June 30, 1970 C. H. DAWSON 3,518,394

OUTPUT TRANSFORMER AND WORK INDUCTOR FOR INDUCTION GENERATORS

Original Filed May 16, 1967 2 Sheets-Sheet 1

Fig 1

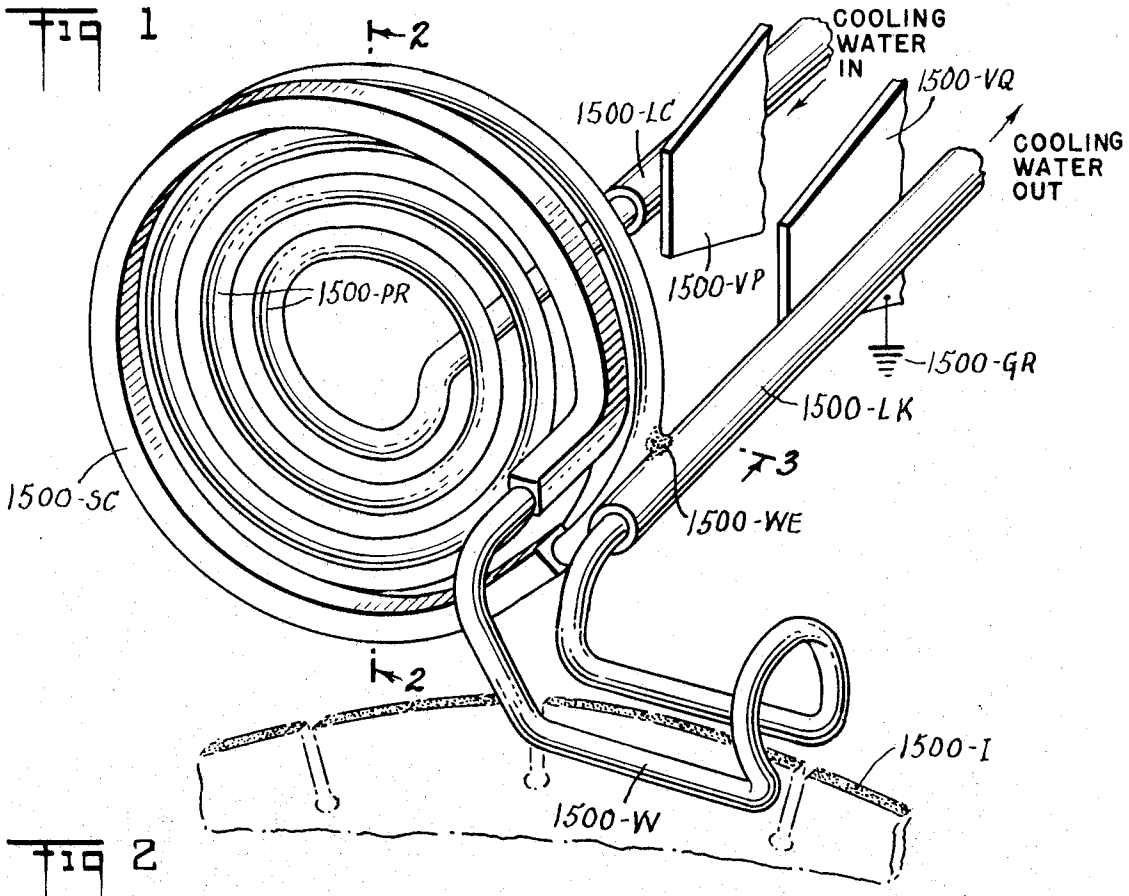


Fig 2

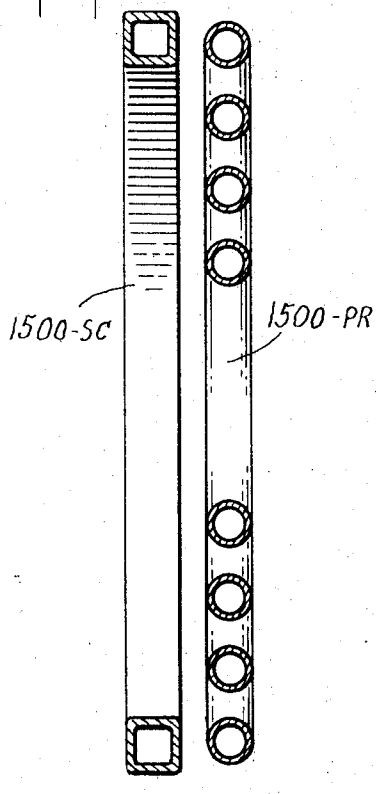


Fig 3

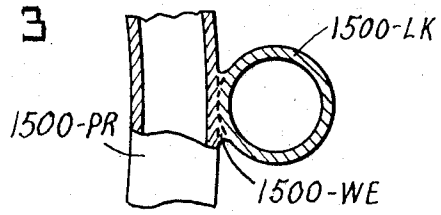
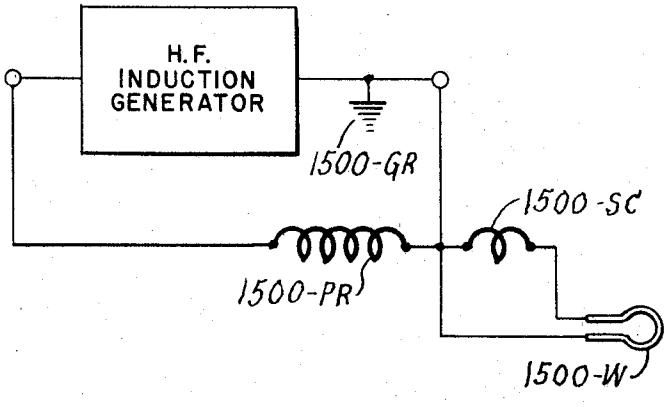


