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Cunningham

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[54] **LOAD CONTROLLED INDUCTION HEATING**

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[52] **U.S. Cl.**......... **219/10.77**, 219/10.49, 323/32 SC

[51] **Int. Cl.**... **H05b 5/04**

[58] **Field of Search**........... 219/10.49, 10.75, 10.77; 323/32 SC; 317/33 SC, 33 VR; 328/151, 129; 307/310

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[57] **ABSTRACT**

An induction heating apparatus employing a series tuned, resonant circuit including a work coil adapted to be coupled to a load to be heated in a parallel, tuned, resonant tank circuit, a current release means for releasing current pulses to the tank circuit so as to cause resonance in this tank circuit and an operation control means for controlling the release of current pulses by the current release means can be made essentially automatic in operation to various degrees by including within the apparatus one or more of several different means.

The apparatus preferably includes a detector means for determining the presence or absence of the load coupled to the work coil and associated means for regulating the release of current pulses in accordance with the presence or absence of such a load. This detection means is preferably a voltage detection means used in conjunction with a sampling means serving to cause a release of current pulses without causing significant heating so that a voltage change in a tank circuit can be detected even when the apparatus has not been used for heating. When a load is detected by the detection means the apparatus is operated for either a time interval or until a predetermined condition of the load is reached unless during such a period the load is for any reason removed from the work coil.

30 Claims, 2 Drawing Figures

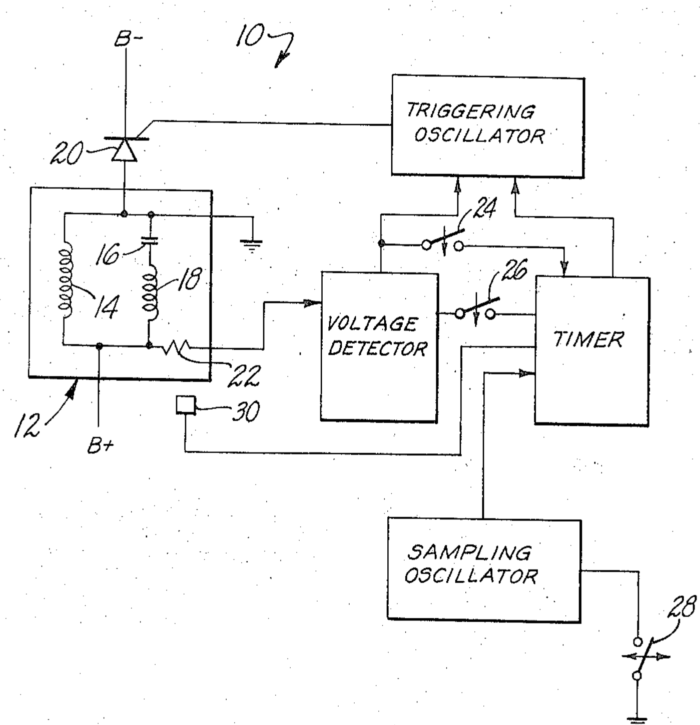
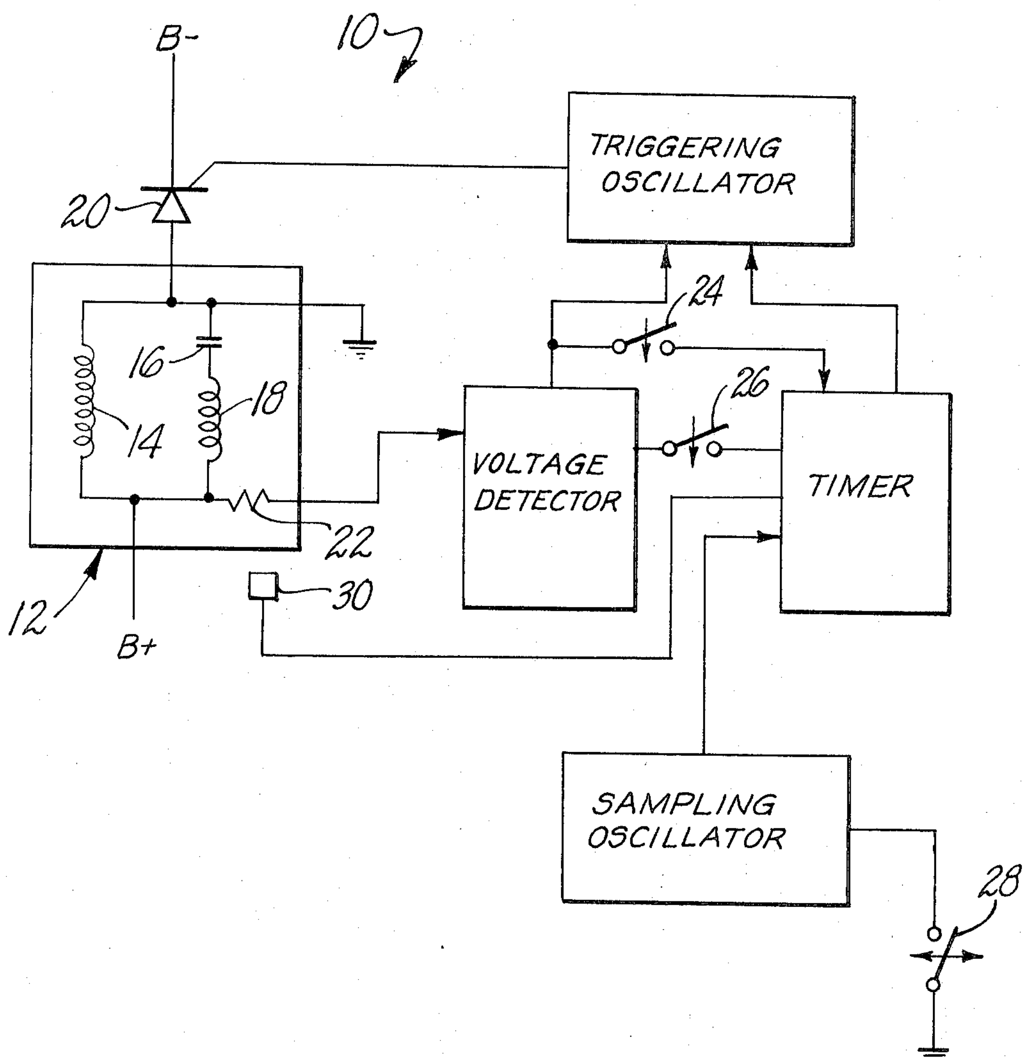


FIG. 1.


