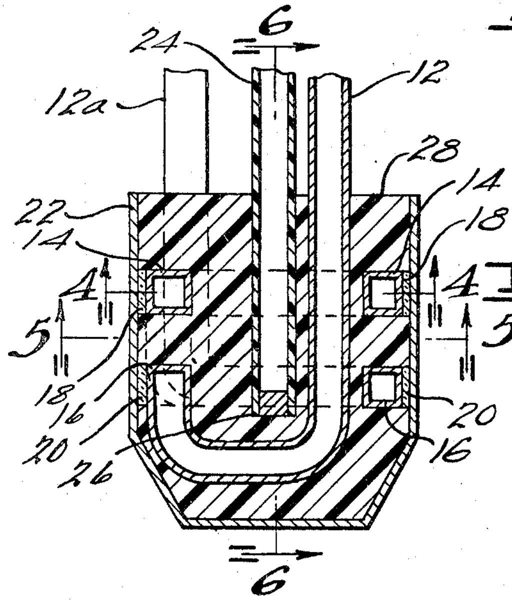

FIG. 3.

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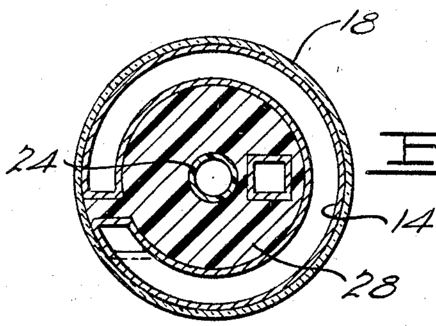

FIG. 4.

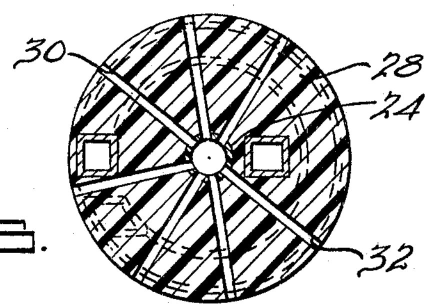

FIG. 5.

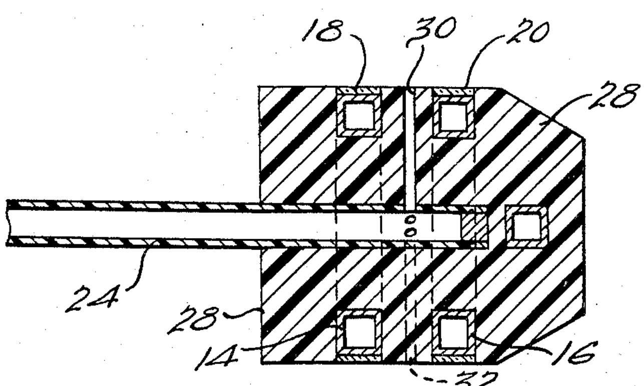

FIG. 6.

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INDUCTION HEATING INDUCTORS

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ABSTRACT OF THE DISCLOSURE

A method for producing an induction heating structure having a heating coil conductor portion securely supported by an integrally formed, electrically non-conducting core. The method comprises shaping a conductor to a desired configuration, surrounding the outer peripheral surface of the shaped portion of the conductor with a vessel such that there is no perceptible space between the surface of the vessel and the conductor surface, introducing a synthetic resin into the vessel and allowing the resin to flow about the contained part of the conductor so as to encompass substantially all surfaces thereof except those which are adjacent the wall of the vessel.

This invention relates to induction heating wherein electrical current at a suitable frequency is transmitted to an inductor unit which sets up a magnetic field causing induced currents within any second electrical conducting material which is in the field. More particularly, this invention relates to an inducting device comprising a hollow electrically conductive member supported by a core. Still more particularly, this invention relates to a method of manufacturing a core supported induction device.