Fig 4



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OUTPUT TRANSFORMER AND WORK INDUCTOR FOR INDUCTION GENERATORS

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Fig 5

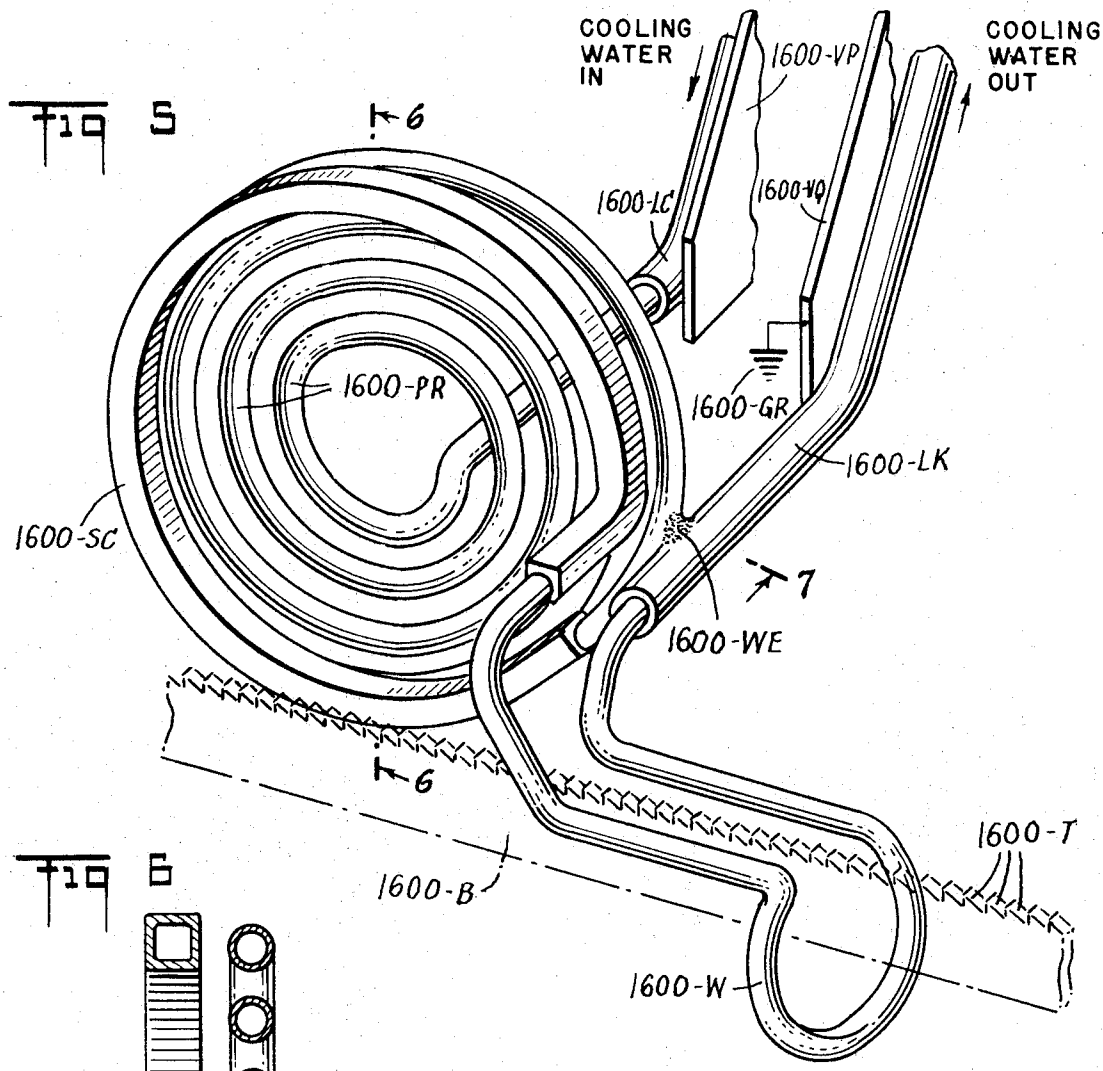


Fig 6

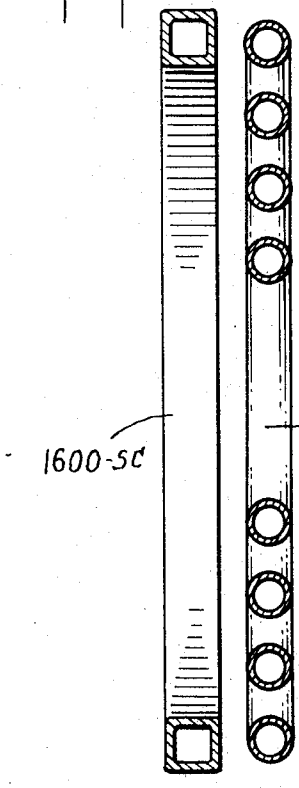


Fig 7

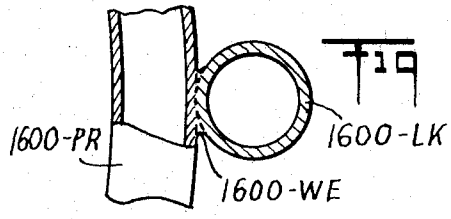
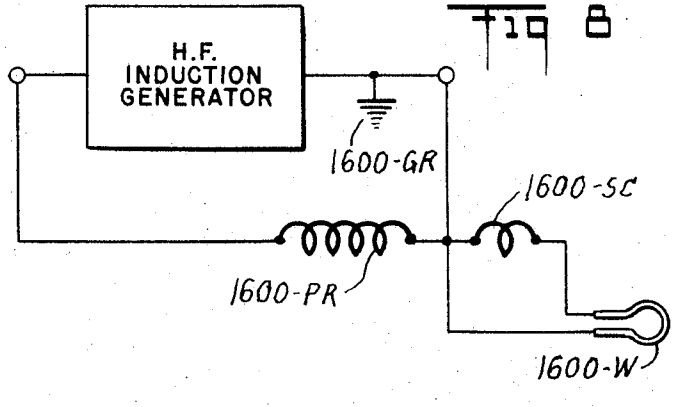


Fig 8



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OUTPUT TRANSFORMER AND WORK INDUCTOR FOR INDUCTION GENERATORS

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Original application May 16, 1967, Ser. No. 638,998, now Patent No. 3,449,146, dated June 10, 1969. Divided and this application Oct. 14, 1968, Ser. No. 767,385
Int. Cl. H05b 5/00, 9/02
U.S. Cl. 219—10.75 10 Claims

ABSTRACT OF THE DISCLOSURE

A combined output transformer and work coil inductor for coupling the output of an induction generator to a workpiece to be heated thereby. In an illustrative embodiment the combination involves a multi-turn transformer primary, a single turn transformer secondary, and a single loop work coil so arranged that there can be series flow of cooling water through the entire assembly and so arranged that one end of each of the coils is maintained at substantially ground potential to minimize problems associated with arc-over and/or short circuits to work being processed in or through the work coil.

