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(54) **Improvements in or relating to induction heating circuits for cooking appliances.**

(57) In an induction heating circuit for a cooking appliance, a pan heating coil (L2) is powered at values determined by the state of conduction of a gate turn-off thyristor (VT1). To reduce the amplitude of current flow through the thyristor at turn-on, a circuit responsive to the voltage across a capacitor (CR) that resonates the pan coil (L2) is employed. The circuit is coupled to the resonant circuit comprising pan coil (L2) and capacitor (CR) by a saturating transformer (T1) and senses the instant when the voltage across capacitor (CR) reaches a minimum and this information is used to turn-on the thyristor (VT1).

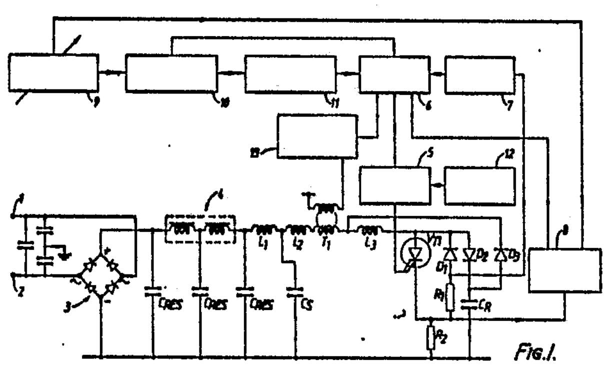

Fig.1.

EP 0 269 413 A2

Description

Improvements in or relating to Induction Heating Circuits for Cooking Appliances

This invention relates to induction heating circuits for cooking appliances.

Such circuits may comprise a rectifier for converting A.C. mains supply to direct current which is then converted by an inverter to an alternating supply at a suitable frequency, usually in the range of from 20-35 kHZ. That supply energises a coil which induces currents in a suitable utensil placed over the coil thereby heating the utensil and its contents.

Operation of the inverter is controlled by a timing circuit which switches the inverter on and off as required to maintain a required power output from the coil.

It is an object of the present invention to provide an arrangement for determining accurately the instants at which switching is to take place.

According to the present invention, an induction heating circuit for a cooking appliance includes an invertor for powering an induction heating coil at values determined by state of conduction of a semi-conductor switching device, the instant of switching on of the switching device is determined by the point in time at which the direction of current flow through the coil reverses.

The point in time at which the flow direction reverses may be determined by means coupled to a circuit including the heating coil by a saturable transformer.

By way of example only, an embodiment of the invention will now be described in greater detail with reference to the accomapnying drawings of which:

Fig. 1 is a circuit diagram partly in block schematic form of the embodiment, and

Fig. 2 shows explanatory waveforms.

In Fig. 1, an A.C. mains input connected to input terminals 1, 2 is rectified and smoothed by full wave rectifier 3 and smoothing circuit 4 respectively. The output of the smoothing circuit is applied to a pan coil L2 in series connection with a semi-conductor switching device which could be a high voltage bipolar device and which is shown in Fig. 1 as a gate turn-off thyristor VT1 and a resistor R2. Also in series conection with coil L2 are inductors L1 and L3 and the primary winding of a saturating transformer T1 which will be referred to again below.

In parallel connection cross thyristor VT1 is the series connected combination of diode D1 and resistor R1. Diode D1 is the so-called commutating or "free-wheeling" diode needed to divert load current through the inductive load when the thyristor is turned off as will be described in detail below, thereby protecting thyristor VT1 from damage by excessive voltages at the end of its non-conducting period.

In parallel connection across thyristor VT1 and resistor R2 is a series connected combination of diode D2 and capacitor CR. The capacitance of capacitor CR determines, with other circuit parameters including the inductance of pan coil L2 and of inductor L3, the resonant frequency of the circuit. Diode D2 also provides a conductive path for circulating currents during periods of resonance when thyristor VT1 is turned-off as will be described below.

A third diode D3 is connected between the junction between the primary winding of transformer T1 and inductor L3 and that between diode D2 and capacitor CR. Diode D3 is poled to provide a further route for current flow during resonant periods in a direction opoposite to that permitted by diode D2.

Connected to the gate electrodes of thyristor VT1 is a drive circuit shown as block 5 and of conventional form which supplies pulses of variable width to control the switching on and off of the thyristor and hence to control the power input to the pan coil L2.