10
B-
20
TRIGGERING
OSCILLATOR
24
16
18
14
26
VOLTAGE
DETECTOR
TIMER
22
30
12
B+
SAMPLING
OSCILLATOR
28

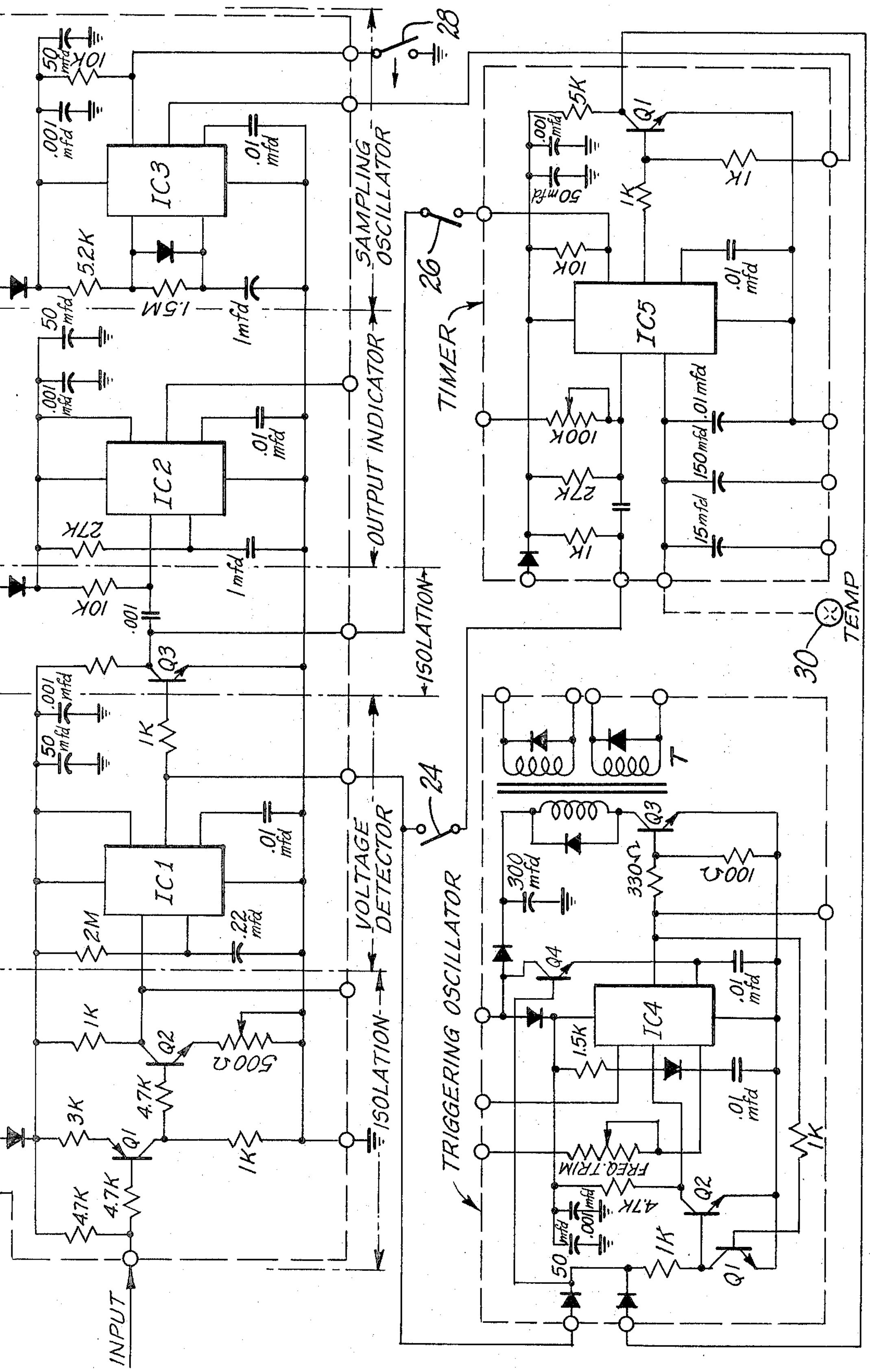

SAMPLING OSCILLATOR
OUTPUT INDICATOR
ISOLATION
VOLTAGE DETECTOR
ISOLATION
TIMER
TRIGGERING OSCILLATOR
IC1
IC2
IC3
IC4
IC5
INPUT
+12V
TEMP
FREQ. TRIM
28
26
24
30
T

FIG. 2.

LOAD CONTROLLED INDUCTION HEATING

CROSS-REFERENCE TO RELATED PATENTS

U.S. Pat. No. 3,637,790 issued to Ronald J. Cunningham, Jan. 25, 1972 entitled, "Induction Heating Apparatus."

BACKGROUND OF THE INVENTION

The expression "induction heating" is utilized to designate processes in which an alternating magnetic flux generated by passing an alternating current through a coil is used to heat an object or a charge inductively coupled to the coil. Because of its function, such a coil is normally referred to as a "work coil." Such an object or charge is normally referred to as a "load," since in a sense the work coil is loaded so as to be inductively coupled when such an object or charge is located so as to be contacted by the magnetic flux generated by the coil.

The field of induction heating is considered to be well-established. Currents of different frequencies are commonly utilized for different types of heating purposes. A number of different types of apparatuses have been developed for generating or providing the alternating currents used in induction heating at various different frequencies. A number of different types of work coils and apparatuses utilizing them have been developed for various specific purposes.