This application is a division of my application Ser No. 638,998 filed May 16, 1967 now Pat. No. 3,449,146, which is a continuation-in-part of my United States application Ser. No. 177,558, filed Mar. 5, 1962, (now abandoned), which in turn is a continuation-in-part of application Ser. No. 546,779, filed Nov. 14, 1955, which in turn was a continuation-in-part of application Ser. No. 379,100 filed Sept. 8, 1953, (now abandoned), and which latter application was a continuation-in-part of my parent application, Ser. No. 41,180 filed July 28, 1948, (now abandoned). U.S. Pats. No. 3,023,490 and No. 3,024,128 issued on applications Ser. No. 548,915 and No. 546,779, respectively.

This invention relates to apparatus which is useful in coupling the output of very high frequency induction generators to members which are to be heated thereby for purposes of welding, brazing, melting, or heat treatment.

Particularly during periods of high humidity or in the presence of fumes emitted from a heating workpiece, the output of such induction generators is likely to arc-over to the work being processed or to short out between turns, to the work or to adjacent supporting structure. When this happens the least troublesome result is to throw out circuit breakers within the induction generator which only temporarily shuts down the equipment. At the other end of the scale there is a chance that such problems will do irreparable damage to the generator and a probability of localized melting or destruction of the work or the work coil and a severe chance of physical injury to the furnace operator and any others who may chance to be in contact with the workpiece or members in electrically conducting circuits including the workpiece.

Although burns resulting from accidental contact with the output of very high frequency induction generators are rarely fatal and seldom involve disabling injury, they usually result in deeply penetrating puncture-like burns which are quite painful and which heal slowly.

A principal object of the invention is to secure highly efficient coupling of the output of the induction generator to the workpiece by means of improved impedance matching, by the avoidance of long leads, and by the use of a stepdown turns ratio which induces high current in the work coil and workpiece while holding the potential difference to values low enough to avoid the arcing and

shorting problems associated with high potential differences.

In the drawings:

FIG. 1 is a perspective view illustrating a combined output transformer and work coil which is the subject of this application;

FIG. 2 is a cross-sectional view on the line **75—75** of FIG. 1;

FIG. 3 is a partial cross-sectional view on the line **76** of FIG. 1;

FIG. 4 is a schematic circuit diagram illustrating the application of the invention;

FIG. 5 is a view similar to FIG. 1 illustrating an adaptation of the invention to a different type of workpiece;

FIG. 6 is a cross-sectional view on the line **79—79** of FIG. 5;

FIG. 7 is a partial cross-sectional view on the line **80** of FIG. 5;

FIG. 8 is a schematic circuit diagram illustrating the application of the form of the invention shown in FIG. 5.

In armoring disc cutters and the like, it was found that a special transformer of novel construction produced improved results.

As is usual in the induction generator art, the generator is provided with a pair of output terminals, not shown, to which a work coil or other output device may be connected, usually by means of a relatively large area and hence low resistance block which is bolted to the output terminal. Usually cooling water connections are provided in the center of each output terminal and communicate with water passages in the connector blocks. A plate is usually made integral with or welded to each connector block and extends outwardly from the generator and is welded to the conductor leading from the connector block to the work coil or other output device. These plates are usually made as mirror images of each other and being parallel and relatively closely spaced act as capacitor plates helping to correct the power factor in the system and thereby reduce electrical losses in the output leads while also providing added bracing and mechanical strength to any output system used.

Such capacitor plates only partially illustrated and shown in FIG. 1 as **1500**–VP and **1500**–GR are utilized to provide connections to my improved transformer to be next described. One of the generator output terminals is preferably internally grounded and this ground is indicated in FIGS. 1 and 4 by the conventional symbol for a grounded connection.

The novel construction is clearly shown in FIGS. 1 to 3. A primary **1500**–PR of a transformer has a plurality of turns closely wound in the form of spiral. The close winding may be clearly seen in FIGS. 1 and 2. Closely adjacent to the primary is a secondary **1500**–SC of the transformer. For best results, the secondary comprises a single coil which may be formed of tubing which is rectangular in cross section (see FIG. 2). A hollow tubular lead-in conductor **1500**–LC is fastened to the capacitor plate and connector block at the high potential terminal **1500**–VP of a high frequency (H.F.) induction generator system and is connected to the inner end of the spirally wound primary whereas a second hollow tubular lead-in conductor **1500**–LK is fastened to a second capacitor plate **1500**–VQ and is connected to the outer end of the spirally wound primary by means of a weld **1500**–WE. The weld may be clearly seen in FIG. 3. As noted above, plate **1500**–VQ is electrically connected to a ground **1500**–GR in the internal circuitry of the generator. To secure the advantage of closest spacing which permits a more effective transfer of energy from the primary to the secondary coil, it is always desirable to couple the single turn secondary coil as tightly as possible to the end turn of the

primary coil which is electrically connected most closely to the grounded output terminal of the generator.

