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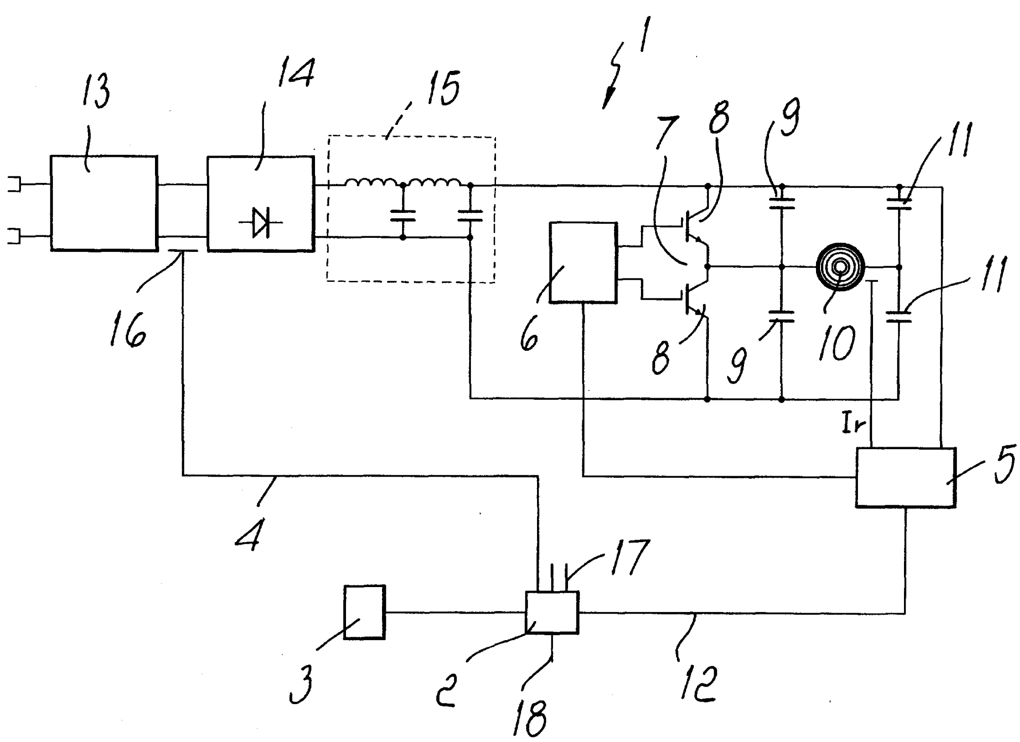
(54) **Induction cooking apparatus with improved characteristics**

(57) An induction cooking apparatus (1), comprising an inductor element (10) driven by an inverter (7), which is in turn controlled by a control circuit (6), resonance capacitors (11) being connected in parallel to the inductor element (10); the apparatus further comprises a real-time control unit (5) suitable to detect the resonance current of a resonance circuit constituted by the inductor element (10) and by the resonance capacitors (11), and the phase current of the power supply line, in order to send, at each half-cycle of the fundamental wave, a driving signal for the control circuit in order to ensure a perfect resonance condition.

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## Description

**[0001]** The present invention relates to an induction cooking apparatus with improved characteristics. More particularly, the invention relates to an induction cooking apparatus that also allows to use conventional pots or pans made of stainless steel or ordinary steel.

**[0002]** It is known that the principle of heating by induction for conducting or ferromagnetic metals dates back to the beginnings of the study of electromagnetic phenomena and its fundamental laws are currently well-known and defined in every detail.

**[0003]** Induction heating, which is one of the radio frequency heating methods, is based on the production of heat due to the parasitic eddy currents generated in conducting materials when they are immersed in a radiofrequency magnetic field. If the conducting material also has ferromagnetic characteristics, heating is also produced by losses due to hysteresis (a closed path whose area represents losses affecting a ferromagnetic material due to magnetic hysteresis, i.e., the fact that a material of this kind tends to demagnetize more slowly than it magnetizes) in addition to losses due to parasitic currents. Heating due to hysteresis increases as the frequency increases and as the area of the hysteresis cycle increases. Accordingly, induction heating is used for conducting materials.

