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(54) INDUCTION HEATING APPARATUS

(71) We, ILLINOIS TOOL WORKS INC., a corporation organized under the laws of the State of Delaware, United States of America, of 8501 West Higgins Road, Chicago, Illinois 60631, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates generally to induction heating apparatus, and more particularly to induction heating apparatus which allows the heating unit to be remotely located from the generator.

Induction heating is a relatively well-known expedient for producing heat in localized areas on metal objects by the use of RF power which develops a varying magnetic field within the metal to be heated. The internal energy losses within the material cause it to heat up in a relatively short period of time.

However, one of the primary disadvantages of induction heating units heretofore utilized is that the RF power generator and the induction heating unit, per se, required a fixed geometry relation therebetween, and movement of the induction heating unit relative to the RF power generator was not easily possible.

Accordingly, it is an object of this invention to provide an induction heating apparatus which allows separation of the generator and the induction heating unit, and such separation readily accommodates movement of the induction heating unit to a plurality of different work locations.

Another object of this invention is to provide an induction heating unit of relatively small size operable in response to a relatively low frequency.

Induction heating apparatus can be used for a plurality of different functions, such as for example, hardening of metals, brazing, soldering, and heating of all kinds. Frequency ranges of such induction heating

apparatus may vary from a few thousand Hertz to several mega-Hertz. The historical development of such induction heating apparatus, initiated by the use of vacuum tube oscillators, led subsequently to solid state devices which would operate at high voltage and over a relatively wide frequency range. However, characteristic of all the prior art induction heating apparatus is their relatively large size, and the necessity of bringing the workpiece, which is to be heated, to the generator, or at least to its immediate vicinity. This then severely restricts the adaptability of the induction heating apparatus, to applications where the workpiece is capable of being transported to the heater, or providing large manipulating apparatus for transporting the heater to the workpiece.

It is therefore another object of this invention to provide an induction heating unit of relatively light weight and small size which can be used for transferring induction heating power to well-defined local areas upon relatively large bodies of metal.

Still another object of this invention is to provide an induction heating apparatus which is capable of detecting the precise amount of energy delivered by the induction heating unit to the load so that the temperature generated in localized areas of large bodies of sheet metal can be precisely controlled.

According to this invention, a solid state induction heating apparatus comprises in combination: an inverter circuit, an output transformer having a primary winding connected to the inverter circuit and a closely coupled secondary winding, both the primary winding and the secondary winding being wound on a ferrite magnetic core, an inductance element with a ferrite magnetic core, a capacitance element connected in series with the inductance element, this series combination being connected across the terminals of the secondary winding of the output transformer, the series combina-

tion of the inductance element and the capacitance element being tuned to a resonant frequency corresponding to the frequency generated by the inverter circuit.

5 Preferably the apparatus includes voltage integrating means operatively coupled with the tuned circuit formed by the inductance element and the capacitance element for
10 integrating a voltage dependent on the quantity of energy supplied thereto, and commutating switch means coupled to the inverter circuit to terminate operation of the inverter circuit in response to an output from the voltage integrating means upon
15 accumulation of a predetermined voltage. Preferably the voltage integrating means includes a rectifier circuit coupled to either the capacitance or inductance element of the tuned circuit, a first "cup" capacitor
20 coupled to the rectifier means, a second "bucket" capacitor coupled to the first capacitor, a silicon-controlled rectifier switch means coupled between the "cup" and "bucket" capacitors, control means
25 coupled to the silicon-controlled rectifier for periodically energizing and de-energizing the silicon-controlled rectifier for transferring electric charge from the "cup" capacitor to the "bucket" capacitor, and pulse
30 means coupled to the "bucket" capacitor to develop a turn-off pulse for terminating operation of the inverter circuit.

35 The accompanying drawings show one example of apparatus embodying this invention.

Brief Description of the Drawings

40 Figure 1 is a simplified block diagram showing the basic construction of the apparatus;

Figure 2 is a detailed partially block and partially schematic diagram of the apparatus;

45 Figure 3 is a detailed schematic diagram of the wattsecond sensing means; and

Figure 4 is a detailed schematic diagram of the over-voltage sensing means.