Below the weld, the end of the outer coil of the flat spirally wound multi-turn primary is connected to one end of the single turn coil on the secondary. The other end of the secondary coil is connected to one end of the electrical work coil **1500**–W (see FIG. 1). The second end of the work coil is connected to the second lead-in conductor **1500**–LK. Although in the construction described above, each coil is formed separately and the coils are then connected together, careful consideration will show that the entire system of the three coils can be formed of a single continuous length of tubing.

In the use of high output induction generators it is desirable that the work coils and other inductors be artificially cooled and it is conventional to form such inductors. from hollow copper tubing through which water can be circulated to remove heat. In the conventional system where more than one coil is used it is usual to arrange for parallel flow of the water through the various coils. By using the illustrated arrangement, a series flow of cooling water may be maintained throughout the system. In this manner, a stream of water or other coolant may be sent through the series connected copper tubes under high velocity to insure rapid heat transfer from the inner walls of the tubes to the stream of water or coolant. The temperature in the tubes may readily be controlled within a selected safe range. Consequently, the difficulties and disadvantages of the conventional parallel system of cooling are avoided. In a parallel circulation system of cooling, overheating in one coil may tend to cause steam to form which tends to block circulation. Since localized overheating tends to increase the electrical resistance of the coil this tends to further overheating which occasionally leads to a runaway condition and to burning out the coil in which circulation has been blocked.

The compactness of the transformer is clearly depicted in the figures and particularly to FIG. 2. This compact arrangement makes it possible to have it connected electrically directly to the work coil without the necessity of using widely spaced or long leads which sometimes have as much inductance as the coils themselves and dissipate generator power in an unproductive way. Those persons skilled in the art will appreciate that the novel combination can effect a great saving in electricity by improving the impedance matching and by eliminating the usual line loss and frequency change resulting from the long leads. Likewise, the new arrangement will be safer with the elimination of long leads. A further safety factor is the grounding of the system at the junction between the primary and secondary transformer coils and the work coil.

A pie type helically wound coil such as the primary **1500**–PR concentrates the magnetic flux in a very intense pattern so that a maximum amount of the flux of such a coil is intercepted by the one turn secondary coil **1500**–SC and the secondary winding turn can be spaced very closely adjacent to the turn of the primary which is electrically connected to the grounded terminal of the generator without dielectric break down. As a result of the flux concentration and the close spacing permitted much more energy can be induced in the secondary turn to be conducted to the work inductor. The voltage drop from the high voltage across each turn of the primary lessens the potential between the turns thus enabling quite close spacing between the turns without dielectric break down so essentially each turn tends to have a shielding effect for the next turn. To secure still closer spacing of turns without diminishing cooling water conducting ability it is sometimes desirable to use tubing of flattened or ribbon like configuration.

When armoring a disc such as **1500**–I, it is very important that just the perimeter is heated to the processing temperature and that no heat is inducted or conducted below the bottoms of the gullets. If heated below the gullets, serious distortion is encountered which is very impractical and uneconomical to remove. The very low voltage and high current in the work inductor **1500**–W makes it possible to couple this inductor extremely close to the area of workpiece to be heated. As a result, the selected area will heat fast enough so that the conduction will not carry the heat below the gullets and the field is not broad enough to heat below the gullets inductively.

The novel electrical circuit is shown diagrammatically in FIG. 4. The high frequency (H.F.) induction generator is clearly illustrated and is connected to the primary **1500**–PR of the transformer. Closely associated with the primary is the secondary **1500**–SC of the transformer. The secondary is directly connected to the electrical work coil **1500**–W. Between the primary and secondary, a branch of the circuit constituted by a lead-in conductor is grounded by a ground **1500**–GR.