In many applications of induction heating, it is necessary that the inductor device or coil be passed through or into the part to be heated as, for example, when heating the internal diameter of a shaft. Accordingly, in this type of application it is most important that the inductor be rigidly held so that there is no danger of accidentally striking the work piece. Since, such inductors are generally fabricated from soft copper metal and must be constantly moved by work-handling equipment into areas where they cannot be supported by external devices, the practice has developed of forming the conductor about a core or mandrel which then becomes an integral supporting part of the inductor. Such a center core also furnishes a considerable advantage in that it can contain a passage whereby a quenching agent may be brought to the heated area of the part being heated. This is important, especially in scanning operations, since the heated area must usually be quenched within a few seconds and often less than one second after the heating is discontinued.

It is also generally necessary that the inductor be provided with insulation so as to protect the copper windings thereof from abrasive particles and radiant heat emanating from workpiece, as well as to prevent their direct contact. However, providing such insulation protection with respect to core supported inductors presents a most difficult problem. Heretofore, core supported inductors have been manufactured by winding a conductor about a mandrel which was constructed of wood or synthetic materials such as glass Micarta. A resin coating is then applied to the turns to provide the needed protection. However, when inductors manufactured in this manner are put into service, the protective winding coating softens due to radiant heat and it was found that metal chips and particles from the surface being heat treated actually worked their way through the protective coating thereby causing abrasion, arc damage and general destruction of

the protective coating and the windings. In an effort to overcome this problem, effort has been made to place a coating on the windings which would provide for greater protection. Such efforts were generally unsuccessful, however, since the mandrel was damaged during the firing step necessary in applying a refractory or ceramic material. Thus, it has become the practice when manufacturing core supported inductors to fabricate a mandrel from material which can stand ceramic firing such as "diamonite." However, the cost of procuring and shaping such heat resistant materials is relatively expensive. Furthermore, the use of such materials presents yet another serious problem. This problem arises from the fact that core supported inductors generally need to be provided with a passage running through the core by which a fluid quneching agent can be transported to the area of the inductor windings and sprayed upon the surface of the workpiece. However, when using heat resistant mandrels such passages must be drilled through the mandrel which is a time consuming, difficult and costly process.

Accordingly, it is an object of this invention to provide a novel method of manufacturing a supporting body for an induction heating device.

A further object is to provide a method of manufacturing a core supported induction heating structure having the windings thereof coated with a refractory or ceramic material.

A still further object is to provide a method of manufacturing a core supported induction heating structure which is simple to carry out, efficient and highly economical.

Other objects of the invention and the invention itself will be understood from the following description and the accompanying drawings.

In furtherance of the above objects, this invention can be practiced by first forming a hollow electrical conductor to a configuration such that a portion of the conductor will substantially conform to the surface to be heat treated. The inductor apparatus can then be coated with a suitable refractory material and fired so as to place a protective coating on the inductor windings. The inductor apparatus is next placed within a containing vessel so that the refractory coated windings are in close proximity to the vessel walls. Then, a suitable synthetic resin is placed in the vessel and allowed to harden about the inductor apparatus. The resin thus forms a core in which all of the inductor apparatus is embedded therein except for that portion of the apparatus which is in close proximity to the surface of the vessel.

It should be understood that it is not always necessary to have the inductor heating surface in tight contact with the vessel walls in order to prevent their being coated with resin. Thus, the portion of the conductor which is not to be coated may be taped or otherwise masked, or a resin may be used which is so viscous and quick to solidify that it will not flow over the outer surface of the windings even if there is a slight space between the windings and the vessel wall. In fact, for some induction heating applications, a 1 or 2 mil thickness resin coating over the refractory coated inductor windings would not be harmful. Accordingly, the terms "in close proximity" and "juxtaposition" are used herein to designate the relationship between the inductor heating surface and the walls of the containing vessel.

The following discussion taken in conjunction with the drawing herein which, by way of illustration, shows preferred embodiments of the present invention will more fully explore the present invention.