At the present time it is considered that there is a need to improve the operation of known induction heating apparatuses so that such apparatuses are safer and easier to use than before. This need is unquestionably related to a number of factors such as a need to minimize the chances of injury to personnel, a need to prevent mistakes which might damage the equipment utilized, a need to avoid mistakes which might tend to damage whatever is heated by an induction heating apparatus and the like. At least to a degree these various considerations are related to a desire to improve induction heating apparatuses so that such apparatuses are simplified and more efficient.

As the field of induction heating has advanced it has become known that effective induction heating can be accomplished through the utilization of a series tuned, resonant circuit in a parallel tuned, resonant tank circuit. In apparatuses using circuits of this type the work coil used for heating purposes is normally a coil in the series tuned, resonant circuit. In apparatuses of this type a current release means, normally an SCR (silicon controlled rectifier), serves to release or supply current pulses to the resonant circuit in accordance with the operation of a separate timing means or circuit connected to the SCR. In apparatuses of this type, the SCR is rendered non-conductive as a result of resonance in the tank circuit and the timing means serves to periodically turn the SCR on or render it conductive.

Circuits of this type are considered to be quite advantageous for a wide variety of different applications for a number of technical reasons which are unimportant to a consideration of the present invention. Prior apparatuses employing these circuits are considered to be somewhat disadvantageous because of the amount of operator "control" which has to be used with them, even though the amount of such control is approximately the same as has to be used with other older types of induction heating equipment. If induction heating apparatuses are to be widely adopted for various industrial use as well as for non-industrial uses such as household cooking purposes it is considered necessary to at least partially and preferably extensively automate such apparatuses.

The word "automate" here is used in the broad sense. As used it covers only making such apparatuses so that they will turn off automatically when loads are removed from them. It, also, is used in such a manner as to cover apparatuses which will both turn on and turn off when a load is placed upon them and when a load is removed from them, respectively. It also covers making such apparatuses so they will not only turn on and off in this manner, but so that they will also heat for either a predetermined period or unitl a predetermined condition is reached after they are turned on.

BRIEF SUMMARY OF THE INVENTION:

The invention is primarily directed to "automating" the operation of induction heating apparatuses employing a resonant tank circuit as indicated in the preceding discussion. Thus, the invention is intended to provide induction heating apparatuses which are of such a character that their operation minimizes the chances of injury and the chances of harmful or damaging mistakes. The invention is also intended to provide various degrees of automation of such apparatuses as may be desired or needed for various specific applications.

Objectives of the invention are also to provide induction heating apparatuses: which, although by necessity are somewhat complex, are nevertheless considered to be comparatively simple; which are capable of being easily and conveniently constructed at a comparatively nominal cost; which are capable of being operated at comparatively nominal costs; and which are capable of providing prolonged, reliable performance. Other objectives of the invention are: to provide methods of operating induction heating apparatus so as to render the operation of such equipment essentially automatic to a degree as may be desired for a particular application which are essentially simple in character and which may be carried out with a minimum of difficulty utilizing electronic techniques as hereinafter indicated.

In accordance with this invention these and various related objectives of it as will be apparent in subsequent portions of this specification are achieved by using an induction heating apparatus employing a series tuned, resonant circuit including a work coil adapted to be inductively coupled to a resonance load to be heated using the apparatus located in a parallel tuned, resonant tank circuit, current release means for releasing current pulses to the tank circuit so as to cause resonance in the tank circuit and an operation control means for controlling the release of such pulses by this release means.

Such components are preferably utilized with at least a detection means for regulating the performance of the operation control means so as to prevent current pulses from being released so as to cause heating in accordance with the location of a load on the work coil. Such a detection means at least is used to monitor the circuit so as to cause the discontinuance of the release of current pulses to cause heating upon the removal of a load from the work coil. It may also be used to monitor the circuit so as to detect the location of a load with respect to the work coil so as to cause the release of current pulses to commence heating. Preferably other means are used in addition to the detection means as hereinafter indicated in the detailed description of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

Further details of the present invention and many additional advantages of this invention will be apparent from a detailed consideration of the remainder of this specification and the accompanying drawings in which:

FIG. 1 is a block diagram showing the nature of the presently preferred embodiment or form of the induction heating apparatus for use in practicing the present invention; and

FIG. 2 is a circuit diagram giving details of various individual circuits which are used in combination in a presently preferred apparatus constructed in accordance with the block diagram illustrated in FIG. 1.

The accompanying drawings are primarily intended for explanatory purposes in illustrating a presently preferred mode of induction heating in accordance with this invention. The invention itself involves certain intangible concepts as are delineated in the appended claims forming a part of this specification. These concepts may be utilized with a wide range of differently constructed equipment through the use of what is considered to be routine skill in the electronics field.

DETAILED DESCRIPTION:

In FIG. 1 of the drawings there is indicated a complete load-controlled induction heating apparatus **10** in accordance with this invention. This apparatus **10** utilizes a parallel, tuned, resonant tank circuit **12** having an inductance **14** in one leg thereof and having in the other leg of this circuit **12** a capacitor **16** and a work coil **18.** This work coil **18** is adapted to be inductively coupled to a load to be heated utilizing the apparatus **10.** The capacitor **16** and the work coil **18** are chosen so that they constitute a series tuned, resonant circuit within the complete tank circuit **12.**

This tank circuit **12** is adapted to be supplied with power from a B- conventional power supply through an SCR **20** serving as a current release means in the complete apparatus **10.** This apparatus **10** may be, and preferably is grounded as indicated in the drawings. The gate of the SCR **20** is directly connected to a triggering oscillator which is designed to provide current pulses to the SCR **20** so as to cause such current pulses to be released to the tank circuit **12** so that resonance will occur in this tank circuit **12.**

Such resonance will, of course, create a reverse current which will back-bias the SCR **20** so as to turn this SCR **20** off or render it non-conductive until it is rendered conductive by a further pulse from the triggering oscillator. As each current pulse is supplied to the tank circuit **12** through the SCR **20** a voltage multiplication affect will be obtained in the series tuned resonant circuit consisting of the capacitor **16** and the work coil **18.**

This voltage multiplication affect as current pulses of constant voltage are released to the tank circuit **12** is caused by well recognized performance considerations. As this voltage doubling or multiplication is achieved in this series tuned resonant circuit comprising the capacitor **16** and the work coil **18,** a further voltage multiplication affect will be achieved in the entire tank circuit **12** as a result of well established, recognized considerations relating to the operation of this type of circuit.