The drive circuit is controlled by a timing circuit shown as block 6 which receives inputs from a pan detector circuit shown as block 7 which responds to current flow through the pan coil L2 during thyristor turn-off periods and which, in the event that the current flow indicates that no utensil or an unsuitable utensil has been placed above pan coil L2, inhibits the action of the timing and drive circuits 6, 5 respectively. As shown, circuit 7 responds to the flow of current through diode D1 as monitored by resistor R1.

In the event that the current through diode D1 assumes a particular value, circuit 7 responds and produces an output which is applied to the timing circuit 6 to inhibit the latter and thereby the operation of the drive circuit 5.

Operation of the timing circuit 6 is also controlled by a load current detector shown as block 8 to ensure that the power input to the pan coil L2 is that set by a power controller indicated by block 9 and which is set by a user in accordance with the heating requirement.

Only a limited range of power control is obtainable by sensing thyristor current by detector 8 and therefore the controller 9 operates, outside that range, to set the mark-space ratio of a mark/space generator shown as block 10 whose output is applied directly to the timing circuit 6.

The output of the mark/space generator 10 is also applied to an interrogation circuit shown as block 11. The interrogation circuit 11 operates, in conjunction with the pan detector 7 in the following manner. In the absence of a suitable pan above the pan coil L2, the pan detection circuit inhibits the timing circuit and this in turn prevents the subsequent turn-on of thyristor VT1. Subsequently, the interrogation circuit 11 switches the timing circuit 6 back into operation at, typically, one-second intervals until the presence of a suitable utensil above the pan coil 12 is detected by detector 7.

It will be appreciated that the interrogation circuit 11 will also operate on normal start-up with a suitable utensil over the pan coil. The circuit provides, on normal start-up, typically, a one-second delay before it produces an interrogation output. During that one-second delay, the complete system settles to a stable condition before any attempt is made to switch on thyristor VT1.

The embodiment also includes protection circuits shown in Fig. 1 as block 12. Such circuits monitor the function of the system and should a malfunction be detected, the drive circuit 5 is prevented from operating and the thyristor VT1 is rendered non-conducting.

For example, the protection circuits may monitor operating potentials for the various control functions, i.e. the generator 10, interrogation circuit 11, timing circuit 6, pan detector 7, control voltage detector and control current detector to ensure those potentials are of the correct value before power is connected to the resonant circuit and associated components. The protection circuits also ensure that a predetermined "powering-up" sequence is followed at the commencement of a cooking operation, following a temporary interruption of the mains supply and following a voltage surge or "gliche" therein.

The system as thus described operates in known manner. Turning on the thyristor VT1 produces a ramped increase in the current through the pan coil L2. When that current reaches a value set by controller 9, and sensed by control current detector 8, the thyristor is turned-off. Resonance now occurs in the circuit including the pan coil L2, inductor L3 and capacitor CR. The resonant circuit is coupled via transformer T1 to a voltage detector shown as block 13 and when the voltage drops to a minimum level, detector 13 responds and inputs to the timing circuit 6 which, via drive circuits, turns on the thyristor VT1. The interrogation function referred to above is inihibited once the presence above the pan coil of a suitable utensil has been sensed.

The use of a saturating transformer is particularly advantageous as it enables a precise indication to be obtained of the instant when the voltage in the resonant circuit reaches its minimum value.

The system shown in Fig. 1 will normally be powered from the mains supply and it is found that the peak voltages developed during resonance are very high but can be limited by the inclusion in series with the pan coil L2 of a ballast inductor L1. This also reduces the effective supply voltage during periods when the thyristor is turned on.

The inclusion of a separate ballast inductor also enables the value of the inductance of the pan coil L2 to be chosen to allow optimisation of both inductance value and geometry of the pan coil L2.

Without an additional inductor L1, the inductance of the pan coil L2 is defined by the circuit operating voltage and current, the frequency of resonance and the power throughput. The resultant inductance value and coil geometry of the pan coil L2 may not be the optimum for the application.

The arrangement allows a rate of current rise through the pan coil that is similar to that obtained with the pan coil only. To obtain that rate of rise, capacitor CS, the filter and resonsant reversed commutation capacitor must be of a value that is a compromise to allow the voltage across capacitor CS to reduce during periods when thyristor VT1 is turned-on and to allow absorption of the circulating current during resonance. That means a reduction in the inductance of the pan coil L2. It also follows that it is necessary to increase the capacitance of capacitor CR to maintain the optimum resonant frequency. The reduction in pan coil inductance and increase in CR capacitance proportionally reduces the voltage excursions across capacitor CR during resonance.