In the drawings:

FIGURE 1 is a perspective view of an unsupported inductor fabricated from hollow, square cross-sectional copper tubing having two circular turns;

FIGURE 2 is a perspective view of an inductor assembly manufactured by the method of this invention showing a conductor shaped as in FIGURE 1 and having a refractory coating on each of the outer surfaces of the two circular turns and having an integral supporting resinous body portion;

FIGURE 3 is a sectional view taken along the line 3—3 of FIGURE 2 generally longitudinally of the inductor showing the inductor positioned in a containing vessel during a step in the process of its manufacture;

FIGURE 4 is a section view taken along the line 4—4 of FIGURE 3, the containing vessel being omitted;

FIGURE 5 is a section view taken along the line 5—5 of FIGURE 3, the containing vessel being omitted; and

FIGURE 6 is a sectional view taken along the line 6—6 of FIGURE 3, the containing vessel being omitted.

Referring now in greater detail to the drawings, FIGURE 1 shows an unsupported inductor **10** comprising a single continuous conducting element **12** and **12***a* shaped so as to provide two circular turns **14** and **16**. It will be understood that circular turns **14** and **16** are only representative of a configuration in which the inductor is made to conform to at least a portion of the surface to be heated. The ends **12** and **12***a* of the conductor can be fitted with means (not shown) whereby they may be connected to an electrical power source. Generally, a hollow or tubular conductor is employed so that a cooling agent can be circulated through the conductor. It will also be understood that the conductor may be fabricated from a plurality of conductor pieces which may be connected as by brazing, rather than a single length of conductor.

Having shaped a portion of the conductor to a configuration conforming to at least a portion of the surface which is to be heated, hereinafter referred to as the "shaped portion" or "turns," the inductor turns **14** and **16** are next coated with a ceramic or refractory material **18** so as to produce an essentially uniform thickness of refractory material over the conductor surface as is illustrated in FIGURE 4. The choice of a particular refractory for use as a coating material in the method of this invention will be determined primarily by the temperature that the material must withstand and the temperature to which the conductor material can be heated. In general, a refractory material will be placed on the shaped conductor portion or turns in a paste, powder, or liquid suspension form. The conductor is then heated or fired so as to cause the refractory material to form a continuous surface film or coating about the conductor. Naturally, a refractory material must be selected which will flow to produce the film at a temperature less than the softening temperature of the conductor metal. If the conductor turns, or shaped portion, are brazed together, as may be desirable in some configurations, then the temperature at which the brazing material softens must be taken into consideration. Subject to the above considerations, any refractory or ceramic composition may be employed in this invention. Useful acid type refractories are silica, zirconium, silicate, zirconium oxide, and fire clays, the chief constituent of which is silicate mineral kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$). Useful basic refractories include those made from dead-burned magnesite (principally MgO), chrome ore ($FeCr_2O_4$ and $MgAl_2O_4$) or mixtures of these materials. Useful neutral refractories include chrome, carbon, silicon, silicon carbide and high alumina (50% Al_2O_3 and over) such as Al_2SiO_5, mullite ($3Al_2O_3 \cdot 2SiO_2$) and corundum (Al_2O_3). Other suitable refractories include siliceous materials such as diatomite and sandstone, aluminous materials such a pyrophyllite, magnesium silicates such as talc, and aluminum fluosilicates. Good reults are achieved in the method of this invention when lead borosilicates, lithium borosilicates, lithium silicates and lead silicates are used as the refractory materials.

Since the function of the refractory materials is to protect the shaped portion of the conductor which is in close proximity to the surface of the piece to be heated, it is not necessary to coat the entire conductor **10**. Accordingly, in FIGURE 2 turns **14** and **16** have been coated on the surface thereof with a refractory material **18** and **20**. As stated above, this coating can be produced by any suitable method such as placing the refractory material in powder or liquid form on the surface to be coated and heating the refractory so as to allow it to flow over the outer conductor surface as shown in FIGURE 4. While it is only necessary to coat that portion of the conductor surface which will be exposed to the work piece, the coating may be extended to other areas if desired without harmful consequence. Likewise, the refractory coating thickness is not critical and will be largely determined by the choice of refractory material. Generally, thicknesses in the range of 2 to 25 mils are sufficient.