Detailed description of the Illustrated

EXAMPLE

50 The induction heating apparatus 10, as shown in Figure 1, includes a generator 12 connected to conventional AC energizing power by means of a cable 14. The generator 12 delivers AC power to an induction
55 heating unit 15, at a frequency of the order of eight to ten kiloHertz. The induction heating unit 15 receives this power through a multiconductor cable 16 which can be flexible and of substantial length. Hence the unit 15 can be manoeuvred relatively to the generator 12, so that a relatively well-defined area on a large sheet of metal 18
60 can be heated. The sheet metal 18 may be an automobile body panel.

The induction heating unit 15 includes a U-shaped, or horse-shoe type inductance element, comprising a ferrite magnetic core member 20 which has the central portion thereof wrapped by an exciter coil 22. Connected in series with the exciter coil 22 is a capacitor 24. This capacitor 24 forms a series resonant circuit with the coil 22 and its value is so selected that the resonant frequency of this series circuit is close to the operating frequency of the apparatus. The generator 12 includes means for presetably selecting the frequency at the output thereof so that substantial coincidence between the output frequency and the resonance frequency of the series combination of elements 22 and 24 is at all times obtained. This then ensures maximum efficiency of energy transfer between the generator 12 and the induction heating unit 15.

Referring now to Figure 2, the coil 22 of the induction unit 15 is shown as being connected in series with a resistor 30 and the capacitor 24. The resistor 30 represents the internal resistance of the circuit as obtained by the reflected losses generated in the load during induction heating. The primary winding 33 of an output transformer 32 in the generator is energized by an inverter circuit 34. The transformer 32 has a ferrite magnetic core. The secondary winding 35 thereof is closely coupled to the primary winding, and energizes the series combination of inductance element 22 and the capacitor 24 which comprises a tuned circuit which is resonant or close to resonance at the operating frequency and represents, together with resistance 30 referred to the series circuit, the load for secondary winding 35.

Energizing current for the induction heating system, including generator 12, is obtained by a pair of lines 38 and 39 which are connected to a conventional source of alternating current voltage operated at 60 Hz. Power transfer means 40 are interposed between the lines 38 and 39 and the inverter circuit 34 to provide direct current energy to the inverter. The direct current energy is obtained by a full wave rectifier circuit arrangement of the power transfer means 40 which is completely void of filter capacitors so that at each half cycle of the applied alternating current voltage there is a zero voltage condition. This zero voltage condition is utilized to render a silicon-controlled rectifier 42 non-conductive whenever the gate electrode thereof is not supplied with a gating pulse.

The gate-emitter terminals of silicon-controlled rectifier 42 are coupled to a gate-controlled timing circuit 44 which is operatively energized by means of a switch 46 to initiate operation of the induction heating system. The gate-controlled timing cir-

cuit 44 is powered by means of a DC full-wave rectifier circuit 47 which may or may not be filtered to eliminate ripple.

Another full-wave DC rectifier circuit 50 is connected to the lines 38 and 39, and it supplies DC current to a variable frequency signal generator 52 which has a double winding primary transformer 54 connected to the output terminals thereof. The transformer 54 includes double winding secondary means coupled to the inverter circuit 34 for controlling operation of the inverter. The operating frequency of the inverter as determined by the signal generator 52 is of the order of eight to ten thousand Hertz. However, since the inverter circuit 34 can be rendered inoperative at each zero crossing of the applied 60 Hertz power line, the duration of operation of the inverter can be controlled to within one one hundred and twentieth of a second.

While the capacitor 24 is shown as a fixed capacitor, it will be understood that it can be a variable capacitor or a bank of capacitors switchably selected so as to be at all times in series resonance at the operating frequency. The frequency of the signal generator 52 and the frequency of the resonant tuned circuit formed by the inductance element 22 and capacitor 24 are selected to provide maximum efficiency of energy transfer between the output transformer 32 of the inverter 34 and the inductance element 22. Once the proper frequency of operation is selected, the apparatus will provide a multitude of repeated operations having the same amount of energy transferred into the metal sheet 18, Figure 1. Readjustment of the frequency of operation or of the resonance characteristic of the tuned circuit is only necessary upon substantial changes in operating characteristics, i.e. either different metal thicknesses being heated or longer cables 16 being used.

To ensure that the exact amount of energy is absorbed by the workpiece, means to terminate operation of the induction heating apparatus is provided. This means takes the form of a voltage integrating circuit 60 having an input thereof coupled across the capacitor 24 and an output thereof coupled to input terminals of the inverter 34. The output of the voltage integrating circuit will render the inverter circuit 34 inoperative when the desired amount of energy has been transferred into the workpiece.