In the event that it is desired to armor a bar or rod **1600**–B provided with a pulrality of teeth **1600**–T, the combination shown in FIGS. 5 to 8 can be used. The combination is similar to the one illustrated in FIGS. 1 to 4. A primary **1600**–PR of a transformer is constituted of a plaurality of coils in a tightly wound spiral and a secondary **1600**–SC is constituted of a single coil (see FIG. 6). It is convenient to make the primary of circular copper tubing and the secondary of square copper tubing. A lead-in conductor **1600**–LC constituted of circular copper tubing is connected to the inner end of the spiral tubing of the primary whereas a second lead-in conductor **1600**–LK constituted of circular copper tubing is joined to the outermost coil of the primary by means of a weld **1600**–WE (see FIGS. 6 and 7). One vertical partition or capacitor plate **1600**–VP is fastened to lead-in conductor **1600**–LC by any convenient means, such as welding. A second vertical partition or capacitor plate **1600**–VQ is fastened to the second lead-in conductor **1600**–LK by welding or the like. This second partition or capactor is grounded within the generator by ground indicated schematically at **1600**–GR.

Due to the compact arrangement, the transformer may be connected directly to an electrical work coil **1600**–W without the necessity of using conventional long lead-in conductors. The armoring operations are similar to those in connection with the circular cutter disc described in connection with FIGS. 1 to 4. However, the workpiece **1600**–B may be moved continuously at controlled speeds to permit continuous armoring. Depending upon the desired product or mode of production, either step-by-step armoring or continuous armoring may be used.

The electrical circuit illustrated in FIG. 8 is similar to the one shown in FIG. 4. A high frequency (H.F.) induction generator is connected directly to a primary **1600**–PR of a transformed. The secondary **1600**–SC is connected directly to an electrical work coil **1600**–W. A branch of the circuit going from the junction of the primary and secondary to the generator is grounded by means of a ground **1600**–GR. The electrical and other operations are the same as those involved in FIG. 4.

It has been found that these circuits including the compact combined transformer and inductor or work coil have many advantages including electrical efficiency and economy, shortness of leads, safety, and close coupling to the work thereby permitting better control of the heat pattern. The secondary of the output transformed is a single turn and the work coil is itself only a simple short loop. Thus, there is a relatively low voltage across these components, although the current they carry is high. Further, the point of common connection of the primary and secondary of the output transformer and the return connection from the work coil are all connected through the lead-in conductor **1600**–LK to the internally grounded terminal of the induction generator. As a result, no part of the work coil or of the secondary of the output transformer is very far above ground potential and stray current circulation is minimized. This is an important

advantage for with close coupling any great potential difference would tend to cause arc-over to the workpiece which is preferably maintained at ground potential. Such tendency to arc-over is aggravated during periods of high humidity or by the emission of smoke or ionizable gases as temporary adhesives and/or fluxes are heated in the coil. Not only will an arc-over be a safety hazard to operators who may be in contact with other parts of the machine but it will usually throw out the circuit breakers in the induction generator and interrupt the operation thereof. Another advantage is the compactness of the combined transformer and inductor or work coil. Due to the compactness, all of the extensions of or from long leads and the like are eliminated and the high frequency can be maintained. Likewise, space radiation tends to decrease with compactness. As is well known, any extra length of leads, extension and the like in the tank circuit affects the frequency of the system which is eliminated by the compact combined transformer-inductor. When long leads of the prior art are used, losses are encountered and such losses require higher voltages across the primary in order to get enough energy to do the armoring in the work coil. It is also known that the tank circuit must be of the least geometry in order to maintain the desired high frequency. Since the new combined transformer-inductor is so compact, the maintenance of the desired high frequency is facilitated.

I claim:

1. A compact transformer-inductor comprising in combination a transformer having its primary coil consisting of a plurality of turns closely wound in the form of a spiral with one end near the center of the spiral and the second end in the outside of the spiral and having its secondary consisting of a single coil in close proximity to the primary coil with one end joined to said second outer end of the primary and a second end joined to one terminus of a compact work coil adapted for close coupling with a workpiece, a lead connected to a high frequency induction generator and joined to a second terminus of said work coil, said lead being joined to said second outer end of said primary coil closely adjacent to the junction with the secondary, a ground connection going to said lead, and a second lead connecting the high frequency induction generator with the inner spiral of the primary thereby completing the electrical circuit.