After the conductor has been shaped and suitably coated with a refractory material, the inductor is placed within a vessel in a position such that the shaped portion is held in juxtaposition with the containing surfaces of the vessel. Thus, in FIGURE 3 the inductor is placed in a vessel **22** so that refractory coated surfaces **18** and **20** of turns **14** and **16** are in close proximity to the interior walls of vessel **22**. After such positioning, a synthetic resin **28** is introduced into vessel **22** and allowed to flow about the inductor so as to substantially encompass all surfaces of the inductor. However, due to the close proximity of the refractory coated surface of turns **14** and **16** with the vessel walls, the resin will not flow therebetween and refractory surfaces **18** and **20** will not be encompassed by the resin. In the event that it is desired that a coating of the resin be formed over refractory coatings **18** and **20**, the vessel can be shaped so as to provide a slight space between the walls thereof and the refractory material. Since the ends of the conductor **12** and **12***a* will be connected to a source of electrical energy, they should project from the resin core. Thus, only a substantial portion of the inductor need be placed within the vessel so as to enable the formation of a resin core suitable to furnish support to the inductor. The portion of the conductor which will be connected to the electrical energy source can project from the vessel as illustrated in FIGURE 3.

The particular synthetic resin, curing agent and/or catalyst which are used in the method of this invention are not critical. Thus, both thermoplastics and thermosetting resins can be used. Likewise, the curing agent may be any compound containing one or more active hydrogen atoms. The term "active hydrogen atoms" refers to hydrogens which display activity according to the Zerewitinoff test as described by Kohler in J. Am. Chem. Soc., 49, 3181 (1927). Examples of suitable thermoplastic resins are acetals such as Delrin marketed by Du Pont, acrylics such as polymethyl methacrylate, cellulosics, as for example, cellulose acetate, cellulose acetate butyrate, cellulose propionate, and ethyl cellulose, fluorocarbons as tetrafluoroethylene and chlorotrifluoroethylene, nylon, polycarbonates such as Lexan marketed by General Electric, polyethylene, polypropylene, polystyrenes and modified polystyrenes such as styrene-acrylonitrile copolymers, styrene-butadiene copolymers, and polymethylstyrene and methylstyrene-acrylonitrile copolymers, and vinyl acetate copolymers and vinyl chloride-vinylidene chloride. Suitable thermosetting resins for use in this invention include epoxies, melamine formaldehydes, phenolics such as phenol formaldehyde, polyesters, polyester alkyds, diallyl phthalate, silicones, ureas such as urea formaldehyde, and urethanes.

The choice of resin for use in this invention will depend primarily on the temperature to which the resin core will be subjected when in service. Thus, if a service temperature of 200° F. were to be encountered, a polystyrene resin having a melting point in the range of 140–160° F. would, naturally, not be considered. In addition to service temperature, other important considerations in the selection of a resin are the necessity of good heat conductivity and adherence. It will be appreciated that the selection of a resin is not difficult once the type and shape of conductor and service conditions are known. In general, for purposes of structural rigidity, a thermosetting resin is preferred in the method of this invention. Furthermore, it has been found that epoxy and phenolic resins are particularly well suited since both of these types of resins exist in liquid state at room temperature and, therefore, are easy to handle and work with. Furthermore, after such resins have hardened they may be conviently shaped as by turning on a lathe or other shaping instrument.