An over-voltage sensing circuit 62 is also coupled across the capacitor 24, and has output terminals thereof connected to the input of the inverter circuit 34. The over-voltage sensing circuit 62 senses the voltage value developed across the capacitor 24 and, should this voltage value exceed a predetermined maximum value as set by a

reference voltage, it will generate a turn-off signal to disable the inverter circuit 34. Although the voltage integrating circuit 60 and the over-voltage sensing circuit 62 are shown as being coupled across the capacitor 24, it will be understood that they can be coupled across the inductance element 22 with equal efficiency.

The voltage integrating circuit is utilized with the induction heating apparatus so that precise quantities of heat can be absorbed by the workpiece time after time so that consistency of operation is obtained. For example, for a given material of given dimensions with similar electrical and thermal characteristics, the temperature reached at any time as the result of the application of induction heating is sufficiently approximated to be proportional to the product of the power applied and the time of exposure. If it can be assumed that the power input remains the same for all similar conditions of operation, then the sole requirement to obtain a given predetermined temperature is to operate the induction heating unit for an exact period of time, which can be measured by any one of the well-known timing circuits. But, in the absence of a constant input voltage, which is most likely the case, a given time period will not produce the necessary constant temperature, because the total watts input will be different. This means that if the power line input varies, so also will the final temperature of the workpiece.

There are several means to obtain a constant voltage input to induction heating apparatus. However, known means, such as constant voltage transformers, are relatively large and expensive. Also, the use of temperature measuring devices at the surface of the workpiece being heated is cumbersome and because of the constant repeated exposure to temperature is subject to excessive wear. The voltage integrating circuit overcomes these problems and, at the same time, provides means for the economical control of the induction heating apparatus.

The voltage integrating circuit is based on building-up the voltage across a capacitive element using the cup and bucket principle i.e. a small "cup" capacitor is repeatedly charged to a given voltage and periodically transfers its charge to a larger "bucket" capacitor.

The charge Q on a capacitor of value C is directly proportional to the product CV , where V is the charging voltage. The "cup" capacitor is initially charged to a voltage V_0 and then this charge transferred to the "bucket" capacitor. If the "bucket" capacitor is n times larger than the "cup" capacitor, the charge Q deposited on the smaller capacitor will have to be deposited n times on the large cap-

acitor in order to obtain the same voltage V_0 as initially existed on the smaller capacitor. If the charge transferred from the "cup" to the "bucket" capacitor has always
 5 been received within the same time interval, then the charge deposited on the "bucket" capacitor will be a measure of the integral of the voltage measured by the "cup" capacitor.

10 If only a fraction m of the total voltage made available on the "bucket" capacitor is to be used for control purposes, then a charge $q_1 = qn/m$ will have to be deposited on the larger capacitor where q is the charge
 15 on the "cup" capacitor.

Referring now to Figure 3 of the drawings, the general arrangement of the voltage integrating circuit is illustrated. The applied voltage to the circuit is obtained
 20 from the resonant tuned circuit comprising inductance element 22 and capacitance element 24, as shown in Figure 2. This AC voltage is applied to the input terminals of a bridge rectifier circuit 70, which rectifies
 25 this voltage and applies it to a first "cup" capacitor 71 through a resistor 72. The source voltage applied to the AC input of bridge rectifier 70 is represented by E_1 and is proportional to the voltage applied to the
 30 induction heating unit. This voltage will vary with variations in line voltage. The charging of the "cup" capacitor 71 by the rectifier system is determined by the time constant t_1 , corresponding to the product of
 35 the resistance of resistor 72 and the capacity of capacitor 71.