2. A compact transformer-work coil combination comprising a transformer having a spirally wound primary constituted of a plurality of tightly wound coils of copper tubing with an inner end near the center of the spiral and an outer end in the outside of the spiral and having its secondary constituted of a single coil of copper tubing in close proximity to the primary coil with one end joined to said outer end of the primary, a compact work coil made of copper tubing and adapted for close coupling with a workpiece and having one terminus joined to the second end of the secondary, a lead-in conductor made of copper tubing and connected to a high frequency induction generator and connected to a second terminus of said work coil, said lead-in conductor being welded to said outer end of said primary closely adjacent to the junction with the secondary, a ground connection grounding said lead-in conductor, and a second lead-in conductor made of copper tubing and connecting the high frequency induction generator with the inner spiral of the primary thereby completing the electrical circuit and thereby permitting the maintenance of series flow of cooling water throughout the system.

3. A compact step-down transformer-inductor for induction heating, comprising, in combination, a transformer having a primary coil consisting of a plurality of turns of electrically conductive material, and having a secondary coil consisting of a single turn of electrically conductive material supported in close proximity to and in inductively coupled relationship with the primary coil, and a compact work coil of electrically conductive material adapted for close inductive coupling with a workpiece to be inductively heated, one end of the material comprising the primary coil being connected by an electrically conductive joint to one end of said secondary coil, the other end of said secondary coil being connected by an electrically conductive joint to a first end of said work coil, a first connecting lead of electrically conductive material connected by electrically conductive joints at one end of the lead to a second end of said work coil and at the other end of the lead to a grounded output terminal of an induction generator, an electrically conductive connection between said first connecting lead and the junction between the said first end of the work coil and said secondary coil, and a second connecting lead of electrically conductive material connected by electrically conductive joints at one end of the lead to the high potential output terminal of an induction generator and at the other end of the lead to the end of said primary coil remote from the end connected to the secondary coil, whereby the work coil and the primary and secondary transformer coils, each have one terminal and electrically directly connected to the grounded terminal of the induction generator.

4. A compact step-down transformer-inductor for induction heating, comprising, in combination, a transformer having a primary coil consisting of a plurality of turns of hollow tubular electrically conductive material, and having a secondary coil consisting of a single turn of hollow tubular electrically conductive material supported in close proximity to and in inductively coupled relationship with the primary coil, and a compact work coil of hollow tubular electrically conductive material adapted for close inductive coupling with a workpiece to be inductively heated, one end of the tubular material comprising the primary coil being connected by an electrically conductive, cooling fluid conducting joint to one end of said secondary coil, the other end of said secondary coil being connected by an electrically conductive, cooling fluid conducting joint to a first end of said work coil, a first connecting lead of hollow tubular electrically conductive material connected by electrically conductive, fluid connecting joints at one end of the lead to a second end of said work coil and at the other end of the lead to a grounded output terminal of an induction generator, an electrically conductive connection between said first connecting lead and the junction between the said first end of the work coil and said secondary coil, and a second connecting lead of hollow tubular eletcrically conductive material connected by electrically conductive fluid conducting joints at one end of the lead to the high potential output terminal of an induction generator and at the other end of the lead to the end of said primary coil remote from the end connected to the secondary coil, whereby the work coil and the primary and secondary transformer coils, each have one terminal end electrically directly connected to the grounded terminal of the induction generator and all are connected for series conduction of cooling fluid from one output terminal of the induction generator through said primary coil, secondary coil and work coil, back to the other output terminal of the induction generator.

5. A transformer-inductor as described in claim 4, in which the secondary coil is formed of a larger size of tubular material having greater electrical conductivity.

6. A transformer-inductor as described in claim 5, in which the secondary coil is formed of tubular material of rectangular cross section material to provide greater rigidity.

7. A transformer-inductor as described in claim 4, in which the primary coil is formed as a flat helix with all turns of the helix in substantially the same geometric plane.

8. A transformer-inductor as described in claim 7, in which the electrical and fluid conductive connection from

the high potential output terminal of the induction generator is made to the innermost end of the flat helix in which the primary coil is formed.

9. A transformer-inductor as described in claim **7**, in which the single turn secondary coil is formed to define a turn having substantially the same diameter as the end turn of the primary coil which is electrically connected to the grounded output terminal of the induction generator and substantially all of the secondary coil is contained within a geometric plane substantially parallel to the geometric plane occupied by the primary coil.

10. A transformer-inductor as described in claim **4**, in which the connecting leads are each secured to a flat plate of electrically conductive material extending outwardly from the connection to the induction generator

output terminals, said flat plates being disposed in facing parallel relationship to act as power factor correcting capacitor plates and also as mechanical bracing to rigidify the connecting leads.

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