If a liquid resin is used, the vessel **22** need only be a simple container open at the top. The resin is then poured into the vessel and allowed to flow about the inductor so as to form a supporting member. Since many resins will cure or harden at room temperature, it is only necessary to allow the resin to remain in the vessel until it has hardened to a degree that the vessel can be separated from the core supported inductor. It may be desirable to coat the inside of the vessel walls with a mold release agent prior to introducing the resin so as to facilitate the removal of the core supported inductor. If desired, the resin filled vessel can be heated in an oven to accelerate the rate of hardening. If the resin components are solids at room temperature, vessel **22** can be provided with, or surrounded by, a suitable heating means to liquify the resin and enable it to flow about the inductor. Naturally, the resin core can be formed by injection or compression molding wherein heat and pressure are used to soften the resin and force it to flow and fill the cavity. Should it be desired to provide a passage extending through the resin core, an additional member **24** can be placed within vessel **22** prior to the introduction of the synthetic resin. Member **24** will have a continuous peripheral surface resulting in a definable space between its surface and the inner surface of vessel **22**. The synthetic resin can then be introduced into the vessel and allowed to surround member **24**. In order to prevent the resin from entering member **24**, the lower end thereof **26** should be sealed or held in firm contact with vessel **22**. If member **24** has a solid cross-sectional area, it will of course be necessary to remove it from the hardened resin to create the passageway. If member **24** is hollow then it can either be left embedded in the resin or removed therefrom. Naturally, if member **24** is to be left in the resin so as to be an integral part of the final core supported inductor, the member should be of an electrically nonconductive material.

FIGURE 6 is a cross-sectional view of a core supported inductor as shown in FIGURE 2 showing conductor turns **14** and **16** embedded in synthetic resin core **28** and having their refractory coated surfaces essentially flush with the outer surface of core **28**. When the resin has hardened and vessel **22** removed from the core supported inductor, a plurality of passages **30** and **32** may be formed, as for example by drilling, extending from the outer surface of core **28** through the surface of member **24**. A quenching agent may then be transported to the work piece by introducing it under pressure to member **24** and allowing it to escape from core **28** via passages **30** and **32**. FIGURE 5 illustrates a plurality of such passages formed in the core. It will be understood, however, that for some induction heating applications only one passage may be needed and, hence, member **24** could extend all the way through the resin core so as to provide this passage.

The invention described herein has been successfully used in manufacturing core supported inductors for use

in heat treating the internal diameter surface of hollow shafts. In manufacturing such an inductor, a length of 1/8 inch square cross-sectional, hollow copper tubing was shaped at a point a substantial distance from one end thereof so as to form two circular turns. The remaining length of tubing was extended back from said turns and in generally offset axial alignment with the first portion of tubing thereby forming an inductor having a configuration similar to the inductor shown in FIGURE 1 of the accompanying drawing.

A ceramic material was then fired onto the top outer surface of the inductor turns as illustrated in FIGURE 4 so as to provide a coating, as at **18**, of approximately 6 mil thickness. The ceramic material used was lithium borosilicate marketed by E. I. du Pont de Nemours Company and identified as Flux N–360. The lithium borosilicate frit obtained from Du Pont was ground with water so as to produce a colloidal suspension. This suspension was then painted on the inductor turns and allowed to dry. Upon drying, the ceramic coated inductor was fired in a furnace at a temperature of approximately 1200° F. After being coated with the ceramic material the inductor was then placed within an aluminum container, which was open at the top, in a position such as is shown in FIGURE 3 such that the coated inductor turns were in contact with the side of the container. A length of Teflon 1/4 inch diameter tubing was then placed around one length of the inductor corresponding to the member **12** of FIGURE 1 so that there was a uniform space between the inner surface of the Teflon tubing and the outer surface of the copper conductor. A liquid epoxy resin composition was then poured into the container and allowed to flow about the inductor so as to contact and encapsulate all surfaces of the inductor except the refractory coated surfaces which were in contact with the container walls, the inductor portion surrounded by the Teflon tubing, and the portion of the inductor which projected above the container. The container was placed in an oven and heated for one hour at a temperature of 150° F. so as to cure and harden the resin. At the end of this period the core supported inductor was separated from the container and a plurality of small passages, similar to those shown in FIGURE 5, were drilled through the epoxy material and into the Teflon tubing so as to provide a means whereby a quenching agent would be brought through the epoxy core and into contact with the workpiece. Lastly, the Teflon tubing and the axially aligned portions of the inductor projecting from the resin core were fitted with means whereby they could be connected to quenching agent and electric power sources. The inductor thus manufactured had an epoxy core approximately six inches in length and one inch in diameter.