A second "bucket" capacitor 73 is connected across "cup" capacitor 71 but only electrically coupled thereto upon conduction
 40 of a silicon-controlled rectifier 74. This capacitor 73 has a value many times larger than that of capacitor 71. Between capacitor 73 and capacitor 71 is the low resistance afforded by the silicon-controlled
 45 rectifier 74, when conductive. As long as the silicon-controlled rectifier 74 is maintained in the nonconductive state, the capacitor 73 is disconnected from the circuit and receives no charge. Therefore, the capacitor 71
 50 receives the entire charge from the bridge rectifier 70 and will charge to a value E_1 . As soon as the gate electrode of the silicon-controlled rectifier 74 is supplied with a trigger voltage, the silicon-controlled rectifier
 55 will switchably become conductive to transfer the charge on capacitor 71 to capacitor 73. The silicon-controlled rectifier 74 remains conductive for a period which is less than the CR time constant of capacitor
 60 71 and resistor 72 so that the capacitor 73 is never charged by the voltage from the rectifier but merely receives the charge accumulated by capacitor 71. The time constant of the capacitor 73 is determined only
 65 by the resistance obtained when silicon-con-

trolled rectifier 74 is conductive, this being a relatively low value. Most advantageously, the time constant of capacitor 71 and resistor 72 is larger than the time constant
 70 of capacitor 73 and internal resistance of silicon-controlled rectifier 74. The period of conduction of silicon-controlled rectifier 74 is controlled by a commutating capacitor 76 which is charged through a resistor 77 from
 75 a separate voltage source 78. Capacitor 76 then commutates silicon-controlled rectifier 74 to the off condition. If capacitor 76 is small enough and resistor 77 is large enough, then the silicon-controlled rectifier
 80 74 will reach a nonconductive state in a very short period of time, this being the result of the time constant between these two components.

The DC source 78 is connected to a zener diode 79 through a resistor 80. The regulated voltage developed across zener diode 79 is used to energize a unijunction transistor 81 which has resistance elements 82
 85 and 83 connected in series with the base electrodes thereof. Connected to the emitter electrode of unijunction transistor 81 is a charging capacitor 84 in series with a variable resistance element 86. Unijunction transistor 81 together with its associated components form a relaxation type oscillator
 90 used as a timing circuit. The output pulses available across resistor 83 apply triggering pulses to the gate electrode of silicon-controlled rectifier 74, thus providing conductive periods thereof at a frequency determined by the time constant of capacitor 84
 95 and variable resistance element 86. The time constant is selected relatively large in comparison to the time constant provided by capacitor 71 and resistor 72. A pair of resistors 88 and 89 connected in series combination across capacitor 73 is chosen with
 100 appropriate values to permit the required triggering voltage to be applied to the emitter of unijunction transistor 90. The value of the series combination of resistors 88 and 89 is sufficiently large so as to prevent premature leakage of the charge on capacitor 73. Once a threshold voltage level is arrived at across the terminals of
 105 capacitor 73, the voltage appearing across the resistor 89 is applied to the emitter electrode of unijunction transistor 90 to render it conductive and produce an output pulse across a pulse-forming transformer 91. The unijunction transistor 90 is connected in series with a resistor 92 and the primary winding 93 of the pulse transformer 91. The secondary winding 94 of the transformer is then coupled back to the input terminals of
 110 the inverter 34, as shown in Figure 2, to disable the inverter at the precise time the threshold voltage level is reached across capacitor 73.

In operation, the voltage integrating cir- 130

cuit is energized by a portion of the AC voltage developed within the induction heating unit. As soon as the threshold voltage is developed across capacitor 73, this voltage will transmit a pulse signal to the emitter electrode of transistor 90 which, in turn, generates a turn-off signal at the output winding of the pulse transformer 91. Therefore, the total amount of energy delivered to the workpiece to be heated, which is represented by the resistance 30, Figure 2, is accurately controlled.

In the illustrated example, the voltage E_1 developed across the bridge circuit 70 may have a peak value of about 200 volts or higher, thus being adequate to operate the voltage integrating circuit.

The following component values are given by way of example, and not by way of limitation. The resistor 72 is 100 k ohms, capacitor 71 is 0.01 microfarads. These two components form a time constant of one millisecond. Capacitor 73 is 0.1 microfarads and the silicon-controlled rectifier 74 is of the type commonly referred to as C35 capable of operating at 250 volts and having an internal resistance, when conductive, of approximately two ohms. The capacitor 84 is of the order of one microfarad and resistance element 82 is approximately 10 k ohms, thus corresponding to a time constant of 10 milliseconds. The time constant provided by the silicon-controlled rectifier 74 and capacitor 73 is very short since the resistance of the silicon-controlled rectifier is very small.