With the tank circuit **12** the capacitance of the capacitor **16** and the inductance of the inductance **14** are fixed. The inductance of the coil **18** while in one sense "fixed" is in another sense variable depending upon whether or not this work coil **18** is inductively coupled to a load such as a metal container or a quantity of metalic material to be heated. Because of the fact that the inductance of the coil **18** can be varied depending upon its being coupled to a load, it is possible to utilize the amount of voltage multiplication within the tank circuit **12** as an indication as to whether or not a load in inductively coupled to the work coil **18.**

With the present invention the voltage within the tank circuit **12** is detected or monitored through the use of a separate voltage detector. This voltage detector is directly connected to the tank circuit **12** at the extremity of this circuit remote from the SCR **20** through the use of a small dropping resistor **22.** As this voltage detector operates it serves to monitor the voltage multiplication occuring in the tank circuit **12** so as to compare the voltage developed in response to a current pulse supplied through the SCR **20** with the voltage developed in response to a preceding pulse supplied through this SCR **20.**

When a load is inductively coupled to the work coil **18** after no load has been coupled to this coil, a voltage fall or drop will be monitored in this manner; when a load is removed from the work coil **18** so as to no longer be inductively coupled to this work coil **18** a voltage rise will be monitored. Such a rise or fall is used in accordance with this invention in either of several manners so as to govern the subsequent operation of the SCR **20.** When the apparatus **10** is operated in what may be regarded sa a manual mode the switches **24** and **26** are open, while the switch **28** is closed.

In this manner of operation the voltage detector will supply a signal directly to the triggering oscillator when a voltage rise is detected indicating the absence of a load inductively coupled to the work coil **18.** The signal supplied in this manner can be used to completely inhibit or block the operation of the triggering oscillator so that this triggering oscillator will no longer function. When this occurs, no further current pulses will be supplied by the SCR **20** to the tank circuit **12.** Thus, the voltage rise occurring can be used to completely shut off the operation of the entire apparatus **10** until a separate switch (not shown) is actuated so as to turn on this apparatus **10** again.

With the present invention, however, it is preferred that the voltage detector only partially inhibit or block the operation of the triggering oscillator to the extent necessary so that no or substantially no heating occurs. The purpose of this is to enable the triggering oscillator to be operated in what may be referred to in a sampling or non-heating mode in which current pulses are supplied to the tank circuit **12** sufficiently infrequently so that no substantial heating will occur as the result of the application of these pulses. It is desired to supply current pulses to the tank circuit **12** in this manner so that a signal can be provided which will provide a voltage in the tank circuit **12** which can be detected by the voltage detector.

In this sampling mode of operation the switch **28** is closed so that a sampling oscillator will supply signals through a separate timer directly to the triggering oscillator. If desired, this sampling oscillator can be directly coupled to the triggering oscillator although for practical reasons pertaining to routine engineering constructional details this is not preferred with the present invention. The purpose of this sampling oscillator is to cause the triggering oscillator to operate in such a manner that the triggering oscillator causes the SCR 20 to release current pulses which will not cause significant heating.

Thus, the sampling oscillator is intended to unblock and permit limited operation of the triggering oscillator so that this oscillator provides spaced, repetitive pulses to the SCR 20 so that the SCR 20 in turn releases current pulses to the tank circuit 20 at intervals which are sufficiently long and/or are sufficiently spaced from one another, and which are of such a time duration which is sufficiently short so that no significant heating is accomplished in the apparatus 10 or by this apparatus as it is operated in a sampling mode. The signals supplied by the sampling oscillator, of course, correspond to the current pulses released by the SCR 20 during this sampling mode of operation.

During this sampling mode of operation when this voltage detector detects a voltage drop indicating that a load has been or is being inductively coupled to the work coil 18, this voltage detector provides a signal to the triggering oscillator which no longer inhibits or blocks the operation of this oscillator. Preferably this triggering oscillator is a free-running oscillator which will thereafter provide a repetitive series of pulses to the SCR 20 so that this SCR 20 releases a repetitive series of current pulses to the tank circuit 12 at a rate sufficient to cause or result in the work coil 18 performing its intended heating function.

The apparatus 10 will thereafter continue to operate in this heating manner or mode until such time as the voltage detector monitors a voltage rise in the tank circuit 12. At such a time the voltage detector will again serve to inhibit or block the triggering oscillator so that it thereafter operates in a sampling mode in which no significant heating is accomplished as a consequence of its operation. This will continue until a voltage drop in the tank circuit 12 again causes operation in a heating mode.

The apparatus 10 may, also, be operated in what may be referred to as an "automatic" mode of operation by closing the switches 24 and 26 and opening the switch 28. In this automatic mode of operation any voltage drop detected by the voltage detector will supply a signal directly to a timer. This timer will thereafter supply a signal to the triggering oscillator so as to cause the triggering oscillator to operate in a normal heating mode as a free-running oscillator for a fixed time period capable of being foreshortened.

In this automatic mode of operation when the voltage detector detects a rise in the voltage in the tank circuit 12, this voltage detector will thereafter "override" the timer so as to directly inhibit or block the operation of the triggering oscillator in a heating mode or manner so as to foreshorten this time period. When the voltage detector has overridden the timer in the operation of the triggering oscillator in this manner, the sampling oscillator will thereafter continue to operats so that current pulses are supplied through the SCR 20 in order for the apparatus 10 to thereafter function in a sampling mode until another load inductively coupled to the work coil 18 is detected by the voltage detector as a result of a voltage drop.

Although it is not necessary, it is preferred to include within the apparatus 10 a thermocouple 30 which is directly connected to the timer employed. This thermocouple 30 is adapted to be utilized either in or in contact with a load coupled by the coil 18 so as to detect the temperature of such a load so as to feedback to the timer a signal indicating such a temperature so as to also foreshorten the operation of the timer in controlling the period when the triggering oscillator is allowed to function in a heating mode if this temperature should be reached before the end of the period set by this timer.