The epoxy resin used in manufacturing the above core supported inductor consisted of the following:

	Parts by weight
Part A:	
Epon 828	50
Aluminum oxide (Al_2O_3)	150
Part B:	
Curing agent U	12.5
Aluminum oxide (Al_2O_3)	20

The two parts were thoroughly blended and immediately thereafter poured into the container. The aluminum oxide in the above formulation was used to impart greater heat transfer and strength properties to the epoxy resin. The aluminum oxide was a 350 mesh material marketed by the Aluminum Company of America and identified as T–60. Epon 828 is marketed by Shell Chemical Company and is the reaction product of epichlorohydrin and bisphenol-A. It is a pourable liquid at room temperature and has an average molecular weight of 380, and equivalent weight of 85, an epoxide equivalent of 185–192, a density of 1.168 grams per milliliters at 20° C. and a flash point greater than 175° F. (Tag open cup). Curing agent U is marketed by Shell Chemical Company and is an amber colored liquid aliphatic polyamine adduct produced by reacting an aliphatic polyamine with an Epon resin. It has a viscosity of approximately 10,000 centipoises at 20° C. and an equivalent weight of about 45.

Although the above discussion of this invention pertains to inductors having an inner resinous supporting core, it will be appreciated that it is equally applicable to the manufacture of inductor units wherein the supporting resinous body is cast about the inductor so as to form a hollow inductor unit thereby permitting the metal which is to be heated to be passed through the inductor.

While the foregoing illustrates and describes what is contemplated to be the best mode of carrying out the invention, it will be understood that many departures from this invention may be made without, however, departing from the spirit thereof or the scope of the appended claims.

I claim:

1. A method of manufacturing an induction heating structure for heating a member to be heat treated comprising the steps of taking a length of elongated hollow electrically conductive member, shaping a portion of the conductive member to a configuration conforming to at least a portion of the surface to be heated, coating the shaped conductive member with a refractory material, surrounding at least a substantial portion of said conductive member with a vessel in a manner whereby said shaped portion of the conductor is held in juxtaposition with the containing surfaces of said vessel so as to eliminate any perceptible space therebetween, introducing a synthetic resin into said vessel, allowing said resin and said conductive member to remain within said vessel for a time adequate to insure at least minimal hardening of said resin, and removing the resin encapsulated structure from said vessel.

2. A mehod of manufacturing an induction heating structure for heating a member to be heat treated comprising the steps of taking a length of elongated hollow electrically conductive member, shaping a portion of the conductive member to a configuration conforming to at least a portion of the surface to be heated, coating the shaped conductive member with a refractory material, placing at least a substantial portion of said conductive member within a vessel in a position whereby said shaped portion of the conductor is held in juxtaposition with the containing surfaces of said vessel so as to eliminate any perceptible space therebetween, introducing a synthetic resin into said vessel and allowing said resin to flow about said contained portion of said conductive member so as to encompass substantially all surfaces thereof except such surfaces as are defined by said shaped conductive member which are also in juxtaposition to said wall of said vessel, allowing said resin and said conductive member to remain within said vessel for a time adequate to assure at least minimal hardening of said resin and removing the resulting resin encapsulated heating structure from said vessel.

3. The method of claim **2** wherein said conductive member is tubular copper.

4. The method of claim **2** wherein said synthetic resin is thermosetting.

5. The method of claim **2** wherein said refractory material is selected from the group consisting of lead borosilicates, lithium borosilicates, lead silicates and lithium silicates.