For a better understanding of the over-voltage control circuit, reference is now made to Figure 4. As mentioned above, the primary function of the over-voltage control circuit is to limit the voltage value applied across certain electronic components. For example, the capacitor 24 has a maximum operating voltage characteristic which, if exceeded, would cause damage thereto. Also various solid state devices within the circuit may be damaged by extreme voltage conditions. The voltage impressed upon such components of an electrical or electronic circuit may depend upon conditions not necessarily inherent in the circuit itself, but rather by changes in such things as material constants, temperature variations, and the like. These changes influence the characteristic elements or devices to which the particular electronic circuit is applied.

One characteristic example is the control of voltages appearing across the tuning elements in a resonant circuit, such as the series resonant circuit in Fig. 1. Depending on the losses associated with the components at a particular frequency, the voltage developed across the capacitance and inductance, at resonance, will reach a relatively

high value. The voltage when off resonance on either side may be relatively low, but at resonance extreme high voltage conditions can occur across the electronic components. It is customary to express the expected voltage ratio between maximum and minimum voltages by the Q of the circuit. The higher the Q the higher the voltage will be under resonant conditions in comparison to the voltage across the elements when the frequency is off resonance or when there is a low Q.

It is the primary function of the over-voltage control circuit to detect voltages exceeding a certain predetermined value across any one of the circuit elements of the electronic circuit, preferably one of the resonant elements of the tuned circuit, and terminate operation of the induction heating unit when such over-voltage condition exists.

The circuit arrangement shown in Figure 4 comprises a pair of input terminals 101 and 102 connected across the capacitor 24 thereby applying a voltage divider network comprising resistors 103 and 104 thereacross. The juncture between resistors 103 and 104 is connected to the emitter electrode of a unijunction transistor 106 which, in turn, has the base electrodes thereof connected to a resistor 107 and the primary winding of a pulse transformer 108. A reference potential source 110 is connected across the base electrodes of the unijunction transistor 106 to provide a reference potential to be compared with the voltage developed at the emitter thereof as received from the capacitor 24. When the maximum value of voltage is sensed across the capacitor, unijunction transistor 106 is rendered conductive to develop a pulse signal in the pulse transformer 108. This pulse signal is then applied to the input terminals of the inverter circuit 34, Figure 2, as mentioned above, to terminate operation of the circuit.

WHAT WE CLAIM IS:—

1. A solid state induction heating apparatus comprising in combination: an inverter circuit, an output transformer having a primary winding connected to the inverter circuit and a closely coupled secondary winding, both the primary winding and the secondary winding being wound on a ferrite magnetic core, an inductance element connected in series with the inductance element, this series combination being connected across the terminals of the secondary winding of the output transformer, the series combination of the inductance element being tuned to a resonant frequency corresponding to the frequency generated by the inverter circuit.

2. An induction heating apparatus

cuit is energized by a portion of the AC voltage developed within the induction heating unit. As soon as the threshold voltage is developed across capacitor 73, this voltage will transmit a pulse signal to the emitter electrode of transistor 90 which, in turn, generates a turn-off signal at the output winding of the pulse transformer 91. Therefore, the total amount of energy delivered to the workpiece to be heated, which is represented by the resistance 30, Figure 2, is accurately controlled.

In the illustrated example, the voltage E_1 developed across the bridge circuit 70 may have a peak value of about 200 volts or higher, thus being adequate to operate the voltage integrating circuit.

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For a better understanding of the over-voltage control circuit, reference is now made to Figure 4. As mentioned above, the primary function of the over-voltage control circuit is to limit the voltage value applied across certain electronic components. For example, the capacitor 24 has a maximum operating voltage characteristic which, if exceeded, would cause damage thereto. Also various solid state devices within the circuit may be damaged by extreme voltage conditions. The voltage impressed upon such components of an electrical or electronic circuit may depend upon conditions not necessarily inherent in the circuit itself, but rather by changes in such things as material constants, temperature variations, and the like. These changes influence the characteristic elements or devices to which the particular electronic circuit is applied.

One characteristic example is the control of voltages appearing across the tuning elements in a resonant circuit, such as the series resonant circuit in Fig. 1. Depending on the losses associated with the components at a particular frequency, the voltage developed across the capacitance and inductance, at resonance, will reach a relatively

high value. The voltage when off resonance on either side may be relatively low, but at resonance extreme high voltage conditions can occur across the electronic components. It is customary to express the expected voltage ratio between maximum and minimum voltages by the Q of the circuit. The higher the Q the higher the voltage will be under resonant conditions in comparison to the voltage across the elements when the frequency is off resonance or when there is a low Q.