This thermocouple 30 in effect serves as a condition sensing device used in employing a predetermined condition of any work load heated within the apparatus 10. Various other related conditioning-sensing devices such as an optical condition-sensing device may be utilized with the invention in lieu of the thermocouple 30 in those cases where it is desired to utilize this conditioning-sensing feature in governing or controlling the operation of the apparatus 10. Any such conditioning-sensing device should be constructed in accordance with established practice so as to utilize established construction and circuity.

Within this automatic mode of operation the timer may be operated essentially as an on-off device so as to supply a signal enabling the triggering oscillator to operate in a heating mode for a period determined by the time interval necessary for such a load to be heated to a condition as detected or determined by a condition-sensing device such as the thermocouple 30. If desired the apparatus 10 can be operated so that the timer partially inhibits operation of the triggering oscillator so as to cause limited heating after such a condition is sensed. With the apparatus 10 such a time interval or heating is, of course, capable of being cut short or foreshortened if the load should be removed prior to such a condition being sensed since the removal of a load coupled to the coil 18 will cause a voltage rise in the tank circuit 12 which will be detected by the voltage detector so as to in turn block or inhibit the triggering oscillator from further operation in a heating mode.

The timer used in the apparatus 10 includes what may be regarded as a "reset means" for preventing operation of the triggering oscillator and various other parts of the apparatus 10 as described in a heating mode after the end of a time period when the complete apparatus 10 has been operated in this heating mode. This is best explained by reviewing the fact that this apparatus 10 will automatically operate in what has been described in the preceding as a sampling mode whenever it is not operated in a heating mode.

As the apparatus 10 is operated in this sampling mode the sampling oscillator permits limited operation of the triggering oscillator so as to provide a voltage multiplication in the tank circuit 12 in response to each pulse released to the tank circuit 12. The voltage detector used monitors the voltage in the tank circuit 12. No significant change will occur in the voltage detected in this manner as long as a load which has been heated remains inductively coupled to the coil 18.

Because of this, unless a reset structure is utilized during the operation of the apparatus 10 in an automatic mode of operation, after the end of a period of operation in a heating mode the sampling oscillator would supply a signal which, through a mechanism as indicated, would lead to the voltage detector detecting or monitoring a voltage indicating that a load was inductively coupled to the work coil **18** and that the apparatus **10** should again function in a heating mode. Thus, without a reset means the apparatus **10** would continue to heat for successive periods which would follow immediately one after another. The reset means utilized prevents this.

In the apparatus **10** the reset means is conventional flip-flop circuit incorporated within the timer used. Each time a signal is supplied to the timer from the voltage detector to cause operation in a heating mode, this flip-flop is actuated so as to prevent reactuation of the timer until such time as the voltage detector has detected a voltage rise indicating that the load which has been previously heated by the work coil **18** has been removed from the work coil **18** to at least a sufficient extent so as to be no longer inductively coupled to it. Such a voltage rise will reset the flip-flop in the timer so as to permit subsequent operation in a heating mode.

The significance of the apparatus **10** and the various features explained in the preceding can be readily illustrated by considering the use of this apparatus **10** in an industrial application or in a common household stove in which the load coupled to the coil **18** would normally be a pan located in proximity to, but isolated from this coil **18.** In any such application, regardless of the inclusion of the other features of the invention, the feature of automatically stopping the operation of the tank circuit **12** in a heating mode or manner in response to removal of the load being heated is quite advantageous.

The operation of the apparatus **10** so as to cause heating under no-load conditions could easily result in inadvertent accidents and/or equipment damage. Further, the concept of operating the apparatus **10** in a sampling mode when it is not being operated in a heating manner is considered to be significant in that it provides induction heating which essentially is automatic in that it is turned on when a load is located so as to be heated and it is cut off when the load is removed from a location where it is inductively coupled to the heating coil employed.

Although these effects can be achieved through the use of weight sensitive switches or the like, it is advantageous to achieve them as indicated in this specification by electronic means. This makes it possible to provide structures such as industrial heaters and stove tops which can be operated on an essentially automatic type basis and which are free from any parts such as switch arms. Conventional switches can be disadvantageous because of the possibility of non-performance as a result of dirt accumulation and the like. In cooking type applications the presence of such switches can also interfere with the maintenance of sanitary conditions.

The apparatus **10** is further considered significant in that when it is operated in the so-called "automatic" mode, this apparatus will heat a load only to the extent desired. This is quite important when the apparatus **10** is to be utilized for heating applications where over heating can cause loss. This apparatus **10** is particularly desirable for such applications because it will not operate so as to cause heating after a heating operation has been performed until the load previously heated has been removed from the apparatus **10.**

The apparatus **10** can be built to operate in various different time intervals and frequencies as may be desired for various different specific applications. It is presently considered preferable that the triggering oscillator provide a signal to the SCR **20** used at a frequency of from about 100 to about 500 KHZ and the power wave of these pulses be of about 10μS duration. The applied power supplied to the SCR **20** may be of any convenient constant voltage desired for use in the complete apparatus.

It is presently considered that the inductance **14** should be from about 250μH to about 150μH, that the capacitor **16** should be from about 0.5 to about 20μF in capacity and that unloaded the work coil **18** have an inductance of from about 1μH to 50μH. At this time it is preferred that the sampling oscillator serve to block operation of the triggering oscillator for about 1 second periods and permit operation of the triggering oscillator for about 5 ms subsequent periods when the apparatus **10** is operated in a sampling mode.

The timer utilized is preferably capable of being set so as to govern the operation in a heating mode for periods of any desired duration. The voltage detector utilized is preferably operated on a continuous basis although, if desired, it can be set so as to monitor voltage changes at rather frequent intervals.

It is believed that those skilled in the art of electronics will be able to practice the invention set forth in this specification through the use or application of routine skill in this field on the basis of the preceding disclosure. In an effort to facilitate utilization of the present invention a complete circuit diagram of the various circuit parts used in connection with two conventional SCR's to supply power to a tank circuit such as the circuit **12** described in the preceding is given in FIG. **2** of the drawings.