6. A method of manufacturing an induction heating structure for heating a member to be heat treated comprising the steps of taking a length of elongated hollow electrically conductive member, shaping a portion of the conductive member to a configuration conforming to at least a portion of the surface to be heated, coating the shaped conductive member with a refractory material, placing at least a substantial portion of said conductive member within a vessel in a position whereby said shaped portion of the conductor is held in juxtaposition with the containing surfaces of said vessel so as to eliminate any perceptible space therebetween, placing a second member within said vessel in a position generally parallel to the longitudinal axis of said conductive member so as to define therein a continuous peripheral surface resulting in a definable space between said peripheral surface and said inner surface of said vessel, introducing a synthetic thermosetting resin into said space and allowing said resin to flow about said contained portion of said conductive member so as to encompass substantially all the outside peripheral surface of said second member and the surfaces of said conductive member except such surfaces as are defined by said shaped conductive member which are also in juxtaposition to said wall of said vessel, allowing said resin and said second and conductive members to remain within said vessel for a time adequate to assure at least minimal hardening of said resin and removing the resulting resin encapsulated heating structure from said vessel.

7. A method of manufacturing an induction coil assembly having an integral center core which comprises the steps of shaping a hollow electrically conductive member so as to form a coil having at least one circular winding, coating the coil winding with a refractory material, placing at least a substantial portion of the induction coil in a vessel in a position whereby said refractory coated circular winding is held in juxtaposition with the containing surfaces of said vessel so as to eliminate any perceptible space therebetween, placing a second elongated electrically nonconductive tubular member within said vessel in a position generally parallel to the longitudinal axis of said induction coil, filling essentially all the space in said vessel between said outside surface of said tubular member and the vessel walls with a thermosetting resin so as to encompass substantially all the outside surface of said tubular member and the surfaces of said conductive member except such surfaces thereof which are in juxtaposition to said wall of said vessel and so as to leave a passage through said resin defined by said tubular member, allowing said resin to harden, forming passages in said resin extending from the surface thereof through the surface of the tubular member so as to allow a quench agent to escape from the induction coil assembly and removing the induction coil structure from said vessel.

8. A method of manufacturing an induction coil having an integral center core which comprises the steps of taking a length of hollow electrically conductive member, bending said conductive member at a point which is at a substantial distance from one end thereof to form a curvilinear heating portion which closely conforms to the surface to be heated, extending the remaining portion of said length of conductive member back towards the said end so as to be in generally offset axial alignment therewith, coating at least a portion of said curvilinear heating portion with a refractory material, placing at least a substantial portion of the induction coil in a vessel in a position whereby said refractory coated curvilinear portion is held in juxtaposition with the containing surfaces of said vessel so as to eliminate any perceptible space therebetween, placing a second elongated electrically non-conductive tubular member within said vessel in a position generally parallel to the longitudinal axis of said induction coil, filling essentially all the space in said vessel between said outside surface of said tubular member and the vessel walls with a synthetic thermosetting resin so as to encompass substantially all the outside surface of said tubular member and the surfaces of said conductive member except such surfaces thereof which are in juxtaposition to said wall of said vessel and so as to leave a passage through said resin defined by said tubular member, allowing said resin to harden, forming passages in said resin extending from the surface thereof through the surface of the tubular member so as to allow a quench agent to escape from the induction coil, and removing the induction coil structure from said vessel.

9. A method of manufacturing an induction heating structure for heating a member to be heat treated comprising the steps of taking a length of elongated hollow electrically conductive member, shaping a portion of the conductive member to a configuration conforming to at least a portion of the surface to be heated, applying an insulating coating to the shaped conductor, surrounding at least a substantial portion of said conductive member with a vessel in a manner whereby said shaped portion of the conductor is held in juxtaposition with the containing surfaces of said vessel so as to eliminate any

perceptible space therebetween, introducing a synthetic resin into said vessel, allowing said resin and said conductive member to remain within said vessel for a time adequate to insure at least minimal hardening of said resin, and removing the resin encapsulated structure from said vessel.

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