It is the primary function of the over-voltage control circuit to detect voltages exceeding a certain predetermined value across any one of the circuit elements of the electronic circuit, preferably one of the resonant elements of the tuned circuit, and terminate operation of the induction heating unit when such over-voltage condition exists.

The circuit arrangement shown in Figure 4 comprises a pair of input terminals 101 and 102 connected across the capacitor 24 thereby applying a voltage divider network comprising resistors 103 and 104 thereacross. The juncture between resistors 103 and 104 is connected to the emitter electrode of a unijunction transistor 106 which, in turn, has the base electrodes thereof connected to a resistor 107 and the primary winding of a pulse transformer 108. A reference potential source 110 is connected across the base electrodes of the unijunction transistor 106 to provide a reference potential to be compared with the voltage developed at the emitter thereof as received from the capacitor 24. When the maximum value of voltage is sensed across the capacitor, unijunction transistor 106 is rendered conductive to develop a pulse signal in the pulse transformer 108. This pulse signal is then applied to the input terminals of the inverter circuit 34, Figure 2, as mentioned above, to terminate operation of the circuit.

WHAT WE CLAIM IS:—

1. A solid state induction heating apparatus comprising in combination: an inverter circuit, an output transformer having a primary winding connected to the inverter circuit and a closely coupled secondary winding, both the primary winding and the secondary winding being wound on a ferrite magnetic core, an inductance element connected in series with the inductance element, this series combination being connected across the terminals of the secondary winding of the output transformer, the series combination of the inductance element being tuned to a resonant frequency corresponding to the frequency generated by the inverter circuit.

2. An induction heating apparatus



according to claim 1, wherein the connection between the inductance element and the secondary winding of the output transformer is a flexible connection allowing freedom of movement of the inductance element and the secondary winding of the output transformer is a flexible connection allowing freedom of movement of the inductance element without movement of the inverter circuit.

3. An induction heating apparatus according to claim 1 or claim 2, including voltage integrating means operatively coupled with the tuned circuit formed by the inductance element and the capacitance element for sensing the quantity of energy supplied thereto, this voltage integrating means including turn-off switch means coupled to the inverter circuit to terminate operation of the inverter circuit upon accumulation of a predetermined voltage integral.

4. An induction heating apparatus according to claim 3, wherein the voltage integrating means includes a rectifier means coupled to the capacitance element, a first capacitor coupled to the rectifier means, a second capacitor coupled to the first capacitor, a silicon-controlled rectifier coupled between the first and second capacitors, control means coupled to the silicon-controlled rectifier for periodically energizing and de-energizing the silicon-controlled rectifier for transferring electric charge from the first capacitor to the second capacitor, and pulse means coupled to the second capacitor to develop a turn-off pulse for terminating operation of the inverter circuit.

5. An induction heating apparatus according to claim 3, wherein the voltage integrating means includes a rectifier means coupled to the inductance element, a first capacitor coupled to the rectifier means, a second capacitor coupled to the first capacitor, a silicon-controlled rectifier coupled

between the first and second capacitors, control means coupled to the silicon-controlled rectifier for periodically energizing and de-energizing the silicon-controlled rectifier for transferring electric charge from the first capacitor to the second capacitor, and pulse means coupled to the second capacitor to develop a turn-off pulse for terminating operation of the inverter circuit.

6. An induction heating apparatus according to any of claims 1 to 5, further including over-voltage sensing means operatively coupled with the tuned circuit formed by the inductance element and the capacitance element, this over-voltage circuit providing automatic turn-off of the inverter circuit upon sensing a voltage that is beyond a predetermined voltage level.

7. An induction heating apparatus according to claim 6, wherein the over-voltage circuit means includes a voltage divider network connected across the capacitance element, a unijunction transistor having the emitter electrode thereof coupled to a junction intermediate the voltage divider network, and a reference voltage coupled across the base electrodes of the unijunction transistor, whereby the reference voltage is compared with the voltage developed across the capacitance element, and the unijunction transistor produces a turn-off pulse for the inverter circuit when the capacitance element develops a voltage beyond a predetermined voltage level.

8. An induction heating apparatus according to claim 1, substantially as described with reference to the accompanying drawings.

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