The rectangular boxes in this FIG. **2** are all intended to designate integrated circuits designated as Signetics linear integrated circuits No. 555 produced by Signetics, 811 East Argues Ave., Sunnyvale, Calif. 94086. The diodes shown in this circuit diagram are conventional blocking diodes and the transistors shown in it are conventional transistors used in a conventional manner. Various representative values for other circuit components are given to facilitate use of this circuit.

As the circuit shown in FIG. **2** is used, an input as shown from a tank circuit such as the circuit **12** is fed through an isolation stage to an integrated circuit used as the voltage detector. The signal from this voltage detector is fed through another isolation stage to an output indicator part of the circuit which is intended to provide an output to an indicator lamp coupled to the circuit at a connection point as shown in the drawings. This second isolation stage is connected to a sampling oscillator as shown. The sampling oscillator is directly connected to the timer. Both this timer and the voltage detector are connected to the triggering oscillator as indicated so as to provide outputs at the transformer of this triggering oscillator which may be used at the gates of two different SCR's used to release current pulses to a single tank circuit.

I claim:

1. An induction heating apparatus having a series tuned resonant circuit including a work coil adapted to be inductively coupled to an inductance load to be heated using said apparatus in a parallel, tuned resonant tank circuit, current release means for releasing current pulses to said tank circuit so as to cause resonance in said tank circuit, said current release means being connected to said tank circuit and an operation control means for controlling the release of current pulses by said current release means to said tank circuit connected to said current release means, said operation control means being capable of causing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil, in which the improvement comprises:

said release means being capable of releasing current pulses of a constant amplitude and a uniform duration at a frequency sufficient to cause heating by said coil in response to a signal by said control means,

detection means which is responsive to the absence of a load inductively coupled to said work coil for preventing said operation control means from causing the release of current pulses at said rate sufficient to cause heating by said release means when there is no inductive load located so as to be inductively coupled to said work coil.

2. An induction heating apparatus as claimed in claim 1 wherein:

said detection means is a voltage detection means capable of detecting a voltage rise in said tank circuit.

3. An induction heating apparatus as claimed in claim 1 wherein:

said detection means is a voltage detection means capable of detecting a voltage rise in said tank circuit.

4. An induction heating apparatus as claimed in claim 1 including:

sampling means for periodically enabling said operation control means to cause said release means to release sampling current pulses to said tank circuit at intervals which are sufficiently long and for time periods which are sufficiently short so that no significant heating occurs as the result of said sampling means operating when said operation control means is prevented from causing the release of current pulses by said detection means, and wherein

said detection means also is for detecting the presence of an inductive load located so as to be coupled to said work coil and for governing the operation of said operation control means so as to cause the release of current pulses by said release means when an inductive load is located so as to be inductively coupled to said work coil.

5. An induction heating apparatus as claimed in claim 3 including:

interval control means for permitting the release of current pulses to said tank circuit for a period which is independent of when an inductive load is located so as to be inductively coupled to said work coil,

said detection means serving to prevent said operation control means from causing the release of current pulses by said release means during said period if there is no inductive load located so as to be inductively coupled to said work coil during said period.

6. An induction heating apparatus as claimed in claim 5 wherein:

said interval control means is a timing means and said period is for a time interval determined by said timing means.

7. An induction heating apparatus as claimed in claim 5 wherein:

said interval control means is a condition sensing means for determining the duration of said period in accordance with the condition of a load inductively coupled to said work coil.

8. An induction heating apparatus as claimed in claim 5 wherein:

said interval control means comprises timing means and condition sensing means, said timing means serving to time a period capable of being shortened upon the occurrence of a condition sensed by said conditioning sensing means.

9. An induction heating apparatus having a series tuned resonant circuit including a work coil adapted to be inductively coupled to an inductance load to be heated using said apparatus in a parallel, tuned resonant tank circuit, current release means for releasing current pulses to said tank circuit so as to cause resonance in said tank circuit connected to said tank circuit and an operation control means for controlling the release of current pulses by said current release means to said tank circuit connected to said current release means, said operation control means being capable of causing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil, in which the improvement comprises:

detection means for preventing said operation control means from causing the release of current pulses at said rate sufficient to cause heating by said release means when there is no inductive load located so as to be inductively coupled to said work coil,

sampling means for periodically enabling said operation control means to cause said release means to release sampling current pulses to said tank circuit at intervals which are sufficiently long and for time periods which are sufficiently short so that no significant heating occurs as the result of said sampling means operating when said operation control means is prevented from causing the release of current pulses by said detection means,

said detection means also being for detecting the presence of an inductive load located so as to be coupled to said work coil and for governing the operation of said operation control means so as to cause the release of current pulses by said release means when an inductive load is located so as to be inductively coupled to said work coil,

interval control means for permitting the release of current pulses to said tank circuit for a period which is independent of when an inductive load is located so as to be inductively coupled to said work coil.

said detection means serving to prevent said operation control means from causing the release of current pulses by said release means during said period if there is no inductive load located so as to be inductively coupled to said work coil during said period,

reset means for preventing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil until after such a load which has been heated through the operation of said apparatus has been removed from said work coil so as to no longer be inductively coupled to said work coil.

10. An induction heating apparatus having a series tuned resonant circuit including a work coil adapted to be inductively coupled to an inductance load to be heated using said apparatus in a parallel, tuned resonant tank circuit, current release means for releasing current pulses to said tank circuit so as to cause resonance in said tank circuit connected to said tank circuit and an operation control means for controlling the release of current pulses by said current release means to said tank circuit connected to said current release means, said operation control means being capable of causing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil, in which the improvement comprises:

detection means for preventing said operation control means from causing the release of current pulses at said rate sufficient to cause heating by said release means when there is no inductive load located so as to be inductively coupled to said work coil,

sampling means for periodically enabling said operation control means to cause said release means to release sampling current pulses to said tank circuit at intervals which are sufficiently long and for time periods which are sufficiently short so that no significant heating occurs as the result of said sampling means operating when said operation control means is prevented from causing the release of current pulses by said detection means, and wherein

said detection means also is for detecting the presence of an inductive load located so as to be coupled to said work coil and for governing the operation of said operation control means so as to cause the release of current pulses by said release means when an inductive load is located so as to be inductively coupled to said work coil,

interval control means for permitting the release of current pulses to said tank circuit for a period which is independent of when an inductive load is located so as to be inductively coupled to said work coil,

said detection means serving to prevent said operation control means from causing the release of current pulses by said release means during said period if there is no inductive load located so as to be inductively coupled to said work coil during said period,

reset means for preventing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil for a time period.