**[0004]** The frequencies used for induction heating are in the kilohertz range and can be generated by using generators that use power devices such as transistors (IGBT), which are merely high-frequency DC-AC converters.

**[0005]** An additional problem is encountered in induction heating for the field of catering: namely, the inductor used for coupling to the element to be heated (pan or container of any type and shape). These generators are also required to have considerable shielding in order to avoid interference during services in the field of telecommunications. Such shielding is provided mechanically and by means of filters on the power supply system. DC power supply is provided by means of solid-state rectifiers (diode bridges).

**[0006]** Induction heating to cook food is currently recognized as a highly efficient and extremely safe process both for operators and for the environment.

**[0007]** One of the drawbacks of currently commercially available induction heating devices is that by generally using an LCR circuit they do not reach a condition of perfect resonance, which provides maximum useful power transmission to the heated element, with the minimum possible current for an equal available voltage.

**[0008]** Failure to achieve perfect resonance with a generic type of pot as the heated element causes a consequent increase in currents and leakages.

**[0009]** Accordingly, currently known devices require the use of pots, or heated elements in general, that are provided specifically for this application.

**[0010]** Furthermore, known types of induction heating apparatus do not allow to perform so-called sautéing, i.e., the operation that consists in moving the pan on the heating plate with an alternating movement, as might be performed on a gas-fired cooking range.

**[0011]** The aim of the present invention is to provide an apparatus for induction cooking that allows to use ordinary stainless steel or ordinary steel pots without losing power and therefore without forcing the user to use special pots.

**[0012]** Within this aim, an object of the present invention is to provide an apparatus for induction cooking that allows to work at all times in optimum resonance conditions, in order to optimize the overall efficiency of the process.

**[0013]** Another object of the present invention is to provide an apparatus for induction cooking that allows to perform so-called sautéing that is substantially similar to the sautéing allowed by a conventional gas-fired cooking apparatus.

**[0014]** Another object of the present invention is to provide an apparatus for induction cooking that allows to minimize leakages, with a consequent increase in the overall efficiency of the apparatus.

**[0015]** Another object of the present invention is to provide an apparatus for induction cooking that can be connected to similar apparatuses, by means of the dedicated local power supply grid, in order to distribute in an optimum manner the loads on the grid and therefore prevent the intervention of protection devices, which in professional environments can interrupt work processes.

**[0016]** Another object of the present invention is to provide an apparatus for induction cooking that is highly reliable, relatively easy to manufacture, and at competitive costs.

**[0017]** This aim and these and other objects that will become better apparent hereinafter are achieved by an induction cooking apparatus, comprising an inductor element driven by an inverter, which is in turn controlled by a control circuit, resonance capacitors being connected in parallel to said inductor element, characterized in that it comprises a real-time control unit suitable to detect the resonance current of a resonance circuit constituted by the inductor element and by the resonance capacitors, and the phase current of the power supply line, in order to send, at each half-cycle of the fundamental wave, a driving signal for the control circuit in order to ensure a perfect resonance condition.

**[0018]** Further characteristics and advantages of the invention will become better apparent from the following detailed description of a preferred but not exclusive embodiment of the apparatus according to the invention, illustrated by way of non-limitative example in the accompanying drawings, wherein the only figure is a circuit diagram of the apparatus according to the present invention.

**[0019]** With reference to the figure, the induction cooking apparatus according to the present invention, generally designated by the reference numeral 1, comprises a microcontroller 2, which is suitable to receive in input commands from a user interface 3, to detect an information item 4 related to the phase current of the power supply line and to drive accordingly a real-time control unit 5, which drives a circuit 6 for controlling the switching of an inverter 7 constituted by one or more pairs of IGBT transistors 8, each provided with a corresponding capacitor 9 in parallel.