The precise instant of time at which thyristor VT1 is turned-on is determined, as explained above, by the control voltage detector 13 that is coupled to the pan coil circuit via saturating transformer T1. Ideally, thyristor VT1 must be turned on again at the instant when the voltage across capacitor CR is zero in order to reduce the amplitude of the discharge current through thyristor VT1. However, under light load conditions, i.e. low power input to the pan coil L2, the voltage across capacitor CR does not return to zero. Thus, when the thyristor is next turned-on, it will be forward biassed resulting in an uncontrolled, potentially destructive short duration current flow through the thyristor. The minimum voltage is coincident with the reversal of current through pan coil L2 as can be seen from the waveforms shown in Figs. 2A-2E.

Fig. 2A shows the waveform of the current through the thyristor VT1, Fig. 2B shows that of the voltage across the thryistor VT1 and that across capacitor CR at power levels of 100% and 75% and it will be observed that the voltage across capacitor CR does reach zero.

Fig. 2C shows the waveform of the voltage across the thyristor and across capacitor CR at power levels less than 50% of maximum and it will be observed that the voltage across capacitor CR reaches a minimum value that is not zero.

Fig. 2D shows the waveform of the current through the pan coil L2 and it will be noted that a reversal of the direction of flow of the current occurs when the voltage across CR is a minimum. Thus by allowing the control voltage detector to initiate a turn-on pulse from the drive circuit 5 at the instant of current reversal, the thyristor VT1 is turned on at the instant of minimum voltage across capacitor CR.

Fig. 2E shows the waveform of current flow through the thyristor at turn-on showing the large magnitude "spike" S. To reduce the amplitude of the spike S, some form of protection is required and such protection is commonly referred to as a "snubber".

In the embodiment shown in Fig. 1, the inductor L3 is added in series connction with the pan coil L1 as shown. The effect of inductor L3 is to limit the rate of current rise through the thyristor VT1 and the inductor will, therefore, reduce the possibility of damage to the thyristor during turn-on. The inductor does not, however, reduce thyristor dissipation and thus it is necesary to extend the power range over which variation is effected by control of mark-space ratio.

Since the inductor L3 is in series connection with the pan coil L2, energy stored in it does not have to be separately dissipated.

It will be appreciated that the minimum value of the voltage in the resonant circuit can be determined in other ways not involving a saturating transformer. For example, detector 13 may respond to voltage changes across a potentiometer in the resonant circuit.

The cooking appliance may be a hob unit in which case one or more of the pan heating units may be of the form described above. Other pan heating units may be gas burners and/or electric heating units.

The invention may also be embodied in a cooker which may be free-standing. One or more of the top heating units may be of the form described above, other top heating units may be gas burners and/or electric heating units.

Claims

1. An induction heating circuit for a cooking appliance including an invertor for powering an induction heating coil at values determined by state of conduction of a semi-conductor switching device and in which the instant of switching on of the switching device is determined by the point in time at which the direction of current flow through the coil reverses.

2. A circuit as claimed in claim 1 in which the point in time at which the flow direction reverses is determined by means coupled to a circuit including the heating coil by a saturating transformer.

3. An induction heating circuit for a cooking appliance substantially as herein described with reference to and as illustrated by the accompanying drawings.

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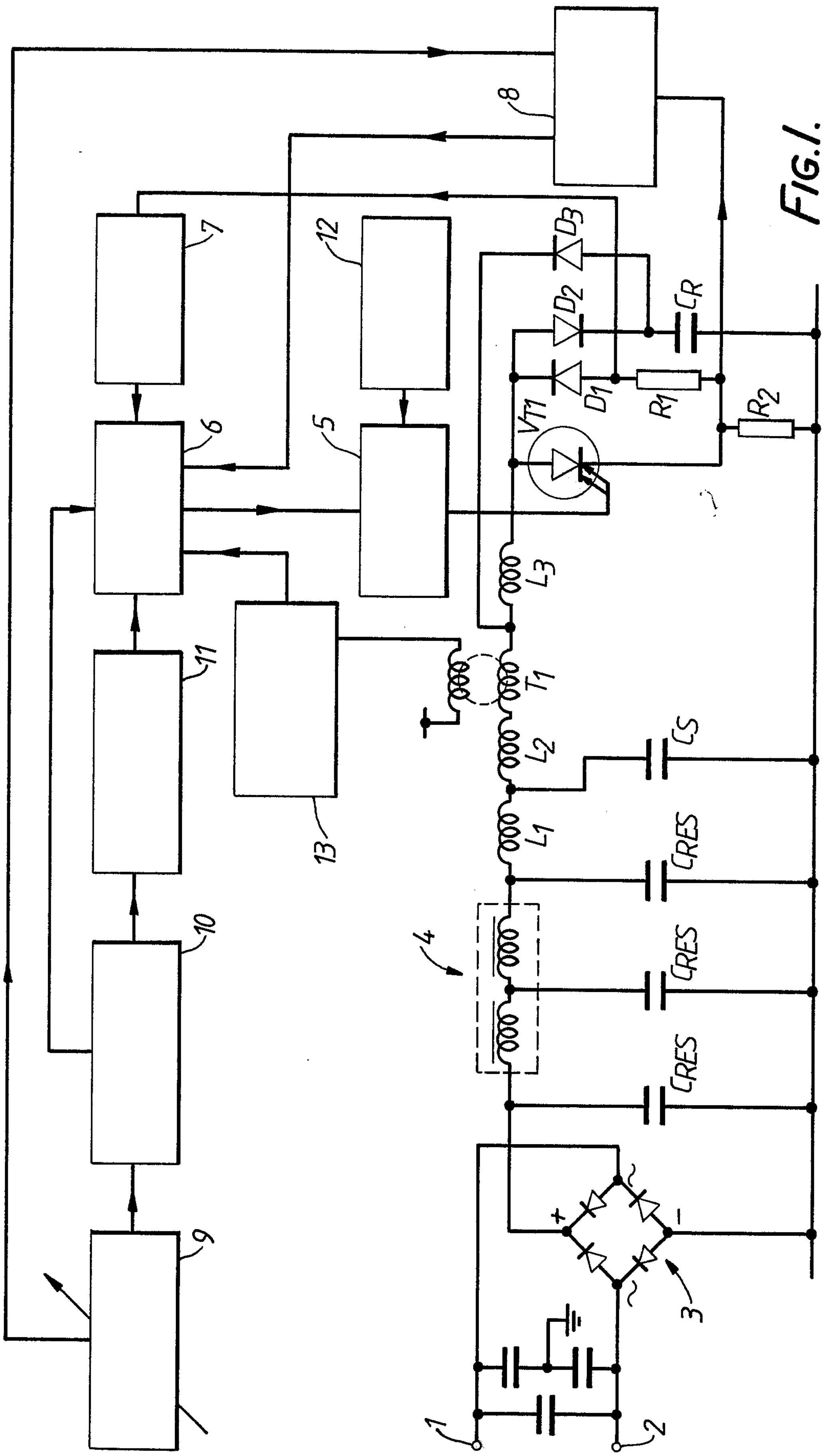

FIG.1.

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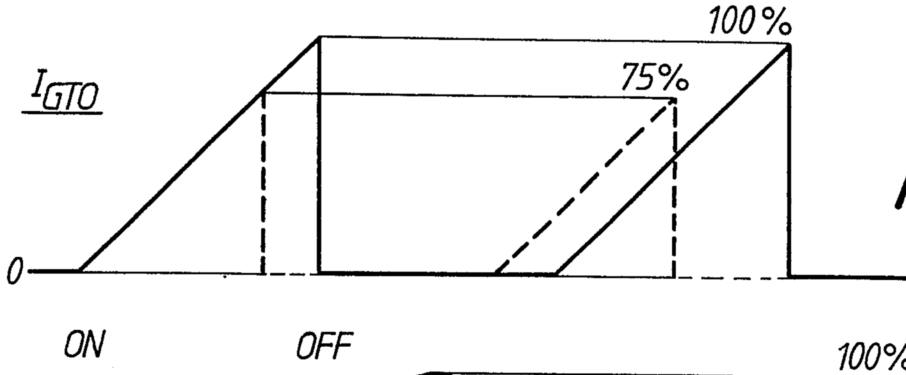

FIG.2A

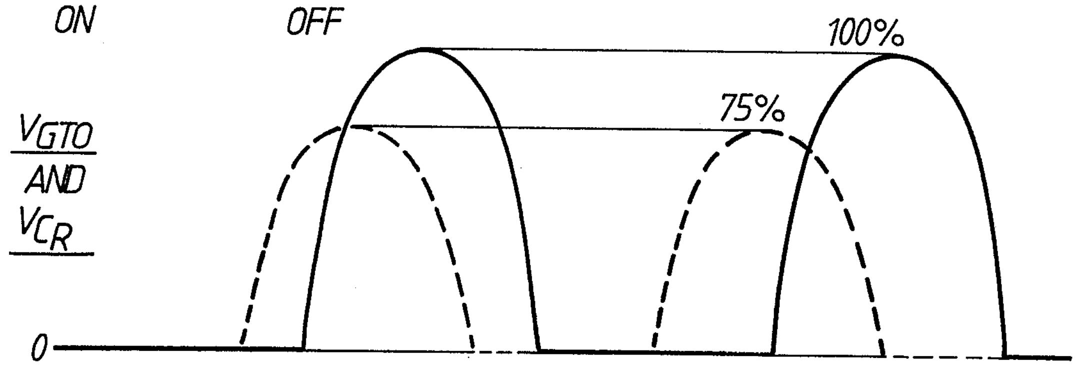

FIG.2B.

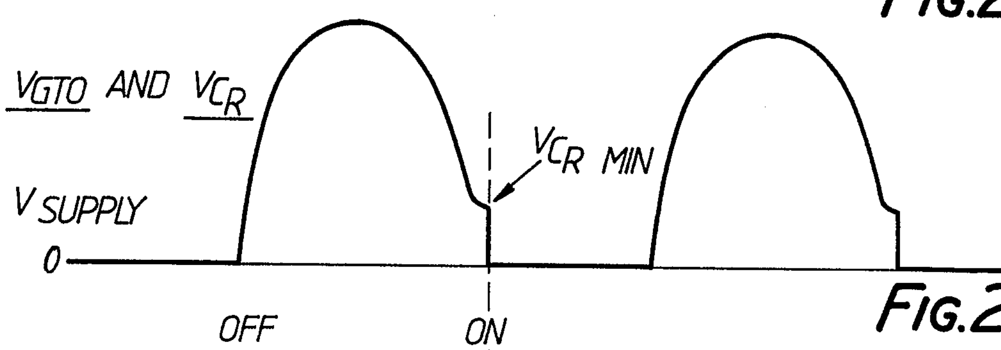

FIG.2C.

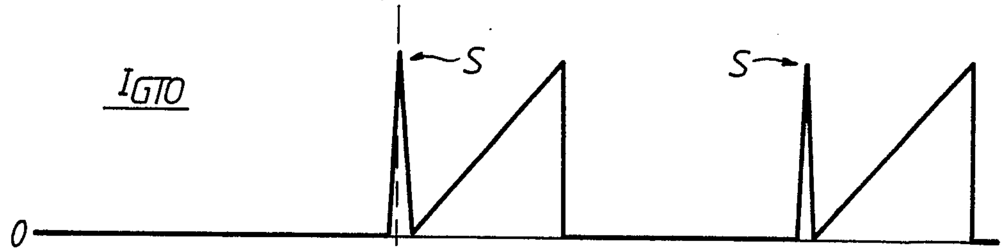

FIG.2E.

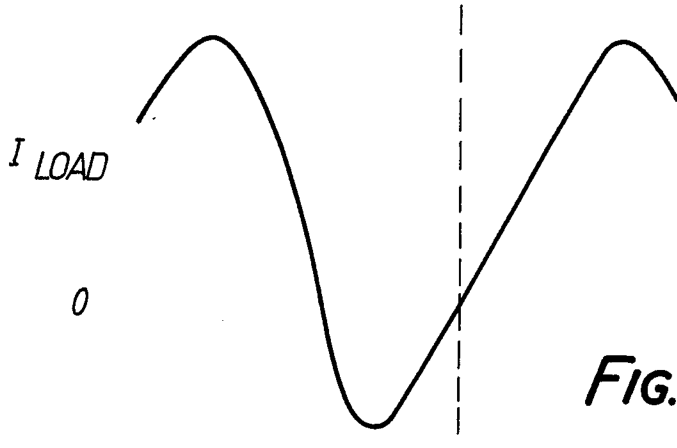

FIG.2D.