11. An induction heating apparatus having a series tuned resonant circuit including a work coil adapted to be inductively coupled to an inductance load to be heated using said apparatus in a parallel, tuned resonant tank circuit, current release means for releasing current pulses to said tank circuit so as to cause resonance in said tank circuit connected to said tank circuit and an operation control means for controlling the release of current pulses by said current release means to said tank circuit connected to said current release means, said operation control means being capable of causing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil, in which the improvement comprises:

detection means for preventing said operation control means from causing the release of current pulses at said rate sufficient to cause heating by said release means when there is no inductive load located so as to be inductively coupled to said work coil and for detecting the presence of an inductive load located so as to be coupled to said work coil and for governing the operation of said operation control means so as to cause the release of current pulses by said release means so as to cause heating when an inductive load is located so as to be inductively coupled to said work coil,

said operation control means being a free-running oscillator,

said detection means being a voltage detection means capable of sensing the voltage in said tank circuit and is capable of controlling the operation of said free-running oscillator in response to the voltage in said tank circuit, and

sampling means for periodically permitting operation of said free-running oscillator when the operation of said free-running oscillator is blocked by said detection means so as to cause said free-running oscillator and said release means to release current pulses to said tank circuit at intervals which are sufficiently long and for time periods which are sufficiently short so that no significant heating occurs as the result of the release of said sampling current pulses in order to provide for a current in said tank circuit which will give a voltage which can be detected by said voltage detection means.

12. An induction heating apparatus as claimed in claim **11** including:

interval control means for permitting the release of current pulses to said tank circuit for a period which is independent of when an inductive load is located so as to be inductively coupled to said work coil,

said detection means serving to prevent said operation control means for causing the release of current pulses by said release means during said period if there is no inductive load located so as to be inductively coupled to said work coil during said period.

13. An induction heating apparatus which comprises:

a parallel, tuned, resonant tank circuit having a series tuned resonant circuit in one leg thereof, said series tuned resonant circuit including a work coil adapted to be inductively coupled to an inductance load to be heated using said apparatus,

current release means connected to said tank circuit for releasing current pulses to said tank circuit so as to cause resonance in said tank circuit,

operation control means capable of being operated in a heating mode and in a sampling mode connected to said current release means for controlling the release of current pulses by said current release means,

said operation control means being capable of causing the release of current pulses by said current release means at a rate sufficient to cause heating of an inductive load coupled to said work coil when operated in said heating mode,

said operation control means being capable of causing the release of current pulses by said current release means at a rate insufficient to cause significant heating when operated in said sampling mode,

detection means connected to said tank circuit for detecting either a voltage increase or a voltage decrease in said tank circuit during the release of current pulses by said current release means,

sampling means connected to said operation control means for operating said operation control means in said sampling mode,

interval control means connected to said operation control means for operating said operation control means in said heating mode,

said detection means being operable to actuate said interval control means when a voltage drop occurs in said tank circuit during the operation of said operation control means so that said interval control means will cause said operation control means to operate in a heating mode for an interval, such a voltage drop serving to indicate the presence of a load inductively coupled to said work coil,

said detection means being operable to actuate said interval control means when a voltage rise occurs in said tank circuit during the operation of said operation control means so that said interval control means will no longer operate so as to cause said operation control means to operate in said heating mode, such a voltage drop serving to indicate the absence of a load inductively coupled to said work coil,

said sampling means being operative to operate said operation control means in said sampling mode when said operation control means is not operated in said heating mode.

14. An induction heating apparatus as claimed in claim 13 wherein:

said operation control means is a free-running oscillator, the operation of which is capable of being blocked by said detection means, said interval control means and said sampling means.

15. An induction heating apparatus as claimed in claim 13 including:

reset means for preventing the operation of said operation control means in said heating mode directly after the heating of a load by said work coil so as to prevent the inadvertent reheating of a heated load heated by said work coil.

16. An induction heating apparatus as claimed in claim 13 wherein:

said operation control means is a free-running oscillator, the operation of which is capable of being blocked by said detection means, said interval control means and said sampling means,

and including,

reset means for preventing the operation of said operation control means in said heating mode directly after the heating of a load by said work coil so as to prevent the inadvertent reheating of a heated load heated by said work coil.

17. An induction heating apparatus as claimed in claim 16 wherein:

said interval control means serves to operate said operation control means in a heating mode for a time period.

18. An induction heating apparatus as claimed in claim 16 including:

sensing means for determining the duration of a period in accordance with condition of a load inductively coupled to said work coil, said sensing means being connected to said interval control means so as to control the time interval said operation control means is operated in said heating mode.

19. An induction heating apparatus as claimed in claim 16 wherein:

said interval control means serves to operate said operation control means in a heating mode for a time period,

and including

sensing means for determining the condition of a load inductively coupled to said work coil, said sensing means being connected to said interval control means so as to cut short the time period said operation control means is operated in a heating mode by said interval control means if a predetermined condition of said load is sensed by said sensing means.

20. In a process for induction heating using an induction heating apparatus employing a series tuned resonant circuit including a work coil adapted to be inductively coupled to a resonance load to be heated using said apparatus located in a parallel, tuned resonant tank circuit, and current release means for releasing current pulses to said tank circuit so as to cause resonance to said tank circuit, the improvement which comprises

operating said current release means so as to cause said release means to release current pulses of a constant amplitude and uniform duration at a frequency sufficient to cause heating by said coil,

monitoring said tank circuit so as to detect a voltage rise occuring in said tank circuit as a result of the removal of a load inductively coupled to said work coil from said work coil, and

discontinuing the release of current pulses to said tank circuit so as to cease heating as a result of the operation of said tank circuit upon the occurrence of such a voltage rise.