**[0020]** An inductor element 10 is connected to the common node between the emitter terminal of the IGBT transistors and the capacitors 9, and a pair of resonance capacitors 11 arranged in parallel to the inductor element 10 form an LCR circuit together with the inductor element.

**[0021]** The control unit 5 detects the instantaneous value of the resonance current Ir and the value of the DC line voltage $V_{CC}$ of the circuit and sends to the control circuit 6 the appropriate control pulses in real time.

**[0022]** Communication with the microprocessor 2 and the real-time control unit occurs by means of a bidirectional line 12.

**[0023]** The LCR circuit formed by inductor elements 10 and by the pair of resonance capacitors 11 is kept always in a perfect condition of resonance by the real-time control unit 5, which is constituted by high-speed digital logic devices, which on the basis of the voltage of the DC bus $V_{CC}$ and of the instantaneous value of the resonance current Ir send to the control circuit 6 the appropriate control pulses in real-time.

**[0024]** A network filter 13 is interposed between the power supply network and the above described circuit and is designed to reduce the harmonic content of the phase current to values within the ranges currently specified in applicable statutory provisions. A rectifier bridge 14 is cascade connected to the network filter 13 and is designed to convert the AC voltage of the bus voltage supply line into a direct current ($V_{CC}$).

**[0025]** An HS filter 15 is cascade-connected to the rectifier bridge 14 and drastically reduces the high-frequency components generated by the current of the inverter 7 at the resonance frequency and at the corresponding higher harmonics.

**[0026]** The microcontroller 2 receives from a phase current measurement transformer 16 information regarding the phase current of the power supply line (signal 4) and also receives temperature signals 17 and signals 18 from serial communications.

**[0027]** The particularity of the invention is that the switching frequency of the transistors 8 that compose the inverter 7 is updated in real time at each half cycle of the fundamental wave.

**[0028]** The circuit is kept in a constant resonance condition by the real-time control unit 5, thus achieving "zero voltage switching"-type switching, because the voltage and current fundamentals are perfectly in phase. Switching losses of the inverters 8 are very small by way of the adoption of a so-called soft switching strategy, which ensures at least one zero current switching ZCS.

**[0029]** Substantially, therefore, the control must monitor continuously the resonance voltage and current and has a parametric identifier in order to detect the type of pot that is present so as to optimize transmitted power resources. Said identifier furthermore drastically reduces the power if the pot is removed, both for reasons of operator safety and to minimize consumption and any radio frequency harmonics introduced into the surrounding environment.

**[0030]** Since the resonance frequency of the inductor/pot system varies according to many factors, the factors that are constant or slowly variable over time have been separated from those that are rapidly invariable over time.

**[0031]** The main factors that are constant or slowly variable over time are:

> the magnetic circuit of the inductor, the electric circuit of the inductor, the temperatures of the two circuits, the type and size of the pots, the temperature of the bottom of the pot, the resistivity of the bottom of the pot, any ferromagnetic characteristics of the material of the pot, direct conduction voltages of the IGBTs 8 and corresponding recirculation diodes.

**[0032]** The factors that are rapidly variable over time are instead:

> the mains voltage, the rectified power supply voltage of the modulator, the current circulating in the IGBT transistors 8, the relative positions of the pot and the inductor.

**[0033]** With self tuning at each half cycle of the fundamental resonance wave, the object has also been achieved of being able to compensate automatically for all variations of the factors that can vary rapidly over time and therefore also the relative position between the pot and the inductor, and this allows to provide so-called sautéing, which is a usual and indispensable operation for a professional cook.

**[0034]** Self-tuning of the real-time control unit 5 ensure, at each half cycle of the fundamental wave, an appropriate driving signal for the control circuit 6 that must ensure the perfect resonance condition in order to utilize all the benefits of soft switching in resonant mode, because the switchings of the transistors must occur in the vicinity of the zero transition of the resonance current and because it is necessary to adopt a certain idle time in order to avoid cross conduction phenomena, the status change command to be given to the control circuit 6 must be given with a certain advance and this optimum advance time is a function of the maximum value of the resonance current Ir, of the resonance frequency, and of the capacitance of the capacitors 9 connected in parallel to the corresponding transistors.

**[0035]** Furthermore, the real-time control unit 5 deduces in real-time the equivalent inductor/pot resistance in order to detect in the shortest possible time the condition in which no pot is present.

**[0036]** This condition is very important, because it allows to reduce the high-frequency alternating magnetic field to very low values (minimum electromagnetic pollution) in order to purely detect the pot read insertion condition.

**[0037]** The microcontroller 2 monitors, by means of the transformer 16, the absorption of current in order to report to the control unit 5 the correct set point in order to obtain the intended transmitted power and perform other auxiliary functions.

**[0038]** The microcontroller, by means of the communications line 18, receives the status of utilization of the maximum power of the three-phase line used: if the status of utilization is higher than a certain preset threshold, the microcontroller 2 decreases adequately the transmission of power until the status of full utilization returns within the threshold.

**[0039]** A general microcontroller can therefore monitor the current of the three lines of the three-phase power supply system and transmit it to the individual heating devices according to the present invention, so as to distribute uniformly all the useful power to all the devices and especially prevent an excessive load from tripping the line protections, consequently halting the cooking cycle, with the well-known consequences and inconveniences.

**[0040]** In practice it has been found that the induction cooking apparatus according to the present invention fully achieves the intended aim and objects, since it allows to operate at all times in a resonance condition in order to optimize the overall efficiency of the process, and it can also use any type of pot available by way of its capacity to detect constantly and in real time the resonance current and therefore adapt the driving of the transistors that constitute the inverter.

**[0041]** Furthermore, the apparatus according to the present invention allows to perform so-called sautéing.

**[0042]** The apparatus thus conceived is susceptible of numerous modifications and variations, all of which are within the scope of the inventive concept; all the details may furthermore be replaced with other technically equivalent elements.

**[0043]** In practice, the materials used, as well as the contingent shapes and dimensions, maybe any according to requirements and to the state of the art.

**[0044]** The disclosures in Italian Patent Application No. MI2001A000910 from which this application claims priority are incorporated herein by reference.

**[0045]** Where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole purpose of increasing the intelligibility of the claims and accordingly, such reference signs do not have any limiting effect on the interpretation of each element identified by way of example by such reference signs.

**Claims**

1. An induction cooking apparatus, comprising an inductor element driven by an inverter, which is in turn controlled by a control circuit, resonance capacitors being connected in parallel to said inductor element, **characterized in that** it comprises a real-time control unit suitable to detect the resonance current of a resonance circuit constituted by said inductor element and by said resonance capacitors, and the phase current of the power supply line, in order to send, at each half-cycle of the fundamental wave, a driving signal for the control circuit in order to ensure a perfect resonance condition.

2. The apparatus according to claim 1, **characterized in that** said real-time control unit receives in input the DC voltage of said power supply line, together with said resonance, processing in real time the received information, said resonance current being detected with an advance on the zero crossing of said current in order to compensate for the switching times of transistors of said inverter.

3. The apparatus according to claim 1, **characterized in that** said inverter comprises one or more pairs of IGBT transistors.

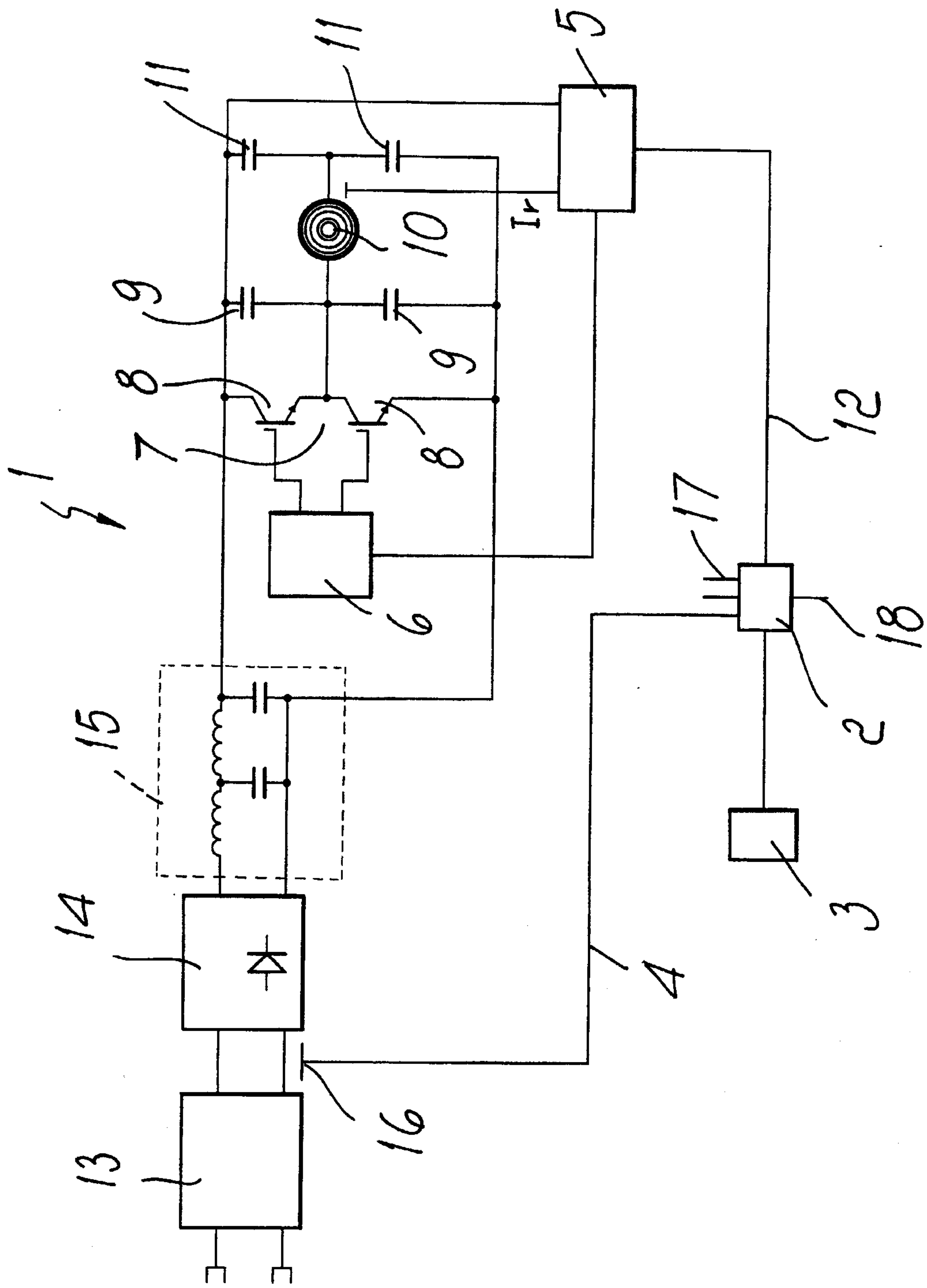
4. The apparatus according to one or more of the preceding claims, **characterized in that** it comprises, between said power supply line and said inverter, a network filter to which a rectifying bridge is cascade connected and to which a high-frequency filter is in turn cascade connected.

5. The apparatus according to one or more of the preceding claims, **characterized in that** it comprises a microcontroller suitable to receive in input the phase current signal of the power supply line, detected by a transformer that measures the phase current, temperature signals and a communications signal, and suitable to drive said real-time control unit.

6. The apparatus according to one or more of the preceding claims, **characterized in that** it comprises a user interface connected to said microprocessor.

7. The apparatus according to one or more of the preceding claims, **characterized in that** said real-time control unit is connected bidirectionally to said microprocessor.

8. The apparatus according to one or more of the preceding claims, **characterized in that** the switching frequency of said transistors that constitute said inverter is updated in real time by said real-time control unit at every half-cycle of the fundamental wave.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