21. A process as claimed in claim 20 including:

sampling said tank circuit after the discontinuance of the release of current pulses to said tank circuit so as to cause heating by periodically releasing current pulses to said tank circuit by causing the release of sampling current pulses at intervals which are sufficiently far apart and which are sufficiently short so as to cause no significant heating as the result of said tank circuit,

monitoring said tank circuit so as to detect any voltage drop occurring during said sampling as the result of the placement of a load so that it is inductively coupled to said work coil,

operating said current release means so as to release current pulses to said tank circuit so as to heat a load inductively coupled to said work coil upon the occurrence of any such voltage drop.

22. A process as claimed in claim 21 wherein:

said operating is carried out for a predetermined time period, and including

monitoring said tank circuit during said time period so as to detect any voltage rise occurring in said tank circuit as the result of the removal of a load inductively coupled to said work coil from said work coil during said time period, and

discontinuing the release of current pulses to said tank circuit so as to cause heating as the result of the operation of said tank circuit upon the occurrence of such a voltage rise during said predetermined time period.

23. A process as claimed in claim 22 including:

blocking the further release of current pulses so as to further heat a previously heated load inductively coupled to said work coil after said time priod for a further, additional time period.

24. A process as claimed in claim 22 including:

sensing a condition of a load heated during said operating and continuing said operating until a predetermined sensed condition of said load is determined,

monitoring said tank circuit during said sensing so as to detect any voltage rise occurring in said tank circuit as the result of the removal of the load inductively coupled to said work coil from said work coil during said operating,

and discontinuing the release of current pulses to said tank circuit so as to cause heating as the result of the operation of said tank circuit upon the occurrence of such a voltage rise during said sensing.

25. A process as claimed in claim 24 including:

blocking the further release of current pulses so as to further heat a previously heated load inductively coupled to said work coil after heating during said sensing until said monitoring has detected the removal of a heated load from said work coil.

26. A process as claimed in claim 24 including:

blocking the further release of current pulses so as to further heat a previously heated load inductively coupled to said work coil after heating during said sensing for a further additional time period.

27. In a process for induction heating using an induction heating apparatus employing a series tuned resonant circuit including a work coil adapted to be inductively coupled to a resonance load to be heated using said apparatus located in a parallel, tuned resonant tank circuit, and current release means for releasing current pulses to said tank circuit so as to cause resonance to said tank circuit, the improvement which comprises:

monitoring said tank circuit so as to detect a voltage rise occurring in said tank circuit as a result of the removal of a load inductively coupled to said work coil from said work coil,

discontinuing the release of current pulses to said tank circuit so as to cease heating as a result of the operation of said tank circuit upon the occurence of such a voltage rise,

sampling said tank circuit after the discontinuance of the release of current pulses to said tank circuit so as to cause heating by periodically releasing current pulses to said tank circuit by causing the release of sampling current pulses at intervals which are sufficiently far apart and which are sufficiently short so as to cause no significant heating as the result of said tank circuit,

monitoring said tank circuit so as to detect any voltage drop occurring during said sampling as the result of the placement of a load so that it is inductively coupled to said work coil,

operating said current release means for a predetermined time period so as to release current pulses to said tank circuit so as to heat a load inductively coupled to said work coil upon the occurrence of any such voltage drop,

monitoring said tank circuit during said time period so as to detect any voltage rise occurring in said tank circuit as the result of the removal of a load inductively coupled to said work coil from said work coil during said time period, and

discontinuing the release of current pulses to said tank circuit so as to cause heating as the result of the operation of said tank circuit upon the occurrence of such a voltage rise during said predetermined time period,

blocking the further release of current pulses so as to further heat a previously heated load inductively coupled to said work coil after said time period unitl said monitoring has detected the removal of a heated load from said work coil.

28. A process for induction heating using an induction heating apparatus employing a parallel tuned, resonant tank circuit having a series tuned circuit in one leg thereof, said series tuned resonant circuit including a work coil adapted to be inductively coupled to an inductance load to be heated using said apparatus, which comprises:

releasing current pulses to said tank circuit so as to continuously operate said tank circuit in either a sampling mode or a heating mode, when said tank circuit is operated in said heating mode said current pulses being released with sufficient rapidity to cause heating of a load inductively coupled to said work coil, when said tank circuit is operated in said sampling mode said current pulses being released in such a manner as not to cause significant heating,

monitoring the voltage in said tank circuit as current pulses are released to said tank circuit so as to detect a voltage rise or fall in said tank circuit indicating the presence or absence of a load inductively coupled to said work coil,

discontinuing the operation of said tank circuit in said sampling mode upon a voltage drop detected by said monitoring means so as to cause said tank circuit to be thereafter operated in said heating mode, and

discontinuing the operation of said tank circuit in said heating mode upon a drop in the voltage in said tank circuit so as to cause said tank circuit to be thereafter operated in said sampling mode.

29. A process as claimed in claim 28 wherein:

when said tank circuit as been caused to operate in a heating mode it is thereafter operated in a heating mode for a time interval and thereafter it is operated in said sampling mode unless during such an interval said tank circuit should be operated in said sampling mode as a result of a voltage drop in said tank circuit.

30. A process as claimed in claim 28 including:

determining the presence or absence of a predetermined condition of a load inductively coupled to said work coil as said tank circuit is operated in a heating mode and causing said tank circuit to be operated in said heating mode until said predetermined condition is determined unless during such operation of said tank circuit in said heating mode said tank circuit should be operated in said sampling mode as a result of a voltage drop in said tank circuit.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,823,297 Dated July 9, 1974

Inventor(s) RONALD J. CUNNINGHAM

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Patent claim 5, Column 9, line 54, the numeral "3" should be changed to --4--.

Patent claim 29, Column 16, line 51, the word "as" should be changed to --has--.

Column 15, line 12, "priod" should be changed to --period--.

Column 16, line 18, "unitl" should be changed to --until--.

Signed and sealed this